AIR FORCE
STTR 09.B PROPOSAL PREPARATION INSTRUCTIONS

The Air Force proposal submission instructions are intended to clarify the DoD instructions as they apply to AF requirements.

The responsibility for the implementation and management of the Air Force Small Business Technology Transfer (STTR) Program is with the Air Force Research Lab, Wright-Patterson Air Force Base, Ohio. The Air Force STTR Program Manager is Mr. Augustine Vu, (800) 222-0336. The Air Force Office of Scientific Research (AFOSR) is responsible for scientific oversight and program execution of Air Force STTRs.

Air Force Research Laboratory
AFOSR/PIE
Attn: Raheem Lawal
875 Randolph Street
Suite 325, Room 3112
Arlington, VA 22203-1954

Phone: (703) 696-7313 / (703) 696-9513
Fax: (703) 696-7320
Email: raheem.lawal@afosr.af.mil

For general inquiries or problems with the electronic submission, contact the DoD Help Desk at 1-866-724-7457 (8:00 am to 5:00 pm ET). For technical questions about the Topics during the pre-solicitation period (27 July through 23 August 2009), contact the Topic Authors listed for each Topic on the website. For information on obtaining answers to your technical questions during the formal solicitation period (24 August through 23 September 2009), go to http://www.dodsbir.net/sitis.

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

Unless otherwise stated in the topic, Phase I will show the concept feasibility and Phase II will produce a prototype or at least show a proof-of-principle.

Phase I period of performance is typically 9 months, not to exceed $100,000.

Phase II period of performance is typically 2 years, not to exceed $750,000.

The solicitation closing dates and times are firm.

PHASE I PROPOSAL SUBMISSION

Read the DoD program solicitation at www.dodsbir.net/solicitation for detailed instructions on proposal format and 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 Air Force, the contract period of performance for Phase I shall be nine (9) months, and the award shall not exceed $100,000. We will accept only one Cost Proposal 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 Air Force 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 Air Force technical point of contact utilizing the criteria in section 4.3 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 so no modification to the Phase I contract should be necessary. **Phase I technical proposals have a 20 page-limit (excluding the Cost Proposal and Company Commercialization Report).** The Air Force will evaluate and select Phase I proposals using review criteria based upon technical merit, principal investigator qualifications, and commercialization potential as discussed in this solicitation document.

ALL PROPOSAL SUBMISSIONS TO THE AIR FORCE MUST BE SUBMITTED ELECTRONICALLY.

It is mandatory that the complete proposal submission -- DoD Proposal Cover Sheet, **ENTIRE** Technical Proposal with any appendices, Cost Proposal, and the Company Commercialization Report -- be submitted electronically through the DoD SBIR/STTR website at http://www.dodsbir.net/submission. Each of these documents is to be submitted separately through the website. Your complete proposal **must** be submitted via the submissions site on or before the **6:00 am ET 23 September 2009** deadline. A hardcopy **will not** be accepted. Signatures are not required at proposal submission when submitting electronically. If you have any questions or problems with electronic submission, contact the DoD SBIR/STTR Help Desk at 1-866-724-7457 (8am to 5pm ET).

Acceptable Format for On-Line Submission: The Technical Proposal should include all graphics and attachments but should not include the Cover Sheet or Company Commercialization Report (as these items are completed separately). Cost Proposal information should be provided by completing the on-line Cost Proposal form.

Technical Proposals should conform to the limitations on margins and number of pages specified in the front section of this DoD solicitation. However, your Cost Proposal will only count as one page and your Cover Sheet will only count as two, no matter how they print out after being converted. 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 Technical 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 SBIR/STTR Help Desk.

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

COMMERCIAL POTENTIAL EVIDENCE

An offeror needs to document their Phase I or II proposal's commercial potential as follows: 1) the small business concern's record of commercializing STTR or other research, particularly as reflected in its Company Commercialization Report http://www.dodsbir.net/submission; 2) the existence of second phase funding commitments from private sector or non-STTR funding sources; 3) the existence of third phase follow-on commitments for the subject of the research and 4) the presence of other indicators of commercial potential of the idea, including the small business' commercialization strategy.

ELECTRONIC SUBMISSION OF PROPOSAL

If you have never visited the site before, you must first register your firm and create a password for access (have your tax ID handy). Once registered, from the Main Menu:

Select "Prepare/Edit Phase I Cover Sheets" –

1. **Prepare a Cover Sheet.** Add a cover sheet for each proposal you plan to submit. Once you have entered all the necessary cover sheet data and clicked the Save button, the proposal grid will show the cover sheet you have just created. You may edit the cover sheet at any time prior to the close of the solicitation.
2. **Prepare a Cost Proposal.** Use the on-line proposal form by clicking on the dollar sign icon.
3. **Prepare and upload a Technical Proposal.** Using a word processor, prepare a Technical Proposal following the instructions and requirements outlined in the solicitation. When you are ready to submit your proposal, click the on-line icon to begin the upload process. You are responsible for virus checking your Technical Proposal file prior to upload. Any files received with viruses will be deleted immediately.

Select "Prepare/Edit a Company Commercialization Report" –

4. **Prepare a Company Commercialization Report.** Add and/or update sales and investment information on all prior Phase II awards won by your firm.

> NOTE: Even if your company has had no previous Phase I or II awards, you must submit a Company Commercialization Report. Your proposal will not be penalized in the evaluation process if your company has never had any STTR Phase Is or IIs in the past.

Once steps 1 through 4 are done, the electronic submission process is complete.

AIR FORCE PROPOSAL EVALUATIONS

Evaluation of the primary research effort and the proposal will be based on the scientific review criteria factors (i.e., technical merit, principal investigator (and team), and commercialization plan). 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 Air Force anticipates that pricing will be based on adequate price competition. The next tie-breaker on essentially equal proposals will be the inclusion of manufacturing technology considerations.

The Air Force will utilize the Phase I evaluation criteria in section 4.2 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 Air Force will use the Phase II evaluation criteria in section 4.3 of the DoD solicitation with technical merit being most important, followed by the Commercialization Plan, and then qualifications of the principal investigator (and team).

PROPOSAL/AWARD INQUIRIES

We anticipate having all the proposals evaluated and our Phase I contract decisions within approximately four months after proposal receipt. All questions concerning the evaluation and selection process should be directed to the Air Force Office of Scientific Research (AFOSR).

ON-LINE PROPOSAL STATUS AND DEBRIEFINGS

The Air Force has implemented on-line proposal status updates and debriefings (for proposals not selected for an Air Force award) for small businesses submitting proposals against Air Force 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 Air Force SBIR / STTR Virtual Shopping Mall (http://www.sbirsttrmall.com). The Small Business Area (http://www.sbirsttrmall.com/Firm/login.aspx) is password protected and uses the same login information as the DoD SBIR / STTR Submission Site. Small businesses can view information for their company only.

To receive a status update of a proposal submission, click the "Proposal Status / Debriefings" link at the top of the page in the Small Business Area (after logging in). A listing of proposal submissions to the Air Force 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 provide 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 Air Force with a notification of selection or non – selection.** The Air Force receives thousands of proposals during each solicitation and the notification process requires specific steps to be completed prior to a Contracting Officer distributing this information to small business.

The Principal Investigator (PI) and Corporate Official (CO) indicated on the Proposal Coversheet will be notified by email regarding proposal selection or non-selection. The email will include a link to a secure Internet page to be accessed which contains the appropriate information. If your proposal is tentatively selected to receive an Air Force award, the PI and CO will receive a single notification. If your proposal is not selected for an Air Force award, the PI and CO may receive up to two messages. The first message will notify the small business that the proposal has not been selected for an Air Force award and provide information regarding the availability of a proposal debriefing. The notification will either indicate that the debriefing is ready for review and include instructions to proceed to the "Proposal Status / Debriefings" area of the Air Force SBIR / STTR Virtual Shopping Mall or it may state that the debriefing is not currently available but generally will be within 90 days (due to unforeseen circumstances, some debriefings may be delayed beyond the normal days). If the initial notification indicates the debriefing will be available generally within 90 days, the PI and CO will receive a follow – up notification once the debriefing is available on-line. All proposals not selected for an Air Force award will have an on-line debriefing available for review. Available debriefings can be viewed by clicking on the "Debriefing" link, located on the right of the Proposal Title, in the "Proposal Status / Debriefings" section of the Small

Business Area of the Air Force SBIR / STTR Virtual Shopping Mall**. Small businesses will receive a notification for each proposal submitted. Please read each notification carefully and note the Proposal Number and Topic Number referenced. Also observe the status of the debriefing as availability may differ between submissions (e.g., one may state the debriefing is currently available while another may indicate the debriefing will be available within 90 days).**

PHASE II PROPOSAL SUBMISSIONS

Phase II is the demonstration of the technology that was found feasible in Phase I. Only those Phase I awardees that are **invited** to submit a Phase II proposal and all FAST TRACK applicants will be eligible to submit a Phase II proposal. Phase I awardees can verify selection for receipt of a Phase II invitation letter by logging into the "Small business Area" at http://sbirsttrmall.com. If "Phase II Invitation Letter Sent" and associated date are visible, a Phase II invitation letter has been sent. If the letter is not received within 10 days of the date and/or the contact information for technical/contracting points of contact has changed since submission of the Phase I proposal, contact the appropriate AF SBIR Program Manager, as found in the Phase I selection notification letter, for resolution. Please note that it is solely the responsibility of the Phase I awardee to contact this individual. There will be no further attempts on the part of the Air Force to solicit a Phase II proposal. The Phase I award winners must accomplish the majority of their primary research during the first six months of the contract. Each Air Force 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 reviewed by the Air Force technical point of contact utilizing the criteria in section 4.3 of the DoD solicitation The awarding Air Force organization will send detailed Phase II proposal instructions to the appropriate small businesses. Phase II efforts are typically two (2) years in duration and do not exceed $750,000. (NOTE) All Phase II awardees must have a Defense Contract Audit Agency (DCAA) approved accounting system**. Get your DCAA accounting system in place prior to the AF Phase II award time frame. 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 proposal - Department of Defense (DoD) Cover Sheet, entire Technical Proposal with appendices, Cost Proposal and the Company Commercialization Report – must be submitted by the date indicated in the invitation. The technical proposal is **limited to 50 pages** (unless a different number is specified in the invitation). The Commercialization Report, any advocacy letters, and the additional Cost Proposal itemized listing (a-h) will not count against the 50 page limitation and should be placed as the last pages of the Technical Proposal file that is uploaded. (Note: Only one file can be uploaded to the DoD Submission Site. Ensure that this single file includes your complete Technical Proposal and the additional Cost Proposal 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**.

NOTE: Key Program Personnel

Ensure that in the Technical Proposal all key personnel who will be involved in this project are identified; include information on directly related education, experience, and citizenship. A resume of the principle investigator, including a list of publications, if any, must be part of that information. Concise 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. For these individuals, in addition to resumes, please provide copies of the individuals' Green Cards. You must also identify all non-U.S. citizens expected to be involved in the project as direct employees, subcontractors, or consultants. For these individuals, in addition to resumes, please provide countries of origin, copies of visas, and explanation of the individuals' involvement.

FAST TRACK
Detailed instructions on the Air Force Phase II program and notification of the opportunity to submit a FAST TRACK application will be forwarded with all AF Phase I selection E-Mail notifications. The Air Force encourages businesses to consider a FAST TRACK application when they can attract outside funding and the technology is mature enough to be ready for application following successful completion of the Phase II contract.

NOTE:

1. Fast Track applications must be submitted not later than 150 days after the start of the Phase I contract.
2. Fast Track Phase II proposals must be submitted not later than 180 days after the start of the Phase I contract.
3. The Air Force does not provide interim funding for Fast Track applications. If selected for a Phase II award, we will match only the outside funding for Phase II.

For FAST TRACK applicants, should the outside funding not become available by the time designated by the awarding Air Force activity, the offeror will not be considered for any Phase II award. FAST TRACK applicants may submit a Phase II proposal prior to receiving a formal invitation letter. The Air Force will select Phase II winners based solely upon the merits of the proposal submitted, including FAST TRACK applicants.

PHASE II ENHANCEMENT POLICY
The Air Force currently does not participate in the DoD Enhancement Program.

PHASE I SUMMARY REPORTS
In addition to all the Phase I contractual deliverables, Phase I award winners must submit a Phase I Final Summary Report at the end of their Phase I project. The Phse I summary report is an unclassified, non-sensitive, and non-proprietary summation of Phase I results that is intended for public viewing on the Air Force SBIR / STTR Virtual Shopping Mall. A summary report should not exceed 700 words, and should include the technology description and anticipated applications / benefits for government and / or private sector use. It should require minimal work from the contractor because most of this information is required in the final technical report. The Phase I summary report shall be submitted in accordance with the format and instructions posted on the Virtual Shopping Mall website at http://www.sbirsttrmall.com.

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 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 that are invited to submit Phase II proposals will be notified. The Air Force also reserves the right to change any administrative procedures at any time that will improve management of the Air Force STTR Program.

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Air Force STTR 09B Topic Descriptions

AF09-BT01 TITLE: Efficient Band-4 Energy Generation and Distribution

TECHNOLOGY AREAS: Air Platform, Sensors

OBJECTIVE: Develop a band-1/band-4 laser source that can operate within the electrical and physical limits available aboard military and commercial transport aircraft.

DESCRIPTION: A key requirement for future DOD aircrafts is that they possess the most current technological advancement in band-1/band-4 laser sources. The principle challenge is to generate and distribute band-4 energy to points that may be tens of meters from the central source. Through recent improvements, system's operational efficiencies have increased, as well as a reduction in the size of modern solid-state laser technology. The operational efficiency, and reduced size of modern solid-state laser technology, makes it an ideal source for many countermeasure applications; however, the ultimate performance of any system is governed by the effective integration of the various sub-systems, as the critical performance parameter is "useful energy on target" (Titterton). The investigation should address the requirements for a laser that produces/distributes power at the terminal end of 750 watts for band-1 and 1000 watts for band-4.

PHASE I: Identify and Determine feasibility of novel methods of generating and distributing a band-4 spectral line, if appropriate through modeling. Identify methods for maximizing distribution system efficiency.

PHASE II: Develop, Demonstrate and Evaluate most promising method(s) from Phase I to develop a band-1/band-4 laser source to produce/distribute total power at the terminal end of 1000 watts in band-4 and 750 watts in band-1.

PHASE III / DUAL USE:
MILITARY APPLICATION: Will assist the military in increasing operational efficiency and reduce the size of modern solid state laser technology.

COMMERCIAL APPLICATION: Will assist in reducing the size of modern solid state laser technology.

