AIR FORCE
14.A SMALL BUSINESS TECHNOLOGY TRANSFER (STTR)
PROPOSAL PREPARATION INSTRUCTIONS

The Air Force (AF) proposal submission instructions are intended to clarify the Department of Defense (DoD) instructions as they apply to AF requirements.

The Air Force Research Laboratory (AFRL), Wright-Patterson Air Force Base, Ohio, is responsible for the implementation and management of the AF Small Business Innovation Research (SBIR) Program/Small Business Technology Transfer (STTR) Program.

The AF Program Manager is Mr. David Sikora, 1-800-222-0336. For general inquiries or problems with the electronic submission, contact the DoD Help Desk at 1-866-724-7457 (1-866-SBIRHLP) (8:00 a.m. to 5:00 p.m. ET Monday through Friday). For technical questions about the topics during the pre-solicitation period (3 February through 4 March 2014), contact the Topic Authors listed for each topic on the Web site. For information on obtaining answers to your technical questions during the formal solicitation period (5 March 2014 through 9 April 2014), go to http://www.dodsbir.net/sitis/.

General information related to the AF Small Business Technology Transfer Program can be found at the AF Small Business website, http://www.airforcesmallbiz.org. The site contains information related to contracting opportunities within the AF, as well as business information, and upcoming outreach/conference events. Other informative sites include those for the Small Business Administration (SBA), www.sba.gov, and the Procurement Technical Assistance Centers, http://www.aptac-us.org. These centers provide Government contracting assistance and guidance to small businesses, generally at no cost.

The AF STTR Program is a mission-oriented program that integrates the needs and requirements of the AF through R&D topics that have military and/or commercial potential.

PHASE I PROPOSAL SUBMISSION

Read the DoD program solicitation at www.dodsbir.net/solicitation **for program requirements.** When you prepare your proposal, keep in mind that Phase I should address the feasibility of a solution to the topic. For the AF, the contract period of performance for Phase I shall be nine (9) months, and the award shall not exceed $150,000. We will accept only one Cost Volume per Topic Proposal and it must address the entire nine-month contract period of performance.

The Phase I award winners must accomplish the majority of their primary research during the first six months of the contract. Each AF organization may request Phase II proposals prior to the completion of the first six months of the contract based upon an evaluation of the contractor's technical progress and review by the AF technical point of contact utilizing the criteria in section 6.0 of the DoD solicitation. The last three months of the nine-month Phase I contract will provide project continuity for all Phase II award winners (see "Phase II Proposal Submissions" below); no modification to the Phase I contract should be necessary.

The Phase I Technical Volume has a 20-page limit (excluding the Cover Sheet, Cost Volume, Cost Volume Itemized Listing (a-k), Company Commercialization Report and NDA Requirement Form.

Limitations on Length of Proposal

The Technical Volume must be no more than 20 pages (no type smaller than 10-point on standard 8-1/2" x 11" paper with one (1) inch margins). The Cover Sheet, Cost Volume, Cost Volume Itemized Listing (a-k), and Company Commercialization Report are excluded from the 20-page limit. Only the Technical Volume and any enclosures or attachments count toward the 20-page limit. In the interest of equity, pages in excess of the 20-page limitation (including attachments, appendices, or references, but excluding the Cover Sheet, Cost Volume, Cost Volume Itemized Listing (a-k), and Company Commercialization Report), will not be considered for review or award.

Phase I Proposal Format

Proposal Cover Sheets: The Cover Sheet does NOT count toward the 20-page total limit. If your proposal is selected for award, the technical abstract and discussion of anticipated benefits will be publicly released on the Internet. Therefore, DO NOT include proprietary information in these sections.

Technical Volume: The Technical Volume should include all graphics and attachments but should not include the Cover Sheet or Company Commercialization Report (as these items are completed separately). Most proposals will be printed out on black and white printers so make sure all graphics are distinguishable in black and white. It is strongly encouraged that you perform a virus check on each submission to avoid complications or delays in submitting your Topic Proposal. To verify that your proposal has been received, click on the “Check Upload” icon to view your proposal. Typically, your uploaded file will be virus checked and converted to a .pdf document within the hour. However, if your proposal does not appear after an hour, please contact the DoD Help Desk at 1-866-724-7457 (8:00 am to 5:00 pm ET).

Key Personnel: Identify in the Technical Volume all key personnel who will be involved in this project; include information on directly related education, experience, and citizenship. A technical resume of the principle investigator, including a list of publications, if any, must be part of that information. Concise technical resumes for subcontractors and consultants, if any, are also useful. You must identify all U.S. permanent residents to be involved in the project as direct employees, subcontractors, or consultants. You must also identify all non-U.S. citizens expected to be involved in the project as direct employees, subcontractors, or consultants. For all non-U.S. citizens, in addition to technical resumes, please provide countries of origin, the type of visa or work permit under which they are performing and an explanation of their anticipated level of involvement on this project, as appropriate. You may be asked to provide additional information during negotiations in order to verify the foreign citizen’s eligibility to participate on a contract issued as a result of this solicitation.

Voluntary Protection Program (VPP): VPP promotes effective worksite-based safety and health. In the VPP, management, labor, and the Occupational Safety and Health Agency (OSHA) establish cooperative relationships at workplaces that have implemented a comprehensive safety and health management system. Approval into the VPP is OSHA’s official recognition of the outstanding efforts of employers and employees who have achieved exemplary occupational safety and health. An “Applicable Contractor” under the VPP is defined as a construction or services contractor with employees working at least 1,000 hours at the site in any calendar quarter within the last 12 months that is NOT directly supervised by the applicant (installation). The definition flows down to affected subcontractors. Applicable contractors will be required to submit Days Away, Restricted, and Transfer (DART) and Total Case Incident (TCIR) rates for the past three years as part of the proposal. Pages associated with this information will NOT contribute to the overall technical proposal page count. NOTE: If award of your firm’s proposal does NOT create a situation wherein performance on one Government installation will exceed 1,000 hours in one calendar quarter, **SUBMISSION OF TCIR/DART DATA IS NOT REQUIRED**.

Phase I Work Plan Outline

NOTE: THE AF USES THE WORK PLAN OUTLINE AS THE INITIAL DRAFT OF THE PHASE I STATEMENT OF WORK (SOW). THEREFORE, DO NOT INCLUDE PROPRIETARY INFORMATION IN THE WORK PLAN OUTLINE. TO DO SO WILL NECESSITATE A REQUEST FOR REVISION AND MAY DELAY CONTRACT AWARD.

At the beginning of your proposal work plan section, include an outline of the work plan in the following format:

1) Scope: List the major requirements and specifications of the effort.
2) Task Outline: Provide a brief outline of the work to be accomplished over the span of the Phase I effort.
3) Milestone Schedule
4) Deliverables
    a. Kickoff meeting within 30 days of contract start
    b. Progress reports
    c. Technical review within 6 months
    d. Final report with SF 298

Cost Volume

Cost Volume information should be provided by completing the on-line Cost Volume form and including the Cost Volume Itemized Listing (a-k) specified below. The Cost Volume information must be at a level of detail that would enable Air Force personnel to determine the purpose, necessity and reasonability of each cost element. Provide sufficient information (a-k below) on how funds will be used if the contract is awarded. The on-line Cost Volume and Itemized Cost Volume Information (a-k) will not count against the 20-page limit. The itemized listing may be placed in the "Explanatory Material" section of the on-line Cost Volume form (if enough room), or as the last page(s) of the Technical Volume Upload. (Note: Only one file can be uploaded to the DoD Submission Site). Ensure that this file includes your complete Technical Volume and the Cost Volume Itemized Listing (a-k) information.

a. Special Tooling and Test Equipment and Material: The inclusion of equipment and materials will be carefully reviewed relative to need and appropriateness of the work proposed. The purchase of special tooling and test equipment must, in the opinion of the Contracting Officer, be advantageous to the government and relate directly to the specific effort. They may include such items as innovative instrumentation and/or automatic test equipment.

b. Materials: Justify costs for materials, parts, and supplies with an itemized list containing types, quantities, and price and where appropriate, purposes.

c. Other Direct Costs: This category of costs includes specialized services such as machining or milling, special testing or analysis, costs incurred in obtaining temporary use of specialized equipment. Proposals which include leased hardware, must provide an adequate lease vs. purchase justification or rational.

d. Direct Labor: Identify key personnel by name if possible or by labor category if specific names are not available. The number of hours, labor overhead and/or fringe benefits and actual hourly rates for each individual are also necessary.

e. Travel: Travel costs must relate to the needs of the project. Break out travel cost by trip, with the number of travelers, airfare, per diem, lodging, etc. The number of trips required, as well as the destination and purpose of each trip should be reflected. Recommend budgeting at least one (1) trip to the Air Force location managing the contract.

f. Cost Sharing: Cost sharing is permitted. However, cost sharing is not required nor will it be an evaluation factor in the consideration of a proposal. Please note cost share contracts or portions of contracts do not allow fee. NOTE: Subcontract arrangements involving provision of Independent Research and Development (IR&D) support are prohibited in accordance with Under Secretary of Defense (USD) memorandum "Contractor Cost Share", dated 16 May 2001, as implemented by SAF/AQ memorandum, same title, dated 11 Jul 2001.

g. Subcontracts: Involvement of a research institution is required in the project. Involvement of other subcontractors or consultants may also be desired. Describe in detail the tasks to be performed in the Technical Volume and include information in the Cost Volume for the research institution and any other subcontractors/consultants. The proposed total of all consultant fees, facility leases or usage fees, and other subcontract or purchase agreements may not exceed 60 percent of the total contract price or cost, unless otherwise approved in writing by the Contracting Officer. The STTR offeror's involvement must equate to not less than 40 percent of the overall effort and the research institutions must equate to not less than 30 percent.

Support subcontract costs with copies of the subcontract agreements. The supporting agreement documents must adequately describe the work to be performed, i.e., Cost Volume. At a minimum, an offeror must include a Statement of Work (SOW) with a corresponding detailed cost proposal for each planned subcontract.

h. Consultants: Provide a separate agreement letter for each consultant. The letter should briefly state what service or assistance will be provided, the number of hours required, and hourly rate.

i. Any exceptions to the model Phase I purchase order (P.O.) found at https://www.afsbirsttr.com/Proposals/Default.aspx (see "NOTE" within "Phase I Proposal Submission Checklist" section, p. AF-5).

j. DD Form 2345: For proposals submitted under export-controlled topics (either International Traffic in Arms (ITAR) or Export Administration Regulations (EAR)), a copy of the certified DD Form 2345, Militarily Critical Technical Data Agreement, or evidence of application submission must be included. The form, instructions, and FAQs may be found at the United States/Canada Joint Certification Program website, http://www.dlis.dla.mil/jcp/. Approval of the DD Form 2345 will be verified if proposal is chosen for award.

k. Certifications: In accordance with 13CFR Part 121, all small businesses selected for Phase I award must complete prescribed certifications at the time of award and prior to receipt of final payment.

Please access the Air Force SBIR/STR site, https://www.afsbirsttr.com/Proposals/Default.aspx, for the certification template that must be completed, signed and submitted with the Phase I proposal. If selected for award the certification form required for submission prior to final payment may also be found at this site.

NOTE: AF support contractors may be used to administratively or technically support the Government's STTR Program execution. DFARS 252.227-7025, Limitations on the Use or Disclosure of Government-Furnished Information Marked with Restrictive Legends (Mar 2011), allows Government support contractors to do so without company-to-company NDAs only AFTER

the support contractor notifies the STTR firm of its access to the STTR data AND the STTR firm agrees in writing no NDA is necessary. If the STTR firm does not agree, a company-to-company NDA is required. The attached "NDA Requirements Form" (page 9) must be completed, signed, and included in the Phase I proposal, indicating your firm's determination regarding company-to-company NDAs for access to STTR data by AF support contractors. This form will not count against the 20-page limitation.

NOTE: If no exceptions are taken to an offeror's proposal, the Government may award a contract without discussions (except clarifications as described in FAR 15.306(a)). Therefore, the offeror's initial proposal should contain the offeror's best terms from a cost or price and technical standpoint. In addition, please review the model Phase I P.O. found at https://www.afsbirsttr.com/Proposals/Default.aspx and provide any exception to the clauses found therein with your cost proposal. Full text for the clauses included in the P.O. may be found at http://farsite.hill.af.mil. Please note, the posted P.O. template is for the Small Business Innovation Research (SBIR) Program. While P.O.s for STTR awards are very similar, if selected for award, **the contract or P.O. document received by your firm may vary in format/content. If there are questions regarding the award document, contact the Phase I Contracting Officer listed on the selection notification.** (See item g under the "Cost Volume" section, p. AF-4.) The Government reserves the right to conduct discussions if the Contracting Officer later determines them to be necessary.

PHASE I PROPOSAL SUBMISSION CHECKLIST

Failure to meet any of the criteria will result in your proposal being **REJECTED** and the Air Force will not evaluate your proposal.

1) The Air Force Phase I proposal shall be a nine-month effort and the cost shall not exceed $150,000.

2) The Air Force will accept only those proposals submitted electronically via the DoD SBIR Web site (www.dodsbir.net/submission).

3) You must submit your Company Commercialization Report electronically via the DoD SBIR website (www.dodsbir.net/submission).

