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RESEARCH AREA 1
MECHANICAL SCIENCES

1.0 Research supported in the mechanical sciences portion of the Mechanical and Environmental Sciences Division of the Army Research Office is concerned with a broad spectrum of fundamental investigations in the disciplines of fluid dynamics, solid mechanics, structures and dynamics, and propulsion and energetics. Though many creative and imaginative studies concentrate on a particular sub-discipline, increasingly, new contributions arise from interdisciplinary approaches such as the coupling between aerodynamics and structures, combustion and fluid dynamics, or solid mechanics and structures as in the structural reliability areas. Additionally, several common themes run through much of these four sub-disciplines, for example, active controls and computational mechanics. Research in such areas is addressed within the context of the application rather than as a separate subject of study. Fluid dynamics research is primarily concerned with investigations in the areas of vortex-dominated flows, unsteady aerodynamics, and the thermal science of micro/meso-scale devices. Solid mechanics include a wide array of research areas such as high strain rate phenomena, penetration mechanics, heterogeneous material behavior, and reliability of structures. The structures and dynamics area is focused on investigations in vehicle structural dynamics and simulation and air vehicle dynamics including rotor aeromechanics. Research in the propulsion and energetics area is concentrated on processes characteristic of reciprocating (diesel) and gas turbine engines and the combustion dynamics of propellants used for gun and missile propulsion. The following narratives describe the details of the scope and emphasis in each of these sub disciplinary areas.

Potential offerors are encouraged to contact the appropriate Technical Point of Contact (TPOC) for preliminary discussions on their ideas. The TPOC may invite the offeror to submit a preproposal. Some TPOC's have provided specific instructions for timing of submittals, see below.

1.1. Fluid Dynamics. Research in fluid dynamics supports the development of improved or new technology for advanced helicopters, small gas turbine engines, improved airdrop (parachute) systems, maneuverable high-speed missiles and high performance gun-launched projectiles. While basic research studies that address the fundamental flow physics underlying these devices are solicited, innovative research in the specific topical thrust areas listed below is especially encouraged.

1.1.1. Vortex-Dominated Flows. In contrast to fixed-wing aircraft, rotorcrafts always operate under the influence of their own wakes. The prediction of rotor performance, vibratory loads, and blade-vortex interaction noise depends strongly on the accurate prediction of the rotor wake, and the prediction methodology of this wake remains one of the major challenges in fluid mechanics. Current computational fluid dynamics (CFD) approaches are computationally intensive, especially for Eulerian methodologies where the vorticity diffuses numerically through the grid points and makes predication inaccurate. The process by which vorticity is shed by the blade and rolls up to form vortex filaments is not now adequately simulated for rotorcraft load distributions. In fact, under certain flight conditions, multiple vortices are observed to form due to negative lift over the blade tip. The application of non-intrusive optical diagnostic techniques should yield new phenomenological understanding for the study of multiple vortices, wake structures, and wake development. New numerical algorithms or different techniques to increase accuracy and reduce the computational requirements are required.

1.1.2. Unsteady Aerodynamics. A high level of unsteady flow, which cannot be adequately predicted by steady or quasi-steady approaches, can characterize the flow field around many modern Army weapons systems. One classical example of very high Army relevance occurs on the retreating blade of a helicopter rotor, where the high angles of attack experienced by the retreating blade of the helicopter rotor leads to boundary-layer separation followed by load and pitching-moment overshoots. Mild separation causes increased vibration and reduces performance, while severe dynamic stall leads to unacceptably large vibratory loads and limits forward flight speeds, load, and maneuver capabilities. The physics of this flow phenomenon are known to depend on the Mach and Reynolds numbers of the flow, and hence future research in this area needs to be performed under realistic flight conditions. Improved theoretical and numerical simulation is needed for understanding the unsteady separation process and evaluating concepts for separation control. The simulations must be capable of accounting for transition of the boundary layer (and under some circumstances, the transition in the separating free shear layer). Detailed experimental measurements of velocity and pressure are needed in the separating region for the fundamental understanding the separation process, the development of new turbulence models valid during the stall process, and the validation of numerical simulations: here, the current focus is on quantitative flow field measurements rather than merely quantitative measurements on the airfoil surface. These measurements will probably require the use of new non-intrusive optical methods. Combined experimental and numerical efforts towards control of unsteady separation using passive and active flow control (including the emerging field of Micro-adaptive Flow Control) are also sought.

