Section 5.2 PEO LS S&T Focus Area

SURVIVABILITY AND MOBILITY

> *"Now, we have a new generation of really battle-hardened leaders, especially in the mid ranks and the senior ranks, multiple combat tours. Through the 13 years of war, they've gained practical battlefield know-how that can't be taught in any training manual. It's the kind of experience that troops pick up only having spent considerable time at the pointy end of the spear. It's my hope that if we keep our eyes on those men and women who are at the pointy end of the spear, we can continue to provide them with what they need to survive on future battlefields and what they deserve."*
>
> **—Deputy Secretary of Defense Robert Work, March 2015**

The Marine Corps will operate in an increasingly complex and uncertain future. Future conflict will be marked by chaos and the proliferation of a variety of threats both conventional and unconventional. The Marine Corps' counter to those threats must be affordable, scalable and a systems-of-systems approach in order to be realized. Improvised Explosive Device (IEDs) will continue to be a challenge in the future battlespace where Marines fight. As an expeditionary force that is concentrating its efforts on re-honing their amphibious skills, the Marine Corps must ensure its tactical vehicle fleet is light, fast, easily transportable and survivable.

Additionally, maintaining legacy vehicles and increasing their capability is a challenge, especially in an environment where affordability is a key capability. One way of keeping development costs low is the use of simulation-based design tools that predict performance, survivability and reliability of systems.

PEO LS continues to collaborate closely with Marine Corps Systems Command (MCSC), Marine Corps Warfighting Lab (MCWL), Marine Corps Combat Development Command, Office of Naval Research (ONR), Research Development and Engineering Command (REDEC), Tank Automotive Research, Development, and Engineering Center (TARDEC), and other agencies to address the competing challenges of Survivability and Mobility.

The Survivability and Mobility focus area consists of technologies that increase survivability of both the Marines and vehicles. The two are addressed as a combined S&T Focus Area since what affects one, often directly affects the other.

5.2.1 Survivability consists of:

- 5.2.1.1 Fuel Containment / Fire Suppression
- 5.2.1.2 Safety

5.2.2 Mobility consists of:

- 5.2.2.1 Crew Visibility
- 5.2.2.2 Corrosion
- 5.2.2.3 Autonomy
- 5.2.2.4 Weight Reduction

Figure 5.2-1. OSHKOSH JLTV

5.2.1 Survivability

The Challenge

The design, development and production of survivable vehicles that adequately protect our warfighters are a highly complex "system of systems" engineering problem. Maintaining legacy vehicles while increasing their capability remains a challenge, especially in an environment where affordability is as important as capability. Additionally, while maintaining the survivability aspects, the vehicles must provide the required mobility for the Marine Corps to successfully conduct expeditionary/amphibious operations.

Potential Solutions

PEO LS Efforts

Mitigation of Blast Injuries

The objective of the JLTV Blast M&S effort is to develop and execute a physics-based model that can account for both soil/structure interaction and gross vehicle response. CORVID Technologies prepared high-fidelity models for the JLTV Programs. The underbody blast M&S efforts will: 1) provide the Joint Project Office (JPO) insight into force protection levels (initially from a structural standpoint and evolving to a crew response standpoint); 2) support engineering design analyses and modifications; and 3) provide supplemental information to support key performance parameter analyses. The JPO also plans to use M&S for future evaluations of vehicle design modifications and Engineering Change Proposals. Funding and timeline information can be found in the M&S section.

MCWL Efforts

Counter Unmanned Systems (CUxS)

This effort involves employment of multiple networked and fused sensors capable of providing detection, identification, tracking, and defeat of enemy unmanned systems. The goal will be to develop an integrated, expeditionary system capable of detecting and countering the effects of enemy unmanned air, ground, and surface systems.

ONR Efforts

Advanced Camouflage

This project will combine technologies to provide advanced camouflage for a ground platform to measurably reduce the probability of detection in a given background at a given range.

APS-Small Target Interceptor, Next Generation (STING)

This effort will investigate technologies to advance the state of the science active protection system applicable to vehicles and watercraft for defeat of air-delivered chemical energy threats with minimal fratricide.

Carbon Nanotube Applications/ Integration

This initiative will examine applications of CNTs in high-strain rate using lessons learned from the 6.2 program for application in hard-armor systems.

Carbon Nanotube in high-strain rate applications

This project will investigate Carbon Nanotube in high-strain rate, i.e., ballistic penetration events, and assess potential for armor application in hard-armor systems.

Crew Seat Protection

The Crew Seat Protection effort will explore the next generation of energy-absorbing seats for Marine Corps ground systems.

Detection Avoidance material and M&S Development

This initiative will examine materials and develop improved M&S for advanced camouflage application.

Directed Energy Weapons Mitigation

This study will investigate Directed Energy Weapons threats and develop countermeasure technologies among three mechanisms; obscuration, reduce probability of EM coupling, and EM reflective surfaces.

Disruption of Conductive Particles by Pulsed Currents

Using pulsed currents and Lorentz Forces, this effort will seek to disrupt a particulated conductive wire. Pulsing the current on the entire wire surface should provide a destabilization mechanism at lower power requirements.

Energy Absorbing Structures for Blast Mitigation

This initiative will develop and demonstrate the use of energy-absorbing structures mounted between the blast hull and the crew compartment of a general class of tactical vehicles (5–15 ton) that substantially mitigates crew injuries from underbody blast with charges of 6 to 10 Kg TNT.

Expeditionary Light Armor Seeding Development

The intent is to develop a two-pronged approach: Modeling & Simulation of unconventional ceramic tile seam design to eliminate weak spots enabling a lighter design and design. It will also fabricate a light armor solution for application to ACV High Water Speed by scaling material solutions characterized in previous ONR 30 Maneuver Survivability programs.

Flawless Glass+P2

This project will further develop the methodology to produce flawless glass as part of a transparent armor system. Reducing surface flaws can increase performance of the TA systems by more than 10%, thereby allowing for a reduced weight armor system.

Functionally Gradient Armor materials (Additive Manufacturing)

This initiative seeks to use additive manufacturing to fabricate light armor ceramic composite systems with novel geometries and seams.

Ground Based Air Defense On the Move (GBAD OTM) – FNC – Enabling Capability (EC)

This FNC-Eabling Capability demonstrates close-in, low-altitude surface-to-air laser fire in defense of MAGTF assets defending forward combat areas, maneuvering forces, vital assets installations, and/or units engaged in special/independent operations. This EC will demonstrate the capability of a rugged expeditionary high-energy laser demonstrator cued by a radar to detect low-radar cross-section threats and perform soft and hard kills of unmanned aerial systems (UAS). This will prevent reconnaissance, surveillance, targeting, and acquisition of expeditionary forces.

High-Strength High-Ductility Nano Composites

This project will engineer a trimodal material with nanoscale reinforcements, in combination with a dispersion strengthened matrix and coarse grained regions that has tailorable plasticity to yield high strength-high ductility.

Light Armor Design

Using knowledge from previous ONR programs, this initiative aims to develop, fabricate, and test light armor systems for ACV threats.

Lightweight Materials

This study will investigate lightweight materials for armor applications for USMC platforms (i.e., ACV and JLTV Objective).

Multi-DOF Rollover-Impact-Blast Effects Simulator

This project will develop the capability of simulating crew response to an underbody blast in a laboratory setting without the use of explosives. It will also capture complex local structural motion by novel fixturing developed through modeling and simulation.

Tandem Threat Defeat and select ATGM

This effort will continue the technology development to defeat tandem CE threats and ATGM.

Transparent Armor Integration

This project will develop and demonstrate advanced transparent armor systems in a field environment using lessons learned from Flawless glass SBIR and polymeric material transparent armor.

Transparent Armor Polymeric Materials

The intent of this study is to investigate novel Transparent Armor technologies using composite technology to reduce weight and improve multi-hit performance.

Transparent Armor SBIR

This project will reduce transparent armor for relevant threat by more than 30% and develop ballistic models useful for other programs.

Underbelly Blast Mitigation

This effort will investigate the ability to write electric discharges onto surfaces to open “tubes” to allow preferential gas to flow through them. This ability to quickly and preferentially channel blast gases has potential for both offensive and defensive applications. One example is the potential to reduce

the impulse from underbody blast due to high-pressure gases by up to approximately 50%.

Vehicle Agnostic Modularity (VAM)

The intent of the VAM program is the structured application of modularity principles to ground platforms to extend tactical range, extend operational reach, and increase endurance in the field. It will also reduce excess capacity and reduce logistic footprint/burden, enhance small unit effectiveness, lighten the MAGTF load, enhance commonality, and reduce Total Ownership Cost (TOC). This program can be applied to a number of mission characteristics for vehicles, but the data architecture will be essential to other modules.