It is mandatory that the complete proposal submission -- DoD Proposal Cover Sheet, Technical Volume with any appendices, Cost Volume, Itemized Cost Volume Information, and the Company Commercialization Report -- be submitted electronically through the DoD SBIR website at http://www.dodsbir.net/submission. Each of these documents is to be submitted separately through the Web site. Your complete proposal **must** be submitted via the submissions site on or before the **6:00 am ET, 9 April 2014 deadline.** A hardcopy **will not** be accepted.

The AF recommends that you complete your submission early, as computer traffic gets heavy near solicitation close and could slow down the system. **Do not wait until the last minute.** The AF will not be responsible for proposals being denied due to servers being "down" or inaccessible. Please ensure your e-mail address listed in your proposal is current and accurate. By mid April, you will receive an e-mail serving as our acknowledgement we have received your proposal. The AF is not responsible for notifying companies that change their mailing address, their e-mail address, or company official after proposal submission without proper notification to the AF.

AIR FORCE SBIR/STTR SITE

As a means of drawing greater attention to SBIR/STTR accomplishments, the AF has developed a SBIR/STTR site at http://www.afsbirsttr.com. Along with being an information resource concerning SBIR policies and procedures, the SBIR/STTR site is designed to help facilitate the Phase III transition process. To this end, the SBIR/STTR site contains SBIR/STTR Success Stories written by the Air Force and Phase II summary reports written and submitted by SBIR/STTR companies. Since summary reports are intended for public viewing via the Internet, they should not contain classified, sensitive, or proprietary information.

AIR FORCE PROPOSAL EVALUATIONS

The AF will utilize the Phase I proposal evaluation criteria in section 6.0 of the DoD solicitation in descending order of importance with technical merit being most important, followed by the qualifications of the principal investigator (and team), and followed by Commercialization Plan. The AF will utilize Phase II evaluation criteria in section 8.0 of the DoD solicitation; however, the order of importance will differ. The AF will evaluate proposals in descending order of importance with technical merit being most important, followed by the Commercialization Plan, and then qualifications of the principal investigator (and team). Please note that where technical evaluations are essentially equal in merit, and as cost and/or price is a substantial factor, cost to the Government will be considered in determining the successful offeror. The next tie-breaker on essentially equal proposals will be the inclusion of manufacturing technology considerations.

The proposer's record of commercializing its prior SBIR and STTR projects, as shown in its Company Commercialization Report, will be used as a portion of the Commercialization Plan evaluation. If the "Commercialization Achievement Index (CAI)", shown on the first page of the report, is at the 20th percentile or below, the proposer will receive no more than half of the evaluation points available under evaluation criterion (c) in Section 6 of the DoD 14.A STTR instructions. This information supersedes Paragraph 4, Section 5.4e, of the DoD 14.A STTR instructions.

A Company Commercialization Report showing the proposing firm has no prior Phase II awards will not affect the firm's ability to win an award. Such a firm's proposal will be evaluated for commercial potential based on its commercialization strategy.

Online Proposal Status and Debriefings

The AF has implemented on-line proposal status updates for small businesses submitting proposals against AF topics. At the close of the Phase I Solicitation – and following the submission of a Phase II via the DoD SBIR/STTR Submission site (https://www.dodsbir.net/submission) – small business can track the progress of their proposal submission by logging into the Small Business Area of the AF SBIR/STTR site (http://www.afsbirsttr.com). The Small Business Area (http://www.afsbirsttr.com/Firm/login.aspx) is password protected and firms can view their information only.
To receive a status update of a proposal submission, click the "Proposal Status" link at the top of the page in the Small Business Area (after logging in). A listing of proposal submissions to the AF within the last 12 months is displayed. Status update intervals are: Proposal Received, Evaluation Started, Evaluation Completed, Selection Started, and Selection Completed. A date will be displayed in the appropriate column indicating when this stage has been completed. If no date is present, the proposal submission has not completed this stage. Small businesses are encouraged to check this site often as it is updated in real-time and provides the most up-to-date information available for all proposal submissions. **Once the "Selection Completed" date is visible, it could still be a few weeks (or more) before you are contacted by the AF with a notification of selection or non-selection.** The AF receives thousands of

proposals during each solicitation. The notification process requires specific steps to be completed prior to a Contracting Officer approving and distributing this information to small businesses.

The Principal Investigator (PI) and Corporate Official (CO) indicated on the Proposal Cover Sheet will be notified by e-mail regarding proposal selection or non-selection. The email will include a link to a secure Internet page containing specific selection/non-selection information. Small businesses will receive a notification for each proposal submitted. Please read each notification carefully and note the Proposal Number and Topic Number referenced.

A debriefing may be received by written request. As is consistent with the DoD SBIR/STTR solicitation, the request must be received within 30 days after receipt of notification of non-selection. Written requests for debrief must be uploaded to the Small Business Area of the AF SBIR/STTR site (http://www.afsbirsttr.com). Requests for debrief should include the company name and the telephone number/e-mail address for a specific point of contract, as well as an alternate. Also include the topic number under which the proposal(s) was submitted, and the proposal number(s). Further instructions regarding debrief request preparation/submission will be provided within the Small Business Area of the AF SBIR/STTR site. Debrief requests received more than 30 days after receipt of notification of non-selection will be fulfilled at the Contracting Officers' discretion. Unsuccessful offerors are entitled to no more than one debriefing for each proposal.

IMPORTANT: Proposals submitted to the AF are received and evaluated by different offices within the Air Force and handled on a Topic-by-Topic basis. Each office operates within their own schedule for proposal evaluation and selection**. Updates and notification timeframes will vary by office and Topic. If your company is contacted regarding a proposal submission, it is not necessary to contact the AF to inquire about additional submissions.** Check the Small Business Area of the AF SBIR/STTR site for a current update. Additional notifications regarding your other submissions will be forthcoming.

We anticipate having all the proposals evaluated and our Phase I contract decisions within approximately three months of proposal receipt. **All questions concerning the status of a proposal or debriefing should be directed to the local awarding organization SBIR/STTR Program Manager.**

PHASE II PROPOSAL SUBMISSIONS

Phase II is the demonstration of the technology found feasible in Phase I. Only Phase I awardees are eligible to submit a Phase II proposal. All Phase I awardees will be sent a notification with the Phase II proposal submittal date and a link to detailed Phase II proposal preparation instructions. If the contact information for technical/contracting points of contact changes after submission of the Phase I proposal, contact the appropriate AF STTR Program Manager as found in the Phase I selection notification letter for resolution. Please note it is solely the responsibility of the Phase I awardee to contact this individual. Phase II efforts are typically two (2) years in duration with an initial value not to exceed $750,000.

NOTE: All Phase II awardees must have a Defense Contract Audit Agency (DCAA) approved accounting system. It is strongly urged that an approved accounting system be in place prior to the AF Phase II award timeframe. If you do not have a DCAA approved accounting system, this will delay/prevent Phase II contract award. If you have questions regarding this matter, please discuss with your Phase I Contracting Officer.

All proposals must be submitted electronically at www.dodsbir.net/submission. The complete Topic Proposal - Department of Defense (DoD) Cover Sheet, Itemized Cost Volume information, entire Technical Volume with appendices, Cost Volume and the Company Commercialization Report – must be submitted by the date indicated in the notification. The technical proposal is **limited to 50 pages** (unless a different number is specified in the preparation instructions). The Commercialization Report, any advocacy letters, and the additional Cost Volume itemized listing (a-k) will not count against the 50 page limitation and should be placed as the last pages of the Topic Proposal file uploaded. (Note: Only one file can be uploaded to the DoD submission site. Ensure this single file includes your complete Technical Volume and the additional Cost Volume information.) The preferred format for submission of proposals is Portable Document Format (.pdf). Graphics must be distinguishable in black and white. **Please virus-check your submissions**.

AIR FORCE PHASE II ENHANCEMENT PROGRAM

On active Phase II awards, the Air Force may request a Phase II enhancement application package from a limited number of Phase II awardees. In the Air Force program, the outside investment funding must be from a Government source, usually the Air Force or other military service. The selected enhancements will extend the existing Phase II contract awards for up to one year. The Air Force will provide matching STTR funds, up to a maximum of $750,000, to non-STTR Government funds. If requested to submit a Phase II enhancement application package, it must be submitted through the DoD Submission Web site at www.dodsbir.net/submission. Contact the local awarding organization SBIR/STTR Program Manager.

AIR FORCE STTR PROGRAM MANAGEMENT IMPROVEMENTS

The Air Force reserves the right to modify the Phase II submission requirements. Should the requirements change, all Phase I awardees will be notified. The Air Force also reserves the right to change any administrative procedures at any time to improve management of the Air Force STTR Program.

SUBMISSION OF FINAL REPORTS

All final reports will be submitted to the awarding Air Force organization in accordance with Contract Data Requirements List (CDRL) items. Companies **will not** submit final reports directly to the Defense Technical Information Center (DTIC).

AIR FORCE
14.A Small Business Technology Transfer (STTR)
Non-Disclosure Agreement (NDA) Requirements

DFARS 252.227-7018(b)(8), Rights in Noncommercial Technical Data and Computer Software – Small Business Innovation Research (SBIR) Program/Small Business Technology (STTR) Program (May 2013), allows Government support contractors access to SBIR/STTR data without company-to-company NDAs only AFTER the support contractor notifies the SBIR/STTR firm of its access to the SBIR/STTR data AND the SBIR/STTR firm agrees in writing no NDA is necessary. If the SBIR/STTR firm does not agree, a company-to-company NDA is required.

"Covered Government support contractor" is defined in 252.227-7018(a)(6) as "a contractor under a contract, the primary purpose of which is *to furnish independent and impartial advice or technical assistance directly to the Government in support of the Government's management and oversight of a program or effort* (rather than to directly furnish an end item or service to accomplish a program or effort), provided that the contractor –

> (i) Is not affiliated with the prime contractor or a first-tier subcontractor on the program or effort, or with any direct competitor of such prime contractor or any such first-tier subcontractor in furnishing end items or services of the type developed or produced on the program or effort; and
>
> (ii) Receives access to the technical data or computer software for performance of a Government contract that contains the clause at 252.227-7025, "Limitations on the Use or Disclosure of Government-Furnished Information Marked with Restrictive Legends."

USE OF SUPPORT CONTRACTORS:

Support contractors may be used to administratively process SBIR/STTR documentation or provide technical support related to SBIR contractual efforts to Government Program Offices.

Below, please provide your firm's determination regarding the requirement for company-to-company NDAs to enable access to SBIR/STTR documentation by Air Force support contractors. This agreement must be signed and included in your Phase I/II proposal package.

☐ Yes ☐ No Non-Disclosure Agreement Required
(If Yes, include your firm's NDA requirements in your proposal.)

____ ______________________

Signer's Name/Position Date
Company

Air Force STTR 14.A Topic Index

Air Force STTR 14.A Topic Descriptions

AF14-AT01 TITLE: Embedded Sensors for Flight Test (Every Aircraft a Test Aircraft)

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop advanced concepts and techniques to design, construct, and integrate structural, sensing, communication, and data storage capabilities into airframes and airframe components.

DESCRIPTION: Advanced aircraft under development are becoming increasingly complex and offer the Air Force enhanced capabilities with decreased size and weight. As these trends continue, systems and test engineers have reduced flexibility in positioning and installing the sensors, instruments, and wiring necessary to measure and assess aircraft performance during test and evaluation. We are looking for advanced concepts and techniques to design, construct, and integrate structural, sensing, communication, and data storage capabilities into airframes and airframe components.

Application to fleet aircraft may still be many years away, so the focus of this topic solicitation will be proof-of-concept demonstration for scaled models undergoing wind tunnel testing as a first step in the development process. Areas of interest include multi-function materials containing embedded sensors, wireless powering and communication, additive manufacturing (AM), digital twin concepts, and design of experiment (DOE). We encourage strong multi-disciplinary team approaches rather than concentrated efforts in a single area. The goal of this effort will be small-scale demonstration that can drive the technology toward full-scale realization.

Proposers should have an expertise in wind tunnel testing, test model construction, and safety as it relates to these tests. While new approaches to sensors and sensor design will be considered, primary emphasis should be on sensors for measuring temperature, pressure, and pressure fluctuations. Sensor performance (accuracy, precision, noise level, frequency response, absolute calibration, and drift) should be comparable to or superior to traditional wind tunnel sensors. For example, detection of spectrally and locally resolved acoustic loads on a test article with minimal on-board hardware would be of high interest. Approaches that allow high sensor element density at reduced unit cost and integrated data collection, storage, and transmission would also be of high interest. Consideration will be given to new model construction or plans to retrofit existing test models with embedded sensing capabilities. Part of the intent of this work is to provide new, high fidelity data to the CFD modeling community, so proposals must include a provision for making all test data available in the public domain.

PHASE I: Develop advanced concepts and techniques for scaled model test aircraft construction.

PHASE II: Develop scaled model and demonstrate capabilities in a wind tunnel test environment. All test data shall be made available in the public domain.

PHASE III: Begin the transition process to bring embedded sensor technology to the current and future Air Force fleet. Potential Phase III customers include Air Force Test Center, Air Force Life Cycle Management Center, NASA and prime contractors such as Boeing, Northrop-Grumman, and Lockheed-Martin.

REFERENCES:
1. Hill, R., Leggio, D., Capehart, S., and Roesener, A. "Examining improved experimental designs for wind tunnel testing using Monte Carlo sampling methods," Quality and Reliability Engineering International, 27 (6), 795-803, 2011.