A second example of the importance of unsteady aerodynamics occurs on maneuvering missiles and projectiles. As future emphasis in flight vehicle control and "smart" systems pervades munitions design, advances in aerodynamic phenomena, such as dynamic high alpha separation, vortex shedding, control surface/vortex interaction, divert thruster/vehicle interaction, roll control stability, and propulsion system integration will be required. New composite material vehicles will have stringent thermodynamic limits and enhanced nonlinear aero elastic response to maneuver forces. Smart structures and MEMS technology will redefine control strategies, control surface shape and control surface dynamics, consequently driving fluid dynamics into new areas of research. All of these developments require the prediction and experimental verification of complex nonlinear transient flow fields. This will require improved CFD for turbulent flow separation prediction, large eddy simulation, vehicle vortex interactions, and accurate computations of gross flow field response to MEMS boundary layer flow perturbations. Parallel developments in experimental techniques will be required to measure these complex flow fields to help verify and guide the predictive technology.

1.1.3. Thermal Science of Micro/Meso-Scale Devices. Over the last decade the same micro fabrication techniques originally developed for the production of electronic integrated circuits have been used to develop miniature mechanical devices (known as Micro Electrical Mechanical Systems, or MEMS). In fluid dynamics applications, the small size and mass of these devices have enabled the production of sensors and actuators with outstanding temporal and spatial bandwidth, enabling multiple applications for micro-flow control. Here the philosophy is the insertion of very small control forces at crucial spatial and temporal locations in order to obtain significant changes in system performance. The application of this micro-flow control technology to Army systems offers the promise of significant performance enhancement at reasonable life-cycle cost.

More recently, the sophistication of these micro fabrication technologies has improved to the point where entire miniature machines can be developed. These miniature machines have a wide range of applications that have high relevance to the Army and specific application to the dismounted soldier. Examples include the development of micro-turbine power generators, air and water purifiers, compact cooling systems, and miniature unmanned aerial vehicles. The physics of these miniature devices can be significantly different than their macro-scale counterparts due to the very small scales involved, the two-dimensional nature of micro fabricated flow channels, and the limitations imposed by the materials used by these fabrication techniques.

As with all ARO-funded programs, the Army uniqueness and relevance of the proposed research should be explicitly addressed. Specifically, in this thrust proposals that seek funding for generic technology development (such as the development of new micro-flow actuators or micro-electronic chip cooling concepts, or the investigation of fluid flow and heat transfer in micro-channels) are discouraged: what are sought are broader technology solutions with specific Army relevance.

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1.2. Solid Mechanics. The light, lethal, survivable, continental United States (CONUS)-based modern Army with quick power projection capabilities around the globe has abiding interest in building fixed and mobile assets in the most efficient manner with advanced materials. Weapons, platforms, ammunition, and ground structures are designed with severe weight and volume restrictions. Innovative use of material combinations for specific applications necessitates understanding of the behavior of materials and structures under complex and severe constraints. Solid mechanics provides the link between material properties and structural response. The program focuses on *high strain rate phenomena* including *impact, penetration, and shock*, *mechanics of heterogeneous systems*, and *fracture and failure*. In this program, relations between material behavior, deformation, fracture and failure under physical constraints and loading conditions are examined. Complete understanding of the behavior of structures made of combinations of advanced materials permits the predictive capability to optimize structural response and is useful in the development of design methodologies. In situations that are ballistic in nature, the Army faces unique constraints of very high strain rates, large deformations, high pressures, and rapid changes in temperature. Interrelated analytical, experimental, and computational formulations are needed to solve multidisciplinary problems. Predictive models, validated by well-characterized experiments, are needed to identify dominant mechanisms at relevant scales. Though imaginative and promising research investigations in all these general areas are of interest, innovative research studies in the specific topical areas outlined below are especially encouraged.

