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**Exhibit R-2, RDT&E Budget Item Justification: PB 2022 Navy** **Date: May 2021**

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| <b>Appropriation/Budget Activity</b><br>1319: <i>Research, Development, Test &amp; Evaluation, Navy / BA 1: Basic Research</i> | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> |
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| COST (\$ in Millions)                     | Prior Years | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total | FY 2023 | FY 2024 | FY 2025 | FY 2026 | Cost To Complete | Total Cost |
|-------------------------------------------|-------------|---------|---------|--------------|-------------|---------------|---------|---------|---------|---------|------------------|------------|
| Total Program Element                     | 0.000       | 452.955 | 487.048 | 484.421      | -           | 484.421       | -       | -       | -       | -       | -                | -          |
| 0000: <i>Defense Research Sciences</i>    | 0.000       | 447.646 | 460.048 | 473.089      | -           | 473.089       | -       | -       | -       | -       | -                | -          |
| 3465: <i>In-House Lab Independent Res</i> | 0.000       | 0.000   | 0.000   | 11.332       | -           | 11.332        | -       | -       | -       | -       | -                | -          |
| 9999: <i>Congressional Adds</i>           | 0.000       | 5.309   | 27.000  | 0.000        | -           | 0.000         | -       | -       | -       | -       | -                | -          |

**A. Mission Description and Budget Item Justification**

The Office of Naval Research (ONR) was established by Congress in 1946 to plan, foster and encourage scientific research in recognition of its paramount importance to the maintenance of American naval power and national security. ONR manages the Department of the Navy's (DON) portfolio of Basic Research, Applied Research and Advanced Technology Development investments to ensure naval forces can effectively deter conflict, but when called upon, fight, win and come home safely. This Program Element (PE) supports the Basic Research portion of the Department of the Navy (DON) science and technology (S&T) portfolio, laying the foundation for new innovative technologies and future capabilities for naval warfighters. This PE's efforts include theoretical and experimental investigations directed toward increasing knowledge and understanding of the physical, chemical, engineering, environmental and life sciences. The huge majority of the research in this PE are performed by academia and government labs, both of which play significant roles in developing the S&T workforce of tomorrow in addition to delivery new knowledge and scientific discoveries.

This PE, and the rest of Naval S&T, supports higher guidance defined by the National Defense Strategy, and responds to requirements identified by the Secretary of the Navy through research priorities set by the Chief of Naval Research, coordinated across the Naval Research Enterprise (NRE), and outlined in the Naval R&D Framework. In addition, ONR's S&T investment portfolio supports National Naval Responsibilities (NNR) critical to the naval services where the Navy has historically taken the lead (ocean acoustics, undersea weapons, naval engineering, undersea medicine and sea-based aviation) to ensure decisive naval capability in the maritime domain. Scientific breakthroughs within the current research activities:

- Atmosphere & Space Sciences;
- Mathematics, Computer, & Information Sciences;
- Ocean Sciences;
- Materials/Processes;
- Human Systems;
- Medical/Biology;
- Science Addressing Hybrid Threats;
- Sensors, Electronics & Electronic Warfare (EW);
- Air, Ground & Sea Vehicles;
- Weapons; and

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Science & Engineering Education, Career Development & Outreach lead to more advanced aspects of applied research and technology development and become solutions to Navy and Marine Corps technical challenges via the Future Naval Capabilities (FNCs) pipeline, and new capability options for the future via the Innovative Naval Prototypes (INPs) portfolio. Just as today's Sailors and Marines are enabled by past naval S&T investments, current investments hedge against uncertainty, providing the scientific basis for near-term solutions to commanders today and options for an unknown future.

The work in this PE can be classified between Technology Readiness Level (TRL) 1 (basic principles observed and reported) and TRL 2 (technology concept and/or application formulation).

Due to the number of efforts in this PE, the programs described herein are representative of the work included in this PE.

| <b>B. Program Change Summary (\$ in Millions)</b> | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
|---------------------------------------------------|----------------|----------------|---------------------|--------------------|----------------------|
| Previous President's Budget                       | 463.829        | 467.158        | 478.089             | -                  | 478.089              |
| Current President's Budget                        | 452.955        | 487.048        | 484.421             | -                  | 484.421              |
| Total Adjustments                                 | -10.874        | 19.890         | 6.332               | -                  | 6.332                |
| • Congressional General Reductions                | -              | -2.936         |                     |                    |                      |
| • Congressional Directed Reductions               | -              | -4.174         |                     |                    |                      |
| • Congressional Rescissions                       | -              | -              |                     |                    |                      |
| • Congressional Adds                              | -              | 27.000         |                     |                    |                      |
| • Congressional Directed Transfers                | -              | -              |                     |                    |                      |
| • Reprogrammings                                  | -0.618         | 0.000          |                     |                    |                      |
| • SBIR/STTR Transfer                              | -10.256        | 0.000          |                     |                    |                      |
| • Program Adjustments                             | 0.000          | 0.000          | 7.718               | -                  | 7.718                |
| • Rate/Misc Adjustments                           | 0.000          | 0.000          | -1.386              | -                  | -1.386               |

**Congressional Add Details (\$ in Millions, and Includes General Reductions)**

**Project:** 9999: *Congressional Adds*

Congressional Add: *Navy ROTC Cybersecurity Training Program*

Congressional Add: *Defense Research Sciences*

Congressional Add: *Silicon-Germanium-Tin Alloy Research*

Congressional Add: *Bio-inspired Engineering and Design for Naval Applications*

Congressional Add: *Predictive Modeling & Simulation for Next Gen Naval Undersea Vessel and Platform*

Congressional Add: *USV Batteries, Materials, and Additive Manufacturing*

|  | <b>FY 2020</b> | <b>FY 2021</b> |
|--|----------------|----------------|
|  |                |                |
|  | 5.309          | 0.000          |
|  | 0.000          | 15.000         |
|  | 0.000          | 5.000          |
|  | 0.000          | 3.000          |
|  | 0.000          | 2.000          |
|  | 0.000          | 2.000          |

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**Congressional Add Details (\$ in Millions, and Includes General Reductions)**

|                                               | FY 2020 | FY 2021 |
|-----------------------------------------------|---------|---------|
| Congressional Add Subtotals for Project: 9999 | 5.309   | 27.000  |
| Congressional Add Totals for all Projects     | 5.309   | 27.000  |

**Change Summary Explanation**

Funding: The increase is associated with initiating the In-House Laboratory Independent Research (ILIR) Project 3465 in the Defense Research Sciences PE. Funds were realigned from Program Element (PE) 0601152N, Project 0000 to PE 0601153N, Project 3465.

Technical: not applicable

Schedule: not applicable

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                    |                |                |                     |                                                                                            |                      |                |                |                                                                         | <b>Date:</b> May 2021 |                         |                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   |                    |                |                |                     | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> |                      |                |                | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |                       |                         |                   |
| <b>COST (\$ in Millions)</b>                                       | <b>Prior Years</b> | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b>                                                                         | <b>FY 2022 Total</b> | <b>FY 2023</b> | <b>FY 2024</b> | <b>FY 2025</b>                                                          | <b>FY 2026</b>        | <b>Cost To Complete</b> | <b>Total Cost</b> |
| 0000: <i>Defense Research Sciences</i>                             | 0.000              | 447.646        | 460.048        | 473.089             | -                                                                                          | 473.089              | -              | -              | -                                                                       | -                     | -                       | -                 |

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- Atmosphere & Space Sciences;
  - Mathematics, Computer, & Information Sciences;
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  - Human Systems;
  - Medical/Biology;
  - Science Addressing Hybrid Threats;
  - Sensors, Electronics & Electronic Warfare (EW);
  - Air, Ground & Sea Vehicles;
  - Weapons; and
  - Science & Engineering Education, Career Development & Outreach
- lead to more advanced aspects of applied research and technology development and become solutions to Navy and Marine Corps technical challenges via the Future Naval Capabilities (FNCs) pipeline, and new capability options for the future via the Innovative Naval Prototypes (INPs) portfolio. Just as today's Sailors and Marines are enabled by past naval S&T investments, current investments hedge against uncertainty, providing the scientific basis for near-term solutions to commanders today and options for an unknown future.

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Due to the number of efforts in this PE, the programs described herein are representative of the work included in this PE.