This ONR 30 effort is focused on developing a scalable, reusable, and subdivided vehicle system that will employ a series of self-contained functional modules (trauma, C2, remote weapons station, power, and others). While the program is exploring potential solutions to a variety of technical challenges, it will require an open plug-and-play architecture to support the various modules and platform elements. This digital data backbone will permit system-wide power and thermal management and provide common interfaces for the different modules, thus enabling vehicle mission optimization. The result of this Science and Technology (S&T) effort will be reconfigurable modules that can provide mission capabilities integrated into vehicle cargo and are applicable across a range of tactical vehicles.

DARPA Efforts

Ground X-Vehicle Technologies (GXV-T)

Ground-based armored fighting vehicles and their occupants have traditionally relied on armor and maneuverability for protection. The amount of armor needed for today's threat environments, however, is becoming increasingly burdensome and ineffective against ever-improving weaponry. GXV-T (depicted in Figure 2.2-2) seeks to develop revolutionary technologies to enable a layered approach to protection that would use less armor more strategically and improve vehicles' ability to avoid detection, engagement and hits by adversaries. Such capabilities would enable smaller, faster vehicles in the future to more efficiently and cost-effectively tackle varied and unpredictable combat situations.

The GXV-T program aims to improve the survivability of ground-based armored fighting vehicles by providing physically and electronically assisted situational awareness for crew and passengers, and semi-autonomous driver assistance and automation of key crew functions similar to capabilities found in modern commercial airplane cockpits to reduce onboard crew and training requirements. The GXV-T program is not a vehicle development program but rather is focused on developing core technologies so future vehicles could be more robust and agile through the provision of innovative protective capabilities such as real-time movable armor that is instantly responsive to incoming threats and novel drive-train technologies able to provide enhanced mobility and power.

Figure 5.2-2. Artist's Concept fro GXV-T

RDECOM & TARDEC Efforts

Underbelly Blast Mitigation

The Occupant Centric Platform project is intended to design vehicles around the occupant. It seeks to identify, develop, and integrate technologies that will protect occupants of ground vehicle systems from underbody threats, crashes, and rollovers, while maintaining or improving the mobility of the vehicle system and reducing the weight required to provide that protection. OCP seeks to accomplish these goals by addressing:

- Gaps in occupant protection standards
- Tools and techniques to research blasts
- Crash and rollover mitigation capabilities
- Ground vehicle interior technologies for protection of occupants
- Ground vehicle exterior technologies to mitigate the effects of underbody blast events

Addressing these elements successfully will enable the OCP project to provide affordable and manufacturable survivability solutions for ground vehicle platforms to protect soldiers against known and anticipated threats. The project's overall purpose is to develop and document a design approach that will lead to the design and demonstration of an occupant-centric ground vehicle with improved vehicle survivability and force protection. It also seeks to prevent or decrease injuries to soldiers and Marines due to underbody IED and mine blast events and the resulting crashes and rollovers.

The OCP Technology Enabled Capability Demonstration (TECD) is in the process of developing an occupant-centric approach that first addresses the safety of operators and crews in the design or reengineering of ground vehicles—an initiative that 12 years of conflict in Southwest Asia have proven to be essential. The project's near-term objectives (FY17) are to establish baselines; develop occupant protection standards; mature interior and exterior occupant protection technologies; increase lab testing capability; and improve confidence in M&S predictions. A longer-term goal is to reduce overall platform weight by 25%. This goal will include reducing casualties and Wounded In Action by 50% across each mission role with scalable protection levels to defeat a wide range of threats, enhance mobility, and maintain freedom of action during full spectrum operations.

Hit Avoidance Development (HAD)

The HAD project provides technology assessment, subject-matter expert integration services and evaluations for Program Managers, as well as core-funded DoD projects. Technologies addressed include Passive and Active Protection Systems (APS). HAD provides unbiased "honest broker" technology evaluations. The lab also works with industry via Cooperative Research and Development Agreements (CRADAs), collaborating with partners to improve available technologies for potential transition to the program manager community.

Capabilities

HAD can characterize threat-point initiators, counter-measure pre-function analysis, technology optimization and system integration. Based on customer input, the lab develops theater-inspired complex attack scenarios to evaluate proposed solutions. HAD optimizes technology integrations based on performance data provided by these complex ambush scenarios. APS technology is assessed for vehicle-specific integrations in a hardware-in-the-loop, virtual battle space environment.

Benefits

- Provides real-time evaluations and assessments
- Optimizes technology concepts against theater-based complex attacks
- Optimizes integration of passive and active defeat systems on tactical and combat vehicles

- Provides a one-team approach to the hit avoidance system optimizations and integration with controlled firing of dynamic threat surrogates and the Rapid Evaluation Capability of live-fire dynamic foreign threats

Advanced Armor

This effort will leverage current investments in combat vehicle armor to develop, mature and integrate lightweight base, add-on, and electrified armors. Advanced Armor will mature and test Pulse Power system to enable electrified armors. This will also demonstrate mature advanced armors into integrated armor solutions while maintaining performance, decreasing weight, and maintaining cost.

Advanced Countermine (ACM) / IED Payloads Competency

The ACM/IED Payloads Competency has the objective of:

- Army elements lack the ability to conduct mounted and dismounted movement and maneuver on and off road, in all terrain conditions where the threat of AT mine and IED engagements exist. This initiative will capitalize on small incrementally funded activities combined with customer-focused efforts to achieve technical capabilities that can ultimately be packaged into a single system adaptable to truck, tracked and robotic platforms.

Advanced Passive/Active Blast Mitigation (BM)

This project explores mature blast mitigation technologies through product development, integration and validation. It meets the ≥4X underbody blast requirements by integrating interior and exterior blast mitigation technologies on combat vehicle representative blast trucks. It also fully recognizes blast load paths through vehicle platforms by decomposing the load paths through each technology and technology interface.

Fire Protection Competency

The Fire Protection Competency effort will provide legacy and future vehicle programs with improved damage mitigation techniques to protect against current and emerging fire threats.

Interior Impact Protective Solutions

This protective solution will enhance Warfighter survivability by using passive energy absorbing methodologies and/or active technologies to prevent, avoid, and abate occupant injury during underbody blast, crash, and/or rollover events.

Warfighter Injury Assessment Manikin (WIAMan)

The goal of WIAMan is to develop an improved blast test manikin that incorporates medical research, which provides an increased capability to measure and predict skeletal injuries of ground vehicle occupants during underbody blast events. The funding and timeline information can be found in the M&S section.

Modular Active Protection System

This project will demonstrate Soft-kill (SK) and Hard-kill (HK) Active Protection Systems (APS), that are compliant with a modular approach, to defeat Rocket Propelled Grenades, Recoilless Rifles and Anti-Tank Guided Missiles.

Modular Active Protection Dazzler

This project will allow commonality across the vehicle fleet, tailoring of systems to meet Program Manager needs and platform constraints, provide growth capability to address emerging threats and facilitate transition.

Head and Neck Competency

Provide Warfighter survivability by using passive energy absorbing methodologies and/or active technologies to prevent, avoid, and abate occupant injury during underbody blast, crash, and/or rollover events.

Combat Vehicle Adaptive Armor

Develop and demonstrate integrated adaptive armor systems comprised of mechanical and electrical subcomponents on a representative combat vehicle platform.

5.2.1.1 Fuel Containment/Fire Suppression

The Challenge

PEO LS S&T representatives continue to investigate all options in potential fuel containment and fire suppression technologies. Addressing fires caused by accelerants and IEDs, accidental fires caused by leaks or malfunctions, or battle damage fires present the same core challenges: to increase the survivability of the vehicle and its occupants.

Potential Solutions

PEO LS Efforts

Lightweight HybridSil Nanocomposites for Ballistic, Blast and Flame Protection to MTVR Fuel Tanks and Engine Components STTR

This project will develop a polymer coating that reduces the potential for fuel tank fires from mine/IED blasts.

Modular Lightweight External Fuel Tank System SBIR

This effort seeks to design and develop a lightweight, modular fuel tank that can withstand hydrodynamic ramming forces and provides protection against a ballistic impact from a 14.5 mm armor-piercing projectile using a multi-layer laminate design at a significant reduction in weight compared to existing systems. A lightweight, modular fuel tank reduces the power and fuel requirements for an amphibious vehicle, while mitigating fire issues and increasing freeboard.

RDECOM and TARDEC Efforts

Common Automatic Fire Extinguishing System (CAFES)

This project will develop a reliable, maintainable, and safe common tactical vehicle Automatic Fire Extinguishing System that will reduce the probability of crew incapacitation and vehicle kills from fire threats, as well as reduce logistics and maintenance costs.

Fire Protection Technology Integration Lab (TIL)

The Fire Protection TIL provides a rapid and thorough evaluation of Automated Fire Extinguishing Systems (AFES) technologies and agents that support the Army's modernization plans for legacy vehicles and future systems. This new test facility also supports AFES integration, engineering and testing designed to protect combat and tactical ground vehicles and their crew members.

Capabilities

HAD can characterize threat-point initiators, counter-measure pre-function analysis, technology optimization and system integration. Based on customer input, the lab develops theater-inspired complex attack scenarios to evaluate proposed solutions. HAD optimizes technology integrations based on performance data provided by these complex ambush scenarios. APS technology is assessed for vehicle-specific integrations in a hardware-in-the-loop, virtual battle space environment.