To establish the suitability of proposed research topics, direct contact by telephone or electronic mail with the Program Manager and submittal of informal preliminary proposals (not to exceed five pages) are strongly encouraged. For the Solid Mechanics Program, preliminary proposals should be submitted no later than 15 October of each fiscal year. These preliminary proposals will undergo technical evaluation in terms of scientific merit and Army relevance. Offerors whose preliminary proposals are assigned a high priority rating by the committee will be invited to submit a complete, formal proposal.

1.2.1. Impact, Penetration, Shock and High Strain Rate Behavior. This research topic addresses the need to understand the response of Army hardware to impact or nearby explosive detonation and integrates fundamental work in finite deformation, high pressure and high strain-rate response, damage, and failure mechanics. It should be carried out through a combination of physically based experiments, theoretical studies, and computations and addresses a wide variety of materials including metals, ceramics, composites, and energetic materials. Since the complex interactions between the shock and release waves usually initiate the damage mechanisms in the target, accurate modeling of the target behavior will require controlled, high fidelity experiments. Because penetration involves erosion and sliding of both the projectile and the target, explicit modeling of these processes with friction-based theories and computational techniques are essential. Innovative research on processes and phenomena in materials and structures that absorb energy, deflect penetrations, and/or laterally disperse momentum is encouraged.

Paramount to this effort is a better understanding of the mechanics of interfaces and impact mechanisms, such as high velocity sliding that might occur at the penetration/target interface or within developing cracks at macroscopic and microscopic scales. To this end, innovative experimental techniques that incorporate high-speed data acquisition or imaging are necessary to capture the deformation processes and relative motion between surfaces. Computational methods for treating discontinuities in a three dimensional context are required. These methods must concentrate not only on the techniques required to track a moving boundary, but also on the relevant physics and mechanics associated with those surfaces. Examples might include boundaries between dissimilar materials, shock fronts, elastic/plastic boundaries, phase boundaries, shear bands and cracks, as well as penetration/target interfaces.

Penetration into brittle materials presents special challenges due to cracking and comminution of material ahead of the penetrator, high-speed granular flow of comminuted material, and the mixing of eroded penetrator material and comminuted target material. Ceramics and geologic materials exhibit extreme sensitivity to loading histories, which may manifest in apparent rate dependence of failure strengths and the propagation of failure waves. All of this requires greatly improved understanding, effective modeling, and efficient computational schemes. Penetration into composite materials presents still another set of challenges. Careful experimental techniques are required to delineate the nature, timing, and evolution of damage and failure in composite targets. Analytical models at multiple scales validated by carefully designed experiments are needed. Future ultra-lightweight armors will involve a combination of layered and graded structures that are highly anisotropy and heterogeneous. Linearized homogeneous isotropic conventional theories will not be adequate to describe the shock and penetration response of such material combinations.

Another important aspect of this area of research is the deformation and fracture of materials under high strain rates (up to 10^7 s^{-1}), large strains (up to 500%), high temperatures (up to melting), and high pressures (up to 5 GPa). Constitutive models should be three-dimensional and should allow for system nonlinearities. Models of behavior for combinations of ductile and brittle solids that encompass coupled deformation and failure modes are sought. These models should be based on new uniquely defined benchmark experiments. An important aspect of this area of research is the development of innovative experimental techniques that can be used to generate data for the wide ranges and combinations of strain rates, strains, temperatures, and pressures of interest. These experiments should provide for quantitative measurements of variables and parameters related to failure.