**B. Accomplishments/Planned Programs (\$ in Millions)**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p><b>Title:</b> Air, Ground and Sea Vehicles</p> <p><b>Description:</b> Sailors and Marines operate air, ground and sea vehicles in some of the most extreme environments on the planet. Basic research advances the capacity of naval platforms operating under, on and above the seas, and to project power ashore. Ongoing research in the Air, Ground and Sea Vehicles activity will increase platform performance, reliability, improve human-machine teaming, reduce the cost of at-sea operations and enhance the effectiveness of distributed maritime operations.</p> <p>The efforts research focus include: surface and subsurface signatures; free-surface, subsurface, and propulsor hydromechanics; hull life assurance; advanced ship concepts; distributed intelligence for automated survivability; advanced electrical power systems; air vehicles; air platforms propulsion and power; air platforms survivability and signature control; special aviation projects; environmental quality; logistics; power generation, energy conversion, and storage; and advancements in naval technology innovations.</p> <p><b>FY 2021 Plans:</b><br/>                     Sea-Based Aviation National Naval Responsibility (Formerly Air Vehicles)<br/>                     - Conduct research for Air Vehicle Science &amp; Technology in aerodynamic interface, advanced manned/unmanned handling qualities and control for Naval operations, control law synthesis methods to improve aircraft launch and recovery, high lift aerodynamics and performance, advanced methods to achieve fixed wing efficiency with Vertical/Short Take-off and Landing (V/STOL) launch &amp; recovery, and autonomous deck operations.<br/>                     - Conduct ongoing research in Aircraft Science &amp; Technology efforts include: advanced analytical methods for achieving guaranteed performance in multibody control systems, advanced modeling and analysis methods for ship/aircraft aerodynamic interface, air vehicle flying qualities and control, and mechanical/environmental failure prediction research.</p> <p>Flight Dynamics &amp; Control (Formerly Air Vehicles)<br/>                     Research will develop theory and analysis methods to better understand the phenomena and natural dynamics of air vehicles operating in the marine environment. Collaborative research will improve our knowledge of control system interactions between piloted aircraft and human performance.</p> | 56.569  | 56.004  | 56.749       | 0.000       | 56.749        |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | FY 2020 | FY 2021 | FY 2022<br>Base | FY 2022<br>OCO | FY 2022<br>Total |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|---------|-----------------|----------------|------------------|
| <p>The Focus areas are:</p> <ul style="list-style-type: none"> <li>- Multibody control systems and the ability to demonstrate guaranteed performance relative to a desired end state;</li> <li>- Robust and precise control in the presence of highly turbulent flow fields;</li> <li>- Algorithms to enable precise ship-relative navigation in GPS-denied environments.</li> </ul> <p>Aerodynamics (Formerly Air Vehicles)<br/>Research will develop advanced computational methods addressing the Navy-unique challenges:</p> <ul style="list-style-type: none"> <li>- Fully coupled aerodynamic interface between ships and aircraft;</li> <li>- Advanced methods for reduced-order modeling of complex flow fields;</li> <li>- Advanced methods for manipulating more precisely the flow fields around air vehicles operating in the maritime environment.</li> </ul> <p>Science of Autonomy and Control of Unmanned Systems<br/>Research related to critical multidisciplinary autonomy challenges that cut across areas/domains, including air, sea, undersea and ground. This includes multi-disciplinary research into the science of autonomy focuses on four interrelated areas:</p> <ul style="list-style-type: none"> <li>- Scalable and robust distributed collaboration among autonomous systems;</li> <li>- Human/unmanned system collaboration;</li> <li>- Perception-based adaptation across uncertain naval environments;</li> <li>- Embodied and situated intelligence and architectures.</li> <li>- Expand research on agile, theory-based tools and methods for safe, assured, robust, verifiable, and trustable autonomy.</li> </ul> <p>Air Platform Machinery and Systems(Formerly Ship and Air Platform Machinery Systems)</p> <ul style="list-style-type: none"> <li>- Conduct basic research to advance the technical superiority of Sea-Based Aviation Science and Technology in Propulsion, Power and Thermal management related technologies with emphasis on propulsion cycles, subsystems, and integration, turbo machinery and drive systems, and hot section materials and coatings.</li> <li>- Conduct basic research to improve the power density, fuel efficiency, speed, range and operating reliability of future large, medium and small engines.</li> <li>- To obtain a better fundamental understanding of the technologies involved with Rotating Detonation Engines and integration into platforms and weapon systems using thermodynamic models, Computational Fluid Dynamics and sub-scale experiments will continue studies in FY21.</li> </ul> |         |         |                 |                |                  |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Conduct basic research for high stage-loading and efficient turbomachinery including distortion tolerant fans, casing treatments and advanced methods in blade-disk aerodynamics; advanced cooling and thermal management for engines and auxiliary systems including new concepts of heat collection, distribution and rejection; advanced turbine engine materials and coatings; highly integrated propulsion inlets and exhausts and dust ingestion research: including modeling, separating, deposition, coatings and sensing.</p> <p>- To improve jet engine material durability and temperature rate capabilities in both benign and corrosive environments will continue its basic research in FY21.</p> <p>Platform Design and Engineering (covers efforts previously called Science of Advanced Naval Platform Performance and Sea Platform Survivability Science)</p> <p>- Conduct basic research related to critical S&amp;T to investigate efforts related to platform performance, platform autonomy and control, platform survivability and tactical submarine evolution plan (TSEP) S&amp;T.</p> <p>- Efforts for platform performance, autonomy and control include, but are not limited to, the following: understanding, predicting and controlling turbulent free-surface and stratified wakes leading to mitigation, tools to accurately predict platform maneuvering performance supporting future designs, current platform operational tactics, platform control and "digital twins" and developing reliability-based knowledge and tools to improve performance and affordability of ship hull structural systems from cradle to grave.</p> <p>- Efforts for platform survivability and TSEP S&amp;T include, but are not limited to, the following: structural acoustic and propulsor source characterization, developing signature mitigation technologies, providing state of the art signature and detection range prediction tools that accurately model platforms to emerging threats and developing wideband, light-weight, affordable low observable materials.</p> <p>Power, Energy &amp; Propulsion (covers efforts previously called Science of Advanced Naval Power and Energy)</p> <p>- Conduct basic research related to critical S&amp;T to investigate efforts related to heat transfer and thermal management; power generation; energy storage; distribution and control; and motors and actuators.</p> <p>- Efforts include, but are not limited to, the following: wide band gap (WBG) materials growth for next generation power electronic devices, improving power density, efficiency and control authority of WBG SiC Power Electronic Building Blocks by increasing switching frequencies, developing multidisciplinary collaborative ship design tools and nanostructured heat transfer surfaces and materials for enhanced thermal transport.</p> <p>Sustainment and Logistics (covers efforts previously called Corrosion Control Science)</p> <p>- Conduct basic research related to critical S&amp;T to investigate maintenance technology, manufacturing and repair, sustainment technologies and advanced logistics.</p> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Efforts include, but are not limited to, the following: corrosion control, condition-based maintenance and prognostics, repair and component replacement technologies, replenishment at sea and decision support.</p> <p>Materials (covers efforts previously called Materials &amp; Coatings Science and Science of Advanced Naval Power and Energy)</p> <p>- Pursue research in computer-aided material design; scarce materials mitigation strategies; electrochemical materials and functional polymeric materials, leading to technological underpinnings for advanced energy capture and power storage and distribution; structural materials for performance improvement and resiliency; identifying new nanoengineered materials and processing for naval applications.</p> <p><b>FY 2022 Base Plans:</b><br/>                     Aerospace Structures and Materials (Formerly Sea Based Aviation National Naval Responsibility)<br/>                     Research is focused on basic research for developing lightweight, reliable, survivable, sustainable, and affordable airframes for naval and marine corps aircraft and weapons.<br/>                     Research concentration areas are:<br/>                     - Galvanic corrosion and mitigation strategies for metallic airframes in naval environment.<br/>                     - Multiaxial fatigue of hybrid airframes.<br/>                     - High fidelity composites prediction methodologies that span multiple length scales.<br/>                     - Novel out of autoclave and out of oven curing technologies.<br/>                     - Short fiber thermoplastic composite forming and joining.<br/>                     - High strain rate characterization of materials.<br/>                     - Computer assisted iterative material development for armor applications<br/>                     - Lightweight material solutions for multifunctional structures for airframes and weapons</p> <p>Flight Dynamics &amp; Control<br/>                     Research will develop theory and analysis methods to better understand the phenomena and natural dynamics of air vehicles operating in the marine environment. Collaborative research will improve our knowledge of control system interactions between piloted aircraft and human performance. Objectives of this basic research portfolio include: increase the operational envelop for air vehicles, tailor airframe dynamics with novel control effectors, improve threat engagement performance, develop fundamentals for coupled human/machine dynamics, adapt to variable airframe conditions, etc.<br/>                     The Focus areas are:<br/>                     - Multibody control systems and the ability to demonstrate guaranteed performance relative to a desired end state;</p> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Robust and precise control in the presence of highly turbulent flow fields;</p> <p>- Algorithms to enable precise ship-relative navigation in GPS-denied environments.</p> <p><b>Aerodynamics</b><br/>                     Research will enhance understanding of Naval-unique aerodynamic challenges by developing advanced computational and experimental methods in the following Focus Areas:</p> <ul style="list-style-type: none"> <li>- Fully coupled aerodynamic interface between ships and aircraft;</li> <li>- Novel state-of-the-art in-situ diagnostics and reduced-order modeling of complex flow fields;</li> <li>- Advanced methods for manipulating precisely the flow fields around air vehicles operating in the maritime environment.</li> <li>- Innovative technologies enabling increased range and/or maneuverability suitable for aircraft operating from the maritime environment and attritable systems such as high-speed weapons.</li> <li>- Interactional and transitional aerodynamics of multi-rotor systems in complex fluid dynamic environments involving multi-body relative motion.</li> </ul> <p><b>Science of Autonomy and Control of Unmanned Systems</b><br/>                     Research related to critical multidisciplinary autonomy challenges that cut across areas/domains, including air, sea, undersea and ground. This includes multi-disciplinary research into the science of autonomy and it focuses on four interrelated areas:</p> <ul style="list-style-type: none"> <li>- Scalable and robust distributed collaboration among autonomous systems;</li> <li>- Human/unmanned system collaboration;</li> <li>- Perception-based adaptation across uncertain naval environments;</li> <li>- Embodied and situated intelligence and architectures.</li> <li>- Expand research on agile, theory-based tools and methods for safe, assured, robust, verifiable, and trustable autonomy.</li> </ul> <p><b>Naval Air Platform Propulsion, Power and Thermal Management (Formerly Air Platform Machinery and Systems)</b></p> <ul style="list-style-type: none"> <li>- Continue basic research to advance the technical superiority of Sea-Based Aviation - Propulsion, Power and Thermal management with emphasis on propulsion cycles, subsystems, propulsion integration, turbo machinery and drive systems, and hot section materials and coatings.</li> <li>- Continue basic research to improve the power density, fuel efficiency, speed, range and operating reliability of future large, medium and small engines.</li> <li>- Continue fundamental studies with Rotating Detonation Engines and integration into platforms and weapon systems using thermodynamic models, Computational Fluid Dynamics and sub-scale experiments.</li> </ul> |         |         |              |             |               |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Conduct basic research for high stage-loading and efficient turbomachinery including distortion tolerant fans, casing treatments and advanced methods in blade-disk aerodynamics; advanced cooling and thermal management for engines and auxiliary systems including new concepts of heat collection, distribution and rejection; advanced turbine engine materials and coatings; highly integrated propulsion inlets and exhausts and dust ingestion research, including modeling, separating, deposition, coatings and sensing.</p> <p>- Continue to improve jet engine material durability and temperature rate capabilities in both benign and corrosive environments.</p> <p>- Develop advanced radio-frequency based sensors to provide ingestion and foreign object damage sensing, as well as overall prognostics.</p> <p><b>Platform Design and Engineering</b><br/>Conduct basic research related to platform performance, platform autonomy and control, platform survivability and tactical submarine evolution plan (TSEP) S&amp;T.</p> <p>- Efforts for platform performance, autonomy and control include, but are not limited to, the following: understanding, predicting and controlling turbulent free-surface and stratified wakes leading to mitigation, tools to accurately predict platform maneuvering performance supporting future designs, current platform operational tactics, platform control and "digital twins" and developing reliability-based knowledge and tools to improve performance and affordability of ship hull structural systems from cradle to grave.</p> <p>- Efforts for platform survivability and TSEP S&amp;T include, but are not limited to, the following: structural acoustic and propulsor source characterization, developing signature mitigation technologies, providing state of the art signature and detection range prediction tools that accurately model platforms to emerging threats and developing wideband, light-weight, affordable low observable materials.</p> <p><b>Power, Energy &amp; Propulsion</b><br/>Conduct basic research related to heat transfer and thermal management; power generation; energy storage; distribution and control; and motors and actuators.</p> <p>- Efforts include, but are not limited to, the following: wide band gap (WBG) materials growth for next generation power electronic devices, improving power density, efficiency and control authority of WBG SiC Power Electronic Building Blocks by increasing switching frequencies, developing multidisciplinary collaborative ship design tools and nanostructured heat transfer surfaces and materials for enhanced thermal transport.</p> <p><b>Sustainment and Logistics</b><br/>Conduct basic research to investigate maintenance technology, manufacturing and repair, sustainment technologies and advanced logistics.</p> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022<br/>Base</b> | <b>FY 2022<br/>OCO</b> | <b>FY 2022<br/>Total</b> |
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| <p>- Efforts include, but are not limited to, the following: corrosion control, condition-based maintenance and prognostics, repair and component replacement technologies, replenishment at sea and decision support.</p> <p>Materials</p> <p>- Pursue research in computer-aided material design; scarce materials mitigation strategies; electrochemical materials and functional polymeric materials, leading to technological underpinnings for advanced energy capture and power storage and distribution; structural materials for performance improvement and resiliency; identifying new nanoengineered materials and processing for naval applications.</p> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>There is no significant funding change from FY 2021 to FY 2022.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                |                |                         |                        |                          |
| <p><b>Title:</b> Atmosphere and Space Sciences</p> <p><b>Description:</b> Effective Naval operations depend upon accurately understanding the maritime and littoral operating environment and predicting its characteristics at high spatial and temporal resolution in areas that may be inaccessible. Understanding atmospheric phenomena and their impact on the electromagnetic spectrum from the sea surface to space provides a significant warfighting advantage. Efforts include: Battlespace Environments, Marine Meteorology and Prediction and Space Research. These efforts support basic research on physical process studies, fundamental observations, data discovery, and modeling and forecasting of the atmosphere and space with the goal of improving the ability to predict the battlespace environment of the Navy and Marine Corps, anywhere on the globe. Emphasis is placed on the marine atmosphere, the tropics, polar regions, the upper atmosphere and ionosphere and other areas where new understanding is needed in order to overcome predictability barriers that limit the accuracy of current forecast models. Efforts are underway to understand the interactions of physics between the atmosphere, space, land, ocean and ice, represent these coupled processes in models, and extend them across scales from local to planetary, with the goal of extending the skill of predictions up to seasonal and interannual timescales. Recent efforts have also focused on the processes that control tropical cyclone formation, structure and intensity changes and phenomena that affect electromagnetic and electro-optic signal propagation in the marine atmosphere and near space domains. Research results provide the foundation for improved global and regional forecasts of the operational environment and for development of next-generation, fully coupled, high resolution prediction systems. Research areas evolve in response to priorities of the Oceanographer of the Navy.</p> | 25.899         | 26.888         | 27.442                  | 0.000                  | 27.442                   |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p><b><i>FY 2021 Plans:</i></b></p> <p><b>Battlespace Environments</b></p> <ul style="list-style-type: none"> <li>- Develop the quality of the environmental products that are provided in support of war fighters and to more accurately assess the impact of the atmosphere on the performance of weapon systems, we must advance our basic understanding of atmospheric processes ranging from thousands of kilometers down to meters, including interactions of the atmosphere with the land, sea, wave, and ice.</li> <li>- Improve our ability to exploit environmental observations to help us characterize those processes more accurately. Navy operations are increasingly taking place in the littoral zone, where complex topography and air-sea-land contrasts affect the environment on very short time and space scales, as well as in the tropics and sub-tropics, where longer time scale oscillations and seasonal signals also affect short-term weather events. While today's numerical analysis and prediction systems are more capable of resolving and predicting highly variable phenomena than were the systems of 10-20 years ago, there are still processes that are not well understood, including, atmospheric clouds and moisture, that require further study to improve their representation in models.</li> <li>- Comprehend the distribution of aerosols in the atmosphere play and important role moisture formation as well as atmospheric visibility. A growing number of non-conventional observational data sources require new and novel data assimilation methodologies to be developed before their potential is fully realized. Systems are being employed which operate in or through the earth's upper troposphere, middle and upper atmosphere and the near space environment where environmental supports are crude or non-existent.</li> <li>- Understand the measurements and predictive models are needed to mitigate these shortfalls.</li> <li>- Recognize the interface between the troposphere and stratosphere is gaining increased attention because of its possible effect upon medium term weather prediction. This is most convincingly seen in the influence of the jet stream on the trajectory of storm systems and air masses in the troposphere. Current analysis indicates that incorporation of correct physics at this boundary and assimilation of stratospheric data into numerical weather prediction models may be almost as important as the physical interaction with the ocean surface.</li> </ul> <p><b>Marine Meteorology and Prediction</b></p> <ul style="list-style-type: none"> <li>- Launch the Land-Air-Sea Interaction Closures research initiative to improve coupled nearshore atmospheric and oceanographic phenomena</li> <li>- Investigate key physical processes, clouds and moisture phenomena in order to improve their representation in models. Efforts will be focused on those phenomena that affect the predictability of parameters of highest relevance to Naval operations. New and non-conventional observational data sources will be explored and novel data assimilation methodologies will be developed and tested that will continue research in FY21.</li> </ul> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy | <b>Date:</b> May 2021 |
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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Conduct deployment of observing systems in the upper troposphere, middle and upper atmosphere and the near-space environment to extend the range of prediction systems to much higher altitude.</p> <p>- Carry forward the research to improve medium range weather prediction through enhanced understanding of the physics of the upper atmosphere and ionosphere, and to improve the representation of the interface between the troposphere and stratosphere.</p> <p>- Move forward the research initiative to improve the understanding of processes that contribute to the poorly predicted rapid intensification of tropical cyclones (TCs) through major observing experiments.</p> <p>- Extend the analysis of high-altitude airborne field observations over major hurricanes (during which an unprecedented set of high-resolution soundings covering the full depth of the storms were obtained) allowed detailed physical processes to be observed for the first time.</p> <p>- The field and modeling initiatives that focus on the origin, evolution and effects of Arctic cyclones believed to have a strong influence on Arctic ice will continue in FY21.</p> <p>- Finished the predictability of Intra-Seasonal Tropical Oscillations (PISTON) research initiative and field studies of monsoonal phenomena in the northern Indian Ocean.</p> <p><b>Space Research</b><br/>This program perform best-in-class, experimentally-led sensing research and development (R&amp;D) that is integrated across three environmental areas -- geospace, heliospace, and high-energy space -- which underpin, connect, and inform successful operations, with metrics to increase technology readiness towards rapidly prototyping solutions for accelerated delivery. The following programs include:</p> <p><b>Geospace</b></p> <p>- To take away key scientific and computational impediments to a future physics-based Navy ionospheric prediction capability recently identified as a critical capability gap for high frequency (HF) radio-wave technologies for electromagnetic maneuver warfare, by means of focused scientific research on identification of which key drivers from the lower atmosphere and thermosphere are necessary to achieve short term forecasts of HF propagation globally.</p> <p><b>Heliospace</b></p> <p>- Launch efforts to advance the understanding for the solar magnetic fields and how it influence the near-earth environment.</p> <p><b>High-Energy Space</b></p> <p>- Launch efforts to understand particle acceleration mechanisms in high energy solar flares by studying gamma-ray and neutron emissions that are measured in space.</p> <p><b>FY 2022 Base Plans:</b></p> |         |         |              |             |               |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p><b>Battlespace Environments</b></p> <ul style="list-style-type: none"> <li>- Continue to improve the quality of the environmental analysis and prediction provided in support of warfighters by assessing the impact of the atmosphere and ionosphere-thermosphere-magnetosphere on the performance of sensors, platforms and weapon systems, and by advancing our basic understanding of atmospheric processes across spatial scales and the interactions of the atmosphere with the land, sea, wave, ice, and thermosphere.</li> <li>- Continue to exploit environmental observations and to characterize environmental processes more accurately, thus providing improved forecast models for the Navy and Marine Corps in regions where operations take place including: the littoral zone, where complex topography and air-sea-land contrasts impact the environment on very short time and space scales; the tropics and sub-tropics; and the Arctic, where longer time scale atmospheric changes affect short-term weather events.</li> <li>- Initiate new research on atmospheric or Earth system coupled processes that are not well understood, including cloud and aerosol interaction, marine boundary layer and coastal prediction, and diurnal and mesoscale variability to improve their representation in forecast models.</li> <li>- Continue to investigate the distribution, transport and time evolution of aerosols in the atmosphere and their impact on atmospheric visibility and laser propagation.</li> <li>- Initiate new research on coupled processes in the high atmosphere, between the troposphere and stratosphere and the stratosphere and ionosphere and their effect on weather and space weather prediction.</li> </ul> <p><b>Marine Meteorology and Prediction</b></p> <ul style="list-style-type: none"> <li>- Continue the Land-Air-Sea Interaction research initiative to improve our understanding and prediction of coupled near-shore atmospheric and oceanographic phenomena impacting naval littoral operations.</li> <li>- Continue to investigate key physical processes, including clouds and moisture phenomena, in order to improve their representation in atmospheric predictive models. Efforts will be focused on those phenomena that affect the predictability of parameters of highest relevance to naval operations.</li> <li>- Investigate new and non-conventional observational data sources and explore novel methodologies to assimilate these data into operational predictive models.</li> <li>- Conduct deployment of observing systems in the upper troposphere, middle and upper atmosphere and the near-space environment, providing information that will allow us to extend our prediction systems into the middle and upper atmosphere and provide longer and higher fidelity forecasts that will impact naval mission planning.</li> <li>- Continue using major observing experiments to understand the processes that contribute to the poorly predicted rapid intensification of tropical cyclones.</li> <li>- Continue field and modeling initiatives that focus on the origin, evolution and effects of Arctic cyclones believed to have a strong influence on Arctic sea ice motion and extent.</li> </ul> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy | <b>Date:</b> May 2021 |
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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>Space Research</p> <p>Perform innovative sensor development and physics-based modeling and forecasting R&amp;D (research and development) that is integrated across three environmental areas: geospace, heliospace, and high-energy space. R&amp;D efforts are motivated and guided by innovative concepts for future resilient, distributed Naval operations, with metrics to increase technology readiness and rapid prototyping, for accelerated delivery. The programs include:</p> <p>Geospace:</p> <ul style="list-style-type: none"> <li>- Continue research into affordable small-sat sensors to investigate and specify the three dimensional structure and evolution of the electromagnetic signal propagation environment in the ionosphere, including ionospheric bubbles. Employ stereo imaging and tomographic reconstruction to access the three dimensional structure and evolution of the upper atmosphere and ionosphere, relevant to Naval communications, intelligence, surveillance and reconnaissance, and geolocation.</li> <li>- Continue development of our understanding and computational representation of upper atmospheric, ionospheric relevant plasma processes and their coupling to the lower atmosphere and solar inputs, towards a future physics-based ionospheric prediction capability for Naval forces.</li> <li>- Initiate a small-sat investigation into improved ionospheric observation and understanding through use of new signal processing approaches, based on anomalous refraction of Global Navigation System transmissions.</li> </ul> <p>Heliospace:</p> <ul style="list-style-type: none"> <li>- Continue efforts to advance the understanding, and advance the forecastability of, the solar radiation and particle fluxes, and magnetic fields. Investigate how they influence the near-Earth environment and the relevant Naval systems that rely on that environment.</li> </ul> <p>High-Energy Space:</p> <ul style="list-style-type: none"> <li>- Continue efforts to understand particle acceleration mechanisms in high energy solar flares by studying gamma-ray and neutron emissions that are measured in space.</li> <li>- Initiate efforts to leverage millisecond pulsars as stable timing sources for precision navigation and timing applications.</li> </ul> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>There is no significant change between FY 2021 and FY 2022.</p> |         |         |              |             |               |
| <b>Title:</b> Science Addressing Hybrid Threats                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 25.823  | 24.135  | 24.460       | 0.000       | 24.460        |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p><b>Description:</b> Naval expeditionary forces increasingly face hybrid adversaries using conventional weapons combined with terror, crime, cyber, information operations, etc. A hybrid adversary is flexible and adapts quickly to synchronize advanced state weapons systems, disruptive commercial technologies, cheap expedient homemade weapons, and a variety of novel tactics. The Sciences Addressing Hybrid Threats (SAHT) (formerly Counter Improvised Explosive Device (IED)) activity seeks to establish and nurture science to counter these growing challenges, while collaborating with and leveraging results from more traditional Naval research portfolios.</p> <p>The SAHT Sciences program provides research for Naval Forces to fight hybrid threats, and adversaries in expeditionary operations. Naval Expeditionary Forces need science advances to address a range of Basic Research challenges that result from physical and operational environmental limitations so harsh that solutions push basic discovery and invention. Naval Forces able to operate amphibiously and in the littoral will have all of their capabilities exposed to degrading sea and land physical effects. Expeditionary forces must be agile and lethal but will be constrained by size, weight, and power requirements and must be sustained across large areas.</p> <p>A hybrid adversary can be state or non-state using a combination of conventional and irregular methods and weapons. For example, a hybrid threat could use criminal acts in concert with conventional artillery and IEDs and in turn social media for combined effects greater and broader than the sum of the parts. These coordinated threats occur across the spectrum of conflict.</p> <p>The efforts research focus include: physics addressing the electromagnetic spectrum for use in Command and Control and high energy physics addressing Directed Energy Weapons; machine perception, reasoning and collaborative behavior; artificial intelligence enabling future Intelligence systems; optics, electronics, and photonics research to enable revolutionary spectral awareness in small low power sensors; computer and network science to enable expeditionary computing coupled with Data Science research to conduct data analysis; fundamental chemistry and materials science research to advance technologies to support sustainment; basic materials research to explore and improve armor and structural materials; electrochemical energy conversion and storage research to sustain the force; chemistry and physics to provide disruptive energetics for expeditionary fires; and biology, physiology, and cognitive sciences addressing the Naval Expeditionary warfighters human abilities.</p> <p><b>FY 2021 Plans:</b></p> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <ul style="list-style-type: none"> <li>- Conduct high specificity standoff detection efforts to provide high probability detection and classification of explosive components in support of hazard defeat to counter continuously evolving explosive threats.</li> <li>- Extend exploring concepts, techniques and methods, for the design, growth, and characterization of electronic and electro-optic sensors to counter improvised explosive devices (IEDs).</li> <li>- Carry-Forward the artificial intelligence / machine learning investigation of multifactorial information environment parameters in order to automate the process of detecting, identifying and distinguishing intent. Conduct discovery research on multi-class, multi-objective deep reinforced learning algorithms with automated training.</li> <li>- Carry-on the investigation of ultra-wideband compact hybrid analog and digital computational devices and algorithms that can adapt to dynamic information and electromagnetic threat environments. Utilizing existing knowledge of emergent behavior in distributed robotic systems as a foundation, conduct discovery research and develop theories for creating swarming behavior in heterogeneous multi-domain autonomous systems.</li> <li>- Launch the research and develop theories to predict adversarial behavior in autonomy-enabled battle spaces.</li> <li>- Conduct researching novel energetic materials that provide order of magnitude increases over current conventional energetics in reactive, explosive, and propulsive phenomena including high-energy ingredient synthesis, modeling, characterization, and the fundamentals of initiation mechanisms for these materials.</li> <li>- The research in materials, chemistry and physics, emphasizing phenomena that demonstrate non-linear behavior for naval applications will continue to expand in FY21.</li> <li>- Conduct research to explore new, rugged, low cost, and high specific power sources, including solar cell technologies, including investigation into the stability of the solar cells.</li> </ul> <p><b><i>FY 2022 Base Plans:</i></b></p> <ul style="list-style-type: none"> <li>- Conduct basic research in sensors and sensing technologies to enable stand-off detection and rapid neutralization of explosive hazards in multiple expeditionary mission environments while maintaining operational tempo.</li> <li>- Continue to extend exploring concepts, techniques and methods, for the design, growth, and characterization of electronic and electro-optic sensors to counter improvised explosive devices (IEDs).</li> <li>- Continue research into reconstructing human physiological features from audio samples based upon brain science to pair vocal tract features with identifiable facial characteristics.</li> <li>- Continue research into enabling secure and efficient sharing of computer hardware accelerators in systems restricted by size, weight, area and power.</li> <li>- Conduct research novel energetic materials that provide order of magnitude increases over current conventional energetics in reactive, explosive, and propulsive phenomena including high-energy ingredient synthesis, modeling, characterization, and the fundamentals of initiation mechanisms for these materials.</li> </ul> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022<br/>Base</b> | <b>FY 2022<br/>OCO</b> | <b>FY 2022<br/>Total</b> |
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| <p>- Conduct research to explore new, rugged, low cost, and high specific power sources, for example solar cell technologies, including investigation into the stability of the solar cells.</p> <p>-Conduct research and develop theories for creating swarming behavior in heterogeneous multi-domain autonomous systems.</p> <p>- Discover methods to identify coherent courses of action from Artificial Intelligence (AI) agents.</p> <p>- Formalize Artificial Intelligence (AI) hybrid learning theories for the purpose of creating heterogeneous multi-agent collaborative autonomy.</p> <p>- Conduct work in immersive sciences for automated methods for generating content, behaviors, and conduct research studies to examine questions of training effectiveness to increase understanding and use of Mixed Reality for naval applications.</p> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>There is no significant change from FY 2021 to FY 2022.</p>                                                                                                                                                                                                                                                                           |                |                |                         |                        |                          |
| <p><b>Title:</b> Human Systems</p> <p><b>Description:</b> Naval forces operate across multiple domains: under, on and above the seas. Coordinating these operations is inherently complex, and understanding the context in which mission tasks are planned and executed is critical to their success. This research is seeking to understand how context is perceived and used in military mission planning and execution. Research is developing techniques to derive mission context from the Naval planning process as data that can be used with advanced automation and schoolhouse training of necessary skills . Human Systems research will contribute to both heuristics-based, and machine learning artificial intelligence solutions, and result in technologies that resolve complexity and respond rapidly to new threats beyond human speed.</p> <p>Research areas include: attention and decision making in goal-directed behavior, information exchange processes in human-human and human-machine teaming tasks related to neuroscience, human interactions with autonomous systems, preparation and adaptation to novel challenge, new approaches to training and training assessment, and mechanisms for human attention.</p> <p><b>FY 2021 Plans:</b><br/>Command Decision Making</p> | 18.563         | 18.743         | 20.907                  | 0.000                  | 20.907                   |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Conduct research to explore Command and Control (C2) human-machine collaboration and management of algorithms that adapt using machine learning (ML).</p> <p>- Utilize machine learning algorithms for analysis and forecasting of "what if" scenarios across the human capital enterprise.</p> <p>Cognitive Science for Human-Machine Teaming</p> <p>- Explore previously developed computational models that act as surrogates, teammates, trainers, and assistants to human warfighters.</p> <p>- Conduct research on empirical and computational models of cognition and create algorithms and architectures that can be embedded into autonomous systems to provide higher-level intelligence and ability.</p> <p>- Explore natural communication between humans and machines in Naval domains, including natural language dialogue for intuitive interfaces that lower cognitive load.</p> <p>Computational Neuroscience<br/>(This thrust was previously part of the Neurosciences and Human Interaction With Autonomous Systems FY20 Plan)</p> <p>- Conduct research to identify neural circuits, architectures, and algorithms that can be emulated to develop novel sensing, control, pattern recognition, neuromorphic processors, and intelligent systems.</p> <p>- Explore neural network dynamics and build large-scale models of cerebral cortex.</p> <p>- Conduct discovery research on neural mechanisms of memory processes.</p> <p>- Explore neural models of sensorimotor control and spatial navigation.</p> <p>Human Interaction with Autonomous Systems<br/>(This thrust was previously part of the Neurosciences and Human Interaction with Autonomous Systems FY20 Plan)</p> <p>- Explore warfighter collaboration with autonomous and mission-capable robotic systems.</p> <p>- Explore approaches for training robots to perform complex manipulation skills using machine learning and human demonstration.</p> <p>- Conduct research to begin developing models of effective collaboration between humans and intelligent machines on complex tasks.</p> <p>Attention in Sensory Processing</p> <p>- Conduct research to create and validate measures of the role of attention in the performance of complex military tasks.</p> |                |                |                     |                    |                      |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Investigate novel, brain-based, approaches to computer vision that incorporate top-down attentional processing to facilitate input interpretation.</p> <p>- Develop novel, neurally inspired, techniques exploiting attentional mechanisms to facilitate recognition of sound sources in highly-cluttered acoustic environments.</p> <p>Social, Cultural, and Behavioral Modeling</p> <p>- Conduct research to improve computational efficiency and effectiveness in modeling human behavior, information and cyber warfare.</p> <p>- Discover improved information warfare models, sensors and associated metrics of conflict and competition for estimating warfighter performance.</p> <p>- Develop models of decision-making and strategy needed to develop synthetic decision makers.</p> <p>- Investigate machine learning and artificial intelligence techniques for effective information environment exploitation.</p> <p>Social Networks and Computational Social Science</p> <p>- Conduct research to develop algorithms, methods and tools for analysis of social hysteria propagation and group polarization; improve methods of information environment assessment and strategic communication.</p> <p>- Refine detection of adversarial information maneuvers across social media platforms.</p> <p>- Conduct research to develop information environment assessment capabilities for humanitarian assistance and disaster response.</p> <p><b>FY 2022 Base Plans:</b></p> <p>Command Decision Making:</p> <p>- Conduct basic research to identify the components of Naval missions or tasks (e.g. environmental, logistical) that will impact mission planning and re-planning and, therefore, mission success. The long-term goal is to develop tools that are proactive in providing relevant information to support tactical to strategic decision making.</p> <p>Cognitive Science for Human-Machine Teaming:</p> <p>- Conduct basic research to understand the foundation of human intelligence that enables innate functions, such as communication, social interaction, and context understanding. Empirical research in computational modeling and natural language processing will support the framework and architecture necessary to develop higher-level intelligence in robotic and autonomous systems. The long-term goal of these efforts is to develop machines that are not just tools that extend human capabilities, but also teammates that enable better team performance.</p> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>Schoolhouse Training</p> <ul style="list-style-type: none"> <li>- Conduct basic research to discover novel theories, methodologies, and models for learning. This research will identify enabling technologies to improve generalized problem solving (e.g., adaptive generalized tutors that introduce new content and facilitate deeper understanding that applies to other knowledge areas) and decision making under risk and uncertainty; and characterize (e.g., the magnitude and time course of skill decay), model, and predict skill decay in Navy-relevant areas to provide appropriate training interventions. The long-term goal of these efforts is to develop enabling technologies that will assist warfighters in generalized problem solving, rapid learning, and skill retention.</li> </ul> <p>Computational Neuroscience:</p> <ul style="list-style-type: none"> <li>- Conduct basic research to identify and understand neural circuits and pathways that will be used to develop models of sensorimotor control and spatial navigation. The long-term goal is to understand the neural foundation of intrinsic cognitive skills, such as attention, memory formation, perception, and problem solving in order to develop novel intelligent systems.</li> </ul> <p>Human Interaction with Autonomous Systems and Human-Machine Teaming:</p> <ul style="list-style-type: none"> <li>- Explore principles of warfighter collaboration with autonomous and mission-capable robotic systems.</li> <li>- Conduct basic research to explore training of robots to perform complex manipulation skills using machine learning and human demonstration. The long-term goal is to provide better interfaces with autonomous systems, as well as provide transfer of control of autonomous platforms and payloads amongst operators.</li> </ul> <p>Attention in Sensory Processing and Intelligent Sensing:</p> <ul style="list-style-type: none"> <li>- Conduct basic research in novel deep-learning techniques applied to computer vision. The long-term goal is rapid and accurate object identification in any Naval-relevant environment.</li> </ul> <p>Social, Cultural, and Behavioral Modeling:</p> <ul style="list-style-type: none"> <li>- Conduct basic research to improve current methods (e.g., algorithms, models) for detecting adversarial information maneuvers across social media platforms. The result will produce a better understanding of how covert actors inflict hysteria, crowd manipulation and group polarization on vulnerable audiences. The long-term goal is to gain a better understanding of how human sociocultural behavior informs and affects operational solutions in Naval-relevant contexts.</li> </ul> <p>Social Networks and Computational Social Science:</p> |         |         |              |             |               |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022<br/>Base</b> | <b>FY 2022<br/>OCO</b> | <b>FY 2022<br/>Total</b> |
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| <p>- Conduct basic research to improve the computational efficiency and effectiveness in modeling human behavior, perception of information, and cyber warfare. Investigate novel techniques for effective information environment exploitation and strategic communication. The long-term goal is to understand the impact of the digital information age on the Naval response to conflict, civil instability, and humanitarian assistance.</p> <p>Manpower, Personnel, Training and Education for Future Warfighting:</p> <p>- Conduct basic research to understand the underlying sociological, experiential, psychological, and neurobiological concepts that optimize an individual's intellectual readiness and adaptability to military-relevant emerging technology (e.g. Artificial Intelligence, autonomous systems). Investigate new modeling approaches to support management of the Naval workforce including through novel means of real-time monitoring, observation, and comprehension of unit behavioral health. The long-term goal is to establish a cohesive strategy for optimizing the readiness and effectiveness of the human capital enterprise.</p> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>The funding increase from FY 2021 to FY 2022 is due to the realignment of the Schoolhouse Training program from the Science and Engineering Education, Career Development and Outreach R2 Activity in Program Element (PE) 0601153N to this R2 Activity. The Schoolhouse Training program has pivoted away from science and engineering education and career development to research models of learning and training strategies that will help warfighters with problem solving and decision making. The Schoolhouse Training program aligns with the objectives of the Human Systems R2 Activity by conducting basic research that will enhance warfighter success during planning and execution of mission tasks.</p> |                |                |                         |                        |                          |
| <p><b>Title:</b> Mathematics, Computer, and Information Sciences</p> <p><b>Description:</b> This activity includes basic research efforts directed toward increasing scientific, mathematical, and computational foundations for integrated command, control, communications, cyber intelligence, surveillance, reconnaissance and targeting. The purpose is to sustain U.S. Naval Science and Technology (S&amp;T) superiority, provide new technological concepts for the maintenance of naval power and national security, and help avoid scientific surprise.</p> <p>Efforts include: Scientific foundations and understanding for robust communications and networking; foundations for novel computing hardware, including nanoscale materials, emerging devices and circuits, emerging computational architecture and nanofabrication; basic research on novel techniques for controlling quantum</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 40.189         | 55.491         | 60.256                  | 0.000                  | 60.256                   |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>states; algorithms for analyzing massive datasets in real time and heterogeneous information integration; science base and computational methods for building versatile intelligent agents; theory, algorithms and tools for decision support; mathematical optimization for resource allocation and usage; modeling and computation of complex physical phenomena; computation and information foundations for cyber defense; secure and reliable information infrastructure for command and control; information assurance; and research to extend state-of-the-science in artificial intelligence for the unique challenges of the Naval domain.</p> <p><b>FY 2021 Plans:</b><br/>           Communications and Networking:<br/>           Develop the scientific foundation and understanding of wireless communications and networking technologies that enable the Naval warfighter to maintain access to mission critical information in contested environments. Research thrust areas include:<br/>           Tactical Communications:<br/>           - Complete cross-layer cooperation and relay forwarding with improved throughput<br/>           - Complete multicast network coding<br/>           - Continue interference alignment studies with improved source and channel coding for better interference management. Transitioned to a 6.2 Applied Research program for prototyping with digital chaos.<br/>           - Continue developing new techniques for wireless distributed computing and device-to-device communication<br/>           - Initiate development of new algorithmic framework for signal retrieval using non-uniform sparse array geometries<br/>           - Initiate novel wireless communications methods across air-water boundary</p> <p>Tactical Networks:<br/>           - Complete developing principles of a Wireless Network Operating System. Transitioned to a 6.2 Applied Research program for software implementation.<br/>           - Complete unified approach to fast-converging multipath congestion control, scheduling and routing<br/>           - Continue developing a feedback control model to determine the limit of fast adaptive traffic engineering.<br/>           - Continue investigations in to new algorithms, protocols and middleware for dynamic and scalable multi-hop ad hoc wireless networking in contested environments<br/>           - Initiate Artificial Intelligence/Machine Learning (AI/ML) techniques for multi-dimensional Quality-of-Service optimization<br/>           - Initiate development of cognitive methods and algorithms to maintain network resiliency under link disruptions without adding excess overhead</p> |                |                |                     |                    |                      |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>Quantum Information Sciences</p> <ul style="list-style-type: none"> <li>- Continue research on novel techniques for controlling quantum states to improve performance of surveillance and navigation sensors and clocks</li> <li>- Continue research on integrated chips for quantum information processing enabled by quantum optics for potential improvements in surveillance and communications</li> <li>- Initiate research on demonstrations of systems having a quantum advantage in the solution of optimization problems and quantum simulation of complex physical systems</li> </ul> <p>Nanoscale Computing Devices and Systems</p> <ul style="list-style-type: none"> <li>- Complete research on neuromorphic chip design and testing. Next phase will be systems level prototyping, carried out under the Technology Candidate program</li> <li>- Continue research on ultra-low power nanoelectronic devices, circuits and systems</li> <li>- Continue research on atomic precision control of graphene nanostructures using chemical synthesis techniques</li> <li>- Continue research on spin based electronics, focusing on single atom and single molecule level control</li> <li>- Initiate research on carbon based quantum systems that are compatible with bottom-up chemical synthesis paradigm</li> </ul> <p>Mathematical Data Science</p> <ul style="list-style-type: none"> <li>- Complete research in decision-making under uncertainty using game-theoretic approaches.</li> <li>- Continue basic research in mathematics, probability, statistics, signal processing, machine learning, data engineering, and information theory.</li> <li>- Initiate research on privacy in complex networks.</li> </ul> <p>Machine Learning, Reasoning and Intelligence</p> <ul style="list-style-type: none"> <li>- Continue developing the science base and computational methods for building versatile intelligent agents which can function autonomously in uncertain, unstructured, uncontrolled, open-world environments, and can collaborate seamlessly with humans and other agents.</li> <li>- Initiate program in developing new mathematical methods for principled design of deep learning architectures and analysis of their behavior. Deep learning is a powerful technique for knowledge acquisition and model-building, however mathematical tools for predicting their performance in cases for which they are not trained does not yet exist. Thus far, deploying learning-based intelligent systems require exhaustive and expensive empirical verification. This program is expected to develop techniques for predicting performance learning-based systems, to improve their generalization abilities, and to reduce the need for empirical verification.</li> </ul> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b> | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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Applied and Computational Analysis Program