REFERENCES:
1. K. C. Kwan, X. M. Tao, and G. D. Peng, "Transition of lasing modes in disordered active photonic crystals," Opt. Lett. 32, 2720-2722 (2007)

2. Takeharu Sakai, Nagoya University Journal of Propulsion and Power 2009, 0748-4658 vol.25 no.2 (406-414)

3. B. J. Feldman, Robert A. Fisher, C. R. Pollock, S. W. Simons, and R. G. Tercovich, "Intense high-pressure sequence-band CO2 laser," Opt. Lett. 2, 16- (1978)

KEYWORDS: Laser, Band, Band-1, Band-4

AF09-BT02 TITLE: Innovative Earth Gravity Reformulation and Numerical Integration for Responsive SSA

TECHNOLOGY AREAS: Battlespace, Space Platforms

OBJECTIVE: Develop a reformulation using state-of-the art fast mathematics and innovative Earth Gravitational representation to significantly improve the responsiveness of precision SSA and space operations.

DESCRIPTION: The historical precision satellite orbital trajectory generation and prediction are based on the classical spherical harmonics representation of Earth Gravitational Model together with traditional numerical integration methods. This approach has failed the SSA and space surveillance needs for precise and responsive tracking together with prediction and simulation in an environment of more than ten thousand orbiting artificial satellites and debris. It is deemed that the current capability in the Maui High Performance Computer environment remains too slow to address the near real-time SSA assessment and analysis supporting the current and future operational needs. Therefore an effort which involves the conception and implementation of an innovative Earth Gravitational Model together with a new numerical integration method for an extremely nonlinear dynamical system in a near operational SSA simulation system is in order.

PHASE I: Conceive a new Earth Gravity Model and a faster, more accurate numerical integration method for orbit prediction in order to establish an initial SSA simulation system compatible with the AFSPC space operational data base.

PHASE II: Implement both of the above into a menu-driven simulation computer code.

PHASE III / DUAL USE:
MILITARY APPLICATION: Military application: Includes the AFSPC Space Surveillance Analysis Model, 14 AF operations, AF space research organizations, military and intelligence space systems, and NASA applications.

COMMERCIAL APPLICATION: Need commercial application

REFERENCES:
1. G. Beylkin and R. Cramer, "Toward multiresolution estimation and efficient representation of gravitational fields", Celestial Mechanics and Dynamical Astronomy, 84(1):87–104, 2002.

2. G. Beylkin and L. Moniz, "On generalized Gaussian quadratures for exponentials and their applications", Appl. Comput. Harmon. Anal., 12(3):332–373, 2002.

KEYWORDS: Gravitational fields, generalized Gaussian quadratures, computational mathematics, celestial mechanics, multiresolution representation, numerical analysis, perturbed astrodynamics and orbital mechanics

AF09-BT03 TITLE: <u>Engineered nanometric architectures or conductive matrices for efficient electron coupling</u>

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop materials & methods that facilitate electron transfer of within electrocatalytic materials. Particular emphasis on engineering interface between biocatalyst redox centers and nanomaterials

DESCRIPTION: Biological evolution provided exquisite mechanisms and architectures for collection and transport of electrochemical charge. Theoretical and experimental understanding has advanced through study of systems like the photosynthetic reaction center and redox cofactors of various enzymes. The systems provide the bioelectrochemical basis for conversion of photo- and chemical energy as well as intermolecular connections for sensing and signaling. Adapting the biological phenomena to yield a practical process or functional device has been experimentally mimicked by appropriately aligning biomolecules with conductive materials or suspending the catalysts with redox-active molecules that can mediate charge transfer. The methods, however, are not developed to the level of a reliable technology. The thrust in the present call is to develop means for effective integration of biomolecules and conductive materials. The product must be reproducible, scalable, and manufacturable in order to support development of the broadly applicable technology concepts.

The topic seeks development and demonstration of materials and techniques that electronically couple biomolecules to engineered surfaces. One approach of high interest is physical arrangement that supports direct electron transfer. For example the offeror may present process to join redox enzyme with conductive nanomaterials, e.g., carbon nanotube or gold nanoparticles that orients redox site and material in appropriate orientation. Mediated electron transfer concepts that meaningfully advance state of the art bioelectronic demonstrations are also of interest in the program. The materials and design concepts are intended to further hybrid photovoltaic and biological fuel cell prototype development.

PHASE I: Demonstrate reproducible approach through fabrication of materials or integration of processes that allow electronic connection between biomolecules and engineered surface, e.g., electrode, PV junction, transducer. The approach should be versatile, and amenable to use with various redox catalysts.

PHASE II: Demonstrate applicability of design approach in a manufacturable prototype of a device in one or more of the appropriate technology areas; sensors, electronic, or energy conversion (biological fuel cells, photovoltaic cells). Materials and performance should surpass existing state of the art and conform to scalable and manufacturable requirements.

PHASE III / DUAL USE:
MILITARY APPLICATION: Environmental energy harvesting/conversion to power modest-power demand devices (systems that require mW to W for extended periods of time). Advanced sensor concepts.

COMMERCIAL APPLICATION: Power for- consumer electronics, implantable biomedical devices, environmental monitors.

REFERENCES:

1. Agüí, L., Yáñez-Sedeño, P. & Pingarrón, J. M. Role of carbon nanotubes in electroanalytical chemistry: A review. Analytica Chimica Acta 622, 11-47 (2008).

2. Lebedev, N. et al. Increasing efficiency of photoelectronic conversion by encapsulation of photosynthetic reaction center proteins in arrayed carbon nanotube electrode. Langmuir 24, 8871-8876 (2008).

3. Willner, I., Willner, B. & Katz, E. Biomolecule-nanoparticle hybrid systems for bioelectronic applications. Bioelectrochemistry 70, 2-11 (2007).

4. Withey, G. D. et al. Ultra-high redox enzyme signal transduction using highly ordered carbon nanotube array electrodes. Biosensors and Bioelectronics 21, 1560-1565 (2006).

KEYWORDS: direct electron transfer, bionano interface, biological fuel cell, photovoltaic, functionalized nanomaterials, photoelectrochemistry, bioelectrochemistry

AF09-BT05 TITLE: SUPER-HIGH ENERGY DENSITY HIGH VOLTAGE CAPACITORS

TECHNOLOGY AREAS: Ground/Sea Vehicles, Space Platforms, Weapons

OBJECTIVE: To conduct basic research to advance compact capacitor technology to achieve >5J/cc at >10kV driving microsecond duration GW-class loads.

DESCRIPTION: Numerous military systems rely on multi-kilovolt, multi-kiloampere, microsecond pulsed power supplies for their operation. Such pulsed power subsystems are generally bulky and heavy, contradicting the military need for portability. To shrink the size and weight of these subsystems the Air Force seeks to increase the energy storage density of their capacitors. In particular, major advances in "supercapacitors," nonlinear dielectrics, and/or fractal capacitor design may hold the key to a major breakthrough in this area. Specifically, "supercapacitors" are rechargeable electrochemical energy storage devices similar to batteries, but with different performance characteristics. Unlike batteries, supercapacitors can operate efficiently in a large temperature window (-40 to +300 C, depending on the electrolyte used), have very long cycle life (> 1,000,000 cycles), and can be charged in under a second. Two types of supercapacitors are available – electrical double layer capacitors (EDLC) with carbon electrodes and pseudo-capacitors with hydrous ruthenium oxide ($RuO_2 \cdot nH_2O$) electrodes. Secondly, novel nonlinear dielectrics may also reduce the mass and volume of pulsed power generators both by enabling higher energy density, submicrosecond discharge, pulsed power capacitors and by improving the efficiency, increasing pulse sharpening, amplitude and operating frequency, and reducing the size of nonlinear transmission lines for high frequency, high power microwave generation. Basic research into nonlinear dielectrics may include but is not limited to new capacitor and pulsed power topologies, chemical compositions and processing techniques, thin films, hybrid composites and multiple phase composites (ferroelectric, paraelectric, antiferroelectric, and even multiferroics). Finally, over the past decade, researchers have made major breakthroughs by applying fractal theory to the design of capacitors and antennas. Specifically, paying careful attention to the detailed multidimensional geometry of internal capacitor electrodes has resulted in higher energy storage density and/or optimized charge/discharge temporal pulse shapes. Unfortunately to-date both fractal capacitor and supercapacitor concepts have generally been limited to relatively low voltage regimes.

PHASE I: Conduct theoretical and computational research on one or some combination of the three innovative capacitor technologies listed above. Demonstrate the feasibility of achieving the Objective. Design carefully diagnosed experiments that can provide empirical evidence of achieving that Objective.

PHASE II: Fabricate and demonstrate a kilojoule-level 10kV capacitor bank based on the scientific outcomes of Phase I.

PHASE III / DUAL USE:
MILITARY APPLICATION: High energy density capacitors are extensively in demand throughout the military. Reliable, high energy storage devices are enabling for aircraft, UAV, sensors, DEW and space applications.

COMMERCIAL APPLICATION: High energy density capacitors are needed throughout the commercial power and automotive industries. Reductions in size and weight will lead to new commercial man-portable pulsed power applications.

REFERENCES:
1. Conway, B.E., Electrochemical Supercapacitors, Kluwer Academic / Plenum Publishers, New York (1999).

2. Rzoska, S.J., and Zhelezny, V., Eds. Nonlinear Dielectric Phenomena in Complex Liquids (NATO Science Series II: Mathematics, Physics and Chemistry), Springer Verlag, Berlin (2004).

3. Portet, C., Yushin, G. & Gogotsi, Y. Carbide Derived Carbons for Electrical Double Layer Capacitors: Electrochemical Performances of Carbon Nanoparticles and Influence of Carbon Particle Size J. Electrochem. Soc 155 (7) (2008).

4. Subramanian, V., Zhu, H.W. & Wei, B.Q. Nanostructured MnO2: Hydrothermal synthesis and electrochemical properties as a supercapacitor electrode material. Journal of Power Sources 159, 361-364 (2006).

5. J. Gouyet, Physics of Fractal Structures, Springer Verlag, Berlin (1996).

KEYWORDS: Supercapacitors, Electrochemical Capacitors, Nonlinear Dielectrics, Fractals, Capacitors, Pulsed Power

AF09-BT06 TITLE: <u>Novel Algorithm/Hardware Partnerships for Real-Time Nonlinear Control</u>

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: To develop novel hardware architecture and corresponding mathematical algorithms that, together, take advantage of new approaches for real-time computation of nonlinear control and games.

DESCRIPTION: Nonlinear dynamics govern most, if not all, processes of interest in aerodynamics, orbital mechanics, and command and control (cf. [4]). Theoretical development of nonlinear controls has advanced dramatically in the past 50 years, but very few computationally efficient numerical approaches have arisen to permit practical implementation. Producing closed-loop controllers that can operate in real-time remains a major challenge to the application of nonlinear control models in fielded and research Air Force systems. In fact, this has been an essentially insurmountable challenge for nearly half a century. Various heuristic approaches and workarounds have been employed (including linearization, gain scheduling, control Lyapunov functions and singular perturbations, among numerous others), but these are typically highly suboptimal and/or do not deal with disturbances well. In this STTR topic, we are seeking major improvements in numerical strategies for nonlinear control computations. It is likely that the advances sought involve a combination of hardware and software.

Classic approaches to nonlinear control belong to two categories: dynamic programming [1], [2] and the maximum principle [5]. Standard numerical methods for solving the resulting sets of differential equations have not yet yielded controllers that can be applied to realistic models and produce real-time controllers. Maximum principle approaches are not well-suited to problem domains with substantial stochastic and/or game-theoretic inputs, and generally require recomputation in real-time at a computationally unfeasible rate. The most common approach is to discretize the partial differential equation (PDE) resulting from the dynamic programming principle [1], [3]. This approach suffers from the curse-of-dimensionality, which precludes solution of general problems with state spaces of dimension over three on current machinery. The complexity growth rate is so high that even dimension five is inconceivable on standard machines in the foreseeable future. Note that we are not seeking massively parallel hardware for application to such a PDE. Instead, we are seeking new concepts for solution of these problems. Ideally, this would bring together novel mathematical and algorithmic methods with hardware specifically applicable to the algorithms.

The hardware must be applicable to some class of problems of interest to USAF. This could include deterministic optimal control, stochastic control and game theory. The relevant applications could be in control of a single air or space vehicle, a subsystem thereof, coordinated vehicles, tracking, estimation, and autonomous control of the battlespace in an adversarial environment.

PHASE I: Develop a numerical approach to nonlinear control that is broadly applicable to a variety of systems, and design the hardware configuration to be used in phase II. Analyze the computational feasibility in terms of dimensionality for a control problem of Air Force interest.

PHASE II: Construct the novel hardware (along with the necessary interfaces), and implement the numerical control algorithm on it. Demonstrate real-time closed loop capability.

PHASE III / DUAL USE:
MILITARY APPLICATION: Military applications include aircraft systems, spacecraft systems, mission design, aircraft and spacecraft guidance and control, command and control and sensing asset tasking, among many others.

COMMERCIAL APPLICATION: Commercial applications include automotive systems, aircraft systems, manufacturing, material processing, option pricing, among many others.

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KEYWORDS: Nonlinear control, game theory, stochastic control, reconfigurable computing, field-programmable gate arrays, parallel computing.

AF09-BT08 TITLE: Inducing Failures in to a Voltage Controlled Oscillator

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Develop a sensitivity model of a crystal based Voltage Controlled Oscillator (VCO) to free-field radio frequency (RF) waveforms.

DESCRIPTION: The Air Force has a need to understand which parameters of a RF waveform can induce a sub-harmonic frequency response in a VCO. VCOs are generally quartz based and have a stable oscillation frequency when an electric charge is applied across them. They are integrated in to electronic circuit boards to provide a timing signal based on the period of the crystal's oscillations. Although the VCO is generally operated at a stable frequency, it has been observed that electromagnetic interference (EMI) can induce the VCO to oscillate at a sub-harmonic. Once a VCO transitions to a new frequency of oscillation, the electronic circuit board is no longer able to operate correctly and will cause the digital system to hang up. Although this new state will persist once the EMI inducing the sub-harmonic mode has been removed, the overall effect to the digital system is only temporary as the VCO will return to its designated parameters once the power is recycled.

The solution must explore the vulnerability of VCOs to free-field RF and define the characteristics of a waveform that are most effective at inducing a sub-harmonic frequency response. It must consider the standards of VCOs and the operating frequencies used in computers, telecommunications and video equipment available to the general public. The basic test group should include at least 4 examples of circuit boards with either VCOs designed to operate at different frequencies or with differing architecture that would influence the result. The research must establish the minimum pulse width, pulse repetition frequency, duty cycle, E field magnitude and bandwidth of single and multiple pulses that can induce a failure mode in a VCO and define the influential waveform parameters needed for the sensitivity model. The solution should be adaptable to a range of different circuit boards and be able to compare the prediction provided by the model with the results from bench testing. The solution should have the ability to be updated as the test group is increased to include new or unknown circuit board architectures but restrict itself to board-level testing to avoid the complexity associated with trying to model particular types of systems.