2. Glaessgen, E.H. and Stargel, D.S., "The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles," AIAA 53rd Structures, Structural Dynamics, and Materials Conference, 2012 http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120008178_2012008334.pdf.

3. Goodrich, M., Gorham J., “Wind Tunnels of the Western Hemisphere,” Library of Congress, 2008.

4. Reimer, L., Braun, C., Chen, B.H., Ballmann, J.: Computational Aeroelastic Design and Analysis of the HIRENASD Wind Tunnel Wing Model and Tests. International Forum on Aeroelasticityand Structural Dynamics (IFASD) 2007, Stockholm, Sweden, Paper IF-071.

KEYWORDS: T&E, embedded sensors, scaled model test aircraft, flight test, multi-function materials, additive manufacturing, digital twin

AF14-AT02 TITLE: Telemetry for Massive Data Transfer and Storage

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop terabyte per second optical data link that can reliably operate on high-speed air platforms and maintain uninterrupted contact with the base station.

DESCRIPTION: Reliable communication and telemetry data links are vital for all air platforms. Data rate requirements for air platforms engaged in surveillance missions, or traveling at high speeds (Mach 5+), rapidly increase - potentially reaching hundreds of gigabits per second. In such situations, data management, processing, and data transfer face significant efficiency and effectiveness challenges. With the shrinking of available RF spectrum it is very difficult to obtain necessary bandwidth for such a link. Free space optical communication technology can facilitate high data rate transmission. It does not compete with users in the RF spectrum and is highly resistant to interference and jamming. It also has a low probability of detection and interception. Compared to an RF link, it offers significant advantages in terms of size, weight and power. It has been demonstrated that TBPS (terabytes per second) optical data links are realizable in fixed networks and it is desired to extend this technology to high-speed air platforms. Indeed, there are issues to overcome. Unlike RF data links, an optical data link has to maintain uninterrupted line of sight contact with its partner. Because of its narrow beam-width there are severe constraints in pointing, acquisition, tracking, and maintaining the line-of-sight contact. The high-g maneuvers of the high-speed aircraft and the associated rolling, pitching, yawing, and air-frame vibrations further complicate the problem. Telemetry links of 30+ kilometers are common in both Test & Evaluation and operations. Atmospheric degradation of an optical telemetry signal over these distances is significant. The Air Force is interested in a TBPS optical data link that can overcome these issues and reliably operate on high-speed air platforms.

Specific areas that need to be addressed include: high data rates (TBPS) from Mach 5+ aircraft to ground; multi-channel communications; characterization of effects of atmosphere and boundary layer turbulence on the communications; methods and equipment to enable pointing, acquisition, and tracking; and analysis of bit error rates. Bit errors should not exceed one bit per gigabit of data. Approaches that allow two-way data transmission will be considered, but the uplink channel may operate at a lower data rate.

PHASE I: Phase I will focus on design of an optical system, with minimal size, weight, and power requirements, capable of TBPS data rates from a Mach 5+ aircraft operating at a range of less than 100 km with receivers on lower altitude aircraft and ground stations. Pointing, acquisition, and tracking in turbulence issues need to be considered as part of the design effort.

PHASE II: Based upon initial design, construct prototype telemetry system and provide preferred protocols. Test system in a flight environment. Demonstrate proof-of-concept for reliable, high-speed optical telemetry as described. Document, deliver, and demonstrate prototype system to Air Force test engineers for further evaluation at the end of Phase II.

PHASE III: Develop commercial optical telemetry system. Government customers may include Air Force, Army, Navy, and NASA. Commercial interests may include Boeing, Lockheed Martin, ATK, etc.

REFERENCES:
1. Gagliardi R.M. and Karp S. (1995) Optical Communications, 2nd Edition, John Wiley.

2. Space ISR in a Contested Environment,
http://www.afcea.org/mission/intel/documents/AFC_FallIntel_WhitePaper_R4.pdf.

3. Anderson, J.D. (2006) Hypersonic and high-temperature gas dynamics, 2nd Ed. American Institute of Aeronautics and Astronautics, Reston, VA.

4. Majumdar, A.K. and Ricklin, J.C. (2008) Free Space laser Communications: Principles and Advances, Springer-Verlag.

KEYWORDS: T&E, optical data link, high speed air platform, high-volume data transfer

AF14-AT03 TITLE: High Resolution / Wide Bandwidth Arbitrary Waveform Generator for Telemetry Applications

TECHNOLOGY AREAS: Electronics

OBJECTIVE: Develop a highly integrated, low power, high resolution, wideband arbitrary waveform generator (AWG) suitable for next generation telemetry systems.

DESCRIPTION: With the continued burgeoning of the commercial wireless market, the demand for EM spectrum allocation toward the commercial market is ever increasing. This situation continues to intensify, resulting in the DoD telemetry spectrum being squeezed at the low RF frequencies and forcing migration toward higher RF frequency of operation and more complex modulated waveforms to increase data rate. Toward that end, the telemetry transmitter technology is facing an ever more challenging scenario where the need for miniaturization and efficient transmission to accommodate a wide range of platforms with size, weight, and power constraints such as UAVs, space-based crafts, and smart weapons.

This solicitation seeks to leverage advanced silicon and/or III-V compound semiconductor technologies with innovations in system architecture to realize low power, high resolution, wide bandwidth, and high dynamic range AWG technology to address long range telemetry transmitter solutions. Existing commercial AWGs, while have grown tremendously in speed and resolution [1,2], still fall short of requirements to address a growing demand for higher operating frequency and more complex digital modulation. In order to increase the modulation density and operate at higher carrier frequency, the AWG will need to scale up accordingly with time resolution while simultaneously reducing power dissipation and size that ultimately will lead to dramatic cost reduction. The goal for this topic is to realize a new generation of reconfigurable/ programmable AWGs with envisioned time resolution in excess of 50 GS/s, 14 bits of resolution, spurious free dynamic range (SFDR) greater than 80 dBc, and RF output power greater than 0-dBm. This novel solution will be applicable to instrumentation and waveform agile telemetry systems as well as phased-array applications.

PHASE I: Survey current state-of-the-art for high speed, high resolution AWGs. Identify key performance metrics, such as sampling rate, resolution, power dissipation, output power, and SFDR, which are consistent with TM transmitters. Develop advanced AWG system architecture concept meeting identified metrics and design hardware prototype.

PHASE II: Based on the analysis and design from Phase I, develop hardware prototype and validate key metrics. Construct prototype, characterize performance, and demonstrate suitability for Air Force telemetry applications. Deliver and demonstrate prototype to AFRL at the end of Phase II.

PHASE III: Refine components for targeted telemetry applications. Work with DoD to target integration into telemetry systems. Commercial radar and communications systems all require AWG components and have increasing needs for low-cost AWG technology.

REFERENCES:
1. Agilent M8190A AWG, http://cp.literature.agilent.com/litweb/pdf/5990-7516EN.pdf.

2. Tektronics AWG7000, http://www.tek.com/datasheet/signal-generator/awg7000-arbitrary-waveform-generator-arbitrary-waveform-generators.

3. Federal Communications Commission (2011). National Broadband Plan accessed at http://www.broadband.gov/download-plan/ on 10 Nov 2011.

KEYWORDS: T&E, telemetry transmitter, arbitrary waveform generator, spurious free dynamic range, UAV

AF14-AT04 TITLE: Fast and Efficient Nonlinear Flutter Prediction Capability

TECHNOLOGY AREAS: Weapons

OBJECTIVE: Development of a rapid, accurate, and physics-based Limit Cycle Oscillation (LCO) predictive tool.

DESCRIPTION: The presence of aeroelastic instabilities in the flight envelope of an aircraft often results in limitations on its capability to safely carry and deliver weapons accurately. Limit Cycle Oscillations (LCO) are one such instability that has been a recurring problem on some fighter aircraft. LCO is a nonlinear aeroelastic phenomenon that exhibits sensitivities to the external store carriage configuration and arises from the nonlinear interaction of the structural and aerodynamic forces acting on the affected aircraft component.

The available LCO prediction methods are empirical or computational in nature. However, many of these methods contain deficiencies indicating that they may not include all of the relevant physics associated with the complex fluid-structure interaction of the nonlinear aeroelastic system. In addition, many of the available methods are impractical for use on a large-scale production basis because they require convergence using iteration, leading to long run times on High Performance Computing (HPC) systems in order to obtain accurate solutions. Consequently, flight testing of the most critical configurations is required in order to determine the critical LCO characteristics. Flight testing continues to become more and more expensive, while the number and combinations of store configurations are continually increasing. Hence, it is desirable to develop physics-based computational algorithms employing advanced mathematical methods that rapidly and accurately determine the flutter and LCO characteristics so that potentially dangerous configurations can be identified with confidence and reduce the need for flight testing.

The development of physics-based, nonlinear flutter/LCO prediction methods that include subsonic and transonic aerodynamics, complex aircraft configurations, and multiple structural interactions of external stores on fighter aircraft, would help reduce the need for flight testing. Methods must be production-run-oriented and capable of generating time history response solutions for numerous flight conditions per day on conventional multi-processor computer platforms. Method must also conveniently interface with commercial finite element solvers and include user-friendly interface capability with pre-/post-processor and runtime utilities. Source code delivery (with limited access) is highly desirable, but approaches that allow use through unrestricted government license will also be considered.

PHASE I: Demonstrate the ability to produce LCO solutions using basic nonlinear source components. Proof-of-concept demonstration of the accuracy, speed, and efficiency of the approach and code for use in a production environment. Document the physics behind the theoretical formulation and mathematics of solutions embodied in the code.

PHASE II: Extend code to include additional and more complex nonlinear sources. Improve speed to produce flutter and LCO solutions in 1 hour or less for each Mach/altitude/AoA combination using conventional Win/Linux multiprocessor platform. Validate accuracy through benchmark comparisons with flight data or high-fidelity HPC test cases. Document test results and benchmark comparisons, including computational hardware and configuration, run times, accuracy, speed, and other performance metrics.

PHASE III: Validate the final code with wide range of F-16 LCO-sensitive flight test configurations. Update gov. license installations. Potential customers include Air Force Seek Eagle Office, Air Force Test Center and HPC centers. Commercial interests may include Boeing, Lockheed-Martin, and Northrop-Grumman.

REFERENCES:

1. Denegri, C. M., Jr., Dubben, J. A., and Maxwell, D. L., "In-Flight Wing Deformation Characteristics During Limit Cycle Oscillations," Journal of Aircraft, Vol. 42, No. 2, 2005, pp. 500-508.

2. Cunningham, A. M., and Meijer, J. J., "Semi-Empirical Unsteady Aerodynamics For Modeling Aircraft Limit Cycle Oscillations and Other Non-Linear Aeroelastic Problems," Proceedings of the International Forum on Aeroelasticity and Structural Dynamics, Royal Aeronautical Society, London, Vol. 2, 1995, pp. 74.1–74.14.

3. Chen, P. C., Sulaeman, E., Liu, D. D., and Denegri, Jr., C. M., "Influence of External Store Aerodynamics on Flutter/LCO of a Fighter Aircraft," AIAA Paper 2002-1410, April 2002.

4. Dowell, E. H., Thomas, J. P., Hall, K. C., and Denegri, C. M., Jr., "Theoretical Predictions of Limit Cycle Oscillations for Flight Flutter Testing of for the F-16 Fighter," Journal of Aircraft, Vol. 46, No. 5, 2009, pp. 1667-1672.

5. Sharma, V. K., and Denegri, C. M., Jr., "Time Domain Aeroelastic Solution Using Exact Aerodynamic Influence Coefficients and Nonlinear Damping," Proceedings of the International Forum on Aeroelasticity and Structural Dynamics, Royal Aeronautical Society, London, 2013, IFASD-2013-29D.

KEYWORDS: T&E, nonlinear aeroelasticity, limit cycle oscillations, aircraft flutter, structural dynamics

AF14-AT05 TITLE: Nondestructive Evaluation (NDE) Techniques for Composite Materials with Low Density Gradients

TECHNOLOGY AREAS: Weapons

OBJECTIVE: Develop and demonstrate nondestructive evaluation (NDE) techniques suitable for resolving the grain structure and damage induced defects in composite energetic materials with low density gradients between binder and the energetic particulates.

DESCRIPTION: We have a need for nondestructive evaluation (NDE) techniques for composite materials, such as energetics, which could help determine how the microstructure, and changes to the microstructure due to some mechanical or thermal insult, affects performance. In target penetration, for instance, the onboard energetic material may be subjected to severe environments of both pressure and shear loading. Damage to this material may result in premature initiation or suboptimal performance. This damage may be physically manifested at a scale far smaller than is usually captured in modern finite element codes. The damage affecting payload sensitivity is believed to occur at and below the grain scale, where the grain may be defined as a single energetic crystal (50–300 microns). Mesoscale simulations are frequently regarded as ones where the mesh or material description is resolved down to the level where individual constituents are treated with separate continuum level material descriptions. For the case of a traditional energetic material, this implies resolving the description down to this same energetic crystal level or smaller. X-ray computed micro tomography has been shown to be effective for many classes of composite materials, but scans of composite materials where the constituents are of similar density have been problematic for commercial off-the-shelf devices.