- Continue to develop robust, reliable and near-real-time computational models for predicting environmental behavior , i.e. atmospheric, oceanic, and material sciences. Research areas include:
- Multi-Scale/Multi-Physics Modeling: Hydrodynamics, salinity and thermodynamics
- Dynamical Systems and Oceanic and Atmospheric Modeling: Develop mathematical tools to understand the complex structure of the oceans and atmosphere
- Inverse Methods: Develop mathematical tools for acoustics, electromagnetism and optics.

Cyber Security and Complex Software Systems

- Complete research on ONR invented BFT++ classes of CPS resiliency, as it has transitioned to FNCs
- Complete research and development of de-bloating and de-layering of COTS for attach surface reduction, as the projects have transitioned to INP.
- Continue ONR signature research on automated exploration of cryptographic algorithms
- Continue further development of heterogeneous processing operating systems & compiler (Popcorn Linux) for supporting hypervisors and virtualization, building an alternative cloud infrastructure that is more efficient, powerful and secure.
- Continue to explore novel application of ONR's concept of hybrid, formal-statistical machine learning (Learn2Reason) in cyber security and software systems environment
- Continue to explore variations of physics-based cyber physical system security approaches beyond ONR's BFT++
- Continue to improve scalability and capability of bottom-up (binary) formal methods
- Continue further development of capability for automatic generation of material decoys (Noise Factory)
- Initiate Investigation on security aspect of non-volatile main memory usage for future computing systems
- Initiate research on applications & efficacy of autonomic computing for cyber physical systems

Networked Sensing

The primary focus of the Networked Sensing program is to conduct basic research in optical components and infrared technologies to enable significant leap-ahead capabilities for the survivability and lethality of Naval forces in complex environments.

- Complete efforts that explored computational imaging techniques for next-generation waveform design for active three-dimensional imaging and measuring and inverting the effects of light scattering on imaging (e.g., seeing through fog).