Benefits

- Provides in-house ability to develop and test lifesaving technologies and quickly transition innovations to the vehicle Program Managers (PMs) and our Soldiers
- Validates AFES performance requirements with physical testing
- Predicts performance of AFES to reduce system testing
- Provides simulations of vehicle AFES system design (temperatures, pressures, oxygen levels and acid byproducts)
- Provides quick turn-around time with on-site support for proof-of-principle testing

SBIR Efforts

Aqueous Based AFES

This ONR SBIR will develop an aqueous solution that provides vehicle crew protection against crew cab fires, fire re-flash and protect occupants from associated hazards. The approach is to identify a breathable foam solution for fire suppression with no harmful/toxic byproducts, and to develop aqueous-based injury criteria. An initial prototype will be developed and tested.

5.2.1.2 Safety

The Challenge

Safety preserves personnel and equipment, but safety considerations cannot contradict the mission of the Marine Corps' operational objectives. Safety considerations include vehicle stability; safety equipment, including restraint harnesses; fire suppression; clear fields of view; training; policy; procedures; and lines of communication with the warfighters.

Potential Solutions

ONR Efforts

Dynamic Vehicle Center-of-Gravity and Gross Weight Estimation Using Readily Available Sensors

Poseidon Systems, in collaboration with Rochester Institute of Technology, proposes to develop and demonstrate a novel system for estimating vehicle gross weight and center-of-gravity location using an innovative nonlinear real-time filter based method. The proposed algorithm uses known physics-based kinematic relationships between vehicle states for the estimation process, and it requires minimal set of low-cost sensors that can be easily integrated into existing vehicle platforms. Funding and timeline information can be found in the Mobility section.

Modular Anthropomorphic Test Device (ATD)

The military will test underbody blast events to help develop improved protection in military vehicles with the development of a Modular Anthropomorphic Test Device (ATD) specifically designed for use in blast and ballistic testing. The ATD offers improved biofidelity compared to existing ATDs, with a frangible skeletal system and soft-tissue covering that simulates the human form. Sensors are provided to document loads experienced during impact events.

Post-IED Hull Inspection Tool (ONR SBIR)

Forward deployed forces often have limited vehicle asset with many mission requirements. Following a vehicle IED event, it is critical to make informed, accurate decisions for damage assessment and repair. Marines are dependent on qualitative visual inspection of hulls to evaluate damage following IED events. This SBIR will provide an integrated suite of tools to quantitatively characterize damage, generate reports, and provide disposition and repair guidance based on an analysis of the data.

This effort seeks to provide forward-deployed Marines with an integrated, low-cost ruggedized, and portable tablet-based 3D capture tool kit to guide and facilitate the assessment of battle damage to combat vehicle platforms. The tool will include:

- Development and integration of ruggedized, low-cost indoor/outdoor 3D scanning technology
- Procedural forms and checklists
- Photo and video documentation
- Expandable framework to incorporate other NDI technologies

Funding and timeline information can be found in the M&S section.

SBIR Efforts

Active Laser Protection System

The use of commercial off-the-shelf laser systems as weapons is happening more frequently. Battery operated visible and infrared lasers can be purchased with powers near 1-watt, sufficient to cause permanent eye damage. Future threats may include frequency agile lasers. It is critical that countermeasure systems provide laser eye protection across the visible and infrared waveband.

Human Body Model

Current Anthropomorphic Test Devices (ATD) used to predict human injury risk in Live Fire Blast testing have several limitations, which are mainly due to a lack of biofidelity and limited injury assessment capability. The ATD is composed of metals, rubbers, and plastics, and the majority of injury metrics used with the ATD were developed under automotive crash loading scenarios. The combination of these two factors leads to a lack of biofidelic response and inaccurate injury risk predictions. Additionally, within the loading regime of vehicular blast events, the current ATD is only able to assess for bone fracture injuries within a limited severity range. Therefore, a large portion of commonly assessed injuries are not assessable with the current system.

Development of a human body model is under way to leverage recent advances in high-fidelity computational physics-based Modeling and Simulation M&S of explosive events against armored vehicles. This major advancement in the ability to accurately predict human injury risk will: 1) allow vehicle designers and evaluators to predict risk of injuries across the severity spectrum experienced in the real world; 2) supplement the test device results with prediction of injuries beyond fracture; 3) expand injury risk assessments beyond the 50th% percentile; 4) support theater event reconstruction; and 4) deliver injury causation determination. Funding and timeline information can be found in the M&S section.

5.2.2 Mobility

The Challenge

The Marine Corps is the nation's premier expeditionary fighting force. Mobility is fundamental for providing the agility and flexibility that expeditionary warfare requires. The challenge is to find an affordable balance between payload, protection, and performance mobility.

Potential Solutions

MCWL Efforts

Additive Manufacturing (3D Printing)

Additive Manufacturing is the process of making a three-dimensional solid object of virtually any shape from a digital image. It is achieved by using an additive process, where successive layers of material are laid down in different shapes. This effort aims to explore potential for significant increased efficiencies

in logistics through reduction of inventories and determine other areas of military application.

Internally Transportable Vehicle – Replacement (ITV-R)

This project aims to refine requirements for a lightweight internally transportable vehicle (MV-22/CH-53) to enable future Company Landing Teams (CLT) and SPMAGTF-CR to conduct expeditionary force operations (EF21).

The warfighting lab's effort in support of CDD/LID and PEO LS future Internally Transportable Vehicle program needs, in order to directly inform and accelerate requirements definition, analysis of alternatives and market research efforts.

ONR Efforts

AAV Sustainment Studies

This effort will develop an electronic log book for capturing logistical data.

Active Sensing and Predictive Mobility

This project will adapt on-board systems and components to proactively adjust the vehicle mobility in real-time and based effort on upcoming terrain/environment.

ACV High Water Speed Parameter Setting Study

This project will determine the bounds of physics for the three ACV High Water Speed lanes.

Advanced Transmission Technology

This effort intends to advance and demonstrate a 32 speed binary logic transmission with increased transmission efficiency (greater than 90%) and reduced power loss (from 35% down to 10%) for 20 – 40 ton tracked military vehicles.

FNC - ACV Water Speed Enhancements

The intent of this FNC is a 50% increase in speed that will reduce ship-to-shore transit times by 1/3, enhance steering control through the surf zone, and increase capacity to execute a river crossing and effectively negotiate cross currents.

Integrated Mobility Dynamics Control

This high-capability active system can walk a vehicle out of an immobilized condition in soft soil and/or prevent a rollover when the road breaks away under a heavy vehicle for 10–37 ton wheeled vehicles traveling at high speed (up to 65 mph).

Tech Insertion for Recapitalization

This effort will develop data-based decision methods for evaluation of potential sustainment and upgrade investments from a Total Life Cycle Management standpoint.

Trafficability and Mobility Analysis from Remote Sensing

This project will use remote sensing products focused on terrain and soil characteristics to generate the mobility corridors from the Modified Combined Obstacle Overlay to improve maneuver planning in the littorals.

Vehicle Agnostic Modularity (VAM)

Under this effort, a well-structured application of modularity principles to ground platforms will extend tactical range, extend operational reach and increase endurance in the field. It will also reduce excess capacity and reduce logistic footprint/burden, enhance small unit effectiveness, lighten the MAGTF load, enhance commonality, and reduce Total Ownership Cost.

Vehicle Agnostic Modularity Virtual Framework

This framework will identify a set of vignettes and mission sets that define the operational environment for Marine Corps ground vehicles. Using these vignettes, the project will develop measures of suitability, measures of effectiveness and measures of performance that can be used in the definition of a balanced set of modular architectures and approaches for vehicle design.

RDECOM & TARDEC Efforts

Joint Tactical Truck System (JTTS) Demonstrator

The objectives of the JTTS are to:

- Aid future acquisition of medium and heavy tactical fleets, by developing concepts that improve commonality and reduce redundancy in mission roles
- Enable trade-offs between affordability and performance in each addressed capability area
- Provide hands-on engineering and integration experience through all phases of development from decision management to requirements, through system evaluation and test
- Provide for cross-TARDEC, multiple technologies integration platforms by aligning with current S&T landscape
- Demonstrate ISEF capability for support of ground vehicle development
- Inform acquisition requirements for future MTV/HTV platform

Advanced Running Gear

The objectives of this initiative are to develop external suspension and high capacity track system that will improve the vehicle mobility and reduce system weight. Smaller objectives within the external suspension unit and high capacity track system include:

- External Suspension Unit (ESU) System
  - Provide flexibility for complex hull shaping while buying back internal hull volume
  - Alleviate effects of increasing GVW, such as degraded mobility and reduced ground clearance
  - Provides for weight growth and adds height management with adaptive damping into the design up front
- High Capacity Lightweight Track (HCLwT)
  - Reduce track system weight and through improved track designs
  - Increase track system durability through advanced elastomer materials

High-Mobility Truck User Forum

This effort will explore, plan and execute the High Efficiency Truck Users Forum (HTUF) for trucks and commercial construction equipment. It will bring stakeholders together to accelerate commercialization of high-efficiency technologies for military and commercial trucks and construction equipment.