It is also desirable that such a device have the capability of deforming the energetic materials in situ such that the evolution of damage might be captured. Device should have a capacity for in situ deformation of the test sample at rates of up to 1/sec. Design to include safety analysis to qualify device for use with explosive or energetic materials. A minimum threshold of 1 micron resolution (not feature size) for a 12.7-mm diameter sample is required, with a goal of 1 micron resolution for a 50.8-mm diameter sample (or 0.25 micron resolution for a 12.7-mm diameter sample). The ability to discern between multiple crystal types is also desired. Device design and safety analysis should be completed during Phase I. Delivery of the device to an Air Force facility and demonstration of capabilities as described should occur by the end of Phase II.

PHASE I: Design experimental and diagnostic techniques for characterizing the microstructure of particulate composite energetic materials with low density gradients and grain sizes ranging from 50–300 microns. Device should have a capacity for in situ deformation of the test sample at rates of up to 1/sec. Design to include safety analysis to qualify device for use with explosive or energetic materials.

PHASE II: Develop and implement the designs and techniques from Phase I. Characterize a representative material. Design and conduct in situ deformation experiments demonstrating the ability to capture the evolution of damage. These tests may be conducted with approved simulant materials. Deliver device to Air Force facility and demonstrate capabilities as described above.

PHASE III: This technology is applicable to the testing of a wide variety of energetic materials and propellants of interest to the Air Force and DoD. Commercial interests may include mining, rocket propellant, and medical industries.

REFERENCES:
1. Wiegand, D. A., Pinto, J. and Nicolaides, N., J. Energetic Materials, 9, 19-80 (1991).

2. Pinto, J. and Wiegand, D. A., J. Energetic Materials 9, 205-263, (1991).

3. Funk, D. J., Laabs, G. W., Peterson, P. D and Asay, B. W., Shock Compression of Condensed Matter 1995, Woodbury, New York, 1996, pp 145-148.

4. Ward, I. M. and Hardley, D. W., An Introduction to the Mechanical Properties of Solid Polymers, John Wiley & Sons, New York (1993), pp 234-236.

5. Wiegand, D. A., Reddingius, B., Mechanical Properties of Confined Explosives, J. Energetic Materials, 23, 75-98 (2005).

KEYWORDS: T&E, confinement, pressure, mechanical properties, explosives, polymers

AF14-AT06 TITLE: Formal Synthesis and Verification Techniques for Autonomous Cyber-Physical Systems

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: To develop new techniques for specification, synthesis, and automated verification of autonomous controls and protocols for cyber-physical systems, especially those that engage in real-time cooperative decision making.

DESCRIPTION: Autonomous systems are in high demand due to their potential to provide new and improved capabilities while increasing manpower efficiencies. However, a lack of appropriate verification and validation methods prevent all but the most rudimentary autonomous systems from being fielded, since current brute-force testing processes are unable to cover the wide range of behaviors exhibited by such systems. This problem is exacerbated by the ad-hoc nature of autonomous system design; current approaches tend to be narrowly tailored to the system's anticipated operational domain. A further complication arises from the fact that many autonomous systems are also cyber-physical systems, i.e., hybrid systems that use computational elements to control physical entities. Thus, new techniques for more standardized and formalized specification, synthesis, and verification of autonomous cyber-physical systems are needed. These techniques need to take into account discrete decision-making portions of the system, continuous dynamics of the physical entities, and environmental effects the system might encounter. Furthermore, these techniques should be applicable to systems that engage in cooperative behaviors, either with other autonomous systems or with human operators. In the latter case, advanced techniques for human-automation collaboration are also needed. And finally, these techniques should be formal in the sense that they are mathematically based and can be used to perform automated or semi-automated system verification and provide analytical proof of performance.

PHASE I: Develop a formal framework for autonomous cyber-physical system specification, synthesis, and verification and show how it can be used in a proof-of-concept application.

PHASE II: Implement a prototype for the Phase I framework and application in a simulated or lab-based environment. Show how the framework demonstrates an improvement over existing techniques, quantifying its performance using appropriate metrics.

PHASE III: Formal techniques for autonomous cyber-physical specification, synthesis, and verification have a wide variety of military and commercial applications, including autonomous cars, UAV cooperative control, terminal area operations for airports, automated materials handling and warehousing, etc.

REFERENCES:
1. E. Clarke and J. Wing, "Formal Methods: State of the Art and Future Directions," ACM Computing Surveys (CSUR), 28(4): 626-643, 1996.

2. R. Alur et al, Hybrid Automata: An Algorithmic Approach to the Specification and Verification of Hybrid Systems, Springer-Berlin, 1993.

3. T.A. Henzinger, P.H. Ho, and H. Wong-Toi, "HyTech: A Model Checker for Hybrid Systems," in Computer Aided Verification, pp. 460-463, Springer-Berlin, 1997.

4. M. Fisher, R.H. Bordini, B. Hirsch, and P. Torroni, "Computational Logics and Agents: A Roadmap of Current Technologies and Future Trends," Computational Intelligence, 23(1):61-91, 2007.

5. T. Shima and S.J. Rasmussen, editors, UAV Cooperative Decision and Control: Challenges and Practical Approaches, SIAM, 2009.

KEYWORDS: verification, agent design, cyber-physical systems, autonomy, formal methods

AF14-AT07 TITLE: <u>Higher Order Mesh Generation for Simulation of Complex Systems</u>

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop a software package for the generation of a computational mesh formed by high-order elements.

DESCRIPTION: The computational analysis of complex systems and multi-scale physics is driving the computational science community to adopt higher order discretization schemes such as the discontinuous Galerkin finite element method. Higher order computational methods have an intrinsic accuracy advantage for a given mesh density over a mesh comprised of linear elements. The accurate simulation of complex systems such as jet noise prediction, combustion, blast injury analysis, turbulence and transition, and bio-mechanical analysis are prohibitively expensive for traditional methods, but become tractable with the computational efficiency of higher order methods.

Many researchers have developed software utilizing higher order methods; however, the creation of a suitable higher order mesh is a bottleneck in the simulation process. Traditional mesh generation efforts have focused on the creation of high-order elements by the simple merging of linear elements. Because a well-suited higher order mesh will be much coarser than a corresponding linear mesh, straight-forward application of existing mesh generation algorithms can lead to distorted and invalid elements for even simple domains. Furthermore, many elements away from the curved boundaries may need to be curved, too, to avoid mesh lines crossing into each other, resulting in negative Jacobians. Conversion from a linear mesh to a higher order mesh must take element quality and surface accuracy into consideration.

The goal of this effort is to provide higher order mesh generation capability within the simulation process currently in use by DoD programs.

PHASE I: Examine the feasibility of high-order mesh generation from a hybrid linear element mesh while retaining boundary geometry. A preliminary design of a software package that can create a high-order (up to 4th order) hybrid element grid about a complex geometry should be developed.

PHASE II: Develop a software package that can be used with existing high-order computational analysis software for the prediction of fluid flow in complex systems. Critical features of the geometry must be retained. The final system should be able to create high-order (user defined up to 4th order) meshes comprised of hybrid elements and provide export in the CGNS format. The software package should be implemented, tested, and demonstrated using a representative complex geometry.

PHASE III: Further research and development during Phase III efforts will be directed toward refining and implementing the new design software to meet U.S. Air Force and end-user requirements. The software package should be implemented and tested on a variety of platforms that are of interest to the DoD.

REFERENCES:

1. HT Huynh, Z. J. Wang, P. Vincent, High-Order Methods for Computational Fluid Dynamics: A Brief Review of Compact Differential Formulation on Unstructured Grids, AIAA 2013-2564.

2. Miguel R. Visbal, Datta V. Gaitonde, “Very High-Order Spatially Implicit Schemes for Computational Acoustics in Curvilinear Meshes,” Journal of Computational Acoustics, volume 9, issue 4, 2001.

3. S.J. Sherwin, J. Peiro, “Mesh Generation in Curvilinear Domains Using High-Order Elements,” International Journal for Numerical Methods in Engineering, volume 53, issue 1, pages 207-223, 2002.

4. Per-Olof Persson, Jaime Peraire, “Curved Mesh Generation and Mesh Refinement using Lagrangian Solid Mechanics,” 47th AIAA Aerospace Sciences Meeting, January 5-8, Orlando, 2009.

5. Zhong Q. Xie, Ruben Sevilla, Oubay Hassan, Kenneth Morgan, “The generation of arbitrary order curved meshes for 3D finite element analysis,” Computational Mechanics, volume 51, issue 3, page 361, 2013.

KEYWORDS: high-order elements, mesh generation, computational fluid dynamics, computational aeroacoustics

AF14-AT08 TITLE: Highly-Resolved Wall-Shear-Stress Measurement in High Speed Flows

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Develop innovative precision micro-scale surface-mountable sensor for measuring local wall shear stress in high speed flow field (approximately $0.8 < M < 5$) to enable characterization of critical boundary layer flows in ground and flight tests.

DESCRIPTION: Since the dawn of aviation, aeronautical sciences and development of flow measurement and diagnostic tools have progressed at the pace of advancements in materials, nano-electronics and computational systems. Understanding the complex flows encountered in ground and flight tests related to hypersonic vehicles, such as HIFiRE, X-51, and other future systems, requires, in addition to sophisticated numerical modeling and analysis, reliable experimental diagnostic tools. Complex flows involve combination of 3-D, unsteady, transitional and flows over rough surfaces, with combustion and shocks; practical Air Force systems mostly include these flow scenarios. Wall shear stress or skin friction is a key parameter critical for assessing energy efficiency and controllability of any aerodynamic system. Researchers have been working for many decades on shear stress sensors for high speed flows. Historically, only indirect methods such as the heat flux measurements have been used to compute skin friction for lack of a reliable, simple and affordable sensor to measure skin friction. A variety of concepts and devices ranging from bulky flexures and floating heads to strain gages to fiber-optic Fabry-Perot interferometer types and, more recently, CNF (carbon nano-fiber) array flexure and metallic nanoparticles-impregnated-rubber sensor with variable electrical conductivity concepts were used.

We are seeking a new method of making the measurement that is ready-to-use, easy, reliable, temporally and spatially resolved as required, capable of withstanding high temperatures up to 1200K, using surface mount or other innovative approaches. It is desirable to have combined pressure measuring capability in these sensors. This sensor system design developer should be aware of current issues in modeling complex flows to elicit the weaknesses of CFD analysis. The design developer is expected also to be able to capture and specify 1) data needs and anchoring/validation methodology to corroborate with computational results, 2) how to discover computational model deficiencies, 3) data acquisition methods, and 4) calibration and uncertainty characterization approaches. The sensor hardware design has to withstand vibration, shock impingement, high-temperature and electromagnetic effects, if any, experienced in hypersonic flow and combustion environment. Recommended wall shear stress measurement error is within + or - 10% whereas the expected CFD analysis error could be up to ~50%. The shear stress range and sensitivity requirements of the sensor for use in potential Air Force test centers and research institutions vary depending on the shock tunnel specifications, test models and test requirements. To be useful for various research needs in the Air Force and industry, it is projected that the shear stress measurement range shall be from 5 to 1500 N/m^2 and frequency response from d.c. signal to 1 MHz in both stream-wise and cross flow directions of 2-D flows. The sensor head shall preferably be smaller than 10 mm^2 in area and flush mountable on the surface of test models and capable of operating up to five minutes at 1200 K and 750 kW/m^2 heat flux environment.

Apart from military applications, great potential exists for affordable skin friction sensors in university shock tunnel test facilities, commercial aviation, naval ship and auto racing industries.

PHASE I: Demonstrate a proof-of-concept version of the sensor system within a high-speed boundary layer with and without chemical reactions. Meet proposed stress, frequency, temperature and physical size requirements. Incorporation of combined pressure measuring capability in this sensor is desirable.

PHASE II: Measure X and Y components of local wall shear stress within a high-speed flow field in external 2-D flow conditions and wall shear stress in 1-D internal flow conditions involving combustion. Meet proposed stress, frequency, temperature and physical size requirements.

PHASE III: Fully demonstrate the entire sensor system within an Air Force-sponsored ground or flight research campaign at subsonic to hypersonic conditions. Non-military applications include university shock tunnel test facilities, commercial aviation, naval ship and auto racing industries.

REFERENCES:

1. Volkan Otugen, Valery Sheverev, “Micro-optical wall shear stress sensor,” Polytechnic Institute of New York University, US patent 7701586 B2, publication date: Apr. 20, 2010.

2. Joseph A. Schetz, “Direct Measurement of Skin Friction in Complex Flows,” Paper No. AIAA 2010-44, 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, 4 - 7 January 2010.

3. Michael L. Kuntzman and Neal A. Hall, “Rotational Capacitive Micromachined Ultrasonic Transducers (cMUTs),” IEEE Journal of Microelectromechanical Systems - JMEMS Letters-2013-0168.

4. Mark Sheplak, Venkataraman Chandrasekaran, Anthony Cain, Toshikazu Nishida, and Louis N. Cattafesta III, “Characterization of a Silicon-Micromachined Thermal Shear-Stress Sensor,” AIAA Journal, Vol. 40, No. 6, June 2002.

5. Osamu TERASHIMA, Takuya SAWADA, Yasuhiko SAKAI, Kouji NAGATA, Hirotaka HIDA and Mitsuhiro SHIKIDA, “Measurement of Wall Shear Stress by Using Micro-fabricated Sensor," Nagoya University, Aichi, Japan, ISEM 2012 – 2nd International Symposium on Experimental Mechanics, Taipei, Nov. 2012.