1.2.2. Mechanics of Heterogeneous Systems. The mechanics of heterogeneous structures involves the development of integrated analytical, computational, and experimental approaches to investigate the response of hybrid structures that may include combinations of high strength and lightweight engineered composites, ceramics, and functionally graded materials. Heterogeneity at all scales should be considered, from nanomaterials to systems created through combinations of different materials at larger scales. Experimental and computational techniques are needed to optimize material microstructure as well as the topology of systems to provide the desired structural response for specific boundary and loading conditions. Physically based structural design guidelines for energy absorbing structural systems comprised of tailored combinations of materials and heterogeneities at different length and time scales are sought. There are continuing technology barriers that need to be overcome if reliable Army structures such as helicopters, ground vehicles, bridges, and weapons systems are to be designed, manufactured, and maintained over a long period of time. Of special interest to the Army is the thermo-mechanical response at strain rates encountered in high-speed impact or explosive loading. Probabilistic as well as deterministic approaches are encouraged. Phenomena of interest are wave propagation, scattering, dispersion, damage evolution, and failure.

At appropriate length and time scales, the quantitative prediction and measurement of parameters related to dominant heterogeneities and mechanisms are needed for specific material systems in order to relate nano and micro effects to the macro scale. Deterministic and statistical scaling methodologies for toughness, strength, and geometrical effects that account for the multitude and variability of heterogeneities such as interfaces, interphases, particulate dispersion, fiber volume fraction and distribution, constituent shape, and their combined effects on failure are needed. Innovative methods and models to control material properties and damage by graded interfaces, coatings, and mechanical impedance mismatches are required. Constitutive relations for multi-scale mechanisms should include failure and damage criteria, which are mechanism-based and experimentally verifiable. The determination of universal scaling laws that can be used to bridge physical scales would greatly enhance our understanding and prediction of phenomena such as inelastic deformations, localization, distributed damage and failure, and fragmentation. Advances and approaches based on analyses of physically representative model problems related to specific phenomena are needed for scaling laws corresponding to an underlying physical universality.

1.2.3. Fracture and Failure. Fundamental research in damage initiation and progression, failure mechanisms, and life prediction is essential for the development of new structural systems for the Army. New theories are needed that can overcome the limitations of traditional continuum fracture models arising from crack tip singularities. Interrelated theory, experiments and computations are required to understand and predict crack nucleation, branching and coalescence and should be used to develop accurate failure theories that can be used by designers for a variety of complex material systems. Methodologies that explore fracture processes at the microscale and relate them to the meso and macroscopic levels should be investigated. Computational models for the creation of free surfaces that are mesh independent and that incorporate evolving time-dependent boundary conditions and physically based failure initiation criteria need to be developed. These computational models should capture the complex interactions of failure processes and defects in three dimensions. Experiments have to be designed to delineate the effects of failure initiation, interaction, and rupture. Necessary and sufficient conditions are needed to determine when to follow failure from initiation to rupture. A better understanding of the effect of damage on a system's operating performance and its remaining life is needed.

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1.3. Structures and Dynamics. A significant challenge facing Army laboratory engineers is the determination of the influence of inertial, thermal, electrical, magnetic, impact, damping, and aerodynamic forces on the dynamic response of adaptive armament systems, ground vehicles, rotorcraft, missiles, projectiles, gears, parachutes, and shelters. Its resolution is of fundamental importance to the design and construction of affordable, reliable, durable, and maintainable Army equipment with acceptable levels of personnel safety and comfort. Consequently, the ARO is supporting basic research in these areas, with emphasis on air vehicle dynamics, including missile and rotorcraft dynamics; the dynamics, non-linear vibrations, structural control, and simulation of land vehicles and weapon systems; and the dynamic response of structural components and systems fabricated from advanced composite materials, with or without embedded actuators and sensors. Submittal of fundamental research proposals on the general topics described above is encouraged, keeping in view the paramount importance of Army relevance. More specific details of the program's predominant thrust areas are described in the following paragraphs.