Extended Life Coolants (ELC)

This project will research and evaluate ELC to determine their compatibility to military ground systems without degradations in performance and durability (i.e., that thermal efficiency is not compromised and that new additive technologies in such coolants do not cause corrosion in legacy ground systems). The use of these coolants can reduce operation and maintenance costs by increasing the intervals between drain and refill (potentially three

years plus) as compared to the coolants in use today. This project will complement the current work being funded by the Defense Logistics Agency (DLA) on the investigation of the current life of CID-approved coolants and the properties of they have when mixed with CID-approved coolants to evaluate compatibilities.

High-Mobility Truck User Forum

This effort will explore, plan and execute the High Efficiency Truck Users Forum (HTUF) for trucks and commercial construction equipment. It will bring stakeholders together to accelerate commercialization of high-efficiency technologies for military and commercial trucks and construction equipment.

Lightweight Track / Active Suspension

The purpose of this initiative is to develop external suspension and high capacity lightweight track system that will improve the vehicle mobility and survivability. The products will support PM CVP with potential to support other heavy tracked vehicle customers.

- External Suspension Unit System will provide flexibility for complex hull shaping while buying back internal hull volume. It will alleviate effects of increasing GVW, such as degraded mobility and reduced ground clearance and provide for weight growth and height management with adaptive damping.
- High Capacity Lightweight Track will reduce track system weight and reduce track system rolling resistance through improved track designs. It will increase track system durability and fire resistance through advanced elastomer materials.

5.2.2.1 Crew Visibility

Crew visibility addresses the tactical vehicle crewman's ability to see the battlefield. Darkness, rain, snow, fog, sandstorms, dust, smoke, obscuration factors caused by weapons firing all have an impact on crew visibility. Navigation, vehicle identification,

Figure 5.2-3. AAV Platoon preps for amphibious operations aboard the USS Ashland (LSD 48)

tactical movement and situational awareness are all important aspects of crew visibility. On the battlefield of the future, it is highly likely that any significant enemy will have access to various types of night vision devices, as well as lasers. Obviously, the enemy will use these devices any way possible to gain an advantage.

The Challenge

Survivability can inadvertently hinder crew visibility. The cost, weight, and optical limits associated with transparent armor often results in vehicles that are burdened with limited visibility. Increasing visibility for Marine Corps vehicles without imposing a heavy penalty on Size, Weight, Power and Cost is the goal, but achieving this goal presents a significant technological challenge.

Potential Solutions

ONR Efforts

Transparent Armor

The goal of this ONR SBIR is to reduce transparent armor for relevant threat by over 30%, and then transition the technology to relevant vehicle platforms. Additionally, the Transparent Armor project will develop a ballistic model useful for other programs.

Transparent Armor Integration

This effort will develop and demonstrate advanced transparent armor systems in a field environment using lessons learned from flawless glass, SBIR and polymeric material TA.

5.2.2.2 Corrosion

For Marines, who preserve and maintain thousands of pieces of ground equipment, fighting corrosion is uniquely challenging. Marines operate in very harsh saltwater environments. The Marine Corps has established an effective corrosion-prevention program for all tactical ground equipment. This program intends to reduce maintenance requirements and costs through the development of corrosion prevention and control products, materials, technologies, and processes.

The Challenge

With a reduced national defense budget and the resulting reduction of new equipment procurements, the Marine Corps cannot afford to ignore corrosion issues. Consequently, the Marine Corps will be required to use much of its current gear and its existing vehicle fleet. Enhanced anti-corrosion technologies will extend vehicle-service life, reduce required maintenance, and prolong the operational viability of legacy systems. Enhanced anti-corrosion technologies and future Service Life Extension Programs will be required to extend the life of the Marine Corps' equipment, keeping them operationally viable and ready for the fight.

Potential Solutions

ONR Efforts

JLTV Self-Healing Paint

ONR partnered with John Hopkins University Applied Physics Lab (JHU/APL) in a three-year effort to develop a self-healing paint that delays the onset of corrosion and extends the life of a particular system. Self-healing paint instantly repairs scratches below a maximum width and protects the material below the paint from corrosion. The current approach is to paint surfaces with a protective coating. However, the currently available protective coating has limited abrasion resistance and can be easily compromised and thus expose the corrosion-susceptible material below. There are a number of self-healing paints available on the market, but none offer the performance and reliability of the

Polyfibroblast self-healing paint that JHU/APL has developed.

MCSC Efforts

Corrosion Prevention and Control (CPAC)

The goal of this MCSC effort is to establish an effective CPAC program to extend the useful life of all Marine Corps tactical ground and ground support equipment. The effort also seeks to reduce maintenance requirements and associated costs through the identification, implementation, and, if necessary, development of corrosion prevention and control products, materials, technologies, and processes. The use of these technologies and processes will repair existing corrosion damage and prevent, or at least significantly retard, future corrosion damage on all Marine Corps tactical ground and ground support equipment.

Recognized by the Office of the Secretary of Defense for its successful corrosion prevention and repair efforts, the Marine Corps CPAC program has become a model Service program. This program continues to deliver best-value return on investment across all phases of Marine Corps' equipment life cycles. Since its inception in 2004, the CPAC Program Management Office has maintained a viable, comprehensive program that is credited with saving the Marine Corps more than $20 million annually. With the expansion of the program and the use of advanced technology, savings are anticipated to continue to grow.

Figure 5.2-4. A corrosion service team member applies corrosion prevention compounds to the interior of an amphibious assault vehicle (AAV)

TARDEC Effort

- Ground Vehicle Coating System

5.2.2.3 Autonomy

Autonomy has the potential of becoming a Marine Corps combat multiplier that will save lives by reducing or removing the human element from the convoy. The Marine Corps has increased its efforts to develop autonomous unmanned ground systems that will work in union with manned systems and augment Marine Corps capabilities. Additionally, autonomous vehicles can free up manpower from logistics missions, making them available for more tactical roles.

Unmanned systems are a relatively new phenomenon on the battlefield. There were zero unmanned ground vehicle systems used in a tactical sense during the 2003 Iraq invasion; by the end of 2008, there were more than 12,000 unmanned systems in the DoD inventory. Notably, these are just the first generation.

Similar to the value UAVs bring to the skies in the form of persistent visibility, UGVs bring benefits to Marines on the ground in standoff capability. These ground vehicles are reducing Marines' exposure to life-threatening tasks. UGVs are largely used in support of counter-IED and route clearance operations, using robotic arms attached to, and operated by, modified Mine Resistant Ambush Protected vehicles and remotely controlled robotic systems.

The Challenge

Because Unmanned Ground Vehicles have been playing an increasingly important role in combat, the need for new capabilities has been steadily increasing. Current unmanned ground vehicles require a "man-in-the-loop" to operate the vehicle remotely. Autonomous vehicles that do not require a man-in-the-loop tend to move slowly and have difficulty traversing terrain, even over minimal obstacles. For autonomous vehicle to be beneficial to the Marine Corps, they must be able to conduct resupply missions with either a "man-out-of-the-loop" or a "man-on-the-loop" (to provide oversight and input when needed). To truly be valuable, future autonomous vehicles should not require Marines for protection, and they must be able to cross rugged terrain quickly and easily without requiring human assistance.

Potential Solutions

MCWL Efforts

Robotic Vehicle Modular (RV(M))

This initiative consists of a surrogate Unmanned Ground Vehicles (UGV) hosting modular payload architecture with open mechanical, electrical, and software interfaces providing the ability to rapidly change out payloads for a variety of missions. Modular payloads can include advanced Intelligence and Surveillance and Reconnaissance systems, call for fires through Combat Area Robotic Targeting, and ultimately enabling a Modular Weapons Payload capability.

The RV(M) will provide a Company Landing Team with a highly mobile, MV-22 Osprey transportable, multiple modular payload, tactical-scale, squad-level infantry support Unmanned Ground Vehicle utilized in a multitude of missions. A modular robotic vehicle will have operational utility for the CLT and increase mission efficiency. Module concept is viable approach to provide rapid mission reconfiguration.

Dense Pack Access Retrieval and Transit (DPART)

The DPART JCTD key deliverables consists of: one hybrid/electric powered Container-Lift and Maneuver System (C-LMS), one electric powered Autonomous Naval Transport-Large Wheeled Vehicle (ANT-LWV), and one Universal Remote Control (URC; not pictured). The systems will complement existing MHE and have a wide array of applications aboard ships and at bases, stations, and depots.