PHASE I: Research and define the waveform parameters that would induce a failure mode in a VCO. Test the sensitivity of the VCO to these parameters and build a model. Define the specifications of VCO that the model applies to. Verify the model in an RF Chamber.

PHASE II: Increase the number of the test assets to include a greater range of VCO operating frequencies or types of circuit board. Test the model against basic systems to see what parameters are insensitive to real world situations.

PHASE III / DUAL USE:
MILITARY APPLICATION: Simulation and Modeling of Electronic Warfare fratricide

COMMERCIAL APPLICATION: EMI Modeling and deconfliction

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KEYWORDS: Susceptibility, EMI, VCO, circuit boards

AF09-BT09 TITLE: Distributed Pattern Detection and Classification in Sensor Networks

TECHNOLOGY AREAS: Information Systems, Sensors

OBJECTIVE: Establish mathematical and computational capabilities for detection of distributed patterns in sensor networks. Demonstrate effectiveness for patterns relevant to surveillance and/or network security.

DESCRIPTION: The ability to detect and classify distributed patterns is a crucial capability enabled by the emergence of distributed sensor networks. Such patterns may arise in the sensor data collected by the nodes of the network, in which case they inform situational awareness objectives relevant to surveillance and other sensing applications of the network. Distributed patterns may also be present in the flow of data within the network. Detection and characterization of such patterns is relevant to Information Assurance (IA), due to their possible association with the compromise of a network by an adversary. Developing a foundational understanding of the detection of such patterns also impinges on Information Operations (IO), where the goal may by to compromise an adversary's network without producing detectable evidence of intrusion.

The scientific focus of this Topic is detection and characterization of extremely weak distributed patterns that are undetectable in the local signatures at individual nodes. Fusion of low-level information from individual nodes will be necessary to achieve this objective. At this level, there is some degree of analogy with recent advances in multiplexed imagers. The imagers described in [1, 2], for example, use sophisticated signal processing to aggregate the outputs of single-pixel detectors. They are capable of detecting much weaker signals than a traditional imaging array, whose sensitivity is essentially determined by the individual noise floor of each pixel. Innovative approaches that also entail higher-level fusion, such as incorporation disparate types of sensor nodes and exploitation of intelligence or other side information in a rigorous manner, are of particular interest in this Topic. And adaptive strategies, that accrue local information necessary to achieve desired confidence in detection and classification of distributed patterns by selectively polling the most relevant nodes, are also especially sought. Creative, rigorous approaches that admit analysis of anticipated performance, e.g., theoretical limits of detection, are preferred to heuristic methods. Attention to computational efficiency and scalability is also an important consideration.

PHASE I: Establish a mathematical framework for detecting and classifying distributed signals in a sensor network with fixed topology. Propose a plan for developing performance bounds and for validating the methodology, ideally using both simulation and actual sensor network data.

PHASE II: Develop and implement algorithms instantiating the approach set forth in Phase I. Undertake theoretical analysis of performance and scalability, and validate the approach on a representative set of problems involving simulated and/or real sensor network data.

PHASE III / DUAL USE:
MILITARY APPLICATION: DoD applications include surveillance situational awareness using distributed sensor networks, e.g., detection of airborne toxins, and in IA, for detecting compromise of sensor or other networks.

COMMERCIAL APPLICATION: Improved tools for detection and isolation of internet-borne viruses and attacks on commercial networks, homeland security surveillance applications, and increasing sensitivity in radio telescopes.

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KEYWORDS: Information Fusion, Integrated Sensing and Processing, Information Assurance.

AF09-BT10 TITLE: High-Fidelity Simulation of Dynamic Weakly Ionized Plasma Phenomena

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop a computational capability to accurately simulate plasma phenomena including magnetic field effects and charged particle motion.

DESCRIPTION: Within the broad spectrum of hypersonic and space capabilities of interest to the Air Force there are a significant number of applications which require detailed insight into the complex dynamics of weakly ionized flowfields. Examples of such flows include the generation of a plasma sheath around a hypersonic flight vehicle, local generation of plasma for flow control or combustion enhancement applications, and expansion of arc-generated plasmas through nozzles to simulate hypersonic flows for material testing.

To facilitate the exploration, characterization and possible exploitation of plasma dynamic phenomena in the rich space of AF applications, validated numerical methods are sought that will enable the simulation of dynamic weakly ionized plasma phenomena across a wide range of conditions.
Research areas of interest related to this topic include, but are not limited to, the following:

- Accurate simulation of plasma phenomena including magnetic field effects and charged particle motion
- Accurate simulation of high-temperature gas chemistry including radiation effects (up to 15,000 K)
- Experimental development and/or validation of physical models associated with the above areas of interest
- Development of analytical models to guide the development of the above areas of interest
- Simulation of complex, three dimensional geometries and flows
- Time accurate simulation of transient phenomena including facility start-up
- Capabilities to simulate laminar and turbulent flows over reactive surfaces
- Flow control with passive or active methods such as electromagnetic fields including MHD and/or energy deposition with microwaves or lasers

Appropriate responses to this topic will develop the essential underlying numerical methods and physical models to enable the eventual development of a numerical simulation capability providing the attributes described above. Responses proposing purely experimental or analytical approaches will be considered non responsive. Flows of significant interest include the generation of a plasma sheath over a hypersonic reentry vehicle and the stagnation chamber and nozzle flow within an arc-heated ground test facility.

PHASE I: Develop the required numerical methods and physical models to address a significant subset of the research topics of interest identified above. Integrate Phase I accomplishments into a preliminary, un-validated, computational tool.

PHASE II: Refine and validate the computational tools and methods developed in Phase I. Demonstrate the utility of the tools on an ionized flowfield of interest to the Air Force. Validate the computational capability against data available from the archival literature.

PHASE III / DUAL USE:
MILITARY APPLICATION: Evaluation of plasma phenomena on hypersonic vehicles and ground test facilities.

COMMERCIAL APPLICATION: Evaluation of plasma phenomena for a broad spectrum of space applications.

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KEYWORDS: need keywords

AF09-BT11 TITLE: Realistic State and Measurement Error Uncertainty Computation and Propagation for Space Surveillance and Reconnaissance

TECHNOLOGY AREAS: Information Systems, Space Platforms

OBJECTIVE: Develop and implement algorithms capturing realistic uncertainties on state and measurement errors in support of autonomous Space Situational Awareness, Control, and Reconnaissance.

DESCRIPTION: Current operational capabilities implement a Differential Correction (DC) or Batch Least Squares (BLSQ) approach to Resident Space Object (RSO) catalog maintenance. In this process, the SSN measurement errors are assumed to be uncorrelated and Gaussian distributed. Measurement biases are solved for infrequently. Because the DC process does not account for process noise, the resultant computed covariances are optimistic at best. Because each RSO is unique and the current operational process assumed all RSOs to be spheres, modeling errors are aliased into catalogued RSO state vectors because they are not properly accounted for. This in turn affects the forward (predictive) model. What are needed are methods which can model more realistic measurement errors and when these are not well known, can provide a means of recovering these. The estimation algorithms in place assume uncorrelated Gaussian distributed and linear measurements. There are methods of pre-whitening data residuals prior to the data reduction process and these can be implemented to account for this discrepancy. An example of an innovative method for recovering the actual Probability Distribution Function (PDF) to the best extent possible is the Adaptive Gaussian Mixture filter. This could yield much more realistic covariances than what are currently computed. Current covariances are either propagated linearly or inferred empirically. We know that the true PDF evolves in a way described by the Fokker-Planck-Kolmogorov Equation. Proposed methods should address this.

All operational decisions in SSA/C2 are based upon knowledge, not the errors because we never know the truth in order to compute the actual error. What we can know is how the errors behave as a function of time, current/future observations, etc. If our knowledge is more realistic, then we can make better informed decisions. Given all of the above, the proposed work should have the following properties:

1) Use a variety of traditional and non-traditional data types, both metric and non-metric such as [but not limited to] radar (range and radar cross section) and optical (angles, photometry, radiometry, polarimetry, spectroscopy).

2) Provide covariances and covariance consistency metrics perhaps via Monte Carlo analyses and others. Covariance Consistency is the property that a computed variance-covariance matrix realistically represents the covariance of the actual errors of the estimate. The computed covariance of the state estimation error is used by many for processes such as data/track association processing, collision avoidance, probability of reacquisition, sensor cueing and tasking, maneuver/change detection, etc.; consequently, degraded consistency causes misassociations (correlation errors) that can substantially degrade system level performance. Hence, degraded covariance consistency or bias errors can mislead the warfighter about the accuracy of a quantity which could trigger a specific decision or Course Of Action (COA).

3) Provide methods to estimate and exploit measurement error covariances whether they are correlated or not as well as properly accounting for measurement biases in the overall state error covariances. Methods of data residual prewhitening should be assessed.

4) Address use of algorithms that allow non-traditional information (such as multi-band photometry, radiometry, etc) to augment realtime metric data towards refining overall RSO state error assessment.

PHASE I: Develop the mathematical basis for and provide a feasibility assessment of realistic measurement and state error covariance recovery concepts using simulated data and key metrics for single and multiple sensors (addressing 1-4 above). What could be achieved given the current SSN?

PHASE II: Develop/update the technology based on Phase I to provide a prototype demonstration of the technology in a realistic environment using realistic data, with errors and biases as well as realistic processing speeds in complex scenarios. This may fit in supporting R&D programs such as the LANL "Thinking Telescope" system, and/or Tasking Autonomous Sensors in a Multiple Application Network (TASMAN).

PHASE III / DUAL USE:
MILITARY APPLICATION: Integrate algorithm enhancement technology into a Major Defense Acquisition Program (MDAP) programs of record such as Integrated SSA (ISSA) and/or ESSA as a path to infuse JSPoC capabilities.

COMMERCIAL APPLICATION: The technology is applicable across DoD, as well as in non-DoD sensor network environments such as air traffic control, medical imaging, meteorology, communications, and security applications.

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KEYWORDS: Kalman filtering, orbit determination, sensor error, sensor characterization, attitude determination, data fusion, decision support systems.

AF09-BT12 TITLE: Advanced Auditory Modeling for Acoustic Analysis

TECHNOLOGY AREAS: Information Systems, Sensors, Human Systems

OBJECTIVE: Develop new methods for automated interpretation and analysis of acoustic events, e.g., speech, based upon the auditory brain's neural computing.

DESCRIPTION: Under operationally realistic listening conditions, the human auditory system out-performs all current machine-based systems for recognizing the acoustic environment and interpreting speech or other coherent acoustic events. Automatic algorithms tend to be especially deficient under conditions of noise or reverberation, or when target events are embedded in a cluttered sonic background. Typically, these engineered systems are built to emulate only the basic, peripheral stages of human audition, and they rely on general statistical or pattern-recognition methods more than upon current theory about higher-level processing in the human or mammalian auditory brain.

The goals of this research topic are to (a) define and model the neural computational processes in the auditory brain, and (b) use this scientific insight to develop significant new approaches for acoustic signal processing. This effort should aim to replace or enhance current technology. The potential areas of application are not defined by any specific or current Air Force operational requirements. Among general areas to consider are those where human auditory performance excels and where conventional technologies are not highly developed, including sound-source localization and segregation, rapid adaptation to acoustic environments (e.g., to echo and reverberation, or to channel distortion and masking), sound texture analysis, classification, tracking, and prediction.

Ideas from current auditory science should motivate the approach. Examples may include, but are not limited to: using spatial locations or motions to disambiguate multiple sources, spectro-temporal modulation filtering and representation, neural transformations that normalize vocal resonances or other variations, asynchronous coding of time-varying signals in neural spike trains, or rhythmic cortical oscillations deemed to enable parsing and binding of acoustic input. Research methods for this topic are interdisciplinary. The scope of this work should extend to computational auditory scene analysis generally, or to specific problems therein, although applications to conventional problems of speech detection and recognition may be proposed. This STTR Topic intends to stimulate investigation of novel concepts. Therefore, proposals should embrace a significant role for fundamental scientific research, and should not offer merely to refine or revise existing technologies.

PHASE I: Identify or develop areas of auditory science that hold promise for computational or mathematical emulation. Perform preliminary research to test these ideas in systems for real-time, or near real-time acoustic analysis.

PHASE II: Develop and evaluate prototype algorithms. Evaluate the approach developed in Phase I, through simulation, psychoacoustic, biophysical or other types of experiments or measurements.

PHASE III / DUAL USE:
MILITARY APPLICATION: Enhancements in acoustic analysis will be useful for military applications where information flow and surveillance must be achieved in sub-optimal conditions, such as in high noise levels.

COMMERCIAL APPLICATION: Similar benefits will accrue in civilian applications, such as for devices for hearing prosthetics or communication, or for enhancement of digital media.

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KEYWORDS: Acoustics, Auditory Perception, Biomimetics, Cortical Mechanisms, Neural Computation, Sensory Processing, Spatial Hearing, Speech Enhancement

AF09-BT13 TITLE: Advanced Computational Methods for Study of Electromagnetic Compatibility

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop a fast and accurate computational electromagnetic (CEM) method and associated high-order surface representation method, which apply to field leakage problems in aircraft.

DESCRIPTION: Until recently, uses of CEM were limited by computational power and geometric representation to rather crude approximations of radar cross section for low frequency configurations. As our ability to solve large, complex problems increases, so do the conceivable applications for which computational methods can be put to use. In particular, accurate simulation of realistic aircraft and weapon systems (as they really are; imperfect assemblies of both PEC and non-PEC materials with complex geometries, electronics, enclosures, etc.) has risen to the realm of the possible. This allows us to begin evaluating the ways in which fields entering cavities through small apertures can interact with internal electronic components, as well as begin quantifying the consequences of that interaction.
The interaction of electromagnetic fields with cavities, and enclosed electronic components pose significant challenges to computational electromagnetic solvers. In particular, a sometimes limited knowledge of the relevant geometry, or geometries, with errors, openings, and omissions, must be treated adequately in order to produce smooth parameterizations suitable for use in conjunction with high-order solvers, while preserving the integrity of the system it is meant to represent. Testing the effects of EM radiation on aircraft, ordinance, and electronics is expensive, time consuming and potentially destructive. Modern weapons are designed to be safe in a variety of environments, and arming and fuzing systems allow safe carriage and release under current wartime constraints. However, the electromagnetic environment of the battlefield is becoming very complex. It is significantly more probable for an armed weapon to be within proximity of friendly forces coincident with high radiation. This is especially likely in proximity to an HPM emitter. Post-release HERO must now be considered. Testing of full-up, armed rounds is expensive, dangerous, and limited. As our ability to accurately model EM phenomenon increases to a point allowing significant decisions applicable to system safety to be made, a method to determine the accuracy of that solution must be perfected in parallel to reduce risk.