To establish the suitability of proposed research topics, direct contact by telephone or electronic mail with the TPOC and submittal of informal preliminary proposals (not to exceed five pages) are strongly encouraged. For the Structures and Dynamics Program, preliminary proposals should be submitted not later than 15 October of each fiscal year. These preliminary proposals will undergo technical evaluation in terms of scientific merit and Army relevance. Offerors whose preliminary proposals are assigned a high priority rating by the TPOC will be invited to submit to ARO a complete, formal proposal in early March of each fiscal year.

1.3.1. Structural Dynamics and Simulation. This topic consists of six thrusts: smart structures, structural dynamics, structural damping, active structural control, structural health monitoring, and inflatable structures. Advances in these areas are required to improve capabilities of modeling, computing the dynamic response, reducing noise levels, suppressing vibrations, detecting the presence of damage, and assuring the integrity and performance of structural components used in military systems.

Adaptive structures are currently being considered for application in helicopter rotor systems, missiles, projectiles, electromagnetic antenna structures, land vehicles and weapon systems. They offer opportunities, for example, to realize structural vibration suppression or isolation in rotorcraft and weapon systems, unsteady load control on rotor blades, reduction of blade/vortex interaction noise, airfoil shape change, gust load alleviation, aeromechanical stability augmentation, beam shaping and steering in antennas, and structural health monitoring. Research areas include sensors and actuators, formulation of suitable constitutive relations, modeling and optimal design of smart composite structures, finite element formulations and control algorithms. Concepts for novel actuation techniques, based on micro-electromechanical systems (MEMS), nanotechnology or other innovative concepts, are encouraged. New active damping techniques, based, for example, on combinations of viscoelastic and active materials, combined with shunted electric circuits and non-linear adaptive control strategies, have emerged as candidates for improving structural performance and reliability. Topics of interest include the role of viscoelastic materials, constitutive equations, elastomeric dampers for missiles and rotorcraft, magnetorheological fluid dampers, modeling and design, actuation of missile flight control surfaces, non-linear control techniques, and techniques for including damping effects in mathematical and computational models.

The trend toward the increasing use of composite materials in the fabrication of military vehicles to reduce their weight and augment fuel efficiency requires that Army engineers have the tools necessary to predict the static and dynamic response of composite structures. During the course of service, virtually all-composite structures should be monitored to assure their condition of health and integrity to prolong their life span or to prevent catastrophic failure. Recent developments in sensor and actuator technologies have opened the way to develop new diagnostic technologies particularly suitable for composite materials. Such enhancements might involve approaches such as wavelet transforms, neural networks, fuzzy logic, probabilistic estimations, system identification, electro-mechanical impedance methods, electric impedance tomography, etc. The development of the associated software will have to include the presence of distributed sensors, actuators, and controllers based on fiber optics, piezoelectric materials, (MEMS) devices, or other concepts. The development of new active materials, such as relaxor ferroelectrics and alkaline-based piezoelectric materials has recently been reported by the materials science research community. These materials appear to offer significant opportunities to create improved actuation devices that will deliver greater authority (force, stroke) than do the conventional piezoelectric materials. The potential of new actuators in Army applications should be energetically pursued.