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <ul style="list-style-type: none"> <li>- Continue efforts exploring advanced photonics techniques to maximize information extraction from individual photons and through tailored optical beams with the goal of being able to image at long-ranges and in degraded conditions.</li> <li>- Continue efforts on fundamental implications of classical entanglement on imaging and metrology.</li> <li>- Initiate efforts to discover highly-sensitive, multi-spectral detector materials and active sensing modalities for imaging through clouds, fog, haze and dust.</li> </ul> <p>Mathematical Optimization and Operations Research</p> <ul style="list-style-type: none"> <li>- Complete advances to special continuous nonconvex programs wherein both the objective to be optimized and the restrictions that enforce the system characteristics are expressed in terms of decision variables that are allowed to realize a continuum of values.</li> <li>- Complete advances to stochastic optimization that include a framework for distributed decomposition of different classes of large-scale problems, and the solving of real-size instances of nonlinear chance-constrained stochastic programs.</li> <li>- Complete the development of new families of cutting planes that effectively remove infeasible or non-optimal solutions from consideration.</li> <li>- Complete a major update of the Pajarito mixed-integer nonlinear programming solver; this code is the fastest open-source mixed-integer second order conic program software.</li> <li>- Continue investigations on discrete and nonlinear-continuous programs for which input parameters are known with certainty, but for which the acquisition of optimal decision strategies can be computationally intensive.</li> <li>- Continue research on optimizing stochastic programs that, due to incomplete or partial information, have input parameters that are not known with certainty.</li> <li>- Continue to Identify exploitable mathematical structures within specific decision problems for the purpose of devising superior solution algorithms.</li> <li>- Initiate new methods for strategically formulating and solving optimization problems that arise in resource allocation, logistics, and system planning.</li> </ul> <p>Science of Artificial Intelligence (AI)</p> <ul style="list-style-type: none"> <li>- Explore principled computational frameworks for integrating domain knowledge and machine learning for fast robust learning of diverse, complex concepts and tasks with light supervision. Domain knowledge includes physical models as well as rules, relations and semantic descriptions. A complementary objective is to gain insights into how humans incorporate prior knowledge and learning from scant data to improve their skills and learn new concepts and tasks, and use these insights to inform the computational framework.</li> </ul> |                |                |                     |                    |                      |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Explore artificial intelligence in support of collaborative, complex command decision making. The objectives are to advance the scientific understanding of collaborative complex-decision making that is typical of Naval command decision making, and to develop AI technologies that actively inform and assist either in individual tasks or in the overall decision-making process. Key features of the desired technologies are that they possess the ability to assess the relative meaning and the context-sensitive importance of new or changing information, and convey or explain the basis of their recommendations in human-understandable terms.</p> <p>- Decentralized perception and planning in dynamics environments. The objective is to develop a unified framework for perception and planning for resources distributed across multiple platforms (agents, platforms, autonomous systems or vehicle swarms) to exploit the massive, diverse data obtained, while subject to communication limitations. Efforts in distributed artificial intelligence will identify principles and tractable computational methods for flexible and resilient approaches to learning, sharing, reasoning, and decentralized situation awareness and action planning. 4. Efforts will develop new brain-inspired artificial intelligence algorithms and architectures that provide richer computational capabilities than current deep learning networks and to model compact neuromorphic hardware suitable for edge computing and signal processing in small Naval platforms.</p> <p>Information Technology</p> <p>- Address the continued need for improving the operational capability of Naval information and communication systems in the areas of: high assurance software; secure tactical connectivity; AI and autonomy; and the processing, integration, and presentation of information. The expected payoff is: the development of improved methods for producing, analyzing, and securing Naval software systems; new design concepts for future Naval tactical communication systems and networks; intelligent autonomy and improved interaction with autonomous systems; and improved methods for information analysis, fusion, and presentation. New research projects will deliver technology for improved AI inference and human/AI interaction, predictive models for human cognitive performance, models for predicting and controlling complex networks in uncertain and hostile environments, and technology for improved presentation of complex, information-rich datasets.</p> <p><b>FY 2022 Base Plans:</b></p> <p>Communications and Networking:<br/>Continue developing the scientific foundation and understanding of wireless communications and networking technologies that enable the naval warfighter to maintain access to mission critical information in contested environments.<br/>Research thrust areas include:<br/>Tactical Communications:</p> |                |                |                     |                    |                      |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <ul style="list-style-type: none"> <li>- Continue developing new techniques for wireless distributed computing and device-to-device communication.</li> <li>- Complete development of new algorithmic framework for signal retrieval using non-uniform sparse array geometries.</li> <li>- Complete novel wireless communications methods across air-water boundary.</li> <li>- Initiate novel coding and modulation techniques to improve the efficiency, capacity and/or resilience of wireless communications.</li> </ul> <p>Tactical Networks:</p> <ul style="list-style-type: none"> <li>- Continue developing a feedback control model to determine the limit of fast adaptive traffic engineering.</li> <li>- Continue investigations in to new algorithms, protocols and middleware for dynamic and scalable multi-hop ad hoc wireless networking in contested environments,</li> <li>- Continue Artificial Intelligence/Machine Learning techniques for multi-dimensional Quality-of-Service optimization.</li> <li>- Continue development of cognitive methods and algorithms to maintain network resiliency under link disruptions without adding excess overhead.</li> </ul> <p>Networked Sensing:</p> <p>The primary focus of the Networked Sensing program is to conduct basic research in optical components and infrared technologies to enable significant leap-ahead capabilities for the survivability and lethality of Naval forces in complex environments.</p> <ul style="list-style-type: none"> <li>- Continue efforts exploring advanced photonics techniques to maximize information extraction from individual photons and through tailored optical beams with the goal of being able to image at long-ranges and in degraded conditions.</li> <li>- Continue efforts on fundamental implications of classical entanglement on imaging and metrology.</li> <li>- Continue efforts to discover highly-sensitive, multi-spectral detector materials and active sensing modalities for imaging through clouds, fog, haze and dust.</li> <li>- Initiate efforts to explore novel optical processing architectures to significantly increase signal processing bandwidth and to enable novel, real-time, distributed sensing applications.</li> </ul> <p>Nanoscale Computing Devices and Systems:</p> <ul style="list-style-type: none"> <li>- Continue research on ultra-low power nanoelectronic devices, circuits and systems.</li> <li>- Continue research on atomic precision control of graphene nanostructures using chemical synthesis techniques.</li> <li>- Continue research on spin based electronics, focusing on single atom and single molecule level control.</li> </ul> |         |         |              |             |               |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <ul style="list-style-type: none"> <li>- Continue research on carbon based quantum systems that are compatible with bottom-up chemical synthesis paradigm.</li> <li>- Initiate research combining molecular quantum science and synthetic electronics.</li> </ul> <p>Quantum Information Sciences:</p> <ul style="list-style-type: none"> <li>- Continue research on novel techniques for controlling quantum states to improve performance of information processors, sensors and clocks.</li> <li>- Continue research on demonstrations of systems having a quantum advantage in the solution of optimization problems and quantum simulation of complex physical systems.</li> <li>- Initiate research on the utilization of photonic and phononic devices for high performance quantum information processing.</li> </ul> <p>Mathematical Data Science:</p> <ul style="list-style-type: none"> <li>- Continue basic research in mathematics, probability, statistics, signal processing, machine learning, data engineering, and information theory.</li> <li>- Continue to develop advanced algorithms for analyzing massive datasets in real time, identify real patterns and avoid false positives.</li> <li>- Continue to develop advanced methods that can integrate and extract common features from large heterogeneous domains. - Initiate research on privacy in complex networks.</li> </ul> <p>Machine Learning, Reasoning and Intelligence:</p> <ul style="list-style-type: none"> <li>- Continue developing the science base and computational methods for building versatile intelligent agents, which can function autonomously in uncertain, unstructured, uncontrolled, open-world environments, and can collaborate seamlessly with humans and other agents.</li> <li>- Continue basic research in developing new mathematical methods for principled design of deep learning architectures and analysis of their behavior. This program is expected to develop techniques for predicting performance learning-based systems, to improve their generalization abilities, and to reduce the need for empirical verification.</li> <li>- Initiate basic research for developing robust computer vision systems, based on human vision, for automated understanding of surveillance imagery, perception for autonomous agents, and managing image/video libraries for after-action analysis and planning.</li> </ul> <p>Mathematical Optimization and Operations Research:</p> |         |         |              |             |               |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <ul style="list-style-type: none"> <li>- Complete advances to special continuous nonconvex programs wherein both the objective to be optimized and the restrictions that enforce the system characteristics are expressed in terms of decision variables that are allowed to realize a continuum of values.</li> <li>- Complete advances to stochastic optimization that include a framework for distributed decomposition of different classes of large-scale problems, and the solving of real-size instances of nonlinear chance-constrained stochastic programs.</li> <li>- Complete the development of new families of cutting planes that effectively remove infeasible or non-optimal solutions from consideration.</li> <li>- Continue investigations on discrete and nonlinear-continuous programs for which input parameters are known with certainty, but for which the acquisition of optimal decision strategies can be computationally intensive.</li> <li>- Continue research on optimizing stochastic programs that, due to incomplete or partial information, have input parameters that are not known with certainty.</li> <li>- Continue to identify exploitable mathematical structures within specific decision problems for the purpose of devising superior solution algorithms.</li> <li>- Initiate new methods for strategically formulating and solving optimization problems that arise in resource allocation, logistics, and system planning.</li> <li>- Initiate new techniques that utilize convex optimization and duality theory to solve non-convex optimization problems.</li> </ul> <p>Applied and Computational Analysis:</p> <ul style="list-style-type: none"> <li>- Conduct basic research in developing analytical and computational tools for models of physical phenomena of critical interest to the Navy waves, flows, materials, structures and information processing.</li> <li>- Continue to develop robust, reliable and near-real-time computational models for predicting environmental behavior in atmospheric and oceanic processes.</li> <li>- Continue to develop theoretical and computational tools to predict the onset of extreme events, whether in materials, such as formation of shocks, cracks and other discontinuities.</li> <li>- Continue to develop reduced models to enable speed up of computational models in acoustics, electromagnetics and optics, in regimes of special interest to the Navy.</li> <li>- Initiate research to develop mathematically rigorous algorithms for employing variable-precision computations in very large-scale multi-physics problems.</li> </ul> <p>Cyber Security and Complex Software Systems:</p> <ul style="list-style-type: none"> <li>- Complete research on computer-driven exploration of cryptographic algorithms, as the work has been successful in changing community thinking.</li> </ul> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <ul style="list-style-type: none"> <li>- Continue to investigate and develop novel computing concepts that lead toward robust, resilient, and dependable cyber systems.</li> <li>- Continue further development of tools and environment for programmability of heterogeneous multiple instruction set architecture systems.</li> <li>- Continue to explore novel application of ONR's concept of hybrid, formal-statistical machine learning (Learn2Reason) in cyber security and software systems environment.</li> <li>- Continue to explore physics-based approaches to various security aspect of cyber-physical systems, including authentication, vulnerability testing, and exploit resilience.</li> <li>- Continue critical emphasis on improving scalability and capability of bottom-up formal analysis that would enable users to prove security properties about binaries directly.</li> <li>- Initiate research on novel methods for attack surface maneuver for cyber physical systems and systems with complex apertures and sophisticated sensing apparatus, to include lightweight decoy synchronization and other resilience techniques.</li> </ul> <p>Science of Artificial Intelligence:</p> <ul style="list-style-type: none"> <li>- Explore principled frameworks for integrating domain knowledge and machine learning for fast, robust learning of diverse complex concepts and tasks with light supervision.</li> <li>- Explore artificial intelligence to advance the scientific understanding of collaborative, complex decision-making that is typical of naval command decision making. Explore formal verification and validation methods for artificial intelligence in the naval domain to enhance trust. Explore explainable artificial intelligence to enhance human-machine collaboration. Explore decentralized perception and planning in dynamic environments to develop a unified framework perception and planning for resources distributed across multiple platforms, autonomous systems and agents. Explore new brain-inspired artificial intelligence algorithms and architecture that provide richer computational capabilities than current deep learning networks, with an emphasis on memory systems and higher vision. Explore neuromorphic spiking neuron hardware designs based on brain models that are suitable for future edge computing and signal processing in small naval platforms. Explore autonomous problem solving and curiosity driven search for robust performance under unexpected conditions.</li> </ul> <p>Information Technology:</p> <ul style="list-style-type: none"> <li>- Continue development of improved methods for producing, analyzing, and securing Naval software systems.</li> <li>- Continue to design new concepts for future Naval tactical communication systems and networks.</li> </ul> |                |                |                     |                    |                      |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Continue research in intelligent autonomy and improved interaction with autonomous systems, and improved methods for information analysis, fusion, and presentation.</p> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>The increase from FY21 to FY22 will fund fundamental research efforts critical to discovering new mathematical and computational principles that will inform the development of a new framework for integrating domain knowledge with machine learning for fast and robust learning of complex concepts and tasks from challenging Naval data. These principles will also form the foundation for creating an AI framework for integrating perception and planning in distributed autonomous platforms to create a common operating picture. This research responds to the CNO's call for Naval-focused artificial intelligence (AI) fundamental research in his Design for Maritime Supremacy 2.0, developing tools and services to support fast, sound decisions.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |         |         |              |             |               |
| <p><b>Title:</b> Materials/Processes</p> <p><b>Description:</b> Lighter, faster, stronger is a winning combination. Naval materials research produces quieter submarines, fuel-efficient ships/vehicles and systems capable of operating under extreme temperature and chemical environments. New materials will result in warfighting advantages, as well as, systems that ensure environmental compliance, improved system reliability/resilience, stealthier materials, reduced manufacturing/maintenance and lower total ownership costs.</p> <p>The Materials/Processes activity generates fundamental scientific understanding for new, advanced and improved materials, and to accelerate materials-driven concepts essential to Naval superiority. The research is conducted in a cross-cutting and interdisciplinary manner covering Structural Materials, Functional Materials, Manufacturing, Chemistry and Undersea Materials to ensure future Naval power and maritime superiority.</p> <p>Fundamental challenges include understanding atomic-scale to meso-scale phenomena; developing robust, accurate and validated computational modeling and simulation capabilities; and translating this understanding into materials composition, synthesis, processing, properties and performance design principals for engineered devices, components and systems. This activity also includes peer-review basic research to develop innovative solutions and enhance the science and engineering base.</p> <p>Research directions in the Focus Area are selected to generate new, advanced and improved materials that enable innovative new technologies or can close critical technology gaps. Successes provide breakthroughs</p> | 58.436  | 56.427  | 57.519       | 0.000       | 57.519        |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

for higher performing, cost effective and/or timely technologies supporting Navy and Marine Corps acquisitions, operations and sustainment.  
Accomplishments and plans described below are examples for each effort category.

***FY 2021 Plans:***

**Structural Materials**

- Conduct basic research related to critical science and technology (S&T) of the composition-processing-structure-property relationships that define structural materials capabilities using and enabling an Integrated Computational Materials Engineering (ICME) approach to build, capture and exploit understanding of key materials systems including, but not limited to, the following: structural metals, polymer composite materials, solid mechanics, propulsion materials, and additive manufacturing.

**Functional Materials**

- Conduct basic research related to critical S&T for functional materials, including, but not limited to, the following: transduction materials, acoustic transduction science, and anti-fouling and fouling release coatings including investigation of effect of new polymers, materials, processes, and novel testing methodologies for coating efficacy for environmental quality control.

**Manufacturing**

- Conduct basic research related to critical S&T for manufacturing science to develop a fundamental understanding of the processes and materials to enable advances in manufacturing technology for naval systems.  
- Efforts include, but are not limited to, the following: multidisciplinary research task into furthering the sciences associated with advances in manufacturing processes, using Integrated Computational Materials Engineering (ICME) approach to develop new naval advanced manufactured (AM) alloys, determining the effects of alloy chemistry, AM parameters and post processing on mechanical and corrosion properties and developing new alloys for expeditionary AM use without post processing.

**Materials and Chemistry**

- Conduct efforts on: atomistic simulations of complex materials chemistry and solid state physics including characterization and control of dopants and defects at the single-atom-scale, 2D materials, heterostructure processing and properties; nanoscale design, synthesis, processing and characterization of functionalized particles, surfaces and solids; magnetoelectronics, spintronics, topological phases and two dimensional materials for low power, high speed microelectronics; surface chemistry for advanced catalytic functions

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**B. Accomplishments/Planned Programs (\$ in Millions)**

supporting advanced synthesis and processing, nanoscale driven reaction and transport mechanisms for power and energy, corrosion science and electrochemical current control; and direct control of a material's magnetic order through metamagnetic phase transitions to enable tunable, ultra-low power and high speed components for electronic and energy harvesting.

**Undersea Materials**

- Laboratory and theoretical/numerical studies focus on creating new techniques for understanding, predicting, and controlling the interactions between acoustic and elastic waves such as: underwater coupling architectures that achieve a broad range of acoustic impedances; the creation of high efficiency silicon based thin film thermoelectric modules for undersea warfare applications by exploiting nanocrystallization, multilayering to control thermal conductivity; and the creation of high performance transducer materials, such as textured ferroelectric ceramics, to achieve high power performance at reduced cost and complexity.

***FY 2022 Base Plans:***

**Structural Materials**

- Continue foundational research in basic materials science on metals, ceramics and composites advances in 2D and 3D materials imaging across spatial scales; multiphysics/multiscale modeling, model reduction strategies and machine learning techniques. This advances Integrated Computational Materials Engineering methods, accelerating materials and process design methods. Novel synthesis and processing routes are also being developed using new temperature, pressure, electromagnetic, aerosol deposition and additive manufacturing strategies. Progress in these areas will enable new high strength and corrosion resistant steel and compositionally complex alloys. Advanced nanoscale core-shell powders promise high temperature performance for hypersonic system components. New microscale composite architectures are pursued which efficiently dissipate energy to enable lighter weight blast, ballistic and impact protection for individuals and vehicles.

**Functional Materials**

- Conduct research on high speed energy efficient information processing by advances in magnetic, electronic and optical materials. Development of nanoscale control of two dimensional materials, interfaces, heterostructures, dopants and defects is used to demonstrate fundamental principles necessary for advanced Naval technologies. Key elements of these efforts are single atom control of multi-atom and quantum systems, fast phase transition materials, novel computational simulation strategies, quantum computing algorithms of material physics, machine learning and artificial intelligence for materials design. Advanced lithographic methods are used to experimentally fabricate and demonstrate novel device concepts and performance.

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**B. Accomplishments/Planned Programs (\$ in Millions)**

Progress enables advances in low Size-Weight-Power and Cost (SWAP-C) information processing for advanced magnetic, chemical, biological, radiological and explosive sensors, Naval edge computing and decision systems for autonomy, communications and networking, energy harvesting and photovoltaics.