KEYWORDS: turbulence transition, supersonic flows, wall shear stress, skin friction, sensor

AF14-AT09 TITLE: <u>Multi-scale Interrogation, Location, and Characterization of Defects using</u>

Electro-Optic Techniques

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop non-destructive, contactless, electro-optical multi-scale interrogation or imaging technique to quickly and accurately measure, locate, and characterize features and defects in coatings on aircraft.

DESCRIPTION: The characterization of materials and coatings in the field by maintainers is required to ensure the operational integrity of aircraft systems employing a variety of materials. Material defects may manifest themselves in coatings due to operational usage, flight loads, environmental conditions, inadvertent damage, and other causes. Many of these defects are visually detectible. The defects need to be catalogued and characterized to ensure that they do not impact the operational capability and performance aircraft and weapons systems. Therefore, the defects must be properly identified and characterized so that an accurate assessment can be made to determine the impact of the defective material on the health of the coating system. Current manual inspection techniques by trained maintainers are time-consuming and prone to human error. Inspection concepts such as fixed location drive through scanners with the ability to quickly capture data over the entire aircraft and other innovative approaches will be considered. The system should be capable of inspecting the entire aircraft outer surface while maintaining high resolution and possessing an automatic defect recognition capability to pass specific data, including the location of defects in aircraft coordinates, back to maintainers or specific databases. While idealized drive-through inspection concepts are not new, the technology needed for successfully implementation has been lacking. Recent advancements in active electro-optical interrogation techniques or passive high resolution, high-dynamic range, imaging systems may now make it feasible to implement automated rapid inspection systems that are suitable of addressing Air Force test needs. Research and development of subsystem technologies, as well as their incorporation into a large-scale measurement system, is desired.

PHASE I: Develop approach for noncontact active and passive sensor electro-optic technology to rapidly identify, characterize and register visual damage/defects in coatings. Sensing system shall include data analysis algorithms to automatically recognize defects in coatings for a large range of sensor-to-material angles, defect sizes, shapes, and orientations, and be capable of large-scale interrogation.

PHASE II: Develop breadboard, laboratory scale version of a system capable of scanning large, complex targets or representative materials and coatings. Demonstrate system's ability to automatically recognize a variety of multi-scale defects in variety of locations on representative, complex objects and provide accurate characterization and positional registration data in local target coordinates as described. Deliver and demonstrate prototype instrument and inspection software to Air Force test facility.

PHASE III: Transition to a full-scale development effort capable of required integration into Air Force environments. Potential customers include Air Force Test Center, Air Force Life Cycle Management Center, and prime contractors, such as Boeing, Lockheed, and Northrop.

REFERENCES:
1. Roman Louban, "Image Processing of Edge and Surface Defects: Theoretical Basis of Adaptive Algorithms with Numerous Practical Applications," Springer Series in Materials Science, 1st Ed., ISBN-10: 3642006825, ISBN-13:978-3642006821, Springer, 2009.

2. M.L. Smith, "Surface Inspection Techniques: Using the Integration of Innovative Machine Vision and Graphical Modeling Techniques," Engineering Research Series, 1st Ed., Duncan Dowson Ed., ISBN-10: 1860582923, ISBN-13: 978-1860582929, Wiley, 2001.

3. Robert E. Green, B. Boro Djordjevie, and Manfred P. Hentschel, Eds., "Nondestructive Characterization of Materials XI: Proceedings of the 11th International Symposium," ISBN: 3540401547, Springer-Verlag Berlin and Heidelberg GmbH & Co. K, Berlin, Germany, June 24-28, 2002.

4. Dwight G. Weldon, "Failure Analysis of Paints and Coatings," Revised Ed., ISBN: 978-0-470-69753-5, Wiley, 2009.

KEYWORDS: T&E, defect characterization, electro-optic sensing, nondestructive evaluation, analysis algorithms

AF14-AT11 TITLE: Nanoscale Field Effect Transistors for Biosensing Applications

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop techniques for fabrication and characterization of high performance biofunctionalized field effect transistors (bio-FETs) for sensing applications.

DESCRIPTION: Nanoscale electronic materials such as silicon nanowires, carbon nanotubes and graphene are considered as promising materials for biosensing applications. Field effect transistors (FETs) using nanomaterials have been demonstrated to be a powerful sensing platform due to their high surface area-to-volume ratio. For bio-FETs, receptor-like moieties such as peptides, nucleic acids and proteins that serve as sensing element are attached to the surface of the nanomaterial and are capable of recognizing and binding to a desired target. The captured target modulates the surface potential of the nanoscale device and alters the electronic properties of the bio-FET device. However, the performance characteristics, device-to-device reproducibility and reliability of bio-FET devices are still elusive. For sensor applications, well-defined and repeatable current response of the FET device characteristics is needed. Many of the emerging and most promising FET technologies do not provide the reliability needed for real-world military applications. Reduced costs of sensor production demands scalable technologies, where devices can also be tested during fabrication to support an objective of <10% variation in their performance. This topic is to demonstrate and develop reliable and well-characterized bio-FETs. The FET devices must be amenable to biofunctionalization and will function in flow-through modules in biological fluids like sweat, saliva or serum. More importantly analysis-of-alternatives must be performed to down-select, based on performance, the appropriate nanomaterial (Si NWs, graphene, CNT, etc.) for the bio-FET device for the desired sensing application. This analysis should target the objectives of narrowing FET sensor variability and feasibility for low-cost using much of the existing large-scale production infrastructure.

PHASE I: Demonstrate fabrication and characterization of bio-FET module. Develop optimal biofunctionalization strategy to detect markers in biological fluids (cytokines, neuropeptides, small molecules). Provide detailed analysis-of-alternatives for bio-FET design selection for biosensing applications. Assess the possibility for achieving <10% variability in FET sensor performance with the selected device.

PHASE II: Optimize the fabrication of the bio-FET devices in sufficiently large quantity for application demonstrations, while maintaining cost effectiveness for potential application implementations. The devices should demonstrate <10% variation in device performance. Generate reliability test data to support reliability objective. Long-term stability and reusability of the device should be addressed.

PHASE III: Military Application: Advance sensors for chem-bio, human performance monitoring and man-machine interfaces. Commercial Application: Sensors for healthcare, environmental monitoring. Sensor modules can also find use with law enforcement and first responders.

REFERENCES:

1. Kybert N. J., (2013) Nano Letts DOI:10.1021/nn400359c.

2. Krivitsky V. et al., (2012) Nano Letts 12, 4748-4756.

3. Kwon O.S. et al., (2012) ACS Nano 6, 1486-1493.

4. Kuang Z. et al., (2010) ACS Nano 4, 452-458.

KEYWORDS: nanomaterials, bio-FETs, biosensors

AF14-AT12 TITLE: Electrically Small Multiferroic Antennas

TECHNOLOGY AREAS: Electronics

OBJECTIVE: To develop electrically small antennas based on new multiferroic systems where a magnetic field of an incident signal causes mechanical strain in magnetostrictive material layers and electrical voltage in piezoelectric material layers under strain.

DESCRIPTION: Traditional design of antennas relies primarily on the electromagnetic (EM) resonance characteristic of an electrically conductive antenna structure. This necessitates large antenna sizes thereby making communication capabilities of small unmanned air vehicles (UAVs) at VHF and UHF frequencies particularly challenging. Recent developments in multiferroic (MF) materials suggest an order of magnitude reduction in antenna dimensions by (i) exploiting voltage control of magnetization and (ii) reducing wave speed. Direct cross-coupling between electric and magnetic states in MF materials allows EM wave without large electrical currents. New systems use an electric field to manipulate intrinsic magnetization of materials rather than flowing electrons through a “lossy” conductor. This provides the potential to improve an antenna’s efficiency in the small-scale systems. MF antennas also allow intrinsic coupling of the EM wave to acoustic modes using the transduction between electromagnetic and mechanical waveforms. Since the mechanical wave speeds (~10^3 m/s) are much slower than EM wave speeds (10^8 m/s), such transduction provides a unique opportunity to dramatically reduce antenna dimensions. The concept is expected to allow the design of a sub-wavelength conformal antenna.

PHASE I: Develop a concept of design and fabrication of transmitting antenna element in the UHF band based on multiferroic (MF) materials and sub-wavelength constraints. Analytically demonstrate the antenna performance using computational tools and provide a fabrication plan for the new MF antenna structure.

PHASE II: Relying on the design concepts proven under Phase I, fabricate and test a prototype MF antenna. Develop a new demonstration prototype based on the first iteration and evaluate its performance. Devise analytical remedies to overcome any issues of undesired antenna performance.

PHASE III: Smaller communications/SIGINT systems for flight in controlled airspace, particularly for UAVs, requiring operational capability in the VHF and UHF frequency range. Extremely small antennas have wide applications in commercial products including cell phones and medical imaging.

REFERENCES:
1. J. Das, Y.-Y. Song, N. Mo, P. Krivosik, and C. E. Patton, “Electric-Field-Tunable Low Loss Multiferroic Ferrimagnetic-Ferroelectric Heterostructures,” Adv. Mater. 21(20), 2045–2049 (2009) [doi:10.1002/adma.200803376].

2. G. Srinivasan, “Miniature antenna based on magnetoelectric composites,” Electron. Lett. 44(8), 506-508, INST ENGINEERING TECHNOLOGY-IET, HERTFORD (2008).

3. S. M. Keller and G. P. Carman, “Electromagnetic wave propagation in (bianisotropic) magnetoelectric materials,” Journal of Intelligent Material Systems and Structures 24(5), 651–668 (2013) [doi:10.1177/1045389X12467518].

4. S. M. Keller and G. P. Carman, “Plane wave dynamics in multiferroic materials using Maxwell's equations and equation of motion,” presented at Behavior and Mechanics of Multifunctional Materials and Composites 2012, 12 March 2012, San Diego, California, USA, 834204–834210, SPIE [doi:10.1117/12.923595].

KEYWORDS: electrically small antennas, multiferroic antennas, multifunctional structures, micro-UAV

AF14-AT13 TITLE: Silicon Photonic-Electronic System Level Integration

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Design and demonstrate photonic information processing and sensor systems in a CMOS compatible silicon photonic-electronic platform, demonstrating distinct functionality on the basis of CMOS integration and scaling.

DESCRIPTION: A major promise of silicon photonics is in system-level integrated systems. Although a few devices built in silicon do exceed the performance of devices in other material systems, most device-level performance numbers for silicon photonic devices are either comparable to or worse than alternatives in specialized materials systems such as lithium niobate, III/V, etc. This is not surprising, since each of these materials systems has been chosen for best-in-type performance for discrete devices. If the world of photonics is going to remain primarily one of discrete components, silicon photonics may have an impact on a few classes of device, but is unlikely to have a huge impact overall on the structure of the industry. The place where silicon photonics will have a significant impact is in systems where scaling to high complexity, or where closely integrated electronics, give unique advantages.

The goal of this program is (a) to explore high military and civilian impact applications of CMOS compatible silicon photonic-electronic integrated circuits and (b) demonstrations of these same systems in Phase II. By CMOS compatible, one specifically references processes which have proven compatibility with the fabrication of transistor-based electronics. Thus, of interest are processes with a proven track record of actually fabricating CMOS devices, not speculative processes that may be made CMOS compatible at some point in the future. In particular, system demonstrators where multiple-order-of-magnitude improvement in SWaP metrics are sought, as are devices which provide different-in-kind functionality on the basis of high complexity or electronics integration, compared to existing optical devices and systems.

PHASE I: Demonstrate feasibility of a highly scaled integrated photonic system through detailed system design, based on known or simulated performance of components in an existing electronic-photonic CMOS platform, of a proof-of-concept demonstrator circuit such as routers, multi-spectral detectors, beamsteering devices, modulators, etc. Demonstrate benefits of large-scale integration.

PHASE II: Develop a manufacturable prototype of the demonstration circuit designed in Phase I. Demonstrate CMOS integration of electronics and photonics, and test both device components and entire system. Demonstrate plausibility of scaling to larger system as needed to establish superiority over alternative approaches. Report on results and analysis, and on project plans for highly scaled system.

PHASE III: Silicon-based integrated photonics-electronic circuits have the potential for revolutionizing communications, information processing, biological and chemical sensing, and medicine. Key applications include RF signal processing, radar, imaging systems and high speed communications.

REFERENCES:

1. Bahram Jalali and Sasan Fathpour, "Silicon Photonics," J. Lightwave Technol. 24, 4600-4615 (2006).

2. Cary Gunn; "CMOS Photonics Technology Overview," Compound Semiconductor Integrated Circuit Symposium, 2006. CSIC 2006. IEEE, pp. 139-140, Nov. 2006.

3. Weiss, B.L.; Soref, R.A.; "Introduction to the Issue on Silicon-Based Optoelectronics," Selected Topics in Quantum Electronics, IEEE Journal of, vol. 4, no. 6, pp. 897-898, Nov/Dec 1998.

4. Soref, R.; "The Past, Present, and Future of Silicon Photonics," Selected Topics in Quantum Electronics, IEEE Journal of, vol. 12, no. 6, pp. 1678-1687, Nov.-Dec. 2006.

5. Tsybeskov, L.; Lockwood, D.J.; Ichikawa, M.; "Silicon Photonics: CMOS Going Optical," Proceedings of the IEEE, vol. 97, no. 7, pp. 1161-1165, July 2009.