PHASE I: Identify and/or Develop optimal CEM methods, geometry representations, circuitry representations, shielding effectiveness that addresses the EM signals propagation/effects through aircraft openings/surface imperfections. Demonstrate integration of the above into a preliminary computational tool.

PHASE II: Present results of induced currents in various examples of geometries and electronic circuitry. Develop, demonstrate and validate a fast and accurate computational electromagnetic (CEM) method and associated high-order surface representation methods applying to field leakage problems in aircraft including the ability to quantify the uncertainties in the models and methods.

PHASE III / DUAL USE:
MILITARY APPLICATION: The ability to predict effects of EM on aircraft and weapons systems

COMMERCIAL APPLICATION: The ability to predict effects of EM on commercial aircraft

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KEYWORDS: Computational Electromagnetics (CEM); Electromagnetic (EM); Hazards of Electromagnetic Radiation to Ordnance (HERO); High Power Microwave (HPM); Modeling and Simulation (M&S); Perfect Electrical Conductor (PEC).

AF09-BT14 TITLE: Advanced Nonlinear Transmission Lines as High Power Microwave Sources

TECHNOLOGY AREAS: Sensors, Weapons

OBJECTIVE: Advance the physics of nonlinear transmission lines to achieve gigawatt-level pulses of microwave radiation at gigahertz-level frequencies.

DESCRIPTION: Nonlinear transmission lines (NLTLs) are currently under worldwide investigation as a class of high power microwave (HPM) sources that offer the potential for compact size, operation at extremely high powers, and a unique combination of pulse parameters which have not yet been obtained in any other way. NLTL generation of high voltage solitons by applying a fast-rising, high voltage pump pulse to a lumped element transmission line which is periodically loaded with either nonlinear capacitors or inductors has been reported in the literature for decades. Theoretically, such solitons can adiabatically adjust their amplitude and width to match the local properties of the medium without losing their form. The periodicity of the lumped elements, their nonlinear properties, the amplitude and shape of the pump pulse, number of stages, parasitic capacitance, inductance and resistance, the load resistance and the characteristic frequency of the transmission line all contribute to determine whether solitons will be generated, the amplitude and width and number of the solitons generated, compression efficiency and how well they maintain their form when extracted to the load. Recent advances in dielectric and magnetic materials have spurred renewed interest in the field of NLTLs. The NLTL approach to HPM and ultra-wideband (UWB) generation is revolutionary because it eliminates the electron beam, vacuum system and magnets required in conventional HPM sources. Furthermore, the novel waveforms of NLTLs offer a degree of frequency diversity unseen in current HPM sources (although perhaps at lower peak powers) due to control of amplitude, oscillating frequency, and temporal envelope. They have the ability to provide aspects of both wideband via pulse length and rise time control and narrowband in the oscillating frequency. Given these challenges and opportunities, it is important to consider sources that are tunable, highly reproducible, compact, and efficient to explore these new waveforms. Recent developments suggest that transmission lines loaded with nonlinear elements offer the capability for pulse rise time sharpening, efficient microwave generation (DC-to-RF conversion), tunability based on system control of the nonlinearity (based on applied voltage or current), and high reproducibility associated with solid-state response times to the applied power. Nonlinear circuit elements in transmission line geometry combine both variable energy storage and energy transmission velocity due to the interaction of the applied and oscillatory fields with the material. While previous work has demonstrated impressive power, efficiency, and reproducibility, it was typically performed at frequencies relatively low to existing HPM sources. Furthermore, there are conflicting reports of how to best design these sources, perhaps due to the conflicting requirements of sharp pulse rise time and RF generation.

PHASE I: Use a combination experimental, simulation & theoretical research to advance the understanding of a specific type of high power nonlinear transmission line (NLTL). Design & fabricate a test NLTL to study pulse sharpening & RF generation at currents > 1000 amperes and voltages < 10 kV.

PHASE II: Based upon the insight developed from the Phase I research results, formulate scaling laws, design & fabricate a NLTL that operates at voltages >100 kV & currents > 100 kiloamperes generating 10's of gigawatts of gigahertz-level pulsed power. Fully characterize the physics of that novel device.

PHASE III / DUAL USE:
MILITARY APPLICATION: Directed energy weapons, ultra wide band radar, tunable filters, phase shifters, compact, tunable (narrowband and wide band) microwave devices

COMMERCIAL APPLICATION: Ultra-wideband HPM sources such as the above technology have a variety of medical applications including cancer therapy, wound healing & in-situ fat removal.

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KEYWORDS: HPM, NLTL, nonlinear transmission lines, high power microwave

AF09-BT15 TITLE: <u>Network Information Flow Analysis</u>

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: To develop mathematical, algorithmic, and protocol approaches to track, manage, bound, and visualize network information flow.

DESCRIPTION: Communication networks can be analyzed in terms of the flow of information between any two nodes or groups of nodes but many of the techniques for this analysis have been tailored to specific scenarios rather than broadly applicable to a wide class of network problems. Information flow can be tracked using correlation or covariance analysis of a time series of information flowing into and out of network nodes. Such correlation analysis can be structured and visualized in terms of matrix, spectral graph, and discrete geometric constructs. All of these analysis areas can be integrated into a unified, typically computational geometric representation which can have properties traceable to specific network behavior. This network behavior has manifested itself different kinds of protocol and analysis such as network coding, network tomography, and dynamic network stability analysis. We wish to have a unifying construct allow all of these areas to interact as one approach. An example of this strategy would be to look at varying time windows or multi-resolution network information transaction where short time windows would reveal structural and coding information about individual network packets. At long time windows we could look at topographic properties of time traces of packets flowing through the network and infer network structure. Intermediate time windows of packets could reveal properties of dynamic protocol behavior in the context of certain kinds of network traffic or network topologies. The unified geometry of the eigen-structure of these multi-resolution observations would result in geometric representations of network behavior that would reveal different fundamental properties of the network depending on what phenomena are of interest.

Such unifying network flow analysis and protocols would enable monitoring of a wide variety of network functions including network policy and protocol, network management effectiveness and stability, and connectivity using an integrated approach rather than a variety of techniques which have to be custom built for particular scenarios. We then wish to use these methods to assess, visualize, manage, and predict information flow in networks. Software resulting from this process could be used for network performance analysis and prediction, unknown network discovery, network anomaly detection, coding and management procedures among others. Relevant applications for this strategy include procedures for monitoring, routing, and network structure analysis in mobile, heterogeneous dynamic airborne networks. Additionally, such information flow methods can be used for assessing stability and security of reach-back and terrestrial networks and design and resource policy assessment of mixed wireless networks.

PHASE I: Complete development of unifying information flow mathematical and algorithm strategy and demonstrate how it can be applied to real network data. The strategy should be applicable to a broad class of network problems including coding, tomography, resource allocation, and stability analysis.

PHASE II: Implement analysis software in a basic application that that can be used on an communications network and demonstrate the technique for several key problem areas including resource allocation and network policy analysis, network anomaly detection, and guarantee of information quality of service to individual network users with time critical information requirements.

PHASE III / DUAL USE:
MILITARY APPLICATION: This topic would be particularly relevant for airborne network policy analysis, security, management, and prediction.

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KEYWORDS: Computational Geometry, Geometric Coding, Network Tomography, Network Dynamics

AF09-BT16 TITLE: Fusion of a Real-time Analytical Model with Facility Control Systems

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Develop an automated analytical model that can be directly linked with a facility data acquisition system and determine/adjust the form of empirical parameters automatically as the facility is run.

DESCRIPTION: Mathematical models are used to model the behavior of complex systems such as wind tunnels, using basic physical principles and simplifying assumptions. These models have been shown to be invaluable, allowing hardware-in-the-loop testing of facility control systems and the initial tuning of these systems under safe, air-off conditions.

No matter the sophistication of the model, some parameters must be determined empirically, since neither the theory nor the computational power exists to exactly compute phenomena such as flow losses in complex geometries, especially in real-time. Lacking a better estimate, these parameters are often set to a constant to either match empirical data at a specific point for which data is available, or roughly fit the data over a range of values. Given the large number of variables involved for most systems and the difficulty in hand-tuning the model, the settings for these parameters rarely approach their optima. No allowance is made for changes in these values over time or that these factors may be complex functions of various parameters, e.g. pressure, temperature, flow rate, etc.

It is desirable to have an analytical model that is directly linked with the facility data system and runs in conjunction with facility testing. In this way, algorithms could be implemented that determine these factors as a function of facility parameters by minimizing the error between predictions and the actual facility response. These factors could then be adjusted to reflect the current state of the facility. Ideally, this process would be automated and run during facility operation without the direct involvement of the facility operators. Methods to deal with redundant, conflicting, or sparse data and noise would also need to be developed, as would a methodology to automatically determine the functional form of the empirical parameters. These functions may take the form of traditional mathematical functions, tabular lists of values, artificial neural nets, or other forms.

PHASE I: Identify and/or develop automated techniques to collect/sort data/determine the optimal functional form of empirical constants in a facility analytical model. No information on govern facilities will be provided in Phase I. It is recommended to use facilities existing at the academic institution.

PHASE II: Develop, evaluate and validate prototype automated analytical models using techniques outlined or developed in Phase I. Demonstrate utility by adopting the model to a government facility specified by AFOSR.

PHASE III / DUAL USE:
MILITARY APPLICATION: Model can be used to optimize running efficiency and increase accuracy and precision of test facilities including wind tunnels, power plants, large vehicles and other hardware-in-the-loop systems.

COMMERCIAL APPLICATION: Model can be used to optimize running efficiency and increase accuracy and precision of commercial test facilities and large commercial transport vehicles involving multiple, complex parameters.

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KEYWORDS: analytical model, mathematical model, data acquisition, facility control system

~~AF09-BT17 TITLE: Multifunctional Metamaterials~~

~~TECHNOLOGY AREAS: Materials/Processes~~

~~OBJECTIVE: Rationally designed meta-materials demonstrate unprecedented opto-electromagnetic properties that are unattainable with naturally occurring materials by changing the unit cell or “meta-atom”.~~

~~DESCRIPTION: On the path to new prospects for manipulating infra-red light, artificially engineered materials have attracted a great deal of attention. Rationally designed meta-materials demonstrate unprecedented opto-electromagnetic properties that are unattainable with naturally occurring materials by changing the unit cell or “meta-atom”. The optical properties of ZnS and related artificially fabricated meta-materials can be tailored by controlling the values of permeability, μ, and permittivity, e. The feasibility of designing and fabricating Low emissivity meta-material films with conductivities of 20 KS/cm and -30dB electromagnetic shielding efficiencies in the 10 to 100 GHz region and 90-95% IR transmittance from 2 to 27 micron has already been demonstrated. Self assembled nano-structured nano-composite thin film systems, which combines optical and electrical properties of these meta-materials can have a remarkable impact on new broad band IR sensors and devices.. In this project the vendor will tailor this system to achieve a perfect absorber with the emissivity reaches to 1 in entire IR region.~~

~~PHASE I: 1. Vendor with academic partner will tailor this low emissivity meta-material system into a high emissivity super absorber.~~

2. Vendor with academic partner will calculate optical parameters spectra for suitable meta-material structures.

PHASE II: In Phase II vendor demonstrate the feasibility and manufacturability of this technology by building prototype broad band IR devices demonstrating the high conductivity. IR transmittance and other proposed high performance properties. Testing and evaluation of the variety of prototype sensors and devices will be accomplished by an appropriate team coordinated by the vendor, which could include facilities at FFRDCs; DoD facilities such as AFRL, NRL and ARL; defense systems contractors; research institutions; as well as the academic partner.

PHASE III / DUAL USE:
MILITARY APPLICATION: This new technology will enable efficient and miniaturized high performance IR sensors and detectors for SSA, surveillance, and IR communications technology.

COMMERCIAL APPLICATION: This new technology will have profound applications in a number of Homeland Security applications, automotive safety considerations, and specialized medical and clinical technology systems.

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KEYWORDS: Multifunctional materials, IR, emissivity, ZnS

AF09-BT18 TITLE: Algorithm Development for Multi-Core GPU-Based Computing Architectures

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: To develop advanced algorithms with multi-core paradigm for scientific computing, modeling, and simulation based on Graphics Processing Units (GPUs) computer architecture.

DESCRIPTION: The availability of modern specialized computing hardware technology brings an unprecedented opportunity for the acceleration of complex computations in engineering applications. The gaming industry in particular relies heavily on hardware-oriented algorithms using Graphics Processing Units (GPUs) that perform 10 to 100+ times faster than traditional serial or parallel algorithms, and can usually be developed for a fraction of the cost of a supercomputer or computer cluster. GPU's are mature and robust technology for high–performance visualization processes. Relatively recently, GPU computing made a quantum leap forward with the introduction of the CUDA development environment from NVIDIA [1, 2]. Their use is now emerging for scientific computing applications [3, 4]. High-performance computations are currently done on clusters of CPUs and the same will be true for GPUs. However, there are still relatively few people who understand GPU architecture deeply enough for algorithm research and development. In order to unleash the full potential of GPU-based architecture in a vast array of scientific computing applications where faster numerical computation is a crucial necessity [5, 6], research is needed to fully understand algorithm development with particular emphasis on scientific computing (i.e., solving differential equations of physics). Algorithm design with the GPU-based computers requires an understanding of the hardware architecture, hardware programming language, compiling, debugging, and synthesis tools. There is also a need for the hardware, software (OS, middleware, libraries and applications) to scale GPU calculations to clusters. For applications, libraries that implement key high-performance computing (HPC) functions and also scale to multiple GPUs are needed. The present initiative seeks innovative algorithm development for scientific computing with GPUs. This should include developing a set of criteria for defining model test problems of a multidisciplinary nature and evaluating existing computational tools for comparison with the methodology developed. Specifically, solving differential equations and stochastic (e.g., Monte-Carlo) techniques on a large-scale are of utmost importance for Air Force scientific computing needs. Examples of such problems include electromagnetic wave propagation, computational fluid dynamics, particle transport and radiation transport.

PHASE I: Develop and demonstrate computationally effective, multidisciplinary solutions to problems of mathematical physics with innovative algorithms for (i) solving differential equations and/or (ii) simulating the physics via stochastic/probabilistic techniques with parallel and distributed computing.

PHASE II: Expand the capability of selected algorithms for multidisciplinary computing into a production–level product capable of solving complex problems in fluids, structures, and electromagnetism taking full advantage of GPU computing architecture.

PHASE III / DUAL USE:
MILITARY APPLICATION: Modeling & simulating realistic analysis, design, & optimization challenges. This includes but is not limited to engine-airframe integration, lifting surface-structure analysis, and RCS minimization.