The assurance of structural reliability of military air and land vehicles and weapon systems will greatly enhance confidence in their safety, reduce the probability of mission failures, and diminish the costs of operation and maintenance. An important element in achieving reliable systems is a strong capability of inspecting and assessing the physical condition of critical structural components. Significantly improved techniques for inspection, analysis, and interpretation are urgently needed to facilitate the assessment of the health of a structure and to promote the design, fabrication, and reliable operation of future and current military systems. Inability to detect damage in heterogeneous structures that may comprise combinations of composites, ceramics, and metals is a limiting factor to their use in practice. The application of active materials to the development of novel sensing techniques, such as MEMS, and the ability to interpret sensor signals effectively and accurately in nearly real time are fundamental for improving the reliability of physical systems. Miniaturized sensory devices could be incorporated into heterogeneous structures to signal the presence, location, and extent of local and global failure modes, such as fiber breakage, fiber pull-out, delamination, and large matrix structural cracking. Accordingly, new design and maintenance technologies are critically needed for military systems. An idea that shows considerable promise in reducing operating costs while enhancing system safety is the concept of condition-based operation. This is a concept that encompasses maintenance, system characteristics, scheduling, and operations. Condition-based operation attempts to enhance the reliability and survivability of the system under adverse conditions, such as battle damage and critical system failures, using on-line system identification, health monitoring and failure detection, and adaptive fault-tolerant reconfigurable operational control. With advances in micro-sensors (including MEMS devices), piezoelectric actuator technology, system identification, information technology, adaptive control theory for sensor nets and wireless telemetry, condition-based operation of military systems will lead to enormous gains.

1.3.2. Air Vehicle Dynamics. Rotorcraft aeromechanics analytical prediction capability must be improved to increase military effectiveness of rotorcraft through better mission performance, improved availability and dependability, and reduced life cycle costs. Advanced comprehensive analyses must address rotor blade control surface devices that use aerodynamic forces to excite structural response in order to minimize blade and fixed system vibratory loads and/or to improve the vehicle's aeroelastic stability characteristics. Of great importance in helicopter dynamics is the development of numerical analysis tools that are applicable to the special challenges associated with moderate to very large systems of equations (typically finite element based) that are needed to determine solutions for rotorcraft trim, periodic response, and transient behavior. The types of numerical analyses that are needed include: (i) the determination of the periodic solutions to the equations (both stable and unstable orbits) and of the unknown parameters that are associated with a specified flight condition, (ii) traditional constant and periodic coefficient eigenanalysis of these system orbits and limit cycle or chaotic behavior of unstable orbits, and (iii) determination of optimal design, optimal trim, and optimal control of such systems. The dynamics and control of micro-aerial vehicles is also of interest to the program.

Smart structures concepts offer the Army the potential to address critical problems in helicopter systems including vehicle vibration suppression, control of rotor blade vibratory loads and fatigue stress, reduction of interior and exterior noise, gust load alleviation, enhancing rotor aerodynamic efficiency and performance, and augmenting aeroelastic/aeromechanical stability. These advances may be achieved by using smart structures approaches, for example, to twist the rotor blade along its length, to actuate a flap or elevon control surface at the blade trailing edge, or to change the airfoil camber or leading edge shape. The development of control algorithms is needed to tailor the inputs to multiple actuation sites, integrate information from multiple sensors, and optimize overall controller architecture including the development of appropriate data processing and software techniques.

The Army's requirement to deploy soldiers and equipment rapidly and safely dictates the use of parachute insertion usually at high speed and low altitude to minimize detection and exposure to enemy fire and maximize the drop accuracy. Parachute deployment and inflation is a challenging problem in aeroelasticity requiring multi-disciplinary modeling for coupling the structural deformations of the parachute material with the three-dimensional and highly unsteady aerodynamic environment. Prediction of a parachute system's response to user control and environmental factors once deployed also requires a coupled approach. For instance, an airdrop problem for which no three-dimensional coupled simulation capability currently exists is that of predicting the aerodynamic performance of fully deployed airdrop systems such as a steerable parafoil or a steerable round or cross canopy. Issues include: determination of (i) the lift to drag ratio of such systems, (ii) the outcome of a control input, and (iii) the system response to environmental inputs such as winds.

1.3.3. Weapon System and Land Vehicle Dynamics. The overarching goal of weapon system research is the improvement of firing accuracy. Improved weapon system accuracy reduces the number of rounds required to complete a mission; thus the ammunition logistics requirements of a unit are reduced. Vehicle generated disturbances (environmental or internal) and firing disturbances excite the structural dynamics between the sighting system and the weapon mount and the dynamics of the weapon itself. Innovative, unique, and far reaching research is required to explore fundamental issues in simultaneous control and structure design, ultra-high performance hybrid weapon drive systems, smart structures for vibration suppression and micro-positioning of gun barrels, high speed emplacement mechanisms and non-traditional barrel structures. Specific areas include mechanism theory and optimization, vibration, multi-body dynamics, smart materials, distributed servo control, software development tools for mechanical design and optimization.