Ground Unmanned Support Surrogate (GUSS)

GUSS is fitted with electro-optics, lasers, and navigation sensors, which provide navigation and obstacle sensing for autonomous missions. The system is controlled by GPS-guided pre-determined waypoints, a "follow me" mode in which it shadows a warfighter, direct tele-operation or can be man driven. GUSS can navigate through wooded areas, urban or open-terrain and has a cruising range of 482km without refueling and carry 1,700lbs of cargo, (2) passengers and (1) litter patient. The project consists of development and testing of an infantry support Unmanned Ground Vehicle to support multiple resupply, CASEVAC, and reconnaissance type missions.

The goals of this project are:

- Deliver quiet (hybrid electric) autonomous solutions for logistics
- Provide dismounted units semi-autonomous resupply and CASEVAC capabilities
- Enable an organic semi-autonomous ground vehicle to "lighten the load" on the warfighter and increase a units' ability to self-sustain themselves
- Provide on board battery recharging capabilities
- Extend the time on station of the warfighter

ONR Efforts

Cognition for UGV/Warfighter Teaming

This project seeks to develop a cognitive framework to enable intelligent interaction between unmanned autonomous systems and human warfighters. The approach is to develop algorithms that will allow for extended situational comprehension from processing of real time sensor data without the need to translate objects and features into semantically identifiable symbols.

Collaborative Heterogeneous Autonomous Systems

This work will develop and demonstrate collaborative robotic behaviors involving multiple autonomous vehicle types, including mixed teams of ground and air platforms.

Complex Scene Analysis

This effort will investigate computationally efficient methods for extracting real-time knowledge and understanding from visual scenes. The approach will focus on merging bottom-up and top-down processes, moving beyond pixel-level analysis, to provide deeper understanding of objects and relationships within a scene. The intent is to exploit vision-based systems to achieve enhanced automated perceptual understanding in a dynamic, complex environment, providing a sufficient level of comprehension to enable advanced autonomous navigation and the development of tactically relevant behaviors.

Coordinated Tactical Behaviors

This project will develop, implement, and demonstrate multi-vehicle autonomy enabling multiple unmanned ground vehicles to perform collaborative behaviors in support of various expeditionary military missions (force resupply, convoy protection and route reconnaissance).

Expeditionary Wingman Navigation

The wingman concept envisions mobile autonomous systems that are fully integrated with small-unit Marine ground forces. Wingman will provide added operational capability, load bearing, and security for multiple mission profiles, environments, and conditions. This project will develop and demonstrate advanced navigation and path-planning algorithms that will allow a robotic wingman to maintain position and pace with a dismounted squad, while autonomously traversing complex terrain and obstacles.

Intelligent Autonomy Architectures

This project seeks to develop, mature, and advance an architectural framework for integrating technology components and subsystems of unmanned autonomous ground vehicles. It will facilitate the use of open, modular hardware and software development while fostering science and technology innovation, multi-developer participation, and interoperability.

ITV Autonomy Conversion - Autonomy Integration

This effort will facilitate transition, integration, and maturation of autonomous capabilities for a full system demonstration and LMUA of Autonomous Logistic Connecter Mission in FY16/FY17.

Model Predictive Motion Planner

This initiative will extend the state-of-the-art in model-predictive motion planning algorithms to include highly reactive driving maneuvers used by professional human operators to develop a model-predictive hierarchical motion planner for navigation of diverse mobile robot systems in heterogeneous environments.

Natural Interaction between UGV and Squad

This project will develop and demonstrate technologies that will enable Marines to communicate with autonomous machines, and vice versa, using the same familiar methods commonly used to communicate with each other. Focus areas include: two-way voice communication, two-way visual sign usage, understanding of intent, implementation of rehearsed coordinated action, and machine interpretation of text, tactical graphics, maps, and overlays.

Neural Perception and Cognition

This project will explore artificial means of replicating the cognitive and perceptual performance of biological systems in a context relevant to use of unmanned autonomous systems in expeditionary war fighting. The approach targets sensing and perceptual processing that leads to knowledge acquisition and understanding.

Night Ops with Electro-optical Perception System

This initiative will enable autonomous Night Operations by developing and quantitatively demonstrating a low cost electro-optical perception system to perform stereo camera-based navigation during night operations and a localization solution (sensors + algorithms) with less than 1% error (2D) over 1hr in GPS-denied environments at 20mph.

Perception Under Adverse Conditions

This project will focus on developing and demonstrating advanced perception capabilities that will enable the continued operation of autonomous systems when optical sensor performance is degraded by photonic absorption or scattering due to rain, snow, fog, smoke, dust, or other visual obscurants.

Robust Traversability in Complex Terrains

This effort will demonstrate that a path planner that uses high-fidelity terrain, kinodynamic vehicle models, and nonholonomic trajectories will enable navigation to be 20% faster and with 25% less interventions through complex (3.5 RMS, Gxx(n)=9.2x10-1(n)-2.1) cluttered environments (50% obstacle density) with an average gap/vehicle width ratio of 1.3 for autonomous unmanned ground vehicles.

Scene Comprehension and Representation

This project builds on previous efforts to further develop and ultimately demonstrate advanced cognitive robotic perceptual capabilities. The objective is to create the ability for a machine to process streaming sensor data into actionable information and knowledge. The approach encompasses advances in scene comprehension, symbolic representation, attention allocation, anticipation, probabilistic expectation, contextual reasoning, learning, and adaptation.

Sensor Fusion for Robust Perception

This initiative will demonstrate a low-cost perception system ($10k-$20k) for an autonomous ITV-sized vehicle that can provide 20cm X/Y spatial resolution at ranges to 40 meters; surface normal data; classify environmental material with an accuracy > 75%; and perform nighttime perception with a perception distance > 63% of daylight requirements.

Squad Level Tactical Behaviors

Autonomous robotic vehicles interacting with human teammates as part of an integrated squad will require the ability to perform tactical movements and behaviors that support the team's overall mission while enhancing its effectiveness. The objective of this project is to develop and demonstrate a functional set of tactically relevant responses and behaviors that will enable a robotic team member to

perform mission-related tasks in close proximity to humans and in accordance with the squad's TTPs.

Terrain and Object Perception

This effort will develop perception algorithms for recognition and representation of operationally relevant objects and features in the environment. The approach will utilize multi-modal sensing, both passive and active, to enable discernment of specific features from within a complex dynamic environment, including: terrain and landscape features, roads/pathways, people, vehicles, structures, and other features to allow improved autonomous navigation, actions, intelligent decision-making, and behavioral learning.

Warfighter/UGV Team Intent Reasoning and Adaptation

This effort is motivated by the need for autonomous systems to make inferences and apply reasoning based on the dynamic information being continuously received from sensors observing the environment and specifically warfighters with which the system is interacting. The project objective focuses the utilization of advanced perception capabilities to support reasoning about friendly and adversarial activities and intent in dynamic situations with evolving context.

Wingman Platform and Mission Packages

This project will design and develop an autonomous test bed vehicle platform for use in testing, maturing, and demonstrating new autonomy-enabling technologies and payloads related to the wingman robotic squad member concept.

World Modeling and Tactical Path Planning

This effort will investigate the potential to extract higher level knowledge elements from World Model datasets. It will use segmentation and clustering techniques to identify distinct regions, paths, and objects for use in advanced navigation and reasoning solutions.

RDECOM & TARDEC Efforts

AMAS Maturation

This project will improve and advance Driver Warning/Driver Assist (DWDA) technology on the M915A5 platform. Reliable warning and assist functionality is paramount to reach more complex autonomy. Also, base driver assist capabilities are warfighters' first exposure to robotics on TWV fleet and robust be-wire actuation is necessary for successful Soldier testing and evaluation.

Autonomous Ground Resupply

Tactical Resupply has two objectives: to develop advanced autonomous behaviors to conduct long range, off-road, extreme terrain supply missions to small units and integrate RTK architecture into AMAS vehicle to provide a standard framework for development and to implement the software across GVR programs. This will merge AMAS capabilities with DSAT(RTK) capabilities.

Autonomous Robotics for Installation & Base Operations (ARIBO)

ARIBO is a strategic initiative to accelerate the adoption and use of intelligent ground vehicle systems for military and commercial applications utilizing a systems approach to link technology with real-world operational settings for use and experimentation in semi-controlled environments.

Multi-UGV Extended Range Experiment (MUER)

The MUER experiment is an S&T demonstration of an autonomous ground vehicle, controlled beyond line of sight, which deploys GVR Bots. It

will influence UGV ICD/CDD/CPD requirements development. It will also develop autonomous algorithms for traversing unexplored routes, with limited map data and limited user interventions.

Sensor Protection from Lasers

The goal of this project is to improve and adapt sensor protection technologies to a variety of platforms as well as develop new materials/devices/strategies for countering advanced laser threats. Other objectives include reduction of optical cross-section, minimization of jamming and dazzling, and overall increase in damage thresholds.

5.2.2.4 Weight Reduction

Weight reduction is an aspect of lightening the MAGTF. This is a significant challenge and every pound counts. Equipping trucks with auxiliary power sources, for instance, can save a generator and potentially reduce the load by 300 pounds. More efficient engines would help reduce fuel demands.