**Manufacturing**

- Conduct basic manufacturing science research to develop a fundamental understanding of materials and processes necessary for emerging manufacturing technologies relevant to Navy systems. Results will advance Navy opportunities to design and produce validated and verified, low production volume replacement engineered parts for aircraft and ships; new gradient, composite and metamaterial architectures expanding design optimization space; and complex shapes enabling new conformal structural, acoustic and thermal component designs.

Efforts are structured around multidisciplinary research on new manufacturing processes, using Integrated Computational Materials Engineering (ICME) approaches and techniques, to advance materials and component production. This includes understanding and modeling key relationships between additive manufacturing alloy chemistry, microstructure, process parameters, part design, high quality properties and certification strategies while minimizing or eliminating the need for post processing.

**Materials and chemistry**

- Develop the scientific foundations for molecular-level understanding of materials synthesis, processing, and physical properties aimed at propelling, equipping and sustaining the US Navy and Marine Corps with tactical and strategic advantage. Nanoparticle surface chemistry for plasmonic mediated reactions, photocatalysis, hydrogen storage, energetic materials, and fuel additives enables new high power and energy density generation, storage, release and harvesting materials and technologies. These fuel generation, energetic, fuel cell and battery material will enable next generation Navy autonomous undersea and air vehicles. Research on combustion and reacting transport, coupled with advanced multiphysics computational simulation, will advance fire suppression for damage control as well as liquid and solid-fueled power and energy for hypersonics. Combinatorial and multivariate chemical approaches inform sensor system designs for aviation fuel surety and complex shipboard atmosphere environment monitoring. Advanced quantum computing simulations of quantum systems are modeling aqueous chemistries to allow design of anti-corrosion additives. Understanding fundamental electrochemistry, (tribo)corrosion, and biofouling will guide materials solutions for fleet sustainment through manpower and life-cycle cost reductions.

**Undersea Warfare**

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| <p>Progress enables advances in low Size-Weight-Power and Cost (SWAP-C) information processing for advanced magnetic, chemical, biological, radiological and explosive sensors, Naval edge computing and decision systems for autonomy, communications and networking, energy harvesting and photovoltaics.</p> <p><b>Manufacturing</b></p> <p>- Conduct basic manufacturing science research to develop a fundamental understanding of materials and processes necessary for emerging manufacturing technologies relevant to Navy systems. Results will advance Navy opportunities to design and produce validated and verified, low production volume replacement engineered parts for aircraft and ships; new gradient, composite and metamaterial architectures expanding design optimization space; and complex shapes enabling new conformal structural, acoustic and thermal component designs.</p> <p>Efforts are structured around multidisciplinary research on new manufacturing processes, using Integrated Computational Materials Engineering (ICME) approaches and techniques, to advance materials and component production. This includes understanding and modeling key relationships between additive manufacturing alloy chemistry, microstructure, process parameters, part design, high quality properties and certification strategies while minimizing or eliminating the need for post processing.</p> <p><b>Materials and chemistry</b></p> <p>- Develop the scientific foundations for molecular-level understanding of materials synthesis, processing, and physical properties aimed at propelling, equipping and sustaining the US Navy and Marine Corps with tactical and strategic advantage. Nanoparticle surface chemistry for plasmonic mediated reactions, photocatalysis, hydrogen storage, energetic materials, and fuel additives enables new high power and energy density generation, storage, release and harvesting materials and technologies. These fuel generation, energetic, fuel cell and battery material will enable next generation Navy autonomous undersea and air vehicles. Research on combustion and reacting transport, coupled with advanced multiphysics computational simulation, will advance fire suppression for damage control as well as liquid and solid-fueled power and energy for hypersonics. Combinatorial and multivariate chemical approaches inform sensor system designs for aviation fuel surety and complex shipboard atmosphere environment monitoring. Advanced quantum computing simulations of quantum systems are modeling aqueous chemistries to allow design of anti-corrosion additives. Understanding fundamental electrochemistry, (tribo)corrosion, and biofouling will guide materials solutions for fleet sustainment through manpower and life-cycle cost reductions.</p> <p><b>Undersea Warfare</b></p> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b> | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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- Conduct laboratory and theoretical/numerical work focusing on creation of new techniques for understanding, predicting, and controlling the interactions between acoustic and elastic waves and the processing routes for associated new materials. A key goal is advanced underwater material coupling architectures that achieve a broad range of passive and active acoustic impedances and control. Success will enable new material technologies and methodologies for achieving acoustic stealth. Creation of high performance source transducer materials, such as textured ferroelectric ceramics, should achieve high power receiver performance at reduced cost and complexity. This would enable high throughput production of high performance transducer ceramics, providing alternatives to current costly and difficult to produce single crystal technology. The creation of high efficiency silicon-based thin film thermoelectric modules for undersea warfare applications will also be pursued by exploiting nanocrystallization and multilayering to control thermal conductivity. This will enable solid-solid thermal management and new options for submarine and Underwater Unmanned Vehicle (UUV) power generation.

**FY 2022 OCO Plans:**  
N/A

**FY 2021 to FY 2022 Increase/Decrease Statement:**  
There is no significant change between FY 2021 and FY 2022.

|                                               |        |        |        |       |        |
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| <b>Title:</b> Medical and Biological Sciences | 19.707 | 19.521 | 15.997 | 0.000 | 15.997 |
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**Description:** The health and performance of Sailors and Marines is a top priority. Extensive research in the medical and biological sciences discover and leverage breakthroughs to improve Naval warfighter performance, so they can fight, win and come home safe. Sailors and Marines operate in the harshest working environments at sea and around the world. Conducting research to gain a better understanding of the biologic challenges of warfighters in their operating environments will ensure optimal performance, prevent injury, and equip the DON to provide the best care for its warfighters.

Research areas include: bio-inspired autonomous systems; bioengineering; biophysics; microbial synthetic biology; microelectronics; microbial electrophysiology; microbiome research; bio-inspired multi-spectral camouflage and sensing; sensory neuroscience and physiology; Naval force health protection; undersea medicine; health monitoring and modeling research; and health and welfare of the Navy's marine mammals.

**FY 2021 Plans:**  
Bio-Inspired Autonomous Systems

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Conduct discovery research on bio-inspired propulsion that enables stealthy propulsion and amphibious ability. Explore bio-inspired closed loop control with biosensor for obstacle avoidance, and high maneuverability. Explore schooling and swarming based on previously identified principles of bio sensing.</p> <p>Bioengineering and Life Sciences</p> <p>- Conduct development of nanometer-sized, 1-, 2-, and 3-dimensional DNA nanostructures with no undesired side products; a semiconductor chip-based device for massively parallel electronic detection of DNA sequences using reconfigurable DNA nanostructures as detectors; and DNA-based approaches for creating chemically-addressable systems with nm-scale precision over mm-scale ranges.</p> <p>- Extend exploring the influence of charge on the bonding of adhesive polymers, the delivery of adhesives underwater using a combination of oppositely charged polymers, and the generation of adhesives from biological polymers.</p> <p>- Carry on with discovery research on the mechanisms underlying the water-responsive behaviors of bacterial spores. Further explore silk-based biomaterials for energy harvesting and energy storage.</p> <p>- Move-Forward to combine machine learning with multiscale computational modeling to design biological composite materials with any optimized material functions.</p> <p>Naval Biosciences and Synthetic Biology for Naval Applications</p> <p>- Research directed toward engineering biological systems for microbial-based sensing, bio-electronics/ electronic materials, and microbiome strategies for warfighter augmentation. Efforts include: synthetic biology studies of electroactive microbial chassis to enable opto-electronic sensing, signaling and electronic materials; elucidating natural/engineered microbial mechanisms of biogenic mineral synthesis and sequestration (including rare-earth minerals); investing synthetic biology approaches for designing microbes/microbial communities to enhance warfighter resilience and sensory capabilities.</p> <p>Warfighter Augmentation</p> <p>- Conduct discovery research on bio-inspired mechanisms to develop multi-spectral camouflage technologies. Efforts include texture and shape modulation, color adaptation, near to far infrared concealment, and mechanisms for tunable regulation of multi-functional textiles.</p> <p>Sensory Neuroscience and Physiology</p> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022<br/>Base</b> | <b>FY 2022<br/>OCO</b> | <b>FY 2022<br/>Total</b> |
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| <p>- Investigate means for enhancing warfighter sensory perception, including exploration of neurological pathways of the auditory system. Advance strategies to improve sound localization, augment auditory function, and discover novel treatments for auditory injury mitigation and therapy.</p> <p>Physiological Monitoring and Modeling</p> <p>- Conduct discovery research on novel sensing capabilities and biomarkers for understanding individual biological functions. Further improve physiologic signal monitoring capabilities that exceed current capabilities. Explore innovative technologies for real-time sensing and observation of individual responses to environmental and operational stressors.</p> <p>Naval Force Health Protection</p> <p>- Conduct exploration of computational models and soft material properties to predict warfighter injuries. Results will guide future development of protective gear and casualty prevention strategies. Conduct discovery research on novel nanoscale therapeutics for treating expeditionary traumas. Explore autonomy as a means to prolonged casualty care and evacuation.</p> <p>Undersea Medicine</p> <p>- Further our understanding of human physiology in the extreme conditions experienced in the undersea environment and compare this to marine mammals, which have adapted to these conditions. Explore oxygen availability in the ocean for novel approaches to undersea life support. Transitioned pharmacological candidates to applied research efforts to validate efficacy and refine treatment protocol.</p> <p>Stress Response</p> <p>- Conduct discovery research on human performance in stressful or austere environments and on indicators (e.g. biomarkers) of human vulnerability and human resilience. Explore the effects of circadian rhythm disruption combined with chronic variable stress on the neuroimmunoendocrine stress axis.</p> <p><b><i>FY 2022 Base Plans:</i></b></p> <p>Bio-Inspired Autonomous Systems and Soft Robotics</p> <p>- Conduct basic research to explore novel bio-inspired sensing, control, and fluid dynamics of underwater propulsion and control systems to expand capabilities of underwater autonomous and unmanned systems. This research will include: (i) Exploration of experimental sensing capabilities and modeling for bio-sensing to enable sensorimotor control including fish schooling for passive swarm coordination in underwater vehicles; (ii) Exploration of bio-inspired locomotion from amphibious animals to enable technologies for amphibious and</p> |                |                |                         |                        |                          |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>cross-domain vehicles; (iii) Investigation of bio-inspired design principles of distributed sensing, actuation, and control in soft biological structures for underwater propulsion and manipulation; and (iv) Design bio-inspired soft robots (e.g. worm-like robots) to characterize and measure geotechnical properties of the ocean floor. The long-term result will be bio-inspired propulsion and control systems to enable high-lift, stealthy propulsion without propellers and achieve high maneuverability for underwater vehicles.</p> <p><b>Bioengineering and Life Sciences</b><br/>                     - Conduct basic research that explores manipulation of biologically-based material design, synthesis, and system assembly. The result of this research will be to discover novel methods and approaches to leverage synthetic biology (e.g., bioengineering and bionanotechnology) to enable material characterization, optimized biomimetic/bio-inspired underwater adhesives, fabricating complex, functional materials from living organisms (e.g., bacteria); endow living mammalian cells with computational capabilities (e.g., information storage), and energy harvesting, storage, conversion, and actuation.</p> <p><b>Naval Biosciences and Synthetic Biology for Naval Applications</b><br/>                     - Conduct basic research to investigate synthetic biology approaches to design microbes/microbial communities to enhance warfighter resilience (e.g., metabolic regulation, stress response, and preventing musculoskeletal injury), sensory capabilities (e.g., olfactory enhancement), and enabling novel technologies for warfighter tools such as electronic sensing, signaling, rapid environmental monitoring, energy harvesting/storage, and biogenic synthesis and sequestration of electronic materials (including rare-earth metals). The long-term goal of this research is to expand the natural capabilities of living organisms (e.g., microbes) to purpose-specific organisms for environmental sensing and monitoring; energy generation, information processing, and material harvesting (important for supply chain security).</p> <p><b>Warfighter Augmentation</b><br/>                     - Conduct basic research to investigate novel bio-inspired mechanisms for multi-spectral camouflage including adaptive texture/shape, color adaptation, and near- to mid- infrared concealment. The long-term result of this research will provide novel enabling materials to protect warfighters from detection in the field.</p> <p><b>Sensory Neuroscience and Physiology</b><br/>                     - Conduct basic research efforts to advance understanding of auditory processing. The long-term goal is to enhance communication, understanding, and mission success in noisy military environments.</p> <p><b>Physiological Monitoring and Modeling</b></p> |         |         |              |             |               |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Conduct basic research to discover novel sensing capabilities and biomarkers to improve warfighter performance including real-time sensing and monitoring of individual biological functions and physiological responses to environmental and operational stressors across domains and in extreme environments. The result of this research will be to improve sensing capabilities, enhance current signal monitoring capabilities, enable physiological monitoring to predict individual outcomes; discover methods and approaches in quantum biology to incorporate into physiological monitoring and modeling; and autonomously collect, distribute, and integrate information about human teams (including the individuals and environment). The long-term goal of this research will be to discover the next generation of sensing capabilities to collect, understand, distribute, and integrate real-time information on the biological / physiological / cognitive status of both individuals and teams for command and leadership situational awareness and action.</p> <p>Naval Force Health Protection</p> <p>- Conduct basic research to discover methods for: (i) Modeling and simulation approaches to improve Warfighter protection and injury treatment; (ii) Autonomy for medical care and logistics; (iii) Maritime casualty prevention; and (iv) Wearable technologies and protective equipment for maritime casualty prevention. The long-term goal of this research will be to integrate models of non-invasive sensors, biomarkers, simulations, and biophysical mechanisms to detect injury and identify preventive/mitigating mechanisms for safer protective equipment and vehicles. Investigate nanotechnologies, microelectronics, and autonomy for use in medical care of combat casualties to repair damage at the scale of cells, tissues, and whole body. Understand use of composite materials, additive manufacturing, and microelectronics to enhance warfighter protective equipment by providing increased biomedical sensing of warfighter status and greater operator situational awareness. The long-term goal of this research is to explore to optimize medical treatment, logistics, and casualty evacuation in the tactical environment.</p> <p>Undersea Medicine</p> <p>- Conduct basic research to identify novel technologies to improve performance of naval divers under extreme conditions (e.g, thermal, extended diving operations). The long-term goal of this research will provide understanding of human physiology (and leverage insights from comparative physiology studies of marine mammals) in extreme conditions experienced in the undersea environment; create synthetic biology approaches for thermal protection during dive operations; and identify novel technologies to support underwater breathing apparatus to include utilizing resources naturally present in the ocean for gas management (e.g., oxygen supply and carbon dioxide disposal). Another long-term goal of this research is to understand gas physiology of high partial pressures (e.g., oxygen, carbon dioxide and nitrogen to include metabolic dysfunction) and discover</p> |                |                |                     |                    |                      |



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**B. Accomplishments/Planned Programs (\$ in Millions)**

areas for naval forces in the open oceans, the Arctic, the littorals, and nearshore and river mouths and inlet environments; elucidating the coupling between oceanographic, geophysical and acoustical phenomena relevant to such mission areas such as Anti-Submarine Warfare and Mine Warfare; development of global, regional and local predictive models that fully couple the ocean-atmosphere-wave-ice domains; development and use of autonomous systems and sampling technologies for the collection of environmental observations and continuing support to research vessels of the U.S. Academic Research Fleet to enable at-sea oceanographic science.

Research within the Ocean Sciences subactivity responds to mission needs of the Navy and Marine Corps as guided by the Oceanographer of the Navy. At-sea research involves ancillary studies to ensure full compliance with environmental requirements.

***FY 2021 Plans:***

Physical Oceanography and Prediction

Areas of research include ocean circulation, thermodynamics and mixing, and the dynamics of surface gravity waves, nonlinear internal waves and the interaction of waves with sea ice in order to inform a basic understanding of sub-mesoscale physical oceanography parameters from the tropics to the poles. Sub-mesoscale understanding of the ocean is necessary to support the required fidelity and accuracy of ocean feature inputs to navy warfighting applications.

- The studies of monsoon intraseasonal variability and air-sea interaction in the Bay of Bengal in the Indian Ocean will complete in FY21.
- The three-dimensional Lagrangian ocean circulation and the prediction of vertical pathways in the ocean will continue its studies.
- The input and fate of near-initial shear and energy in the ocean via observational and predictive studies in the Greenland, Iceland, United Kingdom (GIUK) regions will continue its studies.
- The novel delivery systems of expeditionary ocean instrumentation to support targeted observing will continue its evaluation.
- The ocean fronts, eddies and turbulence; ocean thermodynamics including mixing and acoustic impacts; ocean boundary layer processes and surface gravity waves in sea ice and rogue waves will continue its studies.
- The study on the rapid evolution of the upper ocean in the high North Atlantic between Iceland and the European continent to better understand the physical processes that control vertical and horizontal density structures in the upper ocean will initiate in FY21.
- The seasonal variability of processes that control sea surface temperature in the Arabian Sea to understand the relevant space and time scales that will enable improved prediction of extended range ocean and weather

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**B. Accomplishments/Planned Programs (\$ in Millions)**

forecasts through the reduction of ocean temperature biases in coupled models will initiate a study to explore in FY21.

**Littoral Geosciences and Optics**

Areas of research include understanding processes and predicting the evolution of the highly nonlinear, coupled nearshore region in which mutual interactions of the atmosphere, sea surface, water column and seabed are all important.

- The modeling and field studies of high spatial and temporal resolution coastal land-air-sea interactions and their role in creating atmospheric electromagnetic ducting will initiate its fundamental theoretical in FY21. The objective is to resolve wind forcing in coastal areas in order to more accurately force coastal wave and current models and understand when ducting may occur in such land-air-sea configurations as nearshore mountains, estuaries and urban coastal environments.
- The rocky coasts which line a significant portion of the world's coastline but have been poorly studied will initiate the systematic studies in FY21.
- The autonomous, scalable, hydrographic charting and parameter sampling littoral studies using autonomous systems paired with remote sensing will initiate and distributed in FY21.
- The ocean phenomenologies that can be sensed via airborne and satellite active and passive microwave sensors, overhead optical sensors, and ship or shore-based grazing angle microwave sensors to enable surveillance of the entire battlespace environment will continue research in FY21.
- The sonar undersea remote sensing using autonomous underwater vehicles in conjunction with land, air and satellite remote sensing will continue its efforts in FY21. The objective is to both provide subsea interpretation of undersea dynamics from sonar remote sensing, and to provide the subsea structure of surface dynamics/ manifestations viewed from space.
- The predict physical, geological, geochemical, geoacoustic and geotechnical properties of the seafloor in shallow-water operating environments will continue its research in FY21.
- The field and modeling efforts to elucidate inner shelf dynamics will conclude in FY21.