KEYWORDS: silicon photonics, CMOS photonics, silicon photonic systems integration, integrated photonics, CMOS integration, scaling, nanophotonics, photonic-electronic integrated circuits, chip-scale interconnects, RF photonics, chip-scale optical networks, Group IV photonics, nanofabrication, design tools, information processing, sensor systems

AF14-AT15 TITLE: <u>Quantum-Entanglement Based QKD Security Guarantee Over QoS-Driven 3-D Satellite Networks</u>

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Research, develop, and evaluate algorithms and technologies for quantum-entanglement based QKD security guarantee over QoS-driven 3-D satellite networks.

DESCRIPTION: Security guarantee is one of the most important requirements in military communications. Quantum key distribution (QKD) [1] is a methodology for generating and distributing random encryption keys using the principles of quantum physics, which enables two distant communications parties (sender: Alice, receiver: Bob) to securely communicate in a way that cannot be eavesdropped on without being detected. In particular, QKD technologies seek to provide reliable, efficient security for wireless links between the ground station and the satellite employed in military communications under tactical and strategic environments. To accomplish those requirements, an EPR (Einstein-Podolsky-Rosen) entanglement-based QKD security scheme in satellite system must be established with the efficient quantum channel and classical channel [2].

Recent and ongoing research has mainly focused on applying the QKD technology into various communicating applications, such as global security communication networks, optical networks, and wireless radio networks [3-5]. The communications between different parties can obtain the absolute secret keys by adopting the QKD scheme. However, there is no research focusing on the security guaranteed quality of service (QoS) for the quantum communications, over both the quantum channel and the classical channel, which were used to transmit the secret keys and the transmission message, respectively. The classical channel is capable of exchanging digital data at high bit rates to enable interactive alignment, time synchronization, key sifting and error correction to be carried out in real time. The quantum channel is a communication channel supporting the transmission of quantum signals that are typically encoded as qubits: two-state quantum systems such as the horizontal/vertical polarization states of a single photon. Using the QKD scheme, Alice and Bob can establish the absolute key carried by the accurately measured quantum states. The eavesdropper Eve cannot get the information carried by the non-orthogonal quantum states. Nonetheless, the links between Alice and Bob are always affected by a large number of factors due to the transmission environments, especially in free space communication, including ground-to-satellite, satellite-to-ground, and satellite-to-satellite. So, the transmitted information can be dropped due to the unreliable link quality. Thus, it is very critical to provide the security-guaranteed QoS over both the quantum channel and the classical channel.

Therefore, we need to obtain the absolute security while guaranteeing the QoS of the transmission information, considering the link attenuation including the effect of beam diffraction, attenuation, and turbulence-induced beam spreading caused by the atmosphere, receive aperture diameter, and losses within the telescopes acting as antennas, as well as antenna pointing loss. Also, the QoS performance of each link in terms of the rate of transmit information is limited by the maximal number of photons or entangled photon pairs that can be created and detected [3].

In this effort, the Air Force is soliciting innovative research proposals in the area of performance enhancement of QKD security oriented QoS guaranteeing for current military satellite communication, both in uplink and the downlink between the ground station and the satellite. Particularly, innovative algorithms and responsive technology development and demonstration for QKD security guarantee using the quantum entanglement are of importance. First and foremost, the reliable QKD must be guaranteed for the communication between the ground station and the satellite, in terms of guaranteeing the rate of transmits information of each link. Second, we need to consider the effect resulting from the number of photons or entangled photon pairs. Finally, considering that different services required by distinct applications impose different security and QoS requirements, we also need to develop the novel multi-task QoS mechanism to support different QoS requirements.

PHASE I: Develop and evaluate the algorithms or approaches to guarantee the security based on QoS provisioning with regard to signal-to-noise ratio (SNR) of quantum channels and classical channels between satellite earth stations and Low Earth Orbit (LEO)/Geostationary Orbit (GEO) satellites for military communications.

PHASE II: Refine the Phase I algorithms and system concepts. Demonstrate the effect resulting from the number of photons or entangled photon pairs. To obtain the relationship between the security guarantee based on QoS provisioning and the quantum entanglement distribution, with the purpose of guaranteeing the QKD security performance in harsh and/or contested military communications.

PHASE III: Established comprehensive and innovative multi-task security guarantee system architectures to support QoS provisionings for various military communication applications over 3-D satellite wireless networks.

REFERENCES:
1. J. G. Rarity, P. R. Tapster, P. M. Gorman and P. Knight, “Ground to satellite secure key exchange using quantum cryptography,” New Journal of Physics, 2002.

2. X. Ma and T. Herbst, “Quantum teleportation over 143 kilometers using active feed-forward,” Nature 489, pp. 269-273, 2012.

3. M. Aspelmeyer, T. Jennewein, and A. Zeilinger, “Long-distance quantum communication with entangled photons using satellites,” IEEE Journal of Selected Topics in Quantum Electronics, Vol. 9, No. 6, pp. 1541-1551, 2003.

4. E. David, Martinez-Mateo Jesus, C. Alex, and M. Vicente, “Secure optical networks based on quantum key distribution and weakly trusted repeaters,” IEEE/OSA Journal of Optical Communications and Networking, Vol. 5, No. 4, pp. 316-328, 2013.

5. J. Russell, “Application of quantum key distribution,” IEEE MILCOM 2008.

KEYWORDS: free space quantum cryptography, quantum key distribution, QKD, satellite communication, LEO/GEO downlink/uplinks, quantum channel, classical channel

AF14-AT16 TITLE: A Range Segment Upgrade for Air Force Satellite Control Network with Smart Antennas and Cognitive Satellite Radios

TECHNOLOGY AREAS: Space Platforms

OBJECTIVE: Evolutionary space ground link subsystems, including satellite RF interference modeling & analysis; interference susceptibility of satellite transponder modulations; and adaptive phased array antenna for multi-satellite receptions/multi-path nulling.

DESCRIPTION: The Air Force Satellite Control Network (AFSCN) has provided launch control for space lift vehicles; tracking, telemetry and commanding for on-orbit satellites; and test support for ballistic missiles and space experiments. Its future upgrades and modernization are being planned to include detection and selection of radio spectrum without interfering with other signals; suppression of backlobe and sidelobe receive energy; cancellation of unwanted background noise and interference; and improvements of bandwidth efficiency and occupied channel bandwidth reduction. The primary objective of the STTR topic solicitation is to request industry inputs to address possible near-term (less than 5 years) technology development initiatives that will enable the completion of remote tracking station upgrades. Science and technology solutions as being anticipated for in-band telemetry, tracking and commanding (TT&C) and efficient spectrum usage should enable interoperability among military and civil space assets, commercial space opportunities, and reduction of infrastructure, operational and maintenance costs.

To meet the technical challenges listed above, innovative and emerging system concepts employing software-defined radios and adaptive array antennas for satellite communications, should be capable of 1) migrating the existing uplink of L-band (1760-1842 MHz) to an S-band of 2050-2110 MHz which is to be unified with the current S-band of 2200-2300 MHz downlink capability, 2) effective usages of operational spectrum to eliminate and/or reduce radiometric tracking and efficient waveform modulations for communications data rate increases, and 3) in-band control with standard interfaces and/or plug and use. In particular, scientific breakthroughs and technology development shall be capable of addressing the following satellite operational challenges:

i) Operational issues pertaining to satellite RF interferences (RFI) of various types, e.g., continuous waveform, narrow-band, wideband, impulse and/or pulsed interferences where enabling capabilities of modeling and simulation analysis, in addition of statistical interference prediction of means of satellite RFI durations, times between satellite RFI, etc., are being sought for any given settings of remote tracking stations' beam widths and elevation angles, interfering satellites between Low-Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Orbit (GEO), desired and/or interfering satellite RF, RF power radiations, etc.;
ii) Impacts of satellite RFI on space ground link ground subsystems (SGLS) where semi-analytical models of impact analysis ought to help predicting performance degradation of SGLS under considerations of satellite transmitted powers, waveform structures, antenna patterns, relative geometries, etc.;
iii) Interference susceptibility of various satellite modulation schemes within which operational effects of satellite RFI on performance degradation of satellite communications channels and/or frequency carrier tracking loops are of concerns; and
iv) Design principles of smart RF antennas for flexible antenna patterns, agile signal tracking and efficient use of spectrum energy are of the Air Force interest.

PHASE I: Conceptualize SGLS solution with multi-satellite reception, smart antennas and unified S-band for TT&C/communications. Predict uplink signal powers and margins required by LEO/MEO/GEO satellites for reliable satellite comm. against satellite RFI/orbital propagation latency. Validate end-to-end modeling/analysis of data channels with modulations, coding schemes, radiated powers, symbol rates, QoS.

PHASE II: Assess performance of SGLS toward satellite RFI types. Evaluate bit SNR impacts of coded data channels via numbers of satellite RFI, symbol block sizes, etc. Design software library associated with smart antenna for adaptive beamforming/waveforms, modem modulation/demodulation, adaptive pattern null forms, etc. Integrate software library for smart antennas with hardware emulators for satellite transponders, satellite RFI, SGLS subsystems via GNU radio & universal software radio peripheral (USRP).

PHASE III: If successfully developed, integrate the dual-use adaptive radio technology anticipated into the AFSCN with assistance of DoD primes to ensure future satellite controls/ground-space link operations capable of accessing/using multiple frequencies in congested, contested radio spectrum conditions.

REFERENCES:
1. L. Hodges and R. Woll, "Air Force Satellite Control Network (AFSCN) Support for Operational Responsive Space (ORS)," 6th Responsive Space Conference, CA, 2008.

2. P. Oleski, et. al., "Transmit Receive Module for Space Ground Link Subsystem (SGLS) and Unified S-band (USB) Satellite Telemetry, Tracking and Commanding (TT&C) and Communications," MILCOM 2004.

3. J. Gevargiz, T. Nguyen, and D. Bishop, "Statistical Interference Prediction for Ground Stations from Orbiting Satellites, Part I: Simulation of Interference Duration and Analytical Approach for the Determination of Projection Ratios," 1990.

KEYWORDS: space ground link subsystem, satellite RF interference, smart antenna, antenna nulling, beamforming, adaptive antenna patterns, channel modulation, channel coding, frequency carrier tracking, bit error rate, bit SNR, interference susceptibility, uplink signal powers, link margins, interleaves, symbol rates, GNU radio, hardware emulators, USRP, quality-of-service, QoS

AF14-AT17 TITLE: Protection of DoD Satellite Communications Against RF Interferences and Personal Mobile Telecommunications

TECHNOLOGY AREAS: Space Platforms

OBJECTIVE: Innovative software-defined radios, spectrum access and networking solutions for planning flexibility, guaranteed data rates, frequency reuses and anti-jamming capability, leading to successful demonstration of protected tactical space communications

DESCRIPTION: Currently, the Air Force has an urgent need to protect DoD satellite communications against Radio Frequency Interferences (RFIs) and personal mobile telecommunications. In response to this opportunity of research and technology development, progress in agile satellite radios; low Size, Weight and Power (SWaP) satellite transceivers; and dynamic spectrum access should be able to address the existing capability gaps in military satellite communications such as connectivity (e.g., coverage, capacity, on-demand throughput, etc.), protection (e.g., survivability, restoration, etc.), operations management and availability of operations (e.g., continuity of service, terminal availability and synchronization) in both congested and contested environments. Next-generation frequency agility, dynamic spectrum access, and autonomy for cognitive satellite radios are expected to: i) detect and identify attributes of emerging RFIs from pulsed radars, mobile terminals, base transceiver stations, and potential RF jammers; ii) estimate Low-Earth-Orbit/Medium-Earth-Orbit/Geostationary satellite and/or aerial link margins in presence of weather and scintillation effects, modulation losses for satellite transceiver waveforms and aggregate interference power density from i; and iii) leverage multi-agent game theory, utility and risk optimization for mitigating RFIs from pulsed radars, mobile terminals, base transceiver stations and emergent RF jammers while subject to local situational awareness of Equivalent Isotropically Radiated Powers (EIRPs), delayed RF propagation measurements, and channel feedbacks.

Furthermore, cognitive satellite radio users could possibly share models of mission cooperation and terminal synchronizations, while terrestrial RFIs and cognitive RF jammers might not know about. Henceforth, it remains to be seen whether cooperative satellite radio users with radio resource management policies and active anti-jamming strategies would perform better than the traditional approach of open-loop frequency hopping over ultra-high bandwidth constraints. With regards to the development of 3-D space/aerial/terrestrial modeling, simulation and analysis (MS&A) for operational impacts on DoD satellite communications, it is desired to leverage NASA Whirlwind, OMNET++, GNU radio toolkits, and universal software radio peripheral (USRP) for 3-D visualization and hardware-in-the-loop satellite transceiver hardware emulators.

PHASE I: Develop semi-analytical models for population areas, base transceiver station boresight EIRPs, radar pulses, RFI durations, weather/scintillation losses. Analyze RFI impacts on the existing 16QAM/QPSK/OQPSK modulations, carrier tracking loops, symbol synchronizers, etc. Conceptualize a low SWaP satellite transceiver supported by various levels of autonomy with which cognitive radios will operate.

PHASE II: Refine the end-to-end MS&A capability for RFI analysis of terrestrial radars, 3G/4G mobile telecommunications and rogue RF emitters on the satellite transceiver design from Phase I. Demonstrate an USRP-based terminal with software-based waveforms. Recommend hardware support, interference protection criteria and transmission policies based on actual but not potential RFIs.