The Marine Corps has legitimate concerns about vehicle weight and size. According to Expeditionary Force 21, meeting the Geographic Combatant Command demand for amphibious forces requires an inventory of 40 amphibious ships. The Marines Corps' naval requirement of 38 was developed for a capability for forward presence, crisis response, and forcible entry operations. With a current inventory of 30 operationally available ships, the Marine Corps will be compelled to assess how to mitigate that risk through inventive integrations and employment of alternative naval platforms and land basing. For the future, the Marine Corps must assess its current vehicles, vehicle upgrades, and equipment in terms of weight, size, and modular capability sets. Advanced capability and system upgrades will necessarily address weight up front.

The Challenge

Successful weight-reduction efforts will generate benefits including expanded range, superior mobility, increased energy efficiency, and greater speed. The challenge is to implement weight-reduction measures that are affordable and that will not degrade survivability nor reduce reliability.

Potential Solutions

ONR Efforts

ACV-Scale Light Armor Design

This project will use knowledge from previous ONR programs to develop, fabricate, and test light- armor systems for ACV threats.

Bulk Metallic Glass

This effort will investigate and exploit Bulk Metallic Glass as a key component within a light armor system.

Flawless glass

This initiative will further develop the methodology to produce flawless glass as part of a transparent armor system. Reducing surface flaws can increase performance of the transparent armor systems by more than 10%, thereby allowing for a reducedweight armor system.

Lightweight Materials

This ONR project will investigate lightweight materials for armor applications for Marine Corps platforms (i.e., ACV and JLTV Objective).

Lightweight Vehicle Exhaust for Amphibious Vehicles

This ONR SBIR will evaluate the exhaust systems for Amphibious Vehicles and develop a lightweight alternative.

Transparent Armor Polymeric Materials

The purpose of the Transparent Armor Polymeric Material project is to investigate novel Transparent Armor technologies using composite technology that reduce weight and improve multi-hit performance.

RDECOM & TARDEC Efforts

Affordable Lightweight Materials / Structures (ALMS)

This project will demonstrate best practices in cost-conscious, multi-material design for hull/ structures to reduce ground vehicle weight. It will use and evaluate design tools, advanced materials, manufacturing, and assembly technologies to develop a lightweight hull/structure and enhance core competencies. It can support a demonstrator weight savings of approximately 20 -30% over ground combat vehicles' baseline and can evaluate the current technical capability of the material supply chain. The funding and timeline information can be found in the M&S section.

Lightweight Campaign

The Lightweight Campaign will demonstrate best practices in cost-conscious, multi-material design for components to reduce ground vehicle weight. It will also use and evaluate design tools, advanced materials, manufacturing, and assembly technologies to develop lightweight components and enhance core competencies and develop a weight informed design optimization process / architecture for the Army. It will execute the Lightweight Combat Vehicle Science & Technology Campaign (LCVSTC) recommendations to enable future vehicle weight savings of 25 - 50% and evaluate the current technical capability of the material supply chain & inform future investments.

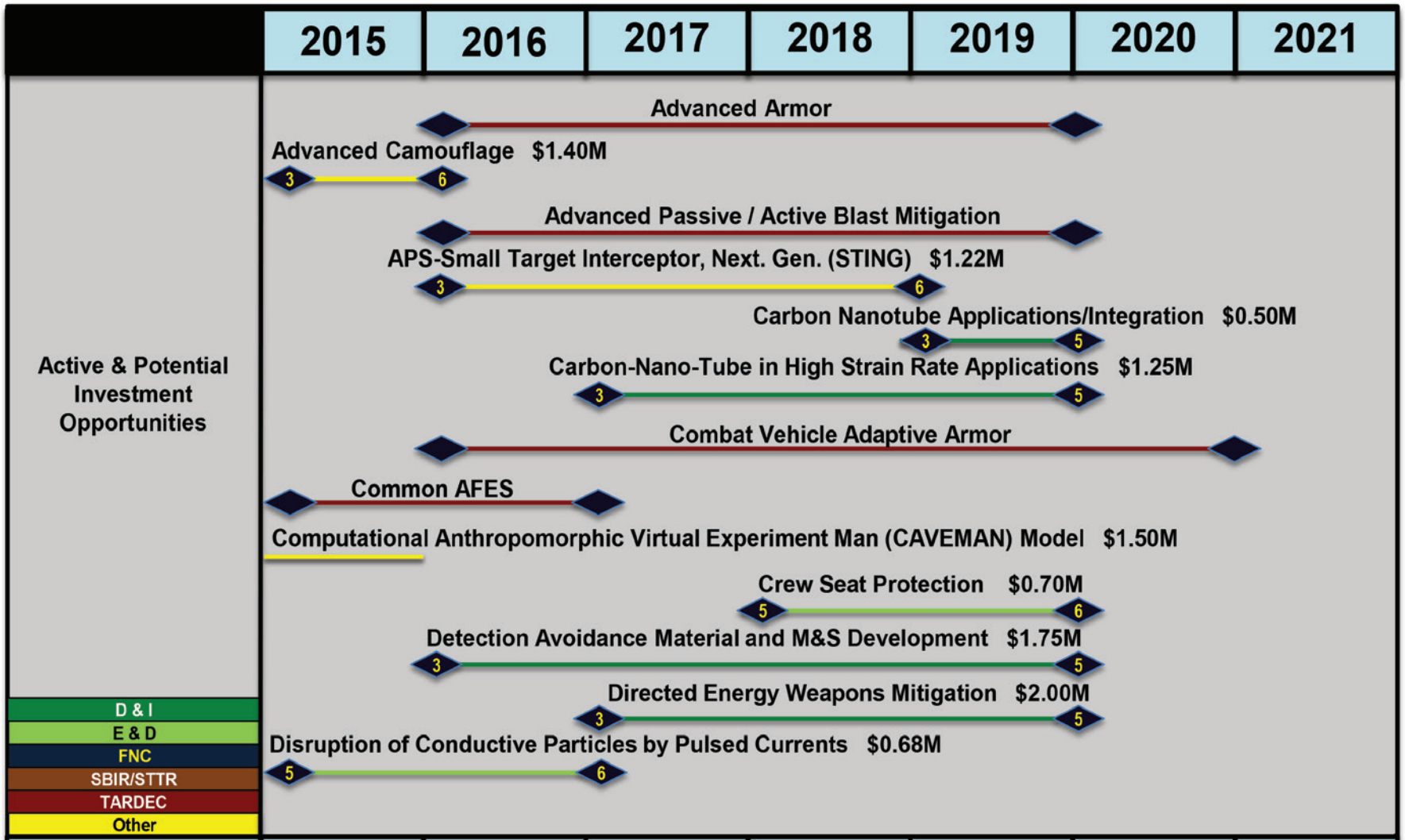
SBIR Efforts

Modular Lightweight External Fuel Tank System

The objective of this effort is to design and develop a lightweight, modular fuel tank that can withstand hydrodynamic ramming forces. The tank must also provide protection against a ballistic impact from a 14.5mm armor-piercing projectile using a multi-layer laminate design that achieves a significant reduction in weight compared to existing systems. A lightweight, modular fuel tank would reduce the power and fuel requirements for an amphibious vehicle, while mitigating fire issues and increasing freeboard.

The Survivability & Mobility Focus Area charts on the following pages highlight critical efforts monitored and supported by the PEO LS S&T Director.