COMMERCIAL APPLICATION: Commercial applications apply to any system or sub-system level optimization where detailed multidisciplinary computational analysis is required.

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KEYWORDS: Reconfigurable computing, graphics processing units, parallel computing, computational mathematics, computational physics.

AF09-BT19 TITLE: Extreme Wear-Resistant Materials

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: To develop novel materials or surface modifications capable of providing superior wear resistance in environments with extreme vibration, friction and thermal loads.

DESCRIPTION: As military assets continue to push technological barriers they will place the materials they are made of under increasingly brutal stresses. To ensure future assets can survive such extreme environments (even if the environments are highly localized and short-lived) it is necessary to develop new materials and surface modification technologies that can withstand exceptionally harsh environments such as those found in supersonic ground test tracks or rail gun environments. Of particular interest are revolutionary formulations capable of surviving repetitive sliding contacts at Mach 8 and above. Sliding contact is not with a constant load, but rather a vibration and loading combination in which contact is obtained on the order of 40% of the time. A highly successful project would result in a new material(s) or surface modification(s) with a drastic improvement in fatigue strength, with the combined reduction in surface sliding wear, friction coefficient, abrasion resistance and oxidation resistance at supersonic speeds.

PHASE I: Identify novel materials, formulation and/or surface treatments capable of surviving repetitive sliding contacts at supersonic speeds and demonstrate support for proof of concept.

PHASE II: Develop and demonstrate material and surface modification technology capable of surviving repetitive sliding contacts at supersonic speeds.

PHASE III / DUAL USE:
MILITARY APPLICATION: Military testing, such as at high speed test tracks, is certainly of immediate concern, with other applications of contact surfaces at extreme hypersonic speeds.

COMMERCIAL APPLICATION: Commercial applications include high load contact surfaces as would be found in industrial processes such as steel production, paper production, or forging presses.

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KEYWORDS: hyper velocity track extreme wear resistance

AF09-BT20 TITLE: Multi-Photon Process High Efficiency Photovoltaics

TECHNOLOGY AREAS: Space Platforms, Weapons

OBJECTIVE: Develop inorganic materials containing nanostructures to enable photovoltaic cells capable of ultra high efficiency (>50%) via multiple photon processes (e.g., intermediate band photovoltaics).

DESCRIPTION: Higher efficiency solar cells are needed to reduce solar array mass, stowed volume, and cost for AF space missions. Current approaches to high performance solar cells are limited in efficiency to approximately 35% air mass zero (AM0). Improving the efficiency beyond this point by adding additional junctions quickly reaches the point where the marginal performance gain is offset by the increased fabrication complexity, difficulties maintaining current matching between the junctions and potentially enhanced radiation degradation. Multi-photon processes, utilizing more than one photon to generate a free carrier, have been proposed as a paradigm shift in fundamental solar cell device physics capable of enabling very high efficiency devices (>50% AM0)1,2. These proposed devices generally incorporate quantum confined structures, which have been shown to alter optoelectronic properties in semiconductors, including size-dependent bandgaps in nanoparticles. Nanostructured materials have been incorporated into conventional III-V multijunction devices in an attempt to balance current between sub-cells, with a predicted increase in device efficiency.3,4 To date, these efforts have demonstrated the difficulty in producing a suitable volume of nanomaterial within the device region capable of providing the optical absorption and carrier collection required to generate the needed current boost. It is expected that devices utilizing quantum confined materials for multi-photon energy conversion will also be challenged to demonstrate full optical absorption of the convertible solar spectrum in addition to highly efficient current collection. Therefore, advanced device designs and material systems are needed in order to realize the ultrahigh efficiency solar cells required by the AF.

PHASE I: Perform feasibility studies through modeling and experiment for nanostructured photovoltaic devices capable of fully absorbing the 'convertible' solar spectrum & collecting resultant generated carriers utilizing a multi-photon conversion process. Determine theoretical efficiency of device design.

PHASE II: Fabricate a prototype for the nanostructured solar photovoltaic device developed in phase I. Identify physical mechanisms limiting performance and develop approaches to optimize device performance.

PHASE III / DUAL USE:
MILITARY APPLICATION: Increasing solar photovoltaic cell efficiency is critically enabling for warfighter missions requiring increases is payload power and mass for constant solar array area.

COMMERCIAL APPLICATION: Increasing solar photovoltaic cell efficiency is also essential to the commecial sector for increasing payload power and mass for constant solar array area.

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KEYWORDS: solar cells, photovoltaic cells, nanomaterials

AF09-BT21 TITLE: Novel protocol for Quantum Key Distribution

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: To develop Novel protocols for Quantum Key Distribution (QKD) that would relax the stringent requirements on devices making QKD much more attractive for many military and comm applications

DESCRIPTION: Quantum cryptography is a relatively young field [1], lying at the intersection of quantum mechanics and information theory and its recent development is based on the extraordinary growth of these two fields in the last years. The main limitation of classical cryptographic schemes is the fact that they do not provide absolute security.

A secure cryptosystem can be achieved if one encodes information in a quantum system. To be more precise, quantum mechanics is able to generate perfectly secure, random keys which can then be used in standard secret-key protocols. The security of quantum key distribution protocols is easy to prove in the ideal case of no technical imperfection and it is based on two fundamental aspects of quantum mechanics: 1) the unavoidable perturbation accompanying any quantum measurement; 2) the impossibility for an eavesdropper to make a perfect copy of an unknown quantum system [4]. The perturbation of an eventual measurement by an eavesdropper manifests itself whenever the bit are encoded into two non-orthogonal states (see Bennett's two state protocol, 1992, [5]). In principle quantum information can be encoded in any two-state system, but it is evident that the most natural carrier of quantum information is the photon. In fact it travels at the velocity of light, it has a very limited interaction with the environment, and it offers the possibility to encode information in various degrees of freedom, such as polarization, phase or energy. In fact, all the experimental realization of quantum cryptographic protocols, since the first one at IBM in 1989 (published in 1992 [6]) employed single photons as quantum bits (qubits). After that, many groups demonstrated quantum key distribution using different protocols and different physical implementations.

The practical interest of quantum cryptography lies in the fact that quantum protocols provide absolute security for certain classes of eavesdropping strategies even in the presence of a limited amount of errors. For example, general proofs in the case when Alice and Bob apparatuses are assumed perfect and no assumption is made on the channel, (the eavesdropper Eve is also assumed to gain maximal information from this noisy channel) show that the BB84 protocol is secure provided that the quantum bit error rate (QBER) on the raw key Alice and Bob get soon after basis reconciliation, is below 11% [1]. In fact, if there are not too many errors, Alice and Bob can achieve an error free key applying classical error correction schemes.

On the other hand, the beginning of commercialization of QKD system has prompted the search of easy implementable schemes, even if at expense of an absolute security with any envisageable technology. True Single Photon Source (SPS) and photon counting detectors operating at respectable rates are still under development and often expensive. By far the most promising techniques employ Weak Laser Pulses (WLP) as the source and realistic semiconductor based detectors. To highlight comparative analysis of various QKD techniques to device imperfections, we have done a study of three well studied techniques, namely, BB84 with ideal SPS and non-ideal detector (BB84SPS), BB84 with WLP and no decoy states (BB84WLP) and BB84 with WLP and decoy sates (BB84Decoy), both employing non-ideal detectors. Our conclusions are as follows:

- the single most important parameter in determining range (i.e., the maximum distance over which a given protocol exhibits non-zero rate) is the detector dark count probability Pdark,
- we have developed novel expressions (to the best of our knowledge) between the dark count probability and range and achievable data rate, for the three protocols studied. The BB84 with ideal SPS and non-ideal detector represents the benchmark of what is the best plausible performance that may be obtained for any binary QKD protocol and the transmission range and achievable data rate is proportional to Pdark,
- the decoy state protocol with the optimal mean photon count is among the most promising since it uses realistic WLP source that is commercially abundant and cheap and the relation between range and achievable rate and Pdark is linear, just like BB84SPS,
- the key rate and range for BB84WLP is proportional to the square root of Pdark. This makes BB84WLP practically useless except for very short distances.

The comparison above suggests that there are great gains possible in terms of protocol development that would relax the stringent requirements on devices making QKD much more attractive for a multitude of applications. In particular, we propose to develop a novel protocol by examining and merging two often disjointly handled problems together in a unique approach, namely, the problem of the communication of the quantum states of the photons and the associated processing (using a novel WLP approach), and the problem of post processing using a traditional communication channel for information reconciliation (using a novel approach).

PHASE I: Do feasibility for novel protocols by examining and merging two problems of communication of the quantum states of photons and the associated processing [using a novel Weak Laser Pulses (WLP) approach] and the problem of postprocessing w/a traditional communication channel for info reconciliation.

PHASE II: In Phase II prototypes will be developed in applications software and Simulations, breadboards/brassboards as required will be developed.

PHASE III / DUAL USE:

MILITARY APPLICATION: Devices when fully developed will have strong application potentials for military communications to and from the satellites.

COMMERCIAL APPLICATION: Numerous commercial applications will follow due to the advantages of Quantum protocols.

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KEYWORDS: Protocol, Quantum Key, Cryptography, RSA, Quantim bit error rate,Weak Laser Pulses (WLP), Range, Key rtae, Post processing

AF09-BT22 TITLE: Nanoscale Conformable Thermal Interface Materials with Electronically Enhanced Heat Conduction

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Define and develop approaches that would enhance these heterogeneous material interfaces with improved heat transfer by electronic heat conduction.

DESCRIPTION: The need for improved thermal management technologies – particularly focused on reducing contact resistance – is reaching a critical point, and it is unlikely that incremental improvements of existing technologies will satisfy future needs. Today, improved understanding of thermal energy transport at nanometer scales, combined with the new means to design new materials at the atomic level, has enabled a broad range of technological advances that can be applied to address the problem of reducing thermal interface resistance between electronic devices and heat sinks, or more generally, between any two solids in contact. As an example technology, carbon nanotubes (CNTs) offer a compelling alternative to traditional thermal interface materials (TIMs) in electronics packages because of their extraordinarily high thermal conductivities [1] and mechanical conformability [2]. We note that the conformability feature is particularly advantageous in addressing coefficients of thermal expansion mismatches, which are a primary cause of device failure. Also, in contrast to state-of-the-art thermal greases, CNT array interfaces are dry and chemically stable in air from cryogenic to high temperatures (~ 450°C), making them suitable for extreme-environment applications. While good performance of CNT-based TIMs has been demonstrated [3, 4], further performance gains appear to be limited by inefficient phonon coupling between CNTs and solid substrates and matrix materials.

PHASE I:
• Define approach to enhance flow across interfaces between dissimilar materials by means of electron transport
• Assess feasibility through foundational transport theory and analysis and basic experiments that could exploit the similarity between electronic charge and heat flow
• Evaluate scaling

PHASE II:
• Conduct rigorous thermal experiments to assess overall thermal performance with appropriate comparisons to existing commercial materials
• Assess performance under thermal cycling and mechanical stress
• Extract interfacial thermal resistances from local regions at the intersection of dissimilar materials
• Fabricate and test the performance of the TIM in a realistic packaged configuration

PHASE III / DUAL USE:
MILITARY APPLICATION: includes Directed Energy Weapons, Satellites, Avionics, and Aircraft thermal management.

COMMERCIAL APPLICATION: includes civilian aircraft and spacecraft, and microelectronics.

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KEYWORDS: nanoscale material conformable electronics heat conduction carbon nanotubes

AF09-BT23 TITLE: Memristive nanoelectronics for analog circuits and neuromorphic computing applications

TECHNOLOGY AREAS: Materials/Processes, Sensors

OBJECTIVE: Fabrication technology for memristive nanoelectronics for advanced computing architectures and analog circuit applications.

DESCRIPTION: Passive electronics utilizes three fundamental two-terminal circuit elements: resistors, capacitors, and inductors. Recently, scientists have observed a fourth element – the memristor [1, 2]. The memristor was predicted to exist by Chua[3] years earlier, but only decades later has such a memristor device been practically demonstrated in the laboratory. Memristors provide a functional relationship between charge, q, and flux, f, where the memristance, M, of the device is described according to the relation M = df / dq . In the case of a resistor, M is a constant and is identical to the resistance. For the case of a memristor, however, M is a function of q, thus yielding a nonlinear circuit element that no combination of resistors, inductors and capacitors can duplicate. Subsequently, memristors present a potentially to transform analog circuit technologies such as tunable and adaptive circuits, analog/digital circuits. Specific Air Force applications that would benefit from this would be tunable RF circuits in software defined radios, delta sigma modulators, and A/D converters. Further, synapse like devices using memristors for non-Boolean neuromorphic computing is attractive because of its massive parallelism, scalability, and inherent defect-, fault- and failure-tolerance. Such neuromorphic computers could lead to game changing capabilities in managing and exploiting the global information grid, as well as enable revolutionary advancements in cyber information processing and “cloud computing,” which requires an IT infrastructure of hundreds of thousands of servers and storage systems.

Progress in production of nanoscale memristive switches has been slowed by the difficulty of unifying complex nanoscale electronic and ionic phenomena in the various memristive nanomaterials which include metal oxides, metal doped amorphous silicon, and chalcogenides. This STTR seeks a university/commercial partnership for the production of electronic grade memristive nanomaterials for use in research and development of memristive nanoelectronic technologies. Memristor nanomaterials developed under this effort must demonstrate bipolar, reversible and non-volatile switching with ON/OFF conductance rations of >102 and switching speeds ~10-100 nsec. Further, a method to incorporate electronically variable memristors at the integrated circuit level with feature sizes comparable to transistor feature size circuits is desired. These electronically controllable memristive devices would then act as a passive component that are nonvolatile and require little power during operation and no power during off-state. Availability of such components would greatly benefit research and development efforts in a broad range of technology areas of interest to the Air Force and DoD.

PHASE I: Provide an initial development effort that demonstrates scientific merit and feasibility of an approach to achieving a memristive nanomaterial exhibiting variable resistance.

PHASE II: : Demonstrate a method to produce memristive nanomaterials with uniform size and response to applied bias, as well as method to incorporate electronically variable memristors at the integrated circuit level with feature sizes comparable to transistor feature size circuits. Prototype electronic grade memristive nanomaterials meeting the Phase II goals will be delivered for testing and evaluation

PHASE III / DUAL USE:
MILITARY APPLICATION: This new circuit element enables further miniaturization and functionalities in military ICs.

COMMERCIAL APPLICATION: ICs using electronically controlled memristor technology would simplify integrated circuit design and allow improved efficiency with lower power operation while enabling robust electrical control.