**Marine Mammals and Biology**

Areas of research include monitoring and detection, integrated ecosystem, and effects of sound on marine mammals.

- Carry out multidisciplinary studies including tagging, visual surveys, and passive acoustics to study baseline measures of marine mammal behaviors and distributions relative to environmental features and marine mammal prey fields. Research on behavioral, physiological and population-level consequences of sound exposure on marine life.

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| <p>- Conduct physiological studies of diving in marine mammals. The objective is to understand the mechanisms that enable marine mammals to dive to deep depths for long durations while mitigating or avoiding health threats.</p> <p>- Extend to study the sound reception mechanisms in large whales through the exploration of the anatomy and sound propagation through various tissues. The objective is to estimate the hearing range of large whales with a particularly emphasis to identify the regions of greatest sensitivity.</p> <p>- Move forward to characterize the stress response in marine mammals to sound exposure and how it may affect animal health, fitness, and survival. Research objectives are to study the natural variation of stress markers, better understand and characterize the relationships among hormones or other biomarkers, and define and compare the quantitative and temporal relationships of hormones. Increased emphasis will be on studies to evaluate and characterize the relationship between the physiological stress response via hormones and biomarkers in marine mammal immune status, and animal health and biologically significant effects on individual fitness and survival.</p> <p>- Extend studies to develop statistical models of the population consequences of acoustic disturbance. The objective is to characterize the causal chain of events leading from sound exposure to biologically significant behavioral and physiological.</p> <p>- Conduct research to develop technologies to detect and classify marine mammals in the marine environment to provide marine mammal density and abundance estimates required for Navy sound effects modeling done under mandate of the federal Marine Mammal Protection Act (MMPA) and National Environmental Policy Act (ESA).</p> <p>Arctic Sciences<br/>Areas of research include the complex processes governing the interaction of the arctic atmosphere, ocean, and sea ice, including formation, deformation, and melting. Physical processes in the arctic environs are inherently different from those in non-polar regions.</p> <p>- Finished stratified ocean dynamics in the Arctic (SODA) research initiative to better understand the evolving oceanic structures and interaction of fresh and salt water in the high latitudes.</p> <p>- Ended the sea ice dynamics experiments (SIDEx) research initiative to better understand the impact of increasing open water on the formation, evolution and disintegration of the Arctic ice pack.</p> <p>- Extend Arctic fieldwork to characterize the behavior of sea ice, including melt and reformation, ice rheology and motion, and interactions with ocean stratification, surface waves, and the atmosphere.</p> <p>- Move forward the development of Arctic System models and data assimilation techniques for improved prediction and development of new sensors and unmanned platforms to collect observations of the Arctic environment, including development new algorithms to characterize sea ice from space-based remote sensing.</p> |                |                |                     |                    |                      |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>- Conduct the remote sensing of bulk properties of Arctic sea-ice over broad two-dimensional areas that previously could be sampled only by localized in-situ methods.</p> <p>Ocean Acoustics<br/>Areas of research contribute to improved basic understanding of the physical, seafloor and biological parameters that affect acoustic propagation in the ocean. Accurate acoustic predictions are required to keep our undersea assets undetected as well as to enable the detection and tracking of adversary assets.</p> <p>- Conduct research to understand propagation and scattering of acoustic energy in shallow-water ocean environments. Areas of research include shallow-water scattering mechanisms related to reverberation and clutter; seabed acoustic measurements supporting geoacoustic inversion; acoustic propagation through internal waves and coastal ocean processes and the development of unified ocean/seabed/acoustic models, including scattering from rough surfaces, biologics and bubbles; and penetration/propagation within the porous seafloor.</p> <p>- Extend the investigation in optimal representations information contained in acoustic data. Specific efforts will include the investigation summary statistics and sparse encoding of underwater acoustic data. The objective is to enable efficient analysis and compact representations of acoustic scenes.</p> <p>- Launch efforts in auralization applicable to the ocean battlespace. Specific efforts will include investigations into source separation, characterization, and recombination along with physical, biological, and anthropogenic sound generating mechanisms. An objective is to model and simulate acoustic phenomena in undersea environments to be rendered as virtual soundfields.</p> <p>- Conduct research into the effects of environmental variability induced by ocean internal waves, internal tides and mesoscale processes, and by bathymetric features including seamounts and ridges, on the stability, statistics, spatial distribution, and predictability of broadband acoustic signals. Also of interest is the coherence and depth dependence of deep-water ambient noise.</p> <p>- Carry out investigations into the effects of Arctic conditions on acoustic propagation and ambient noise, particularly in under-ice environments, as facilitated by an FY20 trans-arctic basin collection effort. Initiate analysis of data from the trans-arctic basin collection effort.</p> <p>- Launch the joint physical oceanography and acoustic field studies to investigate propagation and scattering in regions characterized by complex bathymetry and/or meteorological and oceanographic forcing. Specific efforts will include processes studies with the objective of linking observed ocean and acoustic phenomena. An objective is to characterize oceanographic phenomena and the effects on acoustic propagation and scattering at different frequencies.</p> <p>- Begin the efforts in characterizing and forecasting sediment acoustic properties. Specific efforts will include investigations aimed at linking local physical and biological processes to acoustic observables. Continue analysis efforts related to acoustic seabed characterization experiment. Specific efforts will include development</p> |                |                |                     |                    |                      |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>and verification of geoacoustic models and inference techniques for soft sediments based on experimental evidence.</p> <p><b>Battlespace Environments</b></p> <p>- This research is to improve basic understanding of physical, seafloor and biological oceanographic processes on space and time scales of naval interest. Emphasis is on improved measurements, laboratory and model based experiments to quantify and understand important oceanographic processes that lead to the development of ocean dynamic/thermodynamic models from global to sub-mesoscale scales, and to couple these oceanographic models with atmospheric, ice, biological, sediment response, and optical models. While today's numerical analysis and prediction systems are more capable of resolving and predicting highly variable phenomena than were the systems of 10-20 years ago, there are still oceanographic processes that are not well understood and must be studied including aspects of ocean circulation (fronts, eddies and turbulence), thermodynamics (mixing and acoustic impacts), waves (including their impact on sea ice and rogue waves), sea ice (including landfast ice) as well as ocean boundary layer processes. Navy and Marine Corps requirements also include: a) an improved use of overhead (airborne and satellite) active and passive microwave sensors, overhead optical sensors, surface-based (ships and ground-based) grazing angle microwave sensor, b) use of remote sensing of bulk properties of Arctic sea-ice over broad two-dimensional areas that previously could be sampled only at spot locations by in-situ sampling, and c) use of newly available higher resolution (sub-mesoscale) oceanographic data.</p> <p><b>FY 2022 Base Plans:</b></p> <p>Littoral Geosciences and Optics</p> <p>Areas of research include the highly nonlinear and coupling between atmospheric phenomena and surface gravity and internal waves; the transport of sediment by waves and currents; and the bathymetric evolution of the nearshore and coastal environment. Field, modeling, experimental and remote sensing studies are all used.</p> <ul style="list-style-type: none"> <li>- Continue modeling and field studies of high spatial and temporal resolution coastal land-air-sea interactions and their role in creating atmospheric electromagnetic ducting.</li> <li>- Continue studies of surface gravity waves, currents, tides and internal wave processes along rocky coastlines.</li> <li>- Continue autonomous, scalable, hydrographic charting and coastal parameter sampling studies with concomitant remote sensing for data-assimilative coastal models.</li> <li>- Continue research using airborne and satellite active and passive microwave sensors, overhead optical sensors, and ship or shore-based radars to observe coastal and nearshore phenomena.</li> <li>- Continue field studies of coastal oceanographic phenomena using sonar-equipped autonomous underwater vehicles in conjunction with ground-based, airborne and satellite remote sensing.</li> </ul> |                |                |                     |                    |                      |

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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Continue research to predict physical, geological, geochemical, geoacoustic and geotechnical properties of the seafloor in shallow-water coastal environments.</p> <p>Physical Oceanography and Prediction<br/>                     Areas of research include ocean circulation, thermodynamics and mixing, and the dynamics of surface gravity waves, nonlinear internal waves and the interaction of waves with sea ice in order to understand the sub-mesoscale physical oceanography parameters from the tropics to the poles. Sub-mesoscale understanding of the ocean is necessary to support the required fidelity and accuracy of ocean feature inputs to Naval warfighting applications.</p> <ul style="list-style-type: none"> <li>- Complete study of sources and sinks of near-inertial shear and energy in the ocean in the Greenland, Iceland, United Kingdom (GIUK) region.</li> <li>- Continue study of three-dimensional Lagrangian ocean circulation and the prediction of vertical pathways in field experiments in the Mediterranean Sea.</li> <li>- Continue exploration of novel expeditionary ocean instrumentation to support targeted observing.</li> <li>- Continue study of ocean fronts, eddies and turbulence; ocean thermodynamics including mixing and acoustic impacts; and ocean boundary layer processes and surface gravity waves.</li> <li>- Continue study of the rapid evolution of the upper ocean in the high North Atlantic between Iceland and the European continent to understand the physical processes that control vertical and horizontal density structures in the upper ocean.</li> <li>- Continue study of the seasonal variability of processes that control sea surface temperature in the Arabian Sea to understand the relevant space and time scales that enable improved ocean and weather forecasts through the reduction of ocean temperature biases in coupled models.</li> <li>- Initiate studies to explore the cascade of energy in the sub-mesoscale ocean, including the physics and dynamics of ocean features such as current meanders, vortices, and filaments, with a field program in the Western Pacific, to expand the knowledge of the lifecycle of these features and enable improved predictions.</li> </ul> <p>Arctic Sciences<br/>                     Areas of research include the complex processes governing the interaction of the arctic atmosphere, ocean, and sea ice, including formation, deformation, and melting. Physical processes in the arctic are inherently different from those in non-polar regions.</p> <ul style="list-style-type: none"> <li>- Continue studies to characterize the behavior of sea ice, including melt and reformation, ice rheology and motion, and interactions with ocean stratification, surface waves and the atmosphere.</li> </ul> |         |         |              |             |               |

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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Continue development of Arctic System models and data assimilation techniques for improved prediction of the Arctic region and development of new sensors and unmanned platforms to collect observations of the Arctic environment.</p> <p>- Continue development of algorithms enabling the space-based remote sensing of bulk properties of Arctic sea-ice that previously could be sampled only by localized in-situ methods.</p> <p>- Initiate studies of the circulation of the Arctic Ocean to explore the fate of heat flowing in through the Bering Strait and the impact on the upper ocean density structure of the Beaufort Sea.</p> <p>Ocean Acoustics<br/>Areas of research contribute to the understanding of the oceanographic parameter, including physical, seafloor and biological, that impact acoustic propagation and scattering in the ocean. Accurate acoustic predictions are required to keep our undersea assets undetected as well as to enable the detection and tracking of adversary assets.</p> <p>- Continue research to understand propagation and scattering of acoustic energy in shallow-water ocean environments, including shallow-water scattering mechanisms; seabed acoustical measurements for geophysical properties; acoustic propagation through internal waves and the development of unified ocean/seabed/acoustical models.</p> <p>- Continue investigation of optimal representation of information contained in acoustic data and the sparse encoding of underwater acoustic data to enable efficient analysis and compact representation of acoustic scenes.</p> <p>- Continue research on auralization to understand the full spectrum of physical, biological and anthropogenic sources of sound in the ocean environment, and to enable modeling and simulation of virtual undersea soundfields.</p> <p>- Complete research on the stability, statistics, spatial distribution, and predictability of broadband acoustic signals in the vicinity of seamounts, ridges and other bathymetric features.</p> <p>- Continue investigation of acoustic propagation and ambient noise in the Arctic conditions, particularly in under-ice environments, using data from a trans-Arctic basin experiment.</p> <p>- Continue joint physical oceanography and acoustic field studies to investigate the propagation and scattering in regions characterized by complex bathymetry and/or meteorological and oceanographic forcing. Specific efforts will include processes studies with the objective of linking observed ocean and acoustic phenomena over multiple temporal and spatial scales.</p> <p>- Continue studies to acoustically characterize and forecast seabed properties, including development and verification of geoacoustic models and inference techniques for soft sediment properties derived from experiments.</p> |         |         |              |             |               |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Initiate a joint acoustics and oceanographic experiment to infer full water column and seabed waveguide geoacoustic parameters in a dynamic ocean.</p> <p>Marine Mammals<br/>Areas of research include monitoring and detection, integrated ecosystem, and effects of sound on marine mammals.</p> <ul style="list-style-type: none"> <li>- Continue development and testing of new and existing technologies to detect, classify, localize and potentially track marine mammals.</li> <li>- Continue multidisciplinary ecosystem research including tagging, visual surveys, and passive acoustics to collect baseline measures of marine mammal behaviors and distributions relative to environmental features and marine mammal prey fields.</li> <li>- Continue research on sound reception mechanisms in large whales.</li> <li>- Continue research on the effects of sound include behavioral, physiological and population-level consequences of sound exposure on marine life.</li> <li>- Continue studies to characterize and quantify the cumulative effects of multiple stressors on marine mammal populations.</li> </ul> <p>Battlespace Environments</p> <ul style="list-style-type: none"> <li>- Continue research is to improve basic understanding of physical, seafloor and biological oceanographic processes on space and time scales of naval interest. Emphasis is on improved measurements, laboratory and model based experiments to quantify and understand important oceanographic processes that lead to the development of ocean dynamic/thermodynamic models from global to sub-mesoscale scales, and to couple these oceanographic models with atmospheric, ice, biological, sediment response, and optical models. While today's numerical analysis and prediction systems are more capable of resolving and predicting highly variable phenomena than were the systems of 10-20 years ago, there are still oceanographic processes that are not well understood and must be studied including aspects of ocean circulation (fronts, eddies and turbulence), thermodynamics (mixing and acoustic impacts), waves (including their impact on sea ice and rogue waves), sea ice (including landfast ice) as well as ocean boundary layer processes. Navy and Marine Corps requirements also include: a) an improved use of overhead (airborne and satellite) active and passive microwave sensors, overhead optical sensors, surface-based (ships and ground-based) grazing angle microwave sensor, b) use of remote sensing of bulk properties of Arctic sea-ice over broad two-dimensional areas that previously could</li> </ul> |         |         |              |             |               |

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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b> | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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be sampled only at spot locations by in-situ sampling, and c) use of newly available higher resolution (sub-mesoscale) oceanographic data.

**FY 2022 OCO Plans:**  
N/A

**FY 2021 to FY 2022 Increase/Decrease Statement:**  
There is no significant funding change from FY 2021 to FY 2022.

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| <b>Title:</b> Science and Engineering Education, Career Development and Outreach | 49.014 | 42.489 | 44.948 | 0.000 | 44.948 |
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**Description:** Science and Engineering Education, Career Development and Outreach activity addresses the critical need to maintain maritime superiority that requires a highly skilled technical naval workforce. These efforts inspire, engage, educate and attract participants to pursue naval careers and build the extra-mural performer base community. Department of Navy Science, Technology, Engineering and Math (STEM) education and outreach is designed to increase the number of students and naval civilians with naval-relevant skills and degrees, expand capabilities of the current and future workforce by developing curricula and augmenting education, and augment awareness of Naval opportunities through localized education and outreach initiatives that foster a talent pipeline. The Naval Research Institution was established through a Memorandum of Understanding between the United States Naval Academy (USNA) and the Office of Naval Research. This effort contributes to the technical education of midshipmen by providing a research experience in STEM and its impact on fleet and forces capabilities.

The separately-managed Department of the Navy's (DON) Historically Black Colleges and Universities/Minority Institutions (HBCU/MI) program oversees the Navy's efforts to engage and support research in our nation's HBCU/MIs and is responsible for developing and managing efforts that strengthen and support the capabilities of HBCU/MIs to participate in basic, applied, and advanced development research programs within the Naval Research Enterprise (NRE).

The ONR Young Investigator Program (YIP) attracts outstanding faculty members to the Department of Navy's basic research program by identifying individuals that show exceptional promise for doing creative research and encourage their teaching and research careers through long term support. Young Investigator awards are for a period of three years. Annual request for proposals are solicited via a funding opportunity announcement and is open to tenure-track faculty in science, engineering, and mathematics. Topics are competitively selected based on faculty achievements, technical proposal, benefit to the Navy and Marine Corps, and institution support.