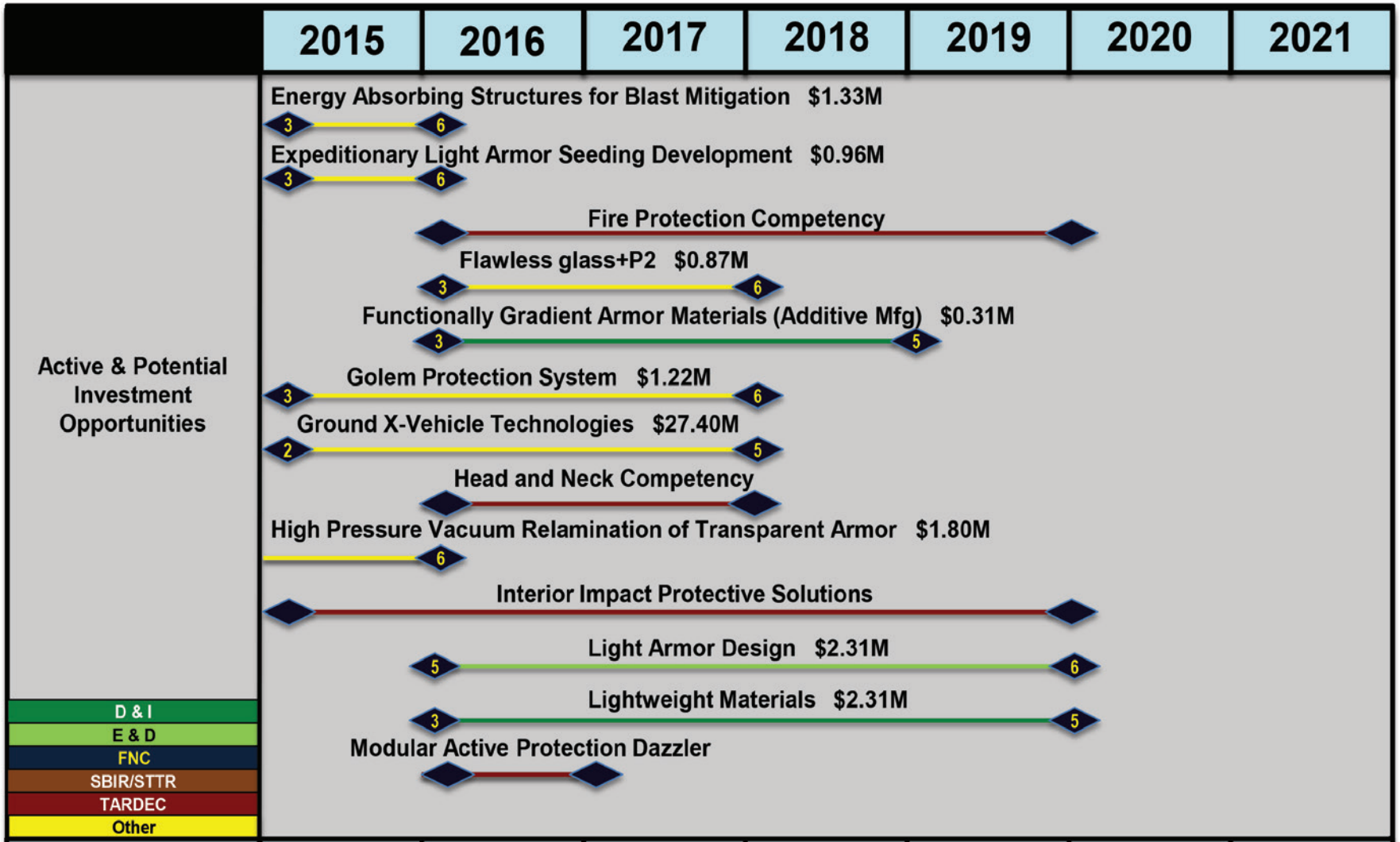
Survivability



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	2.80	44.24	51.08	59.12	52.26	3.26	

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

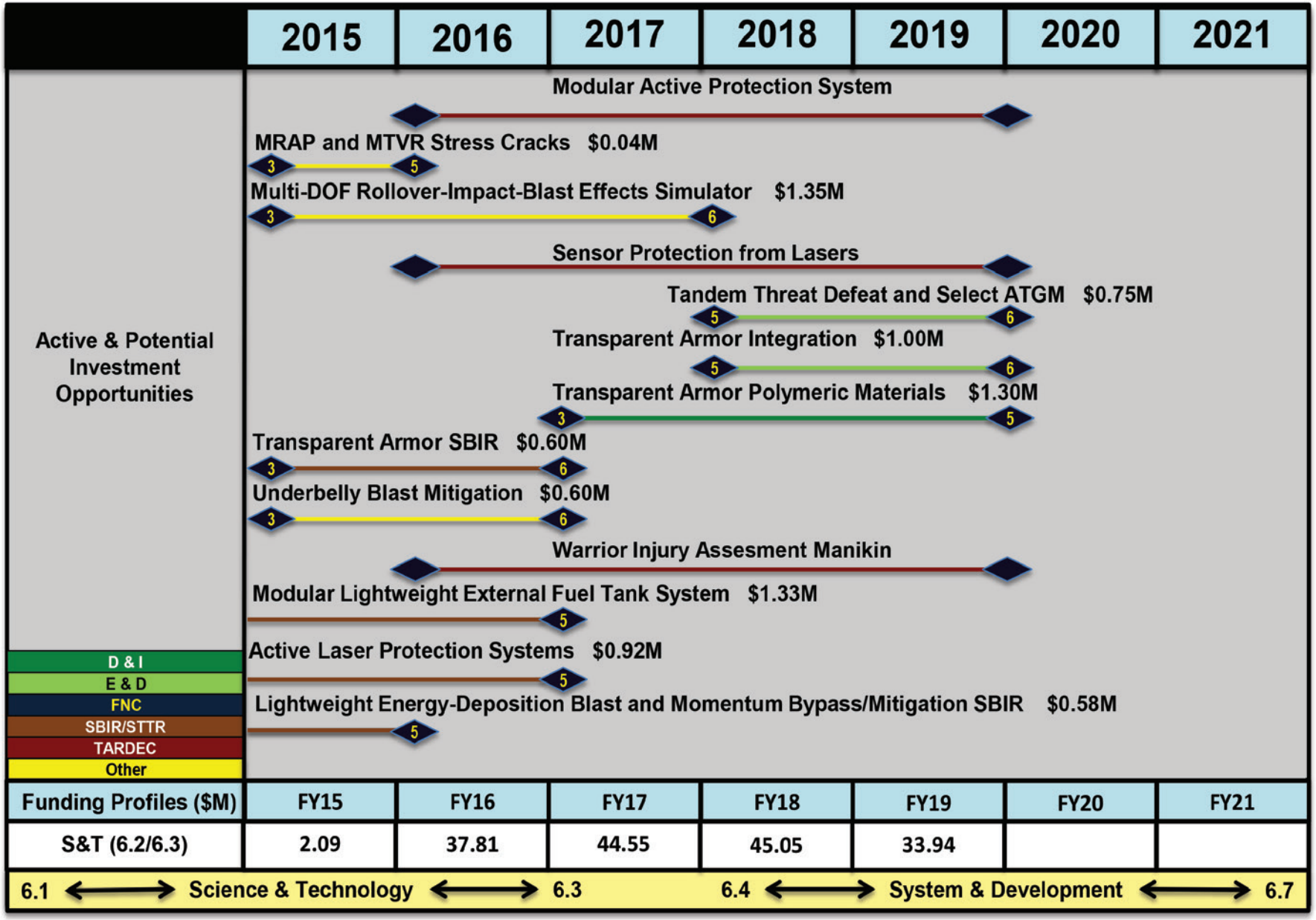
Survivability



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	9.89	20.06	12.24	2.83	3.12		

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

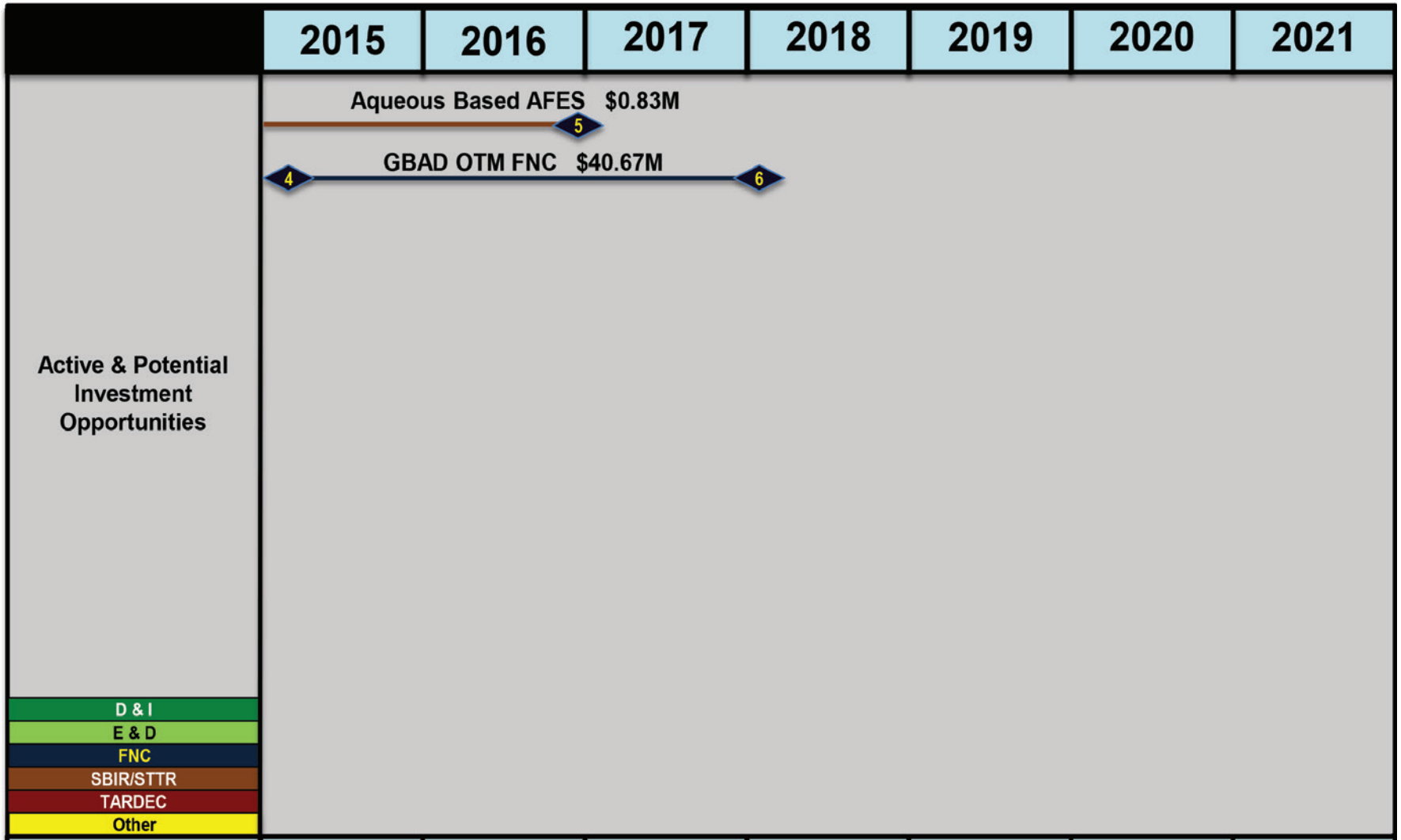
Survivability



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	2.09	37.81	44.55	45.05	33.94		