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KEYWORDS: Neuromorphic, Electronics, filters, memristor, nonvolatile

AF09-BT24 TITLE: Innovative Joining of Ultra-High Temperature Ceramics (UHTC) for TPS Applications

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop innovative solutions to ceramic-ceramic and hybrid ceramic-metal joining for ultra-high temperature thermal protection systems.

DESCRIPTION: Ceramic joining remains one of the major hurdles which prevent certain airframe thermal protection system (TPS) designs from being successfully realized. Reliable ceramic-ceramic and hybrid ceramic-metal joining concepts would enable structurally integrated TPS with improved structural efficiency and lower maintenance. Improved structural efficiency of TPS components could reduce the weight of air and space vehicles for increased payload and range. Similarly, reduced maintenance will reduce costs and increase vehicle availability. Many ceramic-ceramic and ceramic-metal joining concepts rely on complex joints, fasteners, or braze interfaces. Ceramic-ceramic and ceramic-metal joints still lack some of the necessary property requirements which currently leads to added weight and design compromises. This effort will focus on development and demonstration of joining concepts applicable to TPS system for air and space vehicles, with a specific focus on ultra-high temperature ceramics such as refractory diborides (ZrB_2, HfB_2), diboride-based composites (ZrB_2-SiC, HfB_2-SiC), refractory carbides (ZrC, TaC), and similar materials. Such materials are currently under consideration for a number of aerospace applications in which service temperature will exceed 1500°C.

The Air Force seeks novel high strength joining concepts to enable structurally integrated TPS systems that address 3 main requirements: Joints must 1) exhibit mechanical behavior and failure probabilities similar to the parent UHTC composite at ambient and elevated temperatures (>1500°C in air); 2) exhibit manufacturability; and 3) surpass current joining concepts in reliability and function. Concepts that explore, plasma, liquid, solid or vapor phase joining techniques will be considered although approaches that utilize multiple technologies may be more successful at achieving the program goals. Joint concepts that require extensive pre- or post-machining to achieve the tolerances necessary for aerodynamic efficiency are discouraged. Successful concepts will likely deviate from traditional methods used to join similar and dissimilar ceramics and metals. Aerodynamic loading and rapid aerodynamic heating of thermal protection systems require joints to exhibit predictable mechanical behavior at elevated temperatures and must help manage substantial heat fluxes (in excess of 350 W/cm2). Assessment of the effect of the joint concept on thermal management through experimental or analytical means will be required.

PHASE I: Develop and demonstrate a joining concept and assess the ambient temperature failure statistics of the concept using specialty test fixtures and understanding of common test methods for joint analysis. Assess high temperature joint behavior and effect of joint design on thermal management.

PHASE II: Produce and test additional joint prototypes under representative flight conditions to include anticipated temperatures, heat fluxes, thermal gradients, and environmental effects. Full macrostructural and microstructural material characterization of joints before and after testing will be required to assess life-limiting failure mechanisms and joint reliability.

PHASE III / DUAL USE:
MILITARY APPLICATION: Successful joining technologies will enable structurally integrated hybrid TPS systems for both air and space vehicles, leading to improved structural efficiency and decreased maintenance.

COMMERCIAL APPLICATION: Successful joining technologies will enable structurally integrated hybrid TPS systems for both air and space vehicles, leading to improved structural efficiency and decreased maintenance.

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KEYWORDS: joining, hybrid, structures, aerospace, ceramics, diborides, thermal protection

AF09-BT25 TITLE: Ultrafast Hybrid Active Materials and Devices for Compact RF Photonics

TECHNOLOGY AREAS: Materials/Processes, Sensors

OBJECTIVE: Develop a heterogeneously integrated organic-semiconductor platform for photonic, rf photonic, and electronic components for realizing sensing and signal processing systems-on-a-chip (SOC).

DESCRIPTION: With the constant need to reduce the size, weight, and power (SWaP) of military hardware systems, the underlying components which make-up these systems must also undergo the same SWaP reductions. At the same time there is a concomitant requirement that is calling for increased system capability.

The interest exists to investigate the use of organic materials as the functional constituent for integration within conventional semiconductor materials like Si, SiGe, GaAs, InP and GaN on a single SOC. Semiconductor based photonic networks are highly desirable due to their integratability with existing electronics, availability of mature fabrication technology, low loss, and high optical confinement (due to high refractive index) in the mid IR. It has become clear however that not everything can be accomplished within a single materials substrate. For example, the 2 photon cross section in silicon becomes limiting at high optical powers and the silicon electro-optic response is limited due to various factors to somewhere in the 20GHz range. Signal handling at very fast speeds, near 100GHz, will require new solutions. Semiconductor-polymer hybrid structures offer a way to circumvent the limitations of silicon by optically integrating the functions of the best organics directly into the silicon optical platform.

For example, slot waveguides can be used to seamlessly incorporate a functional organic right into the middle of a silicon rectangular waveguide. Due to quasi-electrostatic boundary conditions, the optical field is concentrated into the narrow, very sub-wavelength, slot region which in turn is occupied by a high performance functional organic material. This allows use of the organic optical function while maintaining the device within a silicon photonic network. High-bandwidth and very low voltage electro-optic modulators are fabricated in this manner since the latest generation of electro-optic polymers offer both the highest bandwidth and highest nonlinearity in existence while they can relatively easily be solution deposited into the slot. There are no lattice matching issues since the polymer is an amorphous solid. With direct electronics integration already a reality, it is possible to create complex tuning and stabilization circuitry, however no truly practical ultrafast nonlinear optical devices have yet emerged from the silicon photonics community. A silicon-compatible, low voltage, non-resonant electro-optic modulator at bandwidths in excess of 100 GHz is desirable for a variety of applications including signal processing, advanced radar, and both digital and analog data communications!

It could be possible that other functional organics could be inserted within silicon-photonic structures as well. Polymer hosted quantum dots, plasmonic structures, third order nonlinear organics all may be candidates for the organic constituent while the silicon has been shown to be amenable to fabrication of photonic crystals, quantum dots, resonant cavities, and metamaterials type structures. The design and function space could be large. Work is sought which would lead to a modular, hybrid organic-inorganic photonic device platform. Proposed designs must utilize unique properties of the polymeric materials combined with conventional photonic materials (with silicon based approaches having the higher priority) to enhance device performance, increase flexibility, and reduce cost.

PHASE I: Explore properties of organic-inorganic hybrid material systems. Develop concepts and designs for silicon-organic hybrid ultrafast devices. Perform design study, device fabrication strategy and proof-of-concept for one or more novel devices for Phase II, offering order-of-magnitude improvements.

PHASE II: Demonstrate one or more hybrid devices based on the targeted optical functions in semiconductor-organic hybrid waveguides. Explore and develop rapid, and preferably automated, characterization of nonlinear properties. Demonstrate improvements in SWaP as well as capability.

PHASE III / DUAL USE:
MILITARY APPLICATION: Communication satellites, avionics, networked sensors, and phase array radars.

COMMERCIAL APPLICATION: Photonic signal processing in telecommunications and scientific instruments.

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KEYWORDS: ultrafast nonlinear optics, hybrid silicon-organic waveguides, nonlinear optics, ultrafast nonlinear optical devices, silicon-polymer, electro-optic polymers, slot waveguides, silicon nano-slot waveguides, electro-optic modulators, modulator, polymer photonics, silicon photonics, reconfigurable antenna, mmW photonics, low-power, compact, optical switch

AF09-BT26 TITLE: High Frequency Large Area Flexible Thin Film Transistors

TECHNOLOGY AREAS: Materials/Processes, Sensors

OBJECTIVE: Develop large area thin film transistors on large area flexible plastic substrates with novel materials such as carbon nanotubes, room temperature processes, and n- and p-type (CMOS) technology.

DESCRIPTION: Current state-of-the-art flexible electronics are based on organic or polymer materials, such as regioregular poly (3-hexylthiophene) derivatives and pentacene. However, the carrier (electron or hole) mobility of these materials are less than 0.1cm2/V•s, which is four orders of magnitude lower than conventional single crystal silicon. Such low carrier mobility limits the operating frequency of the organic or polymer based flexible electronics circuit to a few kHz. In addition, conventional organic or polymer based flexible transistors exhibit one order of magnitude difference in electron mobility and hole mobility. The huge mobility difference makes it extremely hard to achieve both n-type and p-type transistors on the same flexible substrate. Consequently, complementary flexible circuits cannot be obtained using conventional organic flexible electronics. The inability to achieve complementary electronic circuits significantly increases the power consumption and limits the functionalities that can be provided by the flexible electronic circuitry. This technological shortcoming suggests the need to develop novel materials for the active layer, which can perform at higher than 5GHz and have similar carrier mobility of both n-type and p-type transistors.

Recently there are many researchers working on carbon nanotube (CNT) based transistors. The carrier mobility of an individual CNT is estimated to be at least 100,000 cm2/Vs. The CNT network in solution was reported to have carrier mobility as high as 46770cm2/V•s, which allows to achieve high-speed (>100GHz) circuits. We are seeking for new materials such as CNTs that can exhibit high carrier mobility, and are able to lead to room temperature processing. The prototype of the transistor array should be able to be printed on a flexible sheet of 1m by a few meters. These new designs and the associated devices should be capable of higher performance, improved stability, higher yield, lower cost and improved scalability over the current state of the art technology.

PHASE I: Phase I must demonstrate the performance of a single thin film transistor. Initial devices may be fabricated on flexible substrates such as Kapton to demonstrate technology advances. The Phase I deliverable will be a device and a report on the performance and processes.

PHASE II: The technology and thin film transistor (TFT) structure designs enabled in Phase I will be scaled up to designs with at least 1,000 thin film transistors. The technology must be demonstrated on plastic substrates (up to size of 1m by 3m) with room temperature processing. The program requests delivery of functional transistor arrays consisting of at least 1,000 TFTs on flexible substrates.

PHASE III / DUAL USE:
MILITARY APPLICATION: Large area flexible transistor arrays will enable applications such as autonomous structures, conformal phase array radar and large apperture conformal sensors.

COMMERCIAL APPLICATION: Thin film transistors on flexible substrates and the associated applications offer significant possible commercialization for RFID and other electronic devices.

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KEYWORDS: Thin film transistors, flexible substrates, materials, carbon nanotube, room temperature, processes

AF09-BT27 TITLE: Fine Scale Modeling and Forecasts of Upper Atmospheric Turbulence for Operational Use

TECHNOLOGY AREAS: Air Platform, Battlespace, Space Platforms

OBJECTIVE: Develop a fine scale forecast model capability to accurately predict areas of clear air turbulence (CAT) in the upper troposphere and lower stratosphere up to 48 hours in advance in less than 2 hours

DESCRIPTION: The problem of high altitude clear air turbulence has been around for several decades. With the advent of more aircraft flying at higher altitudes the risk of these aircraft encountering significant turbulence increases. The primary causes of turbulence at these altitudes appear to be gravity or buoyancy waves that originate from mountains, thunderstorms, jet streams, and other sources. Depending on atmospheric conditions, the gravity waves might be trapped at the altitude of the atmospheric disturbance or at an intermediate altitude, or conditions might allow them to propagate into higher altitudes (where one often finds CAT concentrated in thin layers due to the stable stratification found above the tropopause), which is more common in the winter. The waves grow in amplitude as they gain altitude, undergo certain polarizations due to the earth’s rotation, and eventually break down into turbulence. In addition it has become clear that this atmospheric turbulence is inhomogeneous, anisotropic, non-Kolmogorov, and shear stratified. The waves that seem to bother high-altitude aircraft are usually generated by mountains (“mountain waves”) and the jet stream while storms are clearly episodic sources. It has been reported that disturbance wavelengths of ~1km (~3,300ft) may have the worst affect on some aircraft. These lengths are shorter than those usually associated with mountain waves, and longer than ones usually associates with “turbulence”, which indicates that the waves are probably in a state of breaking down into turbulence when they cause these problems. Today’s weather forecast models do not have a horizontal or vertical resolution with a fine enough grid spacing to adequately define, model, and predict high altitude turbulence. A number of techniques are being studied to improve high altitude turbulence forecasts, including nested fine resolution grid models and automatic adjustment of variable grid spacing models to name a couple. Moreover, not only must any description of such dynamic events be couched in dimensionless variables so that values of the appropriate dimensionless parameters (the Richardson # and the turbulent Prandtl # to name just two) which govern the process can be estimated, but also some modality of inputting random/stochastic initial conditions must be identified in order that the user can include scenarios including storms.

PHASE I: Develop a fine scale model to define and predict high altitude (above the tropopause) turbulence for a specified volume of 100 km X 100 km and up to 30 km vertically.

PHASE II: Refine the model and use enhanced computers to produce a model that can output up to 48 hours forecasts in 2 hours or less.

PHASE III / DUAL USE:
MILITARY APPLICATION: Military has platforms (Global Hawk, U2), operates in the stratosphere. To reduce deleterious effects of Clear Air Turbulence, predict the dynamics of the atmosphere above the tropopause is needed.

COMMERCIAL APPLICATION: Models can be adapted to address other complex problems such as forecasts in complex terrain or urban areas for problems such as biological, chemical, and radiological dispersion.

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KEYWORDS: numerical weather prediction, modeling, adaptive grid, atmospheric processes, turbulence, gravity waves, clear air turbulence (CAT), forecasts

AF09-BT29 TITLE: Multi-scale Physics-Based Models for High Strength Titanium Alloys Accounting for Higher-Order Microstructure Statistics.

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop multi-scale models that link higher-order microstructure descriptions to anisotropic mechanical properties of aerospace titanium alloys using a informatics-based approach.

DESCRIPTION: Parts made of high strength titanium alloys are known to exhibit pronounced anisotropic properties due to the presence of various microstructural heterogeneities [1-3] and the inherent anisotropy of deformation mechanisms of various co-existing phases [4]. However, current modeling approaches utilize highly simplistic descriptors of the microstructure that are empirically correlated to the macroscale (homogenized) properties. This simplistic description of microstructure is utterly inadequate for addressing the design needs of titanium parts with heterogeneous microstructure. Without appropriate models, designers are forced to rely on highly expensive and time consuming experimentation to validate their designs.

Digital representation of complicated microstructural features has been successful by the use of n-point correlation functions [5]. However, there does not exist a basic understanding of how to connect the microstructure correlations between the heterogeneous distributions of different features and the macroscopic behavior of titanium alloys. If an appropriate framework was developed to establish these linkages, it will build better understanding of the sensitivity of the mechanical properties to the effect of heterogeneous distributions of multiple microstructure variables. Thus, minimizing much of the effort that is currently required for certification to introduce a new material in aerospace components (or the application of an existing material for a new application).