PHASE III: Develop transition plans for integrating the satellite transponders/ground terminal products as anticipated herein into Wideband Global Satellite Communications Systems and Glowlink Model 1000 turnkey satellite spectrum monitoring system with coordination from Wideband System Operations Center.

REFERENCES:

1. X. Tian, Z. Tian, K. Pham, E. Blasch, and D. Shen, “Jamming/Anti-jamming Game with a Cognitive Jammer in Space Communication,” SPIE Defense and Security 2012: Sensors and Systems for Space Applications V. Edited by Pham, Khanh D.; Cox, Joseph L.; Howard, Richard T.; Zmuda, Henry. Proceedings of the SPIE, Volume 8385, pp. 83850Q-83850Q-10, 2012.

2. F. F. Digham, M. S. Alouini, and M. K. Simon, "On the Energy Detection of Unknown Signals over Fading Channels," Proceedings of IEEE Int'l Conference on Communications, pp. 3575-3579, 2003.

3. Kydland, F., "Equilibrium Solutions in Dynamic Dominant-player Models," Journal of Economic Theory, Vol. 15, pp. 307-324, 1977.

KEYWORDS: Military satellite communications, mobile telecommunications, pulsed radars, space ground link subsystem, frequency agility, RF Interference, RFI, RFI duration, dynamic spectrum access, smart antenna, link margin, multi-path fading, multi-satellite reception, interference nulling, 16 Quadrature Amplitude Modulation, 16QAM, Quadrature Phase Shift Keying, QPSK, Offset QPSK, OQPSK, channel estimation, feedback channel delays, interference protection criteria, game theory, utility optimization, risk theory

AF14-AT21 TITLE: Breath Based Biomarkers of Fatigue

TECHNOLOGY AREAS: Human Systems

OBJECTIVE: Isolation and ID of biomarkers of fatigue and associated stress via molecular profiling of exhaled human breath. Establish associated sensing requirements, with goal of determining feasibility of incorporation of volatile sensing in an aircrew mask.

DESCRIPTION: Because fatigue continues to be an occupational hazard, leading to cognitive defects in performance, there has been a recognized need for real-time detection technologies that minimize fatigue-induced mishaps. It is generally accepted that humans require approximately 8 hours of sleep to maintain optimal cognitive function when awake (Anch, 1988). Current estimates reveal that people sleep on average 2 hours less than they did 40 years ago. This level of sleep deprivation results in negative health outcomes and is sufficient to produce cognitive deficits and reduced attention. It also well established that fatigue and cognitive performance are linked. Vigilance tasks have been shown to be very sensitive to fatigue induced by sleep deprivation, and result in cognitive performance degradation (Hursh, 2001). Research has also shown that the effects of fatigue directly impact vigilance, mood and cognitive performance (Krueger, 1990). Continuous and sustained actions in military operational environments typically lead to reduction in the amount of sleep required to perform optimally. These operational environments subject the warfighter to intense physical and mental exertion. Other factors present in these environments that impact warfighter performance include reduced caloric intake, dietary changes, and decision-making induced stress. Aircrews are particularly susceptible to the effects of fatigue due to mission-related extended duty hours and irregular sleeping patterns. Rotating shifts, maintenance delays and mission rescheduling can lead to disruptions in normal sleep cycles in pilots and ground crews, causing performance decrements that can have dire consequences on mission effectiveness. The Air Force, Army, and Navy have all reported that sleep deprivation-induced fatigue is a significant problem that has resulted in performance degradation. This creates a situation where a routine task can suddenly evolve into an event with lethal consequences. One potential means of assessing fatigue in aircrews non-invasively is through the analysis of odorants/volatiles in exhaled breath.

The use of odorants emanating from the human body as a diagnostic tool for diseases predates the current era by almost two millennia. Clinicians often relied on their olfactory senses to aid in disease diagnosis. Hundreds of volatile organic compounds (VOCs), many of which are odorous compounds, are detected from human body fluids (Phillips et al., 1999). Some of them are produced by endogenous metabolic processes in and on the body, and others are derived from the environment. Expressions of some endogenous VOCs can be affected by pathophysiological changes, and several disease-specific volatile biomarkers, particularly from the exhaled breath, have been identified and used as diagnostic aids (Kwak, 2011). Monitoring volatile markers in exhaled breath is particularly attractive in aircrews as the procedure can be performed in a noninvasive manner with little or no exposure to biohazardous body fluids or interference with performance of duties. Some early work has been done on assessing the relationship between sleep deprivation and breath composition (Cailleux, 1989) but did not focus on the feasibility of incorporation of identified markers into exhaled breath sensor elements.

The hypothesis is that operational fatigue and sleep deprivation induced stress may cause physiological changes and subsequently abnormal VOC profiles may be observed, which can be quantitatively monitored in exhaled breath. This is supported by the fact that volatile organic compound signatures have been proven capable of identifying other physiological states in humans.

PHASE I: Successful completion requires development of a rapid, continuous, selective, and sensitive analytical method for detection of the individual molecular components in exhaled human breath. Once a statistically valid baseline has been established in non-fatigued/stressed individuals, a time-course profile will be developed to correlate with the level of experimental fatigue induced in subjects.

PHASE II: Define VOC sensitivity and specify sensing requirements required for accurate ID of profiles established in Phase I. Validation testing may involve hand-held detection, using both single point, enhanced “E-nose” type detection, as well as multiple single compound detectors. Successful completion will include empirical validation of accuracy and reproducibility of the utilized detection systems in response to standard mixtures containing physiological levels of the profiles identified in Phase I.

PHASE III: Demonstrate design and feasibility of an integrated sensor suite for assessment of the identified Phase I profile in a minimal form factor prototype that is ideally wearable and in a format amenable to incorporation in an aircrew oxygen mask for direct monitoring of biomarkers in exhaled breath.

REFERENCES:
1. Anch, A.M., Browman, C.P., Mitler, M. and Walsh, J.K. (1988). Sleep: A Scientific Perspective. Englewood Cliffs, NJ: Prentice-Hall, Inc.

2. Hursh, S.R. and Bell, G.B. (2001), Human Performance Cognitive Model for Air Force Information Operations, SAIC, December 2001.

3. Krueger, G.P. (1990) Sustained Military Performance in Continuous Operations: Combatant Fatigue, Rest and Sleep Needs. Handbook of Military Psychology, Gal, R. and Mangelsdorff, A.D. (eds.). Chichester, England: John Wiley & Sons, Ltd. 244-277.

4. Kwak, J., & Preti, G. (2011). Volatile disease biomarkers in breath: a critique. Current Pharmaceutical Biotechnology, 12(7), 1067-1074.

5. Cailleux, A., & Allain, P. (1989). Isoprene and sleep. Life sciences, 44(24), 1877-1880.

6. Phillips, M., Herrera, J., Krishnan, S., Zain, M., Greenburg, J., Cataneo, R., "Variation in Volatile Organic Compounds in Breath of Normal Humans, " Journal of Chromatography B, 1999, 14 pages, uploaded in SITIS 03/11/2014.

KEYWORDS: fatigue, stress, sleep deprivation, breath analysis, volatile organic compounds, biomarkers, point of care testing

AF14-AT22 TITLE: Particulate Composite Mixing Processes

TECHNOLOGY AREAS: Weapons

OBJECTIVE: Develop model(s) for particulate composite mixing processes and resultant microstructures high shear environments considering particle and binder properties and mixer parameters capable of being implemented utilizing desktop computing capability.

DESCRIPTION: Granular and composite mixtures have application in the pharmaceutical industry, food processing, plastics and composites, energetic materials, and mineral processing. The mixing of granular materials and particulate composites, i.e. particles in a polymer matrix, is a critical processing step in a these industries. For all of these applications, homogeneous mixtures are required. For example, in the pharmaceutical industry, each pill must have the exact same mixture as all the other pills to ensure accurate dosage. The process variables resulting in homogeneous mixtures are often determined through trial and error resulting in wasted time, material, and money. Additionally, the parameters that define a material as homogeneous are often ill-defined, particularly microstructural metrics.

Recent advances in Discrete Element Modeling (DEM) have enabled modeling and simulation of these dynamic mixing processes providing insight into physics previously inaccessible experimentally. These models consider the individual particles and their relationship to each other under a given set of processing conditions. They provide insight into the physical process occurring during mixing leading to inhomogeneous mixtures and can guide the development of process parameters for stable, in-control, homogenous mixtures. Typically, these simulations are performed for laboratory scale mixing.

Materials processors require fast running models for large scale mixing machines that they can use to optimize processes that may change on a day-to-day basis. DEM can be computationally intensive and require considerable time to produce results for a single system due to the fine scale and large number of particles in a simulation. In order to make these results useful to large-scale processing facilities, a critical connection must be made between the particle-scale models and the continuum-scale processes, perhaps through reduced order models describing the trade space as a function of input parameters, e.g. particle size and shape and mixer type and speed. Additionally, the changes in parameters associated with scale-up from laboratory/DEM scale to production scale must be understood.

PHASE I:
• Proof-of-concept model for mixing of bimodal distributions of two particle types in a viscous fluid under the influence of gravity in a high shear mixing environment
• Experimental validation of proof of concept model
• Propose homogeneity metrics for particulate composite mixtures and castings containing 2-4 particle types with random particle size distributions

PHASE II:
• Model realistic mixing scenarios to determine optimum homogenous mixing parameters and fully understand the system. Realistic scenarios include up to six particle types, random distributions, and mixer parameters that can be correlated to production machines
• Experimental validation of modeling and simulation results
• Develop reduced order models or simple tables that describe the complex mixing processes and can be implemented on desktop computers to rapidly optimize processing

PHASE III: Models to predict homogeneity as a function of mixing parameters are applicable in many industries greatly reducing cost and increasing yield. The model will be transitioned to the Air Force for use in processing energetic materials as part of a virtual environment for the design of new materials.

REFERENCES:
1. L.R. Aarons, S. Balachandar, and Y. Horie, “The mixing of cohesive granular materials featuring a large size range in the absence of gravity,” Powder Technology, 235, p. 18-26 (2013).

2. P.W. Cleary and M.D. Sinnott, “Assessing mixing characteristics of particle-mixing and granulation devices,” Particuology, 6, p. 419-444 (2008).

3. Rm. Muthiah, V.N. Krishnamurthy, and B.R. Gupta, “Rheology of HTPB Propellant: Development of Generalized Correlation and Evaluation of Pot Life,” Propellants, Explosives, and Pyrotechnics, 21, p. 186-192 (1996).

KEYWORDS: Composite, granular material, mixing, processing, modeling and simulation

AF14-AT23 TITLE: Phase Transitions, Nucleation and Mixing Modeling through Trans-Critical Conditions

TECHNOLOGY AREAS: Battlespace

OBJECTIVE: Based on state-of-the-art understanding from basic research, develop and implement physics-based models in simulation packages/tools to accurately capture trans-critical phenomena relevant to AF propulsion systems.

DESCRIPTION: Mixing and combustion performance are primary parameters for determining and improving the stability and overall performance of many propulsion systems including rocket engines, scramjets and turbine engines. Reliable, accurate, cost-effective simulations and well-validated models are required to improve the predictive capability of combustion codes, ultimately lowering the cost of engine development and improvement programs. Typically, propellants are treated either as gases or evaporating liquids throughout their lifetime within the engine. However, within many combustion applications the propellants experience significant changes in temperature and composition. The associated range of environments may alter the critical point such that the fluids undergo phase transitions. For instance, propellants may be at a supercritical pressure in a manifold and may be injected into a combustion chamber where the pressure is subcritical, or the critical pressure of the combusting mixture itself may change and cause phase transitions. In other situations, propellants may be at a subcritical temperature when injected but may heat to a supercritical temperature during combustion. Liquid-phase propellants will atomize and vaporize in an engine, while supercritical components will mix and diffuse differently due to factors such as vanishing surface tension and enthalpy of vaporization. These transitions can have a profound effect on predictions of combustion performance because small errors in the initial mixing can propagate through the calculations. The trans-critical nature of the environment coupled with the gradients in temperature, pressure and composition can also have a profound impact on the thermophysical properties of the propellant, modifying both the mixing and combustion processes.

This topic seeks the development of advanced predictive models that account for trans-critical phase transitions that occur under conditions representative of aerospace propulsion applications. Predictive tools must address the continuum of phases and the corresponding variability of thermophysical and boundary properties in trans-critical environments. Because the ultimate goal of the improved trans-critical modeling is to enhance predictions of mixing and combustion, the impact of all associated model assumptions should be carefully evaluated in that context. Tools that improve the prediction of phase states, thermodynamic and transport properties and enable mixing models to account for these changes in phases and properties throughout the trans-critical environments are sought. In addition, innovative methods to model phase transitions including phenomena such as nucleation and condensation are of interest. The physical models must be implemented and tested within a CFD code infrastructure and validated with appropriate datasets. It is expected that the model validation will utilize experimental datasets, such as those available at the Air Force Research Labs or obtained through related AFOSR programs.

Model development should be carried out in a modular fashion through the specification of standardized application programming interfaces (API's), which would enable the models or sub-models to be available as plug-in libraries for CFD codes of relevance to the Air Force and its contractors. Relevance to Air Force propulsion interests and approaches based on well-reasoned, logically-connected, first-principles-based substantiation aided by existing experimental evidence are among key evaluation considerations.