Numerous large, complex mechanical systems used by the Army consist of interconnected multi-body structures, e.g., heavy machinery, wheeled/tracked military land vehicles, machine tools, rotorcraft, weapon systems, etc. These complicated systems often consist of numerous combinations of rigid and flexible elements. New and innovative approaches are needed for the efficient analysis, design, and control of large vehicles that consist of interconnected flexible bodies. Recent advances in computer and graphics hardware and software capabilities are stimulating recent advances in motion based simulators with computer generated imagery that interfaces vehicle dynamic models and their physical environments. Innovative approaches for modeling the deformation of vehicle system components based on the finite element method and experimental identification techniques are needed to develop more detailed models of complex vehicles. Examples of potential research areas are automatic formulation of the constrained equations of motion, symbolic equation processing, generation of computational methods and associated computer codes, algorithm optimization for computer architectures, model reduction and error quantification techniques, fluid payload dynamics, suspension systems and control, weapons positioning control, optimization techniques, and non-linear control algorithms.

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1.4. Propulsion and Energetics. Propulsion and energetics research supports the Army's need for higher performance propulsion systems. These systems must also provide reduced logistics burden (lower fuel/propellant usage) and longer life than today's systems. Fundamental to this area are the extraction of stored, chemical energy and the conversion of that energy into useful work, for vehicle and projectile propulsion. In view of the high temperature and pressure environments encountered in these combustion systems, it is important to advance current understanding of fundamental processes as well as to advance the ability to make accurate, detailed measurements for the understanding of the dominant physical processes and the validation of predictive models. Thus, research in this area is characterized by a focus on high pressure, high temperature combustion processes and on the peculiarities of combustion behavior in systems of Army interest.

1.4.1. Engines. Research on combustion in engines is focused on intermittent, reacting flows encountered in diesel combustion chambers and on continuous combustion characteristics of small, gas turbine combustors. Optimizing engine performance, through understanding and control of in-cylinder combustion dynamics, while retaining high power density, is a major objective. This focus leads to a strong emphasis on fuel injection processes, jet break-up, atomization and spray dynamics, ignition and subsequent heterogeneous flame propagation. Research on heterogeneous flames requires supporting study into kinetic and fluid dynamic models, turbulent flame structure, soot formation and destruction, flame extinction, surface reactions, multiphase heat transfer, and other factors which are critical to an understanding of engine performance and efficiency. An additional consideration is the high pressure/temperature environment, encountered in advanced engines, which influences liquid behavior and combustion processes at near-critical and super-critical conditions. Of particular interest are investigations of fundamental characteristics related to highly stressed engines such as elevated temperature combustion, accelerated mixing, and transient heat transfer. Engine performance degradation under low temperature conditions, due to reduced fuel volatility, high oil viscosity, poor atomization and vaporization, etc., is a major concern. Fundamental research is needed in many areas, including low temperature physical and chemical rate processes, instantaneous friction and wear mechanisms, and combustion instability effects at low temperatures. With advances in sensing, modeling and control architectures, it is becoming possible to further optimize the performance of combustion systems. Providing the foundations for such active control is also a major goal of the program.