To meet this goal, it is necessary to develop computational tools to accurately represent the main topological details of a multi-phase heterogeneous microstructure and simulate the mechanical properties (strength, ductility, toughness, fatigue, etc.) exhibited by that microstructure. In addition, validation component requirements are necessary to support the development of the computational tools. Technical hurdles that remain are alloy- and design-requirement specific. Such issues are best resolved through the a concurrent engineering approach to research critical fundamental mechanisms on multi-length scales and link basic concepts to component specific design requirements through advanced computational tools. This includes microstructural and macrostructural information/parameters as they impact mechanical response at different length scales.

PHASE I: Demonstrate feasibility of approach and identify means of integrating computational tools into a larger protocol for advanced aerospace applications. Identification of challenge problem (specific alloy and application) that would be attempted in Phase II.

PHASE II: Demonstrate effectiveness of computational tools for the alloy system identified, showing ability to accurately predict the mechanical properties for a range of realistic microstructure variations. Fully integrate system with other relevant computational tools and databases. Develop business case analysis to support adoption of system by DoD commercial industry.

PHASE III / DUAL USE:
MILITARY APPLICATION: This research is critical for high temperature and strength multi-phase, anisotropic structural materials commonly used in missile fins, engine wash areas, and propulsion systems.

COMMERCIAL APPLICATION: The research is directly applicable to aerospace propulsion systems and high temperature structural applications using titanium base alloys.

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KEYWORDS: Informatics, titanium alloys, higher-order statistics, multi-scale simulations, heterogeneous materials, property prediction

AF09-BT30 TITLE: Tools for Modeling & Simulation of Molecular and Nanomaterials for Optically Responsive Devices

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop, implement, verify and validate, and integrate in user friendly software, a capability to predict the optical response of nanoscale materials, accurately, reliably, and efficiently.

DESCRIPTION: Prediction of the optical response of molecular-to-nanomaterials is fundamental to a myriad of relevant Air Force applications, ranging from sensing and detection, imaging, solar energy harvesting, to nonlinear optical absorption, in support of requirements for CBRNE/GWOT and C4ISR. However, although progress was made in experimental synthesis and characterization, many challenges still remain, particularly in providing insight into the material’s behavior for further improvements, which can be addressed, in part, by computation. Computational prediction can also provide guidance to experimental efforts in developing new materials with a required optical response. However, although quantum chemistry calculations of optical properties have been an active area of research for a long time, limitations are still recognized for application to large molecular systems or newly emerging nanomaterials. Although it has by now become common to apply a time-dependent density functional theory (TDDFT) approach to evaluate the optical properties of molecules, including multi-photon absorption characteristics, even within a multiscale TDDFT approach that includes a continuum method for modeling the solvent, limitations are still encountered in USA available codes. For example, lack of a higher order response for multi-photon absorption, including quadratic and cubic response, inefficient implementations, inadequate exchange-correlation functionals that were not extensively validated for materials of interest, solvent effects not taken into account reliably, or limitations that can be addressed by higher level theory, beyond TDDFT. The development of accurate, reliable, and efficient simulation tools to predict the optical response of materials ranging from large molecules in the condensed phase, semiconductor and metal nanoclusters, to hybrid nanostructures, is highly desirable. We seek to develop, implement, verify and validate, and integrate in a user friendly software package, the capability to predict optical properties for molecular-to-nanomaterials, accurately, reliably, and efficiently using massively parallel computational resources.

PHASE I: Demonstrate capability to predict optical properties for molecular-to-nanomaterials, accurately, reliably, and efficiently by a concept for development, implementation, verification and validation, and integration in user friendly software. Utility of the tool for AF applications to be clearly shown.

PHASE II: Implement highly scalable software to predict optical properties for molecular-to-nanomaterials, accurately, reliably, and efficiently, by the development, code implementation, verification & validation, and integration a in user friendly environment.

PHASE III / DUAL USE:
MILITARY APPLICATION: CBRNE/GWOT and C4ISR.

COMMERCIAL APPLICATION: Photovoltaic cells.

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KEYWORDS: M & S, Optical Properties, Density Functional Theory, Solvent Effects, Multi-Photon Absorption, GWOT, C4ISR

AF09-BT31 TITLE: Innovative Combat Simulation to Craft Tomorrow's UAV Operational Doctrine

TECHNOLOGY AREAS: Air Platform, Information Systems

OBJECTIVE: Use state-of-the-art strategy wargaming to advance understanding of how next-generation unmanned aerial vehicles (UAVs) can optimally affect realistic combat scenarios. Note: Development of actual UAV control algorithms is out-of-scope.

DESCRIPTION: Advanced technology unmanned aerial vehicles (UAVs) are wreaking a major revolution on modern battlefields. As their loiter capabilities, payload, and autonomous intelligence continue to improve, the scope of UAV operations is sure to expand. Unfortunately, a key element is lagging behind current deployments; namely, a tested doctrine that can promise optimized success in the range of UAV combat taskings from recon to deadly force. The experience gained from actual battle operations certainly generates guidelines for improving mission results but the cost for knowledge gained in that manner can be both expensive and only incremental. Furthermore, considerable expenditures of precious R&D dollars may be made based on situational combat "needs" without the benefit of comprehensive multi-scenario benefits analysis. Fortunately, there exists today a significant number of smart, user-friendly combat simulation software modules (strategy wargames) that realistically model tactical and operational battle scenarios anywhere in the world and with user-specified orders-of-battle. It is now desired to insert physically accurate models of current and planned UAVs into an existing strategy wargame to observe how a given set of UAVs with specified capabilities can modify the outcome of precisely modeled real-world combat scenarios. Realistic strategy wargames can address that requirement if they could accurately model such UAV elements of today's asymmetric warfare environment. The challenge here for the wargame developer is to formulate new algorithms to capture the crucial nuances of what combat effects are within the capabilities of current UAVs while also maintaining flexibility for the real-time updating of emerging UAV technologies. Finally, the software's artificial intelligence should actively "observe" the tactics employed by a given human opponent and thereby "learn" what concepts work best to defeat its human adversary. This capability would help to capture the patient scouting preparations and adaptive tactics often employed by seasoned insurgent organizations. Our tacticians using the software would thus be forced to constantly rethink approaches to given scenarios. Overall, this would create a wargaming environment optimized for useful learning on the part of the human warfighter. To maximize chances for formulating new UAV operational doctrine that can realistically succeed with maximum success against a complex and intelligent foe, the "strategy" rather than "arcade" ("first-person shooter") genre of wargames will be the focus of this effort. Also, algorithms designed specifically for control of UAVs themselves would be out-of-scope for this topic.

PHASE I: Create a detailed plan and a software prototype that will explain how a specific existing combat strategy simulation software package will be enhanced so that it can realistically model the employment of current and future UAVs in various roles in modern combat scenarios.

PHASE II: Create a user-friendly, PC-based, artificially intelligent strategy combat simulation system based on the results of Phase I. It is essential that the software contain a user-friendly editor module that will permit the user to directly modify the physical properties and combat capabilities of the UAVs that are modeled therein.

PHASE III / DUAL USE:
MILITARY APPLICATION: This software might attract the interest of commercial "security services" that represent a huge market, to perfect the use of UAVs against both terrorist and criminal threats, or as a training tool.

COMMERCIAL APPLICATION: The resultant wargame software will be immediately salable to the large, multi-million commercial wargaming market, and/or to commercial "security services" whose aim is to protect UAVs.

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KEYWORDS: Wargame, Combat Simulation, Unmanned Aerial Vehicles, UAVs, Military Doctrine

AF09-BT32 TITLE: <u>Instrumentation for hypersonic, air-breathing engines</u>

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop innovative sensing systems applicable to the flowfield and/or engine structure for short-duration ground and flight testing of a supersonic combustion ramjet flowpath/vehicle.

DESCRIPTION: Air-breathing propulsion engines to support high-speed flight, above Mach 4, are difficult to develop without the use of in-flight experimentation. The high enthalpy associated with simulating high-Mach conditions (> 4) results typically in ground-test air that is contaminated with particulates or combustion gas products, or results in steady-state test times that are short -- measured in milliseconds. Also, in ground tests of such engines, high-fidelity simulation of key engine transients, such as ignition and acceleration, is difficult or impossible. Thus, flight testing of hypersonic engines is a crucial part of the development process. Acquisition, processing, and transmission of engine performance, operability, and durability from a flight test, while meeting the standards of a typical ground test, remain challenging. The following, in particular, are areas of interest: local skin friction and heat flux; core flow properties of temperature, pressure, and species concentrations; and, engine area change. All need to be measured in flight with the accuracy, speed, and spatial density typical of a ground test. This announcement is broad in that focusing on any one or more of these issues is acceptable. The payoff is making flight testing, even of short duration, a source of high-quality and high-density flow and structure data to complete the development process for supersonic combustion ramjets. Requirements for innovation in diagnostics and sensors are the following: have a tolerance for high temperatures from 425 K within an instrument bay and up to 1000 K near combustor surfaces, and provide data rates of at least 100 Hz. Goals for measurement error (within quoted value) and spatial dimension/resolution are as follows:
1. Surface skin friction and heat flux: 10 percent of measured value; 15 mm2 surface area.
2. Core temperature, pressure, and species concentration: 10 percent of measured value; 3 mm, though averaging across duct spanwise dimension is acceptable.
3. Engine flowpath area: detect changes as small as 2 percent of flowpath area; 25 mm along flowpath axis, typically 2 meters.
Additional performance goals include the following: lifetime at least 10 minutes during scramjet-powered flight; respective volume and weight of instrument package less than 1 L and 2 kg; power consumption less than 10 Watts.

PHASE I: Develop concepts for measuring basic engine performance, operability, and/or structural integrity. Concepts must enable measurement of a specific parameter with reasonable accuracy and spatial resolution at high temperatures.

PHASE II: Validate the sensor system in a ground test of an appropriate engine component. Demonstrate the accuracy and environmental tolerance of the system along with acceptable data rates, power consumption, and size.

PHASE III / DUAL USE:
MILITARY APPLICATION: Success will yield sensor systems that can be used in any propulsion application; requirements of hypersonic propulsion should be the most severe.

COMMERCIAL APPLICATION: Such instrumentation can be applied to certified engines as part of the engine control instrumentation.

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KEYWORDS: hypersonic, scramjet, propulsion, high speed, instrumentation, diagnostics, sensors

AF09-BT33 TITLE: Terahertz Focal Plane Arrays

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Develop fast (video rate), portable, multi-element, semiconductor nanostructure-based focal plane arrays (FPA) that respond in the 1-10 THz range for military and security applications.

DESCRIPTION: Real time THz imaging has found numerous applications in the areas of security, biometrics, quality control, and atmospheric studies, due to T-ray's ability to penetrate and distinguish between non-polar materials. For example, a THz camera can image objects through fog and smoke, providing application in imaging terrain and other potential obstacles through all-weather conditions. However, current THz imaging technologies have various drawbacks. Bolometer based FPAs and hot electron bolometer (HEB) heterodyne FPAs [1] generally require operation at cryogenic temperatures, hence they are bulky. Schottky barrier diode arrays (SBDs) have achieved room temperature operation. However, due to their dependence on high local oscillator power, which is very difficult to produce at THz frequencies, they can barely respond beyond the 1THz limit. VOx microbolometer FPA camera has been utilized in real time THz imaging at room temperature [2]. But its poor sensitivity in the THz range demands additional THz source, which limits the functionality in passive detection tasks. Therefore, a need exists for fast, portable (operating temperature >150K, cryogen free) THz FPAs with high responsivity and high detectivity. The FPAs should have >30fps frame rate (video rate) and noise equivalent power (NEP) less than 10-12 W/Hz1/2. There has been recent progress in the development of long wavelength normal incidence detectors [3] and focal plane arrays [4] with self-assembled quantum dots and similar nanostructures. It is possible that these devices can be used at high temperatures for THz detection. The goal of this project is to develop new nano-structures and/or fabrication technologies to produce THz FPAs which meet the aforementioned properties. Enhanced detection concepts using plasmonics may also be considered.

PHASE I: Explore nano-structure growth/development and fabrication techniques that can lead to the desirable THz absorption. Demonstrate key concepts by theoretical calculations or preliminary device demos. Emphasize feasibility and potential improvement over conventional technologies.

PHASE II: Demonstrate single pixel THz detector working at temperatures above 150K with reasonable responsivity (>0.05A/W) and detectivity (~1010 Jones) in the frequency range of 1 to 10 THz. Develop prototype FPA systems based on phase I research and phase II efforts.

PHASE III / DUAL USE:
MILITARY APPLICATION: Compact, real time THz FPAs would have important applications for aircraft terrain avoidance, concealed weapon detection, and chemical or explosives monitoring

COMMERCIAL APPLICATION: Commercial applications would include the military ones, as well as product quality control and biometric instruments

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KEYWORDS: terahertz, THz, bolometer, cryogen, nano-structures, focal plane arrays, detectivity, quantum dots, plasmonics, detector, sensing, sensor

AF09-BT34 TITLE: Plasmon-Enhanced Laser Desorption Ionization

TECHNOLOGY AREAS: Chemical/Bio Defense, Weapons

OBJECTIVE: Demonstrate and optimize a flexible, efficient method to use localized surface plasmon excitation to enhance laser desorption of materials for vapor phase detection techniques; e.g. mass spectrometry.

DESCRIPTION: Mass spectrometry has long been a highly versatile and fairly general analytical method for determining the molecular composition of unknown analytes. One hurdle in analyzing some non-volatile materials is getting those species into the gas phase without fragmenting them. Developments such as electrospray methods and matrix-assisted laser desorption ionization (MALDI) have greatly increased the applicability of mass spectrometric methods to new classes of polymers and biomolecules. One limitation of MALDI is that vaporization of the matrix can interfere with the mass spectrometric analysis of the analyte. To avoid this interference, one might use plasmon excitation to deposit energy into a substrate and rapidly lift analytes into the gas phase without an accompanying matrix. The wavelength of the plasmon resonance can be tailored for optimum performance by the judicious choice of the size, shape, and composition of the substrate metal. Plasmon-enhanced laser desorption and ionization can provide a quite general and versatile method for lifting molecules into the gas phase for detailed analysis, particularly if the mechanisms of desorption and ionization are understood.

PHASE I: Develop and demonstrate feasibility of a plasmon-enhanced laser desorption as a controlled and reliable method to lift polymers, biomolecules, and other analytes into the gas phase without fragmentation and detect them by mass spectrometry or other analytical method.

PHASE II: Construct, demonstrate, and optimize a prototype plasmon-enhanced laser desorption ionization system coupled with mass spectrometric detection. Report understanding of mechanisms of plasmon-enhanced desorption & ionization. Demonstrate sensitive and selective mass spectrometric detection of analyte molecules without fragmentation or matrix interference. Demonstrate system at multiple wavelengths.

PHASE III / DUAL USE:
MILITARY APPLICATION: A plasmon-enhanced laser desorption ionization mass spectrometer will lead to commercial development of sensors for analysis trace species including chemical weapons, toxins, and biological agents.