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>Funding also supports the Office of Naval Research (ONR) Global mission to serve as the enduring Navy and Marine Corps global presence in technical and operational communities, investing in trusted partnerships to discover and connect science and technology leaders for sustained maritime security. This is accomplished by establishing quality, relevant connections between the international research and development community, Naval fleet/forces, Department of Defense (DOD), other US Government agencies and international partners. The direct impact of this investment is to leverage international basic research during increasingly dynamic global interdependence and improve the ability to solve DON Science &amp; Technology challenges through shared knowledge with partners.</p> <p><b>FY 2021 Plans:</b><br/>Support Science, Technology, Education and Mathematics (STEM) initiatives and multi-year efforts that are intended to be approximately three years in length and in topics supporting STEM education relevant to naval science and technology workforce development. Start development of pilot efforts to improve STEM through the development of new curricula and experiential learning activities that respond to new naval Science and Technology personnel and knowledge needs. Expand existing successes to scale working projects and achieve greater impact and implementation of funded efforts. Support new activities to targeting regional efforts to drive greater impact on educational systems and increase workforce opportunity for the naval Science and Technology community. Continue coordination of Department of the Navy (DON) STEM efforts.</p> <p>This effort will continue to support programs that provide hands-on research experiences in STEM fields for United States Naval Academy (USNA) midshipmen and faculty members to enhance the midshipmen's educational environment at the USNA.</p> <p>Young Investigator Program (YIP)<br/>Each year, 25 to 35 individuals that show exceptional promise for performing creative research receive YIP awards. Topics are competitively selected based on faculty achievements, technical proposal, benefit to the Navy and Marine Corps, and institution support. Ongoing efforts cover a wide range of topics of naval S&amp;T interest. Recent topics include innovative technical approaches to: vortex flow in hypersonic aerodynamics; real-time accurate positioning in robotics, acoustic meta-materials for marine surfaces, cyclone intensity forecasting, advanced mathematical optimization for statistical applications, cephalopod inspired camouflage, digitization of human performance, soil characterization capability from remote sensing, thermal transport at solid-solid interfaces, and high-temperature multi-principal alloys. These and other research topics will benefit today's and the next generation warfighter by improving lethality, survivability, communications, and training.</p> |         |         |                 |                |                  |

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**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>Additionally, many of these investigators will provide long-term support and knowledge in solving naval related S&amp;T challenges. Complete Young Investigator Program projects initiated in fiscal year 2019.</p> <p>ONR Global will continue to foster collaboration with international organizations and researchers by awarding grants in innovative basic research to discover, access and assess revolutionary, high-payoff technologies for future Naval missions and capabilities.</p> <p>SCHOOLHOUSE TRAINING: Research efforts include: (i) Developing optimized training and retention models; (ii) Designing better training schedules; and (iii) Developing skill tutors for maintenance tasks.</p> <p>The Naval Enterprise Partnership Teaming will continue with the Universities for National Entrepreneurship (NEPTUNE) program to promote and sponsor Naval Postgraduate School personnel to conduct research in the areas of Navy Energy Education &amp; Training and course curriculum development for NPS energy-related courses for energy security and energy resiliency. Additionally, the US Naval Academy (USNA) will perform research on the combustion chemistry of Navy engines and other energy-related areas. Conduct discovery research to develop simulators for teaching dynamic tasks using new cognitive models. Develop artificial intelligence-based tutors to teach transfer across military career ratings.</p> <p>Historically Black Colleges and Universities / Minority Institutions (HBCU/MI)<br/>Expand the opportunities for HBCU/MI's faculty and student to participate in fellowships and internships at warfare centers and labs thereby increasing the number of STEM and Defense-related research. Develop new outreach plans to increase the number of HBCU/MI white paper and grant proposal submissions. Establish a HBCU/MI Post-doctoral program that supports the efforts of increasing the number of HBCU/MI students working within the Navy STEM related fields. Increase the number of science fairs at HBCU/MI that have partnerships with local schools.</p> <p><b>FY 2022 Base Plans:</b><br/>Conduct Science, Technology, Education and Mathematics (STEM) initiatives to foster and cultivate a diverse, world-class STEM workforce in order to maintain the U.S. Navy and Marine Corps' technological superiority.<br/>- Continue existing successful efforts, while examining approaches to further scale up these efforts to achieve greater impact across the Department Of the Navy (DON).<br/>- Continue transparent and accountable coordination of DON STEM efforts aligned with the DON STEM strategy.</p> |         |         |                 |                |                  |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>- Continue activities targeting regional efforts to augment awareness of naval opportunities and increase diverse workforce opportunity for the naval science and technology community.</p> <p>- Continue to support programs that provide hands-on and virtual research experiences in STEM fields for United States Naval Academy (USNA) midshipmen and faculty members to enhance the midshipmen's educational environment at the USNA.</p> <p>- Initiate the development of highly scalable pilot efforts to expand STEM education and outreach through the development of new virtual and in-person curricula as well as virtual and in-person experiential learning activities.</p> <p>- Initiate new outreach and communication approaches to significantly broaden and increase awareness of naval STEM opportunities and careers.</p> <p>Naval Enterprise Partnership Teaming with Universities for National Entrepreneurship (NEPTUNE) program:</p> <p>- Continue to sponsor Naval educational institutes (e.g. Naval Postgraduate School) to conduct research that provides Navy Energy Education &amp; Training for students and promotes the use of entrepreneurial practices to accelerate the delivery of technologies to the warfighter.</p> <p>Historically Black Colleges and Universities / Minority Institutions (HBCU/MI):</p> <p>- Continue to provide robust research opportunities, such as faculty fellowships and student internships that address critical Naval S&amp;T challenges through collaborations with Naval scientists, engineers and academic researchers. Through the coordination of symbiotic engagements between Naval researchers, industry partners and minority serving institutions to advance Naval-relevant research, this program cultivates long-term partnerships that leverage knowledge sharing and empower scientific global discovery.</p> <p>- Develop new outreach plans to increase the number of HBCU/MI white paper and grant proposal submissions. Establish a HBCU/MI Post-doctoral program that supports the efforts of increasing the number of HBCU/MI students working within the Navy STEM related fields.</p> <p>- Increase the number of science fairs at HBCU/MI that have partnerships with local schools.</p> <p>Young Investigator Program (YIP):</p> <p>- Continue YIP awards to 25 to 35 assistant professors that show exceptional promise for performing creative research. Topics are competitively selected based on faculty achievements, technical proposal, benefit to the Navy and Marine Corps, and institution support. Ongoing efforts cover a wide range of topics of Naval S&amp;T interest. Recent topics include innovative technical approaches to: next generation wireless technology, symbolic deep learning, safe autonomous navigation, artificial intelligence in weather prediction, underwater artificial gills, scalable Ytterbium tweezer arrays, high-speed liquid-fueled combustion, remote sensing and</p> |                |                |                     |                    |                      |

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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b> | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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forecasting in coastal environments, multi-frequency high-power microwave, van der Waals metamaterials, heat transfer in nanomaterials, 3-D accelerated tissue repair, and automated machine intelligence. These and other research topics will benefit today's and the next generation warfighter by improving lethality, survivability, and communications. Additionally, many of these investigators will provide long-term support and knowledge in solving Naval related S&T challenges.

- Complete Young Investigator Program projects initiated in fiscal year 2020.

ONR Global

- Continue international outreach efforts to foster collaboration through PhD-level scientists located in Asia, Europe, South America and Australia, providing coverage in these regions by awarding grants in innovative basic research to discover, access and assess revolutionary, high-payoff technologies for future Naval missions and capabilities.

**FY 2022 OCO Plans:**  
N/A

**FY 2021 to FY 2022 Increase/Decrease Statement:**  
The increase from FY 2021 to FY 2022 is due to increased investment in STEM outreach through virtual platforms and learning activities.

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| <b>Title:</b> Sensors, Electronics and Electronic Warfare (EW) | 48.604 | 52.527 | 53.650 | 0.000 | 53.650 |
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**Description:** Basic research efforts directed toward increasing knowledge, components and algorithmic advances for electronics, sensing and EW ensuring the Navy can counter current and future threats. These efforts are applicable to sensing and EW on individual Naval platforms, as well as, efforts that aggregate capabilities in a Distributed Maritime Operation.

The efforts research focus include: sensing, diagnostics, and detectors; navigation and timekeeping; nanoelectronics; wide band gap power devices; real-time targeting; Electro-Optical/Infra-Red (EO/IR) electronics; EO/IR electronic warfare; EO/IR sensors for surface/aerospace surveillance; Radio Frequency (RF) sensors for surface/aerospace surveillance; solid state electronics; vacuum electronics; and RF electronic warfare.

**FY 2021 Plans:**  
Sensors, Electronics and Electronic Warfare (SEEW)

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <p>- Conduct basic research in the areas of solid state transistors and devices for high frequency analog and digital operation; high efficiency, highly linear amplifiers for microwave, millimeter-wave, low-noise, and power applications; superconducting and other technologies which are designed to deliver software defined, wide band, simultaneous signal functionality for conventional system contexts, including, but not limited to, satellite communications (SATCOM), Surveillance, Electronic Warfare (EW), signal intelligence (SIGINT), and communications; electronics and photonics technology that provides for the control, reception, transmission and processing of signals.</p> <p>- Continue work on single photon emission in solid state materials and approaches to manipulate emitter properties through structured materials.</p> <p>- The novel techniques for the cooling and trapping of atoms and molecules. Continue the development of protocols for sensing and timekeeping devices based on quantum systems, including clocks with improved short and long term performance and electromagnetic field sensors will continue basic research in FY21.</p> <p>- The development of inertial and gravity sensors based on light-atom interferometry will continue in FY21.</p> <p>Electronics</p> <p>- Create new theories and explore new concepts, components, techniques and methods, for the design, growth, and characterization of electronic, electromagnetic, quantum phenomenology, and electro-optical materials, fabrication processes, electronic and electro-optic components, including novel electromagnetic concepts and techniques, and plasma phenomena and theory.</p> <p>- Develop a understanding for quantum computing algorithms and their use to create new understanding of materials by design, process optimization, and quantum simulation.</p> <p>Electromagnetic Warfare</p> <p>The projects in this area conduct basic research efforts with the overarching objective to establish the mathematical constructs, techniques, computational procedures, and scientific foundations the for analysis/ design of signal, image, control, and data generating systems for use in Navy, other DOD, dual-use, or commercial development programs. Each project has defined objectives within the contexts of the Naval Research Enterprise Research and Development Strategic Framework and Marine Corps S&amp;T Strategic Plan. These efforts include:</p> <p>- Develop ultrafast, efficient, and accurate time domain (TD) algorithms to predict the ultra-wideband radar cross-section (RCS) of complex naval platforms by solving the long-standing late-time instability problem;</p> <p>- Investigating mathematical, statistical and algorithmic issues associated with performing robust and adaptive detection and discrimination of targets when sensed by multiple, resource-constrained, unmanned vehicle sensors operating in a decentralized fashion and in highly cluttered environments.</p> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

**B. Accomplishments/Planned Programs (\$ in Millions)**

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| <ul style="list-style-type: none"> <li>- Conducting research to establish basic feasibility of novel emerging non-linearized imaging and feature extraction techniques with respect to existing and/or realistic multi-static sensing geometries, research to utilize and enhance the understanding and applicability of topological techniques to enable improved capabilities for target detection, object identification, and data fusion.</li> <li>- Carrying out research to enable the imaging of self-illuminating thermal objects occluded by walls by sensing non-specular reflections from rough surfaces such as open doors and around corners to allow for asymmetric warfare through image recovery in previously denied conditions.</li> <li>- Engage in research to develop advanced multi-dimensional Convolutional Neural Network approaches and algorithms to investigate and demonstrate improved means of analyzing high-dimensional data resulting in improved results for classification, segmentation, anomaly/ target detection.</li> </ul> <p>Materials and Chemistry</p> <ul style="list-style-type: none"> <li>- Design novel experiments and theoretical models to create advanced or improved materials using new concepts and techniques for applications and sensors and advanced electronics.</li> <li>- Improve target identification algorithms utilizing nonlinear dynamics. Understand and demonstrate the principles and mechanisms of DNA-based molecular-scale machines to amplify detection of biochemical agents.</li> <li>- Fabricate single atomic layer of materials to create 2-dimensional ferromagnets and semiconductors. The material of choice will be single layer MoS2 for utilization as indirect gap semiconductors.</li> <li>- Conduct unique single stage accelerator mass spectrometer to evaluate the fine scale detection limits of fusion products and isotopes.</li> <li>- Recognize the protein-surface interactions leading highly sensitive biosensors.</li> <li>- Develop principle theoretical models to understand the principles governing the interactions between surfaces and small molecules. Prior studies in these areas have demonstrated success in designing biological and chemical sensors with parts per trillion sensitivity as well as understanding of electronic mobility of graphene due to the effects of edge and defects.</li> </ul> <p>Undersea Warfare</p> <p>Efforts include research in Laboratory, field, and theoretical/numerical studies to investigate physical phenomenon related to acoustic propagation and scattering in oceanic environments such as:</p> <ul style="list-style-type: none"> <li>- Prediction of the scattering signature of a structure using noise sources of opportunity.</li> <li>- Fundamental physical phenomena of wave propagation in ocean environments.</li> <li>- Develop approaches to separate an acoustical field from turbulent flow on an acoustic array.</li> <li>- Create new structural acoustics theory for scattering from large, complex undersea objects.</li> </ul> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>- Develop new approaches to monitoring the acoustic signature and structural state of undersea vessels.</p> <p><b>FY 2022 Base Plans:</b><br/>                     Electronics:<br/>                     Continue to create new knowledge and understanding and explore new concepts, components, techniques and methods, for the design, growth, and characterization of electronic, electromagnetic, quantum phenomenology, and electro-optical materials, fabrication processes, electronic and electro-optic components, including novel electromagnetic concepts and techniques, and plasma phenomena and theory.</p> <ul style="list-style-type: none"> <li>- Continue efforts in nitrogen-polar GaN materials and device development.</li> <li>- Continue efforts in superconducting GaN materials and device development.</li> <li>- Continue efforts in plasmonic photomixer devices and circuits.</li> <li>- Continue effort to use generative neural networks to design topology-optimized metasurfaces and apply results to generate dual-level short-wave infrared antireflective coatings.</li> <li>- Continue efforts to develop novel materials for linear, low-power, broadband switches, including phase-change materials such as GeTe, as well as two-dimensional hexagonal boron nitride.</li> <li>- Continue to utilize the unique quantum properties of superconductors and photonics to deliver new devices and integrated circuits, which enable real time, software defined, wide band, and simultaneous signal, receive functionality.</li> <li>- Continue to investigate how to realize increased receiver dynamic range over entire DC to 200 GHz spectrum. Stimulate demonstrations of increasingly complete receive capabilities. These systems will be applicable to all the RF applications while being most important to Surveillance, Electronic Warfare (EW), signal intelligence (SIGINT).</li> <li>- Continue work on squeezed lasers, optical cooling, and new superconducting sensors of magnetic field sources, even if cloaked.</li> <li>- Initiate work on quantum entanglement and measurement as applied to RF signal analysis.</li> <li>- Initiate device reliability studies of nitrogen-polar GaN devices.</li> <li>- Initiate studies on superconducting GaN functional circuits.</li> <li>- Initiate efforts to create new knowledge and understanding for quantum computing algorithms and their use to create new understanding of materials by design, process optimization, and quantum simulation.</li> </ul> <p>Quantum Information Sciences:</p> <ul style="list-style-type: none"> <li>- Continue the development of protocols for sensing and timekeeping devices based on quantum systems, including clocks with improved short and long-term performance and electromagnetic field sensors.</li> <li>- Continue the development of inertial and gravity sensors based on light-atom interferometry.</li> </ul> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022<br/>Base</b> | <b>FY 2022<br/>OCO</b> | <b>FY 2022<br/>Total</b> |
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| <p>Electromagnetic Warfare:</p> <p>Continue research efforts with the overarching objective of establishing the mathematical constructs, techniques, computational procedures, and scientific foundations for analysis/design of signal, image, control, and data generating systems for use in Navy, other DoD, dual-use, or commercial development programs. Each project has defined objectives within the contexts of the Naval Research Enterprise Research and Development Strategic Framework and Marine Corps S&amp;T Strategic Plan.</p> <ul style="list-style-type: none"> <li>- Continue developing ultrafast, efficient, and accurate time domain (TD) algorithms to predict the ultra-wideband radar cross-section (RCS) of complex naval platforms by solving the long-standing late-time instability problem.</li> <li>- Continue investigating mathematical, statistical and algorithmic issues associated with performing robust and adaptive detection and discrimination of targets when sensed by multiple, resource-constrained, unmanned vehicle sensors operating in a decentralized fashion and in highly cluttered environments.</li> <li>- Continue research to establish basic feasibility of novel emerging non-linearized imaging and feature extraction techniques with respect to existing and/or realistic multi-static sensing geometries, research to utilize and enhance the understanding and applicability of topological techniques to enable improved capabilities for target detection, object identification, and data fusion.</li> <li>- Continue research to enable the imaging of self-illuminating thermal objects occluded by walls by sensing non-specular reflections from rough surfaces such as open doors and around corners, to allow for asymmetric warfare through image recovery in previously denied conditions.</li> <li>- Continue research to develop advanced multi-dimensional Convolutional Neural Network approaches and algorithms to investigate and demonstrate improved means of analyzing high-dimensional data resulting in improved results for classification, segmentation, anomaly/ target detection.</li> </ul> <p>Materials and Chemistry:</p> <ul style="list-style-type: none"> <li>- Continue to design novel experiments and robust theoretical models necessary to enable new warfighter capabilities through advanced sensors and electronics.</li> <li>- Complete target identification algorithms utilizing nonlinear dynamics.</li> <li>- Understand and demonstrate the principles and mechanisms of DNA-based molecular-scale machines to amplify detection of biochemical agents.</li> <li>- Complete the fabrication of single atomic layer of materials to create 2-dimensional ferromagnets and semiconductors. The material of choice will be single layer MoS2 for utilization as indirect gap semiconductors.</li> <li>- Complete research on unique single stage accelerator mass spectrometer to evaluate the fine scale detection limits of fusion products and isotopes.</li> <li>- Complete research to recognize the protein-surface interactions leading to highly sensitive biosensors.</li> </ul> |                |                |                         |                        |                          |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>- Complete the development of principle theoretical models to understand the principles governing the interactions between surfaces and small molecules. Prior studies in these areas have demonstrated success in designing biological and chemical sensors with parts per trillion sensitivity as well as understanding of electronic mobility of graphene due to the effects of edge and defects.</p> <p>- Initiate the design and fabrication of single-monolayer or low-dimensional materials with unique and useful fundamental properties distinct from bulk materials, e.g. ferromagnets and semiconductors, capable of being functionalized for high performing sensors, computer memory elements or electronic components.</p> <p>- Initiate the use of precision molecular placement and orientation to design and create bio-inspired materials exploiting quantum phenomena to perform functions such as ultrasensitive photon detectors and energy generation</p> <p>- Initiate highly sensitive measurement and modeling techniques to design, detect, diagnose and/or quantify physical, chemical and biological processes and properties affected by trace impurities, subtle composition changes and chemical species with high spatial resolution, sensitivity, and precision.</p> <p><b>Undersea Warfare:</b></p> <p>- Continue to conduct laboratory, field, and theoretical/numerical studies to investigate physical phenomena related to acoustic propagation and scattering in oceanic environments such as: prediction of the scattering signature of a structure using noise sources of opportunity; fundamental physical phenomena of wave propagation in ocean environments; approaches to separate an acoustical field from turbulent flow on an acoustic array; new structural acoustics theory for scattering from large, complex undersea objects; and creation of new approaches to monitoring the acoustic signature and structural state of undersea vessels.</p> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>The funding increase from FY 2021 to FY 2022 is due to an increase in advanced electronics projects; primarily in quantum-based components and technologies as well as Electro-optics/Infrared (EO/IR) components and technologies.</p> |                |                |                     |                    |                      |
| <p><b>Title:</b> Weapons</p> <p><b>Description:</b> Naval S&amp;T discovers, develops and delivers decisive naval capabilities. Superior defense deters aggression, but when called upon, enables naval forces to fight, win and come home safe. This Program focuses on a number of fundamental scientific areas aimed at expanding the underlying understanding of disciplines that are broadly useful for a wide range of naval weapon applications. Research into emerging technologies</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 23.401         | 25.379         | 27.535              | 0.000              | 27.535               |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy | <b>Date:</b> May 2021 |
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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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**B. Accomplishments/Planned Programs (\$ in Millions)**

like directed energy explore the scientific limitations of laser technology for utilization in maritime environments. Continued research in hypersonics will address unique challenges like extreme temperatures and air flow. Ultimately, naval S&T strives to ensure that no Sailor or Marine will ever be in a fair fight.