1.4.2. Propellant Combustion Processes. Research on propellant combustion processes is focused on understanding the dynamics of the planned and inadvertent ignition and subsequent combustion of energetic materials used for propulsion in gun and missile systems and in ordinance. The program is also addressing the characterization of advanced energetic materials, e.g. those based on nano-scale structures and/or ingredients. Basic research is needed in several areas, including, plasma- and laser-induced ignition; thermal pyrolysis of basic ingredients and solid propellants; flame spreading over unburned surfaces (particularly in narrow channels); surface reaction zone structure of burning propellants; chemical kinetics (including possible ion kinetics in the presence of plasmas) and burning mechanisms; propellant flame structures; characterization of physical and chemical properties of propellants and their pyrolysis products; and coupling effects among the ignition, combustion, and mechanical deformation/fracture processes with or without the presence of a plasma. The use of advanced combustion diagnostic techniques for reaction front measurements, flame structure characterization and determination of reaction mechanisms is highly encouraged. This includes characterization of radiative and convective stimuli delivered by plasma injection sources as well as the thermal, kinetic, and mechanical responses of the propellant. Complementary model development and numerical solution of these same ignition and combustion processes are also essential. There is also need to understand the unplanned or accidental ignition of energetic materials due to stimuli such as electrostatic discharge, impact, friction, etc. This requires, for example, research on the processes of energy absorption and energy partitioning in the materials, the effect of mechanical damage on the ignition events, and other topics relating to the safety of energetic materials.

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RESEARCH AREA 2
ENVIRONMENTAL SCIENCES

2.0. The Environmental Sciences Division of the Army Research Office supports fundamental research in the Atmospheric and Terrestrial Sciences, i.e. research in the physical sciences of planet Earth in support of Army requirements. The need for research in the environmental sciences stems from the impact that the environment has upon virtually all aspects of Army activities. As military technology become ever more complex and sophisticated, both systems and operations are increasingly influenced by the natural environment and variability in environmental conditions. Despite continuing Army efforts to develop an all-weather/all-terrain capability, environmental conditions still constrain Army operations. Thus, the potential impact and leverage of environmental factors must be clearly understood in order to increase existing system capabilities and performance, take advantage of environmental weakness within adversary systems, and optimize the design of new systems. The ability of the Army to function properly and efficiently in all these environments requires equipment and tactics designed with full knowledge of the potential effects of the environment. Intelligent planning for the battlefield must take advantage of the environment. An in-depth understanding of individual environments on micro- to macro-scales and capabilities to predict environmental effects and behavior for places and times differing from the “here and now” are required. Advanced simulators for training and mission rehearsal require realistic behavior of atmospheric processes and terrain. Domains of specific interest range from the shallow subsurface, the land surface and the earth-air interface, to the lower atmosphere and cover surficial environments which vary from the polar regions to the tropics under all weather conditions, both favorable and adverse.

The Army is also committed to be a national leader in environmental and natural resource stewardship for the present and future generations as an integral part of its mission. Responsibilities in this arena include the restoration of sites contaminated through prior Army activities, as well as achieving a state of environmentally sustainable operations on all military installations, particularly those utilized for training and testing. Cost-effective land use and restoration requires in-depth knowledge and understanding of the physical principles and processes operating in the terrestrial and atmospheric domains across a variety of scales which range from the microscopic to megascopic.

The natural environment is, by nature, a multifaceted and dynamic system so that there is an increasing need for multidisciplinary approaches to address the complex research issues that presently characterize the atmospheric and terrestrial sciences. Because of limited resources, not all subjects that fall within the broad interest areas defined below can be included in the current ARO Environmental Sciences research program at any point in time. Emphasis areas are reviewed periodically and funding concentrated in specific areas on a 3-5 year time frame. The submission of white papers is strongly encouraged. For Terrestrial Sciences funding consideration, white papers should be submitted in November of each fiscal year. Offerors whose pre-proposals are evaluated and are found to have significant technical relevance and merit will be requested to submit a complete proposal during the April-May time frame of each fiscal year.

Potential offerors are encouraged to contact the appropriate Technical Point of Contact (TPOC) for preliminary discussions on their ideas. The TPOC may invite the offeror to submit a preproposal.

2.1. Terrestrial Sciences. In general, the Terrestrial Sciences program is concerned with the impact of the Earth's surficial environment on Army activities. Program interests cover a broad spectrum, ranging from terrain