COMMERCIAL APPLICATION: A Plasmon-enhanced laser desorption ionization mass spectrometer will lead to commercial development of sensors for analysis of polymers, biomolecules, nucleic acids, proteins, etc.

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KEYWORDS: Plasmon Desorption Ionization Mass Spectrometry

AF09-BT35 TITLE: Nanotechnology and Molecular Interconnects

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop low-cost, large area, high throughput nanoscale device architecture.

DESCRIPTION: The materials technology at nanoscale dimensions offers a broad range of applications in micro and nanoelectronics, molecular electronics, and growth of novel materials. Physics at nanoscale (~ 5-50 nm) dimensions creates novel opportunities for materials and device synthesis that are otherwise not accessible in the microscopic domain. Fundamental limits prevent straightforward extension of optical lithography to nanoscale dimensions. Non-conventional lithography techniques such as x-ray and particle based methods possess the requisite resolution albeit at very high cost and process complexity. Self-assembly methods are sought for nanoscale patterning resolution such as developing integrated circuit interconnects utilizing molecular structures. These methods are attractive due to their ease of fabrication, low-cost and large area throughput capability. At present, no pathway to arbitrarily pattern a typical VLSI device architecture has been identified. Proposals are solicited for fabrication of self-assembled nanoscale device architecture capable of integration with functional logical circuits.

PHASE I: Identify and evaluate nanoscale device architecture capable of functional logical operation in a VLSI format.

PHASE II: Establish the feasibility of the approach identified in phase I in a nanoscale circuit such as an inverter, or a memory element. Emphasis should be on low-cost manufacturing capability consistent with VLSI design rules.

PHASE III / DUAL USE:
MILITARY APPLICATION: Military applications consist of rapid processing of focal plane array data, high speed digital signal processing.

COMMERCIAL APPLICATION: Commercial applications improved desktop processing, very low power circuitry enabling long lived portable electronic devices.

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KEYWORDS: Nanotechnology, Self-assembled Monolayers, Molecular Electronics

AF09-BT36 TITLE: Multifunctional Nanocomposite Structures Via Layer-by-Layer Assembly Process

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: To achieve large scale manufacture of multifunctional nanocomposites, which are comparable in physical characteristics to the standard aerospace composites, based on layer-by-layer assembly process.

DESCRIPTION: Layer-by-layer (LBL) assembly, also known as electrostatic assembly, for multilayer deposition is a recently established laboratory-scale method that can produce multifunctional nanocomposites with exceptional physical properties. Over the past 5 years, a great deal of progress has been made in demonstrating that the stiffness, tensile strength and electrical conductivity of these LBL composites reinforced with carbon nanotubes are one order of magnitude greater than those of analogous nanocomposites prepared using the conventional manufacturing methods. The LBL method consists of sequential dipping of a solid substrate in solution of positively and negatively charged polymers or colloids. In each dipping a nanometer scale layer of the material is adsorbed. This makes the LBL method inherently slow and difficult to apply for large-scale manufacturing of aircraft components. Innovative solutions from the industry-academia partnership are sought for: (a) drastic acceleration of LBL composite manufacturing process without any compromise of physical properties; and (b) development of integrated manufacturing cycle for appropriate aircraft components utilizing the formulated LBL assembled nanocomposite rolls or sheets.

PHASE I: Demonstrate accelerated LBL deposition with the rate of materials adsorption at least 2 orders of magnitude faster than the current laboratory technique. Demonstrate manufacturing of 300 x 300 x 1mm sheet of the LBL nanocomposites with high strength and electrical conductivity.

PHASE II: Achieve large-scale manufacturing capabilities for LBL-assembled multifunctional nanocomposites with high degree of reproducibility and acceptable physical characteristics. Demonstrate manufacturing of appropriate aircraft components from the formulated LBL nanocomposite rolls or sheets and compare their performance to the currently used conventional composite parts.

PHASE III / DUAL USE:
MILITARY APPLICATION: Extensive manufacturing and testing programs will be conducted for utilization of the LBL-assembled multifunctional nanocomposites in new unmanned aircraft and surveillance platform structures.

COMMERCIAL APPLICATION: Cost analysis and affordability validation will be performed for utilization of the LBL-assembled multifunctional nanocomposites in developing new civil transport structures.

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KEYWORDS: Layer-by-layer assembly, Nanoreinforcement, Ultrastrong materials, Multifunctional composites

AF09-BT37 TITLE: Nano-Structured Multi-Mode Detectors

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Develop novel nanostructure-based detector elements and element integration schemes enabling for adaptive multi-modal (spatial, spectral, polarimetric) sensing within a single co-boresighted device.

DESCRIPTION: The premise of this research is that developing adaptive multi-modal sensors that can capture multiple electromagnetic observables (intensity, wavelength, polarization, phase, etc.) in a time-resolved, ‘staring’ imaging format will provide dramatically enhanced detect and identification capability for extremely challenging military problems involving low contrast targets over broad areas in a highly dynamic scene. Limitations facing current multi-spectral imagers include their ‘step-stare’ mode of operation (vs. desired staring mode) with revisit times that compromise detection of rapid moving targets, their fixed multi-band construct that can result in a tremendous amount of unproductive data, and the large size, mass, and complexity in their manufacturing and operation. To avoid problems with unnecessary or unproductive sensor use and data computation, it would be desirable to enable an ability to select the optimum set of sensors and sensor settings that are most decision-relevant.

The most desired approach is to innovate a tunable multi-mode, vertically-integrated (common sensor package), large-format staring focal plane array to accommodate the dynamic sensing requirements dictated by the dynamic target scene. This would involve actively controlling sensor modes and settings to optimize information gathering in a knowledge-based manner with an identifiable selection criterion. Sensing modalities of interest include spatial, spectral, polarimetric, radiometric, and temporal; wavelengths of interest span ultraviolet (0.2um) to infrared (12um). The envisioned multi-modal device design should build from extensive developments in passive remote sensing concepts and methods and specifically address basic research aspects of multi-modal integration into a common sensor package (e.g., detector array).

PHASE I: Perform feasibility studies for specific novel integrated adaptive multi-mode sensor designs through modeling and experimental demonstrations, and calculate and quantify potential multi-modal sensor design performance parameters and potential capabilities.

PHASE II: Demonstrate a working prototype for an adaptive, integrated multi-mode sensing device concept and implementation scheme based on high priority spectrum and mode considerations provided by the government. Perform appropriate sensor design modeling and performance analysis of hardware and software design implementations, and fabricate and characterize full-up prototype devices.

PHASE III / DUAL USE:
MILITARY APPLICATION: Military applications include very compact, adaptable high-fidelity battlespace remote sensing capabilities enabling for emerging performance-based layered sensing architectures, concepts & methods.

COMMERCIAL APPLICATION: Commercial applications include fabrication of high fidelity multi-functional sensing capabilities enabling for a multitude of emerging photonics applications.

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KEYWORDS: multi-spectral, hyperspectral, polarization, infrared detectors, nanotechnology, imager, polarimeter, optical properties, nano-

AF09-BT38 TITLE: Theoretical Innovations in Combining Analytical, Experimental, and Computational Combustion Stability Analysis

TECHNOLOGY AREAS: Space Platforms, Weapons

OBJECTIVE: Develop innovative theoretical approaches to aid systematic design of analytical, experimental, and computational approaches to understand and predict the combustion stability of liquid rockets.

DESCRIPTION: Designing combustion chambers for combustion stability in liquid propellant rocket engines is currently performed using a combination of approximate analysis, institutional experience (most often empirically based), and continuously growing amounts of computational fluid dynamics (CFD). The theoretical basis of approximate analysis can be quite rigorous, for example those based on forms of Galerkin's method (1). All physical mechanisms are accounted for and can be seen explicitly in the expansions; approximations come in the form of various terms which are empirically modeled to various levels of fidelity, or modeled in very simplified ways, or neglected. The difficulty with this approach is that it is often difficult to understand the validity of the approximations or foresee their overall effect on the solution. Computational fluid dynamics also has the potential to account for all physical mechanisms, but these tend to be less explicitly revealed and have to be deduced from often vast amounts of numerical data. The ability of computational fluid dynamics to compute combustion transients in general (2) and stability behavior in particular (3) has been steadily growing. However, in most cases the full complexity of combustion instabilities requires computational power which remains beyond current capabilities. Finally, while experiments of course capture physical mechanisms, it is often desired to define simplified experiments that isolate important or dominant coupled mechanisms, and it is often difficult to be certain that some aspect of the problem has not been changed in an important way as a result of performing the simplification.

Sought here are innovative theoretical approaches to give guidance to computational and simplified experimental approaches. Of particular interest is the identification of coupling mechanisms which are dominant and the identification of mechanisms which are not dominant. Examples include but are not limited to using multi-scale asymptotic expansions in the spatial and time domain, using computational fluid dynamics tools to perform sensitivity analyses, using these and other ways to reliably defining key experiments, and combinations of the above. The goal is to identify the most important processes so the problem can be simplified in ways that are more tractable for currently available tools.

PHASE I: Identify and demonstrate the feasibility of innovative theoretical approaches to aid systematic design of the analytical, experimental, and computational approaches to understand and predict the combustion stability of liquid rocket engines.

PHASE II: Develop the approach or approaches identified in phase I into a workable framework and demonstrate the approach on a variety of cases.

PHASE III / DUAL USE:
MILITARY APPLICATION: Combustion stability is broad problem spanning many military applications, including liquid rockets, solid rockets, gas turbines, and augmentors.

COMMERCIAL APPLICATION: Combustion stability is also broad problem for non military applications, especially gas turbines for land based power. It is of special concern when burning alternative fuels for energy independence.

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KEYWORDS: combustion, stability, rockets, theory, CFD, coupling

AF09-BT39 TITLE: <u>Plasmonics for Energy Generation</u>

TECHNOLOGY AREAS: Ground/Sea Vehicles, Sensors

OBJECTIVE: Enhance the energy harvesting in power generation systems such as photovoltaics, thermoelectrics or photosynthetic systems through the use of plasmonic structures or subcomponents.

DESCRIPTION: Plasmonics describes the interaction of electromagnetic radiation with a metal at the metal/dielectric interface. Photons incident on a nanostructured metal surface can be converted into surface plasmon polaritons (SPP), which are coherent electron oscillations that can travel along the surface of the dielectric/metal interface. Based on the structure of the metal surface certain wavelengths will be absorbed strongly, the so called surface plasmon resonance. Therefore, correct design of the metal surface is crucial to achieve absorption of the desired wavelength region. Recent advances in the fabrication of nanostructured metal surfaces such as nanoparticles with precisely controlled size and shape have boosted the research into applications for plasmonics.
The ability to significantly enhance the absorption of light makes plasmonics an interesting technology to improve power generation systems based on electromagnetic radiation. For example, plasmonics can be used to improve light harvesting in photovoltaic systems. The enhanced absorption achieved by plasmonic structures allows improving the conversion efficiency of photovoltaic devices and thereby reduce the $/Watt cost of energy. In thermoelectrics, plasmonic structures can enhance the efficiency by creating larger temperature gradients through improved photon harvesting. Artificial photosynthetic systems can benefit from the enhanced localized absorption of light achieved with plasmonics structures.

PHASE I: Proof-of-concept demo of application sub-systems showing improved efficiency. Design and demonstrate a plasmonic structure that enhances light absorption in the desired wavelength range to enhance energy harvesting for applications for photovoltaics, thermoelectrics or photosynthetic sub-system.

PHASE II: Build upon Phase 1 work and demonstration of system components and implementation of a prototype with reduced cost/size/weight and with higher efficiencies. Perform appropriate analysis and modeling, and optimize the system. Develop manufacturing plan for insertion into desired application.

PHASE III / DUAL USE:
MILITARY APPLICATION: The AF seeks alternative energy sources for a broad range of systems deployed in air, space or the field. Needed are strategies that can increase the harvested energy or efficiencies.

COMMERCIAL APPLICATION: This work is expected to result in higher efficiency devices for converting waste heat and sunlight into electricity. As such, it is expected to find use in both the commercial and defense arenas.

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KEYWORDS: nanophotonics, nanoengineering, plasmon, plasmonics, energy, energy harvesting, photovoltaic, thermoelectric, efficiency, nanostructures, metamaterials

AF09-BT40 TITLE: Coupled Cluster Methods for Multi-Reference Applications

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop robust, efficient, easy-to-use CC theory computational methods to predict ground and excited state molecular properties; characterize regions of PESs with significant multi-reference character.

DESCRIPTION: Single reference coupled cluster (CC) theory is generally recognized as one of the most accurate methods for describing ground electronic states of atoms and molecules. CC approaches provide a suitable compromise between relatively low computer costs and high accuracy. These methods are particularly effective in accounting for dynamical correlation effects. In particular, the CC method denoted as CCSD(T) (CC singles plus doubles with a perturbative estimate of triples) is widely regarded as the "gold standard" of single-reference quantum chemical methods for accurate prediction of molecules at near-equilibrium geometries. However, the reliability of single-reference CC methods may be suspect in describing systems far from equilibrium (e.g., undergoing bond breaking or bond formation), for which non-dynamical correlation effects may be important (e.g., open shell species, transition metal compounds, etc.), or in characterizing potential energy surfaces (PESs) in some excited electronic states.

Extension of single-reference coupled cluster methods for characterization of excited states is possible via, for example, the equations-of-motion (EOM) CC approach. Similarly, several techniques exist for the generalization of single-reference CC methods to capture important non-dynamical correlation effects, including the renormalized and the rigorously size-extensive completely renormalized approaches. However, these methods are limited in their ability to examine large sections of potential energy surfaces and, for example, cannot correctly break multiple bonds. On the other hand, truly multi-reference (MRCC) procedures have not been implemented into generally available robust electronic structure codes and are typically only available to and usable by experts in the field of coupled cluster theory.

PHASE I: Evaluate computational efficiency and robustness of new or existing CC-based methods for capturing non-dynamical correlation effects and for characterization of excited electronic states. Devise initial algorithms/programming strategies for efficient computational implementation of selected methods.

PHASE II: Implement proof-of-concept computer code to demonstrate reliability and efficiency. Identify suitable molecular systems with high multi-reference character to benchmark the reliability of calculated electronic excited state properties and non-dynamical correlation effects. Perform key benchmark calculations. Begin development of beta version that includes scalable implementations.

PHASE III / DUAL USE:
MILITARY APPLICATION: Energetic materials for propellants and explosives, insensitive munitions, fuels, gas generators, and chem-bio defense for military applications.

COMMERCIAL APPLICATION: Commercial/industrial applications include development of advanced nanomaterials and small-molecule drug design.

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KEYWORDS: Coupled-cluster theory; molecular dynamics; electronic state properties