The efforts research focus includes undersea weaponry; air weaponry; energetic materials and solid rocket propulsion; directed energy and counter directed energy; and hypersonic aerodynamics and materials. This activity includes peer-review basic research to develop fundamental knowledge and enhance the science and engineering workforce and technology base.

***FY 2021 Plans:***

**Undersea Weapons**

Conduct basic research related to critical S&T to develop technologies for legacy and next-generation offensive and defensive undersea weapons (USWs) and payloads capable of engaging threat submarines, surface ships and torpedoes. Efforts include, but are not limited to, the following:

- Undersea and Surface Vehicle Autonomy
- Advanced concepts for Sea Warfare
- USW Hydro and Propulsion,
- USW Warheads
- Naval Undersea Research Program

**Air Weaponry**

Research will focus on the areas of solid and hybrid rocket propulsion, advanced structural and aperture materials, navigation, aerodynamics, single and multi-missile control, and power management. This effort will enable missiles with greatly increased speed, range and lethality to meet future naval warfare needs.

**Directed Energy and Counter Directed Energy**

Research will focus on the fundamental scientific processes of laser and microwave technologies leading towards Naval utilization at tactically significant ranges in offensive and defensive applications. Program goals included the research:

- Laser/Microwave Sources
- Adaptive Optics
- Antennas
- Power/Energy Conversion and Modulation
- Understanding of Propagation/Interaction Physics

| FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>- Characterization of laser-matter interactions for ultra-intense laser beams</p> <p>- Electromagnetic-Electronic Coupling</p> <p>- Identifying new nanostructured materials and coatings processing for naval applications.</p> <p>- Investigate unique interactions of photons with materials and coatings, including nonlinear optical materials and unique photochromic materials that react by creating direct mechanical strain from photons.</p> <p><b>Energetic Materials and Rocket Propulsion</b><br/>                     Research will investigate advanced energetic materials which provide reactive, explosive, and propulsive phenomena including high energy ingredient synthesis, modeling, characterization, and the fundamentals of initiation, decomposition and combustion/shock. Research will include:</p> <ul style="list-style-type: none"> <li>- Synthetic methodology for new energetic materials and material concepts with superior specific energy and energy density, brisance, insensitivity, etc. for useful warhead fills and solid rocket propellants.</li> <li>- Novel Diagnostic methods for improved understanding of formulations and dynamic combustion/shock and related energetic materials dynamic phenomena.</li> <li>- Advanced modeling and simulations on energetic materials, along with new methods and instrumentation for characterization.</li> </ul> <p><b>Hypersonics</b><br/>                     Basic research will address long-range weapon components able to survive high temperature exposure for several minutes and thwart anti-access/ area denial countermeasures. Additional areas of research include:</p> <ul style="list-style-type: none"> <li>- Hypersonic boundary-layers and shock-wave / boundary-layer interactions</li> <li>- Prediction of hypersonic weapon flight performance and control including the influence of non-continuum, non-equilibrium and aero-thermo-servo-elastic effects</li> <li>- Environment-material interactions</li> <li>- Test facilities, instrumentation and diagnostics</li> <li>- Ultra-High temperature materials</li> <li>- High-Speed Propulsion</li> </ul> <p><b>FY 2022 Base Plans:</b><br/> <b>Undersea Weapons (USWs)</b></p> <ul style="list-style-type: none"> <li>- Conduct basic research to understand science and technology that will contribute to undersea and surface vehicle swarm autonomy, undersea weapons (USWs) and advanced concepts for sea warfare. This research will allow further development of technologies for legacy and next-generation offensive and defensive USWs and payloads capable of engaging threat submarines, surface ships and torpedoes.</li> </ul> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy |                                                                                            | <b>Date:</b> May 2021                                                   |
| <b>Appropriation/Budget Activity</b><br>1319 / 1                   | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b> | <b>FY 2022 Total</b> |
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| <p>- Additionally, the Naval Undersea Research graduate-level STEM program will continue to support the development of the Navy lab workforce.</p> <p><b>Air Weaponry</b></p> <p>- Basic research will focus on the areas of solid and hybrid rocket propulsion, advanced structural and aperture materials, navigation, aerodynamics, single and multi-missile control, and power management. Specific research in the area of multi-functional material structures include making missile skins with embedded (woven in) antennas, sensors, power sources, computational resources, and energetic materials. These efforts will enable missiles with greatly increased speed, range and lethality to meet future naval warfare needs.</p> <p><b>Directed Energy and Counter Directed Energy</b></p> <p>- Conduct basic research in high-energy lasers, optical components, infrared technologies and high power microwaves to enable significant leap-ahead capabilities for the survivability and lethality of naval forces. Efforts will explore advanced photonics and optical techniques that vary energy levels in individual photons at energy density levels significantly above those needed for other applications, advanced photonics techniques to maximize extraction of the highest energy levels available from individual photons, and advanced photonics from unique sources otherwise not commercially viable.</p> <p>- There will be continued exploration of computational and photonic creation that model next-generation waveform interactions and power conversion designs.</p> <p>- Additional basic research will contribute to identifying new nanostructured materials and coatings processing for naval applications and investigate unique interactions of photons with materials and coatings.</p> <p><b>Energetic Materials and Rocket Propulsion</b></p> <p>- Basic research will investigate advanced energetic materials, which provide reactive, explosive, and propulsive phenomena including high-energy ingredient synthesis, modeling, characterization, and the fundamentals of initiation, decomposition and combustion/shock. This research will include synthetic methodology for new energetic materials and material concepts with superior specific energy / energy density, brisance, and insensitivity for useful warhead fills and solid rocket propellants.</p> <p>- Additional research in novel diagnostic methods for improved understanding of formulations and dynamic combustion/shock and related energetic materials dynamic phenomena will be conducted.</p> <p>- Finally, further efforts in advanced modeling and simulations on energetic materials, along with new methods and instrumentation for characterization will continue.</p> <p><b>Hypersonics</b></p> |                |                |                     |                    |                      |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy | <b>Date:</b> May 2021 |
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| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>0000 / <i>Defense Research Sciences</i> |
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| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
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| <p>- Basic research will address technologies needed for long-range weapon components that are able to survive high temperature exposure for several minutes and thwart anti-access/ area denial countermeasures.</p> <p>- Additional research will be conducted in hypersonic boundary-layers and shock-wave / boundary-layer interactions, prediction of hypersonic weapon flight performance and control, environment-material interactions, exploration of ultra-high temperature materials, and technologies needed for high-speed propulsion.</p> <p><b>FY 2022 OCO Plans:</b><br/>N/A</p> <p><b>FY 2021 to FY 2022 Increase/Decrease Statement:</b><br/>The increase in funding from FY 2021 to FY 2022 is due to additional research efforts in the areas of hypersonics and directed energy.</p> |         |         |              |             |               |
| <b>Accomplishments/Planned Programs Subtotals</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 447.646 | 460.048 | 473.089      | 0.000       | 473.089       |

**C. Other Program Funding Summary (\$ in Millions)**  
N/A

**Remarks**

**D. Acquisition Strategy**  
Not applicable.

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**Exhibit R-2A, RDT&E Project Justification:** PB 2022 Navy **Date:** May 2021

|                                                  |                    |                |                |                     |                                                                                            |                      |                |                                                                            |                |                |                         |                   |
|--------------------------------------------------|--------------------|----------------|----------------|---------------------|--------------------------------------------------------------------------------------------|----------------------|----------------|----------------------------------------------------------------------------|----------------|----------------|-------------------------|-------------------|
| <b>Appropriation/Budget Activity</b><br>1319 / 1 |                    |                |                |                     | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> |                      |                | <b>Project (Number/Name)</b><br>3465 / <i>In-House Lab Independent Res</i> |                |                |                         |                   |
| <b>COST (\$ in Millions)</b>                     | <b>Prior Years</b> | <b>FY 2020</b> | <b>FY 2021</b> | <b>FY 2022 Base</b> | <b>FY 2022 OCO</b>                                                                         | <b>FY 2022 Total</b> | <b>FY 2023</b> | <b>FY 2024</b>                                                             | <b>FY 2025</b> | <b>FY 2026</b> | <b>Cost To Complete</b> | <b>Total Cost</b> |
| 3465: <i>In-House Lab Independent Res</i>        | 0.000              | 0.000          | 0.000          | 11.332              | -                                                                                          | 11.332               | -              | -                                                                          | -              | -              | -                       | -                 |

**Note**

Effective in FY 2022, In-house Laboratory Independent Research (ILIR) funding and associated requirements are realigned from Program Element (PE) 0601152N, Project 0000 to PE 0601153N, Project 3465. This is not a new start project.

**A. Mission Description and Budget Item Justification**

The In-house Laboratory Independent Research (ILIR) initiative seeks to improve the quality of defense research conducted predominantly through the Naval Warfare Centers/Laboratories. It also supports the development of technical intellect and education of engineers and scientists in disciplines critical to national defense needs through the development of new knowledge in a military laboratory environment. Initial research focus is often conducted in an unfettered environment since it is basic research, but many projects focus on applying recently developed theoretical knowledge to real world military problems with the intention of developing new capabilities and improving the performance of existing systems.

**B. Accomplishments/Planned Programs (\$ in Millions)**

**Title:** In-House Laboratory Independent Research (ILIR)

**Description:** The In-house Laboratory Independent Research program provides opportunities to strengthen the Naval Science and Engineering workforce capabilities through basic research conducted at the Naval Warfare Centers and Laboratories. These research efforts address high risk/high payoff warfighter science and technological needs, as well as attract the next generation of researchers to consider employment within the Department of the Navy. ILIR also provides opportunities for advanced degrees, technical publications, presentations, and patents.

**FY 2021 Plans:**

N/A

**FY 2022 Base Plans:**

Further develop and maintain the Science and Engineering workforce by providing funding to Naval Warfare Centers and Laboratories to foster high risk/ high reward basic research initiatives of Naval interest. Each of the Naval sites will evaluate existing research projects and propose new topics. All efforts will be selected based on warfighter needs, researcher capabilities, and science and technology alignment.

**FY 2022 OCO Plans:**

|  | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
|--|---------|---------|--------------|-------------|---------------|
|  | 0.000   | 0.000   | 11.332       | 0.000       | 11.332        |

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|--------------------------------------------------------------------|-----------------------|
| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy | <b>Date:</b> May 2021 |
|--------------------------------------------------------------------|-----------------------|

|                                                  |                                                                                            |                                                                            |
|--------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>3465 / <i>In-House Lab Independent Res</i> |
|--------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                             | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO | FY 2022 Total |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|---------|--------------|-------------|---------------|
| N/A                                                                                                                                                                                                                                                     |         |         |              |             |               |
| <b><i>FY 2021 to FY 2022 Increase/Decrease Statement:</i></b><br>The increase from FY 2021 to FY 2022 is due to the realignment of resources and associated requirements from Program Element (PE) 0601152N, Project 0000 to PE 0601153N, Project 3465. |         |         |              |             |               |
| <b>Accomplishments/Planned Programs Subtotals</b>                                                                                                                                                                                                       | 0.000   | 0.000   | 11.332       | 0.000       | 11.332        |

**C. Other Program Funding Summary (\$ in Millions)**

N/A

**Remarks**

**D. Acquisition Strategy**

N/A

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**Exhibit R-2A, RDT&E Project Justification:** PB 2022 Navy **Date:** May 2021

| <b>Appropriation/Budget Activity</b><br>1319 / 1 |             |         |         |              | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> |               |         |         | <b>Project (Number/Name)</b><br>9999 / <i>Congressional Adds</i> |         |                  |            |
|--------------------------------------------------|-------------|---------|---------|--------------|--------------------------------------------------------------------------------------------|---------------|---------|---------|------------------------------------------------------------------|---------|------------------|------------|
| COST (\$ in Millions)                            | Prior Years | FY 2020 | FY 2021 | FY 2022 Base | FY 2022 OCO                                                                                | FY 2022 Total | FY 2023 | FY 2024 | FY 2025                                                          | FY 2026 | Cost To Complete | Total Cost |
| 9999: <i>Congressional Adds</i>                  | 0.000       | 5.309   | 27.000  | 0.000        | -                                                                                          | 0.000         | -       | -       | -                                                                | -       | -                | -          |

**A. Mission Description and Budget Item Justification**

Congressional Interest Items not included in other Projects.

**B. Accomplishments/Planned Programs (\$ in Millions)**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | FY 2020 | FY 2021 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|---------|
| <b><i>Congressional Add:</i></b> Navy ROTC Cybersecurity Training Program<br><b><i>FY 2020 Accomplishments:</i></b> N/A<br><b><i>FY 2021 Plans:</i></b> N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 5.309   | 0.000   |
| <b><i>Congressional Add:</i></b> Defense Research Sciences<br><b><i>FY 2020 Accomplishments:</i></b> N/A<br><b><i>FY 2021 Plans:</i></b> Conduct multidisciplinary basic research to enable the U.S. Navy to maintain its technological superiority. FY21 efforts include grants such as "Synthesis Planning and Reaction Discovery for Photochemistry and Chemistry in Novel Environments". This basic research grant produced 9 peer-reviewed publications and support to 6 graduate students and 4 post-doctoral fellows. By employing cutting edge computational methods to identify unusual reaction pathways and retrosynthetic path generation, new ways to discover viable reactions and their use in synthesis planning are taking shape. | 0.000   | 15.000  |
| <b><i>Congressional Add:</i></b> Silicon-Germanium-Tin Alloy Research<br><b><i>FY 2020 Accomplishments:</i></b> N/A<br><b><i>FY 2021 Plans:</i></b> Conduct basic research on Silicon-Germanium-Tin Alloy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 0.000   | 5.000   |
| <b><i>Congressional Add:</i></b> Bio-inspired Engineering and Design for Naval Applications<br><b><i>FY 2020 Accomplishments:</i></b> N/A<br><b><i>FY 2021 Plans:</i></b> This research project will be on mobility, maneuverability and agility, and will focus on locomotion and mechanics (e.g., fin-based swimming, flapping flight and legged locomotion), modalities of distributed sensing and processing (visual, echolocation, lateral-line and vibrissae "imaging" and cognitive-neural processing, neuroscience and machine learning), and distributed actuation (neural activation and muscle mechanics, hard and soft robotics).                                                                                                      | 0.000   | 3.000   |
| <b><i>Congressional Add:</i></b> Predictive Modeling & Simulation for Next Gen Naval Undersea Vessel and Platform                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 0.000   | 2.000   |

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| <b>Exhibit R-2A, RDT&amp;E Project Justification:</b> PB 2022 Navy | <b>Date:</b> May 2021 |
|--------------------------------------------------------------------|-----------------------|

|                                                  |                                                                                            |                                                                  |
|--------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| <b>Appropriation/Budget Activity</b><br>1319 / 1 | <b>R-1 Program Element (Number/Name)</b><br>PE 0601153N / <i>Defense Research Sciences</i> | <b>Project (Number/Name)</b><br>9999 / <i>Congressional Adds</i> |
|--------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------|

| <b>B. Accomplishments/Planned Programs (\$ in Millions)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>FY 2020</b> | <b>FY 2021</b> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------|
| <b><i>FY 2020 Accomplishments:</i></b> N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| <b><i>FY 2021 Plans:</i></b> This effort will advance naval warfare capabilities by providing focused research on experimentally validated, multi-physics and multi-fidelity predictive modeling to support undersea smart systems design. Augmented by machine learning capabilities the research will support applications such as digital twin, situational awareness and vessel health monitoring.                                                                                                                                                                                                                                                                                                                                                                  |                |                |
| <b><i>Congressional Add:</i></b> USV Batteries, Materials, and Additive Manufacturing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 0.000          | 2.000          |
| <b><i>FY 2020 Accomplishments:</i></b> N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                |                |
| <b><i>FY 2021 Plans:</i></b> The research will focus on developing: (i) multifunctional batteries, which offer lightweight energy storage that could enhance the range and performance of undersea vehicles, including their potential integration with hybrid and regenerative energy sources; (ii) metamaterials with tunable acoustic properties, structural materials with computationally optimized microstructures and advanced coatings for extreme marine environments such as extended exposure to sea water and high strain-rate deformation; (iii) transformative multi-material (multi-metal and multi-polymer) additive manufacturing methods for fabrication of materials and structures with designed microstructures at micro-scale spatial resolution. |                |                |
| <b>Congressional Adds Subtotals</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5.309          | 27.000         |

**C. Other Program Funding Summary (\$ in Millions)**  
N/A

**Remarks**

**D. Acquisition Strategy**  
N/A