PHASE I: 1. Review current understanding and modeling approaches; 2. Key rate-controlling processes and critical scales and parameters; 3. Canonical test cases and initial modeling capabilities; 4. Plan for physical/ numerical model development, integration strategy, and validation procedure for Phase II. Results from items 1 and 2 shall be of sufficient quality for citable AIAA meeting or journal papers.

PHASE II: Implement the above physical models into RANS- or LES-based CFD codes. Validate models and codes as defined in Phase I. Demonstrate of model's ability to interface with combustion performance and stability tools. The physics models, associated computational approaches as well as integration strategies shall be delivered at levels of detail sufficient to demonstrably verify and validate the models for Air Force relevant propulsion applications, as determined by sponsor.

PHASE III: Develop software package usable for relevant Air Force and other applications.

REFERENCES:
1. Zong, N. and Yang, V., "Cryogenic fluid jets and mixing layers in transcritical and supercritical environments", Combustion Science and Technology, Vol. 178, No. 1-3, 2006.

2. Sirignano, W.A. and Delplanque, J.-P., "Transcritical vaporization of liquid fuels and propellants", Journal of Propulsion and Power, Vol. 15, No. 6, 1999.

3. Schmitt, T., Mery, Y., Boileau, M., Candel, S., "Large-Eddy Simulation of oxygen/methane flames under transcritical conditions", Proceedings of the Combustion Institute, Vol. 33, No. 1, pp 1383-1390, 2011.

KEYWORDS: Supercritical; trans-critical; high-pressure; phase transitions; combustion; mixing

AF14-AT26 TITLE: Large, High Transparency Non-Isotropic Ceramics

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop processes for producing innovative new highly transparent ceramic materials for future AF applications.

DESCRIPTION: High-quality transparent optical materials are essential in numerous critical technologies. Many of these materials must be grown as single crystals to achieve the needed properties and level of performance. Often, crystals produced must satisfy two conflicting requirements: uniform high optical quality and large size. These requirements often limit the applicability of a material due to the high cost and physical constraints inherent in crystal growth. Consequently, techniques have been developed in recent years to produce optical ceramic materials with properties comparable to those of single crystals. In addition to lower manufacturing cost, ceramics have a number of important advantages over single crystals, including being more resistant to thermal or mechanical shock. For example, it has been reported that Nd:YAG ceramics are 30% to 50% stronger than single crystals. Ceramics processing also provides other benefits, including higher yield through increased dopant concentrations and better control of composition, relaxed constraints on size and shape, higher purity, and improved uniformity. It is possible to make ceramics with compositions and doping distributions which cannot be grown in single crystals. Increased doping levels, for example, could lead to the fabrication of higher power lasers.

Most ceramics are inherently opaque because of scattering from particle interfaces and voids. Some materials, such as YAG, and a few other cubic materials, can be produced optically clear because they are cubic, and scattering from surfaces of adjacent grains, if they are in close contact, is eliminated since the index of refraction is isotropic. Unfortunately, there are very promising materials for important applications that not isotropic, and have differing index of refraction in different directions, so making macroscopic optically transparent samples is challenging, and only very small samples have been produced to date.

Innovations are needed for producing high quality transparent ceramics of non-isotropic materials to significantly increase the number of materials that are available for applications such as, for example, high power laser development.

PHASE I: Identify potential approaches to produce significant grain alignment in promising non-isotropic ceramic materials. Demonstrate at least 20% alignment in three dimensions in ceramic precursors or green bodies.

PHASE II: Develop processes to fabricate optical ceramics that retain the orientation achieved in Phase I. Increase the alignment to more than 50% by optimized orientation relationship and demonstrate improved transparency. Produce a laser ceramic sample that exhibits gain at least in one direction. Develop a path for the production of high quality transparent ceramics.

PHASE III: Produce transparent ceramic material with >99% alignment. Scale up the process.

REFERENCES:

1. Akio Ikesue, Yan Lin Aung, Takunori Taira, Tomosumi Kamimura, Kunio Yoshida, Gary L. Messing, "Progress in ceramic lasers", Annu. Rev. Mater. Res. Vol. 36 (2006) 397-429.

2. Akiyama, J., Sato, Y., Taira, T., "Laser ceramics with rare-earth-doped anisotropic materials", Optics Letters, Vol. 35, No. 21 3598 (2010).

3. Chen, C.T. et. al. "Grain-oriented calcium hydroxyapatite ceramic and film prepared by magnetic alignment", Materials Letters 61, p 6 (2007).

4. Feldman, R., Golan, Y., Burshtein, Z., Jackel, S., Mosha, I., Meir, A., Limer, Y., Shimony, Y., "Strengthening of Poly-Crystalline (Ceramic) Nd:YAG Elements for High Power Laser Applications, Opt. Mat., vol. 33, 695 (2011).

5. Hovis, D.B., and Faber, K.T., "Textured microstructures in barium hexaferrite by magnetic field assisted gelcasting and templated grain growth", Scripta Met., 2000, 44, pp. 2525-2529.

KEYWORDS: transparent ceramic, non-isotropic, alignment

AF14-AT27 TITLE: Physics-Based Models for Mid-IR Bismides Semiconductor Lasers

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Develop a rigorous understanding of the "atom-up" physics and behavior of room-temperature mid-IR semiconductor lasers. Provide a quantitative gain/loss simulation tool of laser structures producing Watt-level outputs at 3-5 microns.

DESCRIPTION: Over the past decade, great advances have been made in mid-wave (2-5 micron) semiconductor lasers. Devices such as intersubband quantum cascade lasers (QCLs) [1] and interband cascade lasers (ICLs) [2] have shown drastic improvement at both cryogenic and room temperature operation. Moreover, some type-1 quantum well devices have also obtained significant achievements at the shorter wavelengths of this spectral region. Both QCLs and ICLs rely on complicated band alignment and many quantum well repeats to achieve suitable gain to sustain lasing--numbers of layers reaching into the 100's. Moreover, QCLs also only operate in transverse magnetic (TM) polarization which prohibit them from being employed in high brightness cavities such as vertical external cavity surface emitting lasers (VECSELs). Also both QCLs and ICLs begin to suffer at shorter wavelengths because of conduction-band offsets and monolayer changes in bandgap. Achieving shorter wavelengths would require making drastic material changes. Moreover, type-1 quantum well lasers have not achieved Watt-level powers above about 2.5 microns, necessary for Air Force applications. Presently type-1 quantum wells (typically InAlGaSb/InAlGaAsSb grown on GaSb or similar) are plagued by several deleterious effects such as increased Auger current losses, poor hole confinement, and limited wavelength coverage due to a miscibility gap issue. Recent studies have shown that incorporating dilute amounts of large atoms such as bismuth have decreased the bandgap energy in both III-As and III-Sb materials. Bismides have been shown to increase the valence band offset, decrease the bandgap (to wavelengths up through the long-wave infrared spectral regime), and reduce conductance-band driven Auger processes through shallow conduction-band offsets [3]. While trend analysis has been used to support both band and anti-crossing and defect/band broadening models, origins of the influence of bandgap and subband positioning remain unclear and even controversial. If novel material systems such as bismides are to be useful for DoD applications then rigorous physics-based modeling will be necessary to understand the influence of large atoms on the crystal bands. This modeling, when incorporated with a robust gain/loss quanturm well model, will allow for systematic band engineering and gain/loss balancing that have been key for other material systems [4].

PHASE I: Proof of concept demonstration of systematic theoretical modeling for understanding band positioning, bending, and influences of effects such as temperature and carrier density in bismide semiconductor materials for use in mid-IR (3-5 micron) wavelength regime. Establishment of reliable data bases for systematic modeling.

PHASE II: Based on results from Phase I, the incorporation of these material systems into robust microscopic many-body modeling of gain and loss in semiconductor quantum confined structures such as type-I and type-II quantum wells. Concepts for the reduction of non-radiative losses must be developed with the goal of multi-Watt room temperature operation at various wavelengths covering the desired range.

PHASE III: Dual-Use Applications: This effort will produce simulation tools to best design mid-IR semiconductor sources for uses in DoD systems as well as potential commercial applications such as chemical effluent detection and medical purposes.

REFERENCES:
1. N. Bandyopadhyay, et al, Appl Phys Lett, 100, 212104 (2012).

2. I. Vurgaftman, et al, J of Select. Topics Quant. Electron., 17, 1435, (2011).

3. S. Sweeney, et al, Appl Phys Lett, 113, 043110 (2013).

4. R. Bedford, et al, J Appl Phys, 110, 073108 (2011).

KEYWORDS: semiconductor lasers, microscopic modeling, long-wavelength operation

AF14-AT28 TITLE: Electronic Warfare: EMS Monitor & Broadcast Training Capacity Enhancement

TECHNOLOGY AREAS: Electronics

OBJECTIVE: The electromagnetic spectrum is one of the most vulnerable points for communication disruption and rogue data injection. There is a strong need for a low-cost, man packable device that can emulate opposing force electronic warfare capabilities.

DESCRIPTION: Modern electronic communication technologies create new battlefield conditions; cyber and electronic warfare (hereafter referred to as joint electromagnetic spectrum operations [JEMSO]) can create as much disruption as conventional weapons. These new conditions make realistic war fighter training imperative. We cannot expect to win in an operational environment unfamiliar to joint forces.

These modern communications employ complex spread spectrum waveforms. These waveforms are natively broadband with very low power spectra density. Several communication channels can use the same spectral allocation. We must develop an advanced, man-packable EMS monitoring and broadcast capacity. The spectral density of a single code-division multiple access (CDMA) waveform is frequently below the noise floor and conventional spectrum monitoring of such signals is ineffective. The spectrum analyzer may not discover a CDMA signal, for example, but even if it would be able to discover the communication signature, it will be difficult to characterize and monitor these signals. The CDMA communications exhibit significant processing gain; conventional, uncorrelated broadband noise (BBN) jammers have to overcome this gain. Moreover, the broadband high power jamming may not be effective in a congested EMS. Some conventional jammers use partial band noise (PBN) jammers; these jammers can disrupt part of the spectrum of communication waveform erasing only a portion of the data bit stream. All modern electronic communications employ some form of forward error correction (FEC) procedure that can recover missing bits. Even old 15/31 Reed-Solomon (RS) procedure, that is employed by one prolific current military waveform, can recover more than 50% of the missing bit erasure. Newer FEC procedures have even better performance. On top of FEC, modern waveforms employ additional anti-jamming measures and the PBN jamming may be very ineffective.

In spite of little effectiveness for many conventional electronic warfare methods in the modern environment, new publications and techniques illustrate that modern communication can be successfully monitored and disrupted ([2],[3],[4]). For example, second order statistic and time-frequency analysis can lead to discovery of spreading sequence for direct sequence spread spectrum (DSSS) and fast frequency-hopping spread spectrum (FFHSS) waveforms respectively. A weak point of advanced spread spectrum communication is sequence synchronization. There are some methods that make sequence synchronization more robust, but all of them have potential weak points. Research will show that these and other modern techniques will make advanced EMS monitoring, broadcast and spoofing very possible. The device under development should be able to: monitor advanced communication waveforms, classify the waveform, discover the spreading sequence and match the discovered waveform to a predefined waveform-database. Based on discovered information, the developed device should be able to execute an optimal broadcast strategy. It is very likely that an opponent will employ an array of networked jammers. The network of synchronized transmitters can alter the EM wavefront of the transmitted signal and obscure the location of broadcast platforms. A properly prototyped device will allow OPFOR to accurately and efficiently replicate advanced adversary capabilities; making warfighters battle ready.

The device under development should employ an open platform principle, so the new methods can be implemented easily. It is expected that research will fully utilize a software defined radio (SDR) concept. Only commonly available tools and languages should be implemented.

PHASE I:
- Conduct computer simulation of developed spectrum monitoring method for advanced communication. Develop and simulate sequence discovery procedures for common communication waveforms
- Simulate waveform spoofing
- Evaluate modern EW methods using computer simulations
- Adopt or design open system SDR methodology including Integrated Development Environment (IDE) with extensive SDR library

PHASE II:

- Build the prototype developed in Phase I that can accommodate most common military communication standards. Employ only standard tools and languages (example; VHDL, C/C++, Python, etc.)
- Implement procedures that were developed in Phase I
- Create Capabilities Development Document for the Phase II research

PHASE III: -Develop the limited rate initial production of the device developed during the Phase I and Phase II
-Apply system capabilities to modern EM OPFOR training methodology

REFERENCES:
1. Y. Zhan,Z. Cao ,J. Lu, "Spread-spectrum sequence estimation for DSSS signal in non-cooperative communication systems", Communications, IEEE Proceedings- (Volume:152, Issue:4).

2. C. Liang, W. Fuping, W. Zanj, "Low complexity method for spreading sequence estimation of DSSS signal in non-cooperative communication systems", Systems Engineering and Electronics, Journal of (Volume:20, Issue:1).

3. Y. Jo, D. Wu, "On Cracking Direct-Sequence Spread-Spectrum Systems", WIRELESS COMMUNICATIONS AND MOBILE COMPUTING, Wiley InterScience, 2008.

4. X. Liu, "Signal Detection and Jammer Localization in Multipath Channels for Frequency Hopping Communications", http://www.dtic.mil/dtic/tr/fulltext/u2/a440468.pdf.

5. R.A. Poisel, "Modern Communications Jamming Principles and Techniques", Artech House, 2011.

KEYWORDS: Electronic, EW, Spread-Spectrum, communication, monitoring, CDMA, Sparse Array, EM Wavefront Obfuscation, JEMSO