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

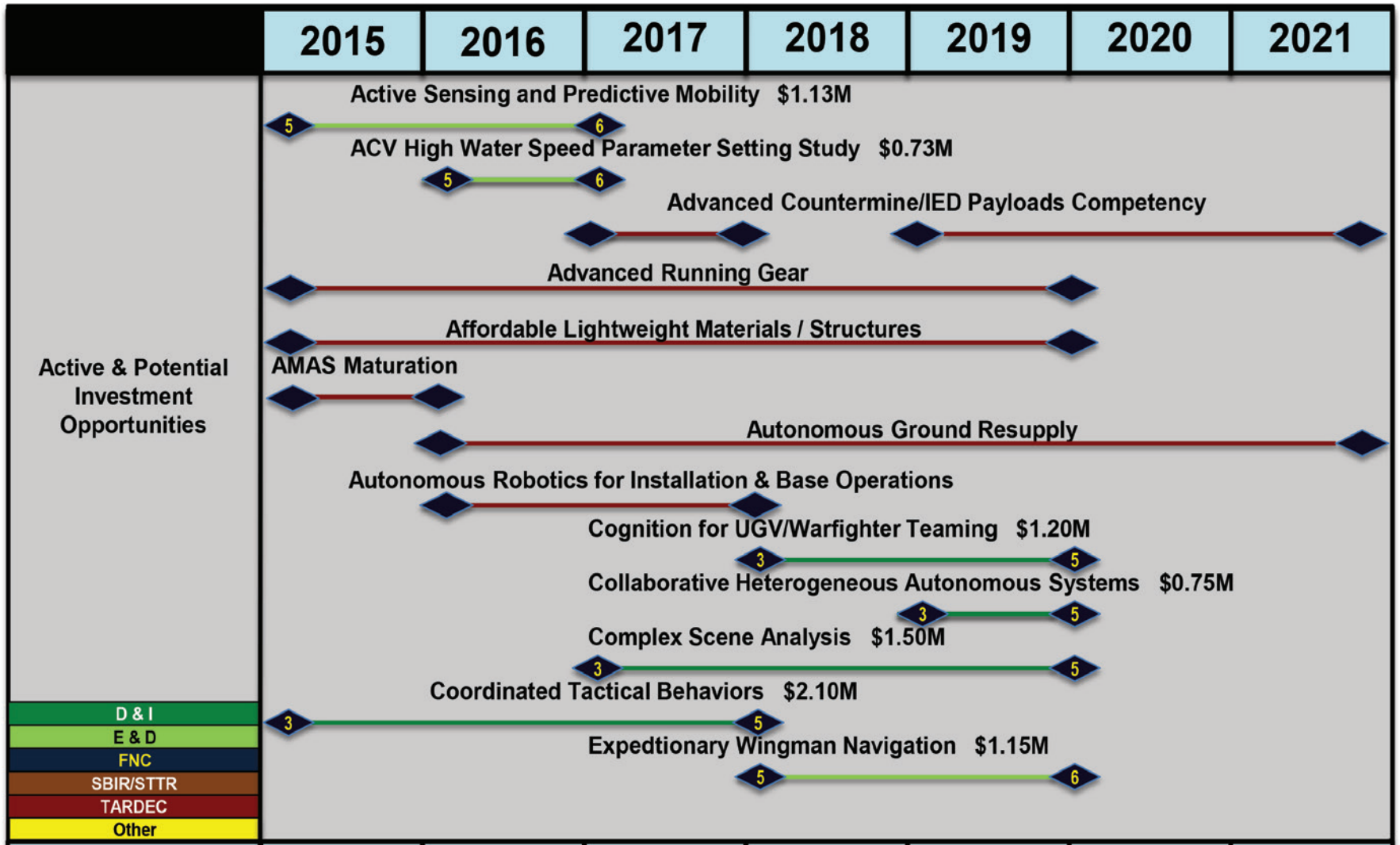
Survivability



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	9.85	6.25	5.81				

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

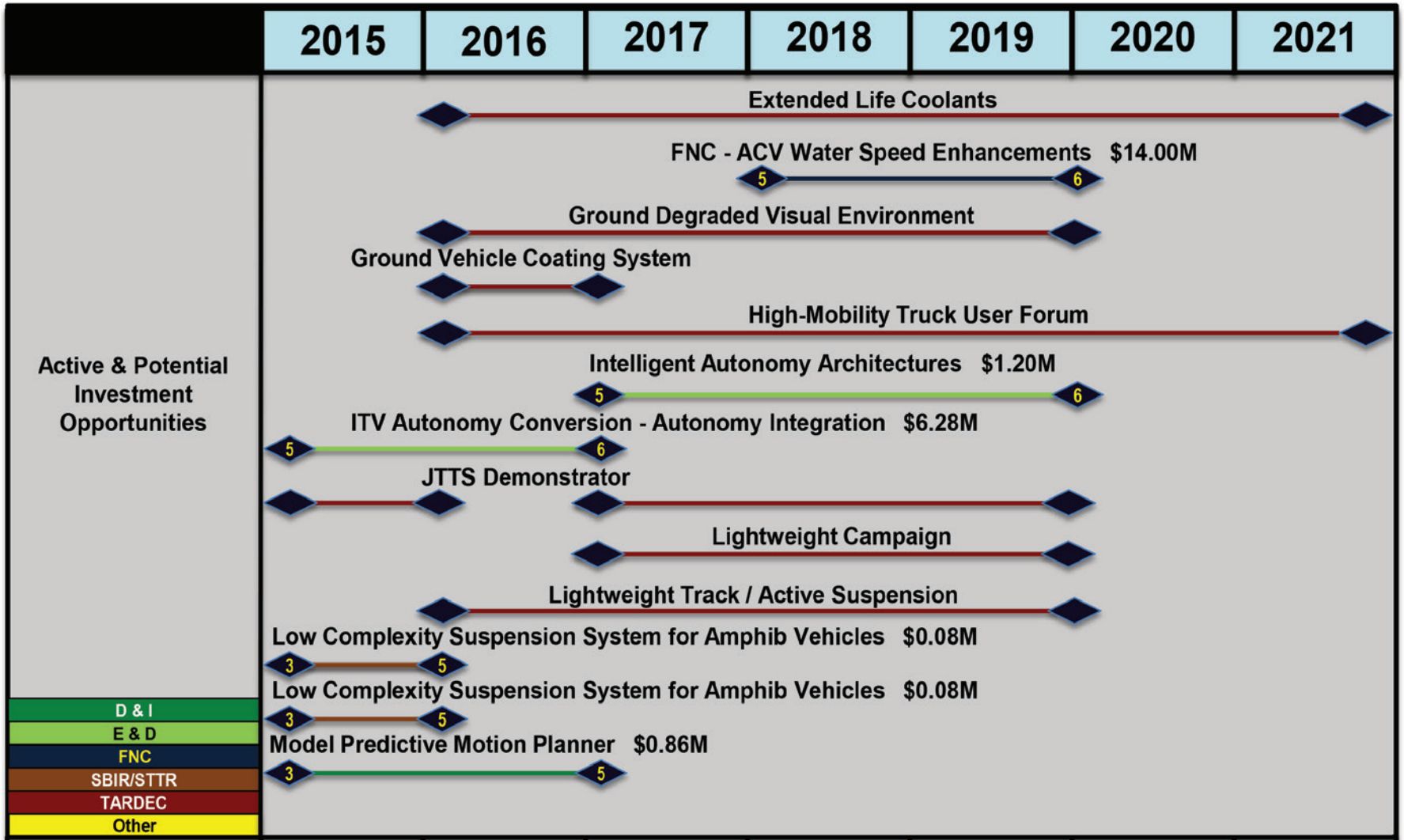
Mobility



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	19.21	34.47	48.25	46.97	38.42	28.58	28.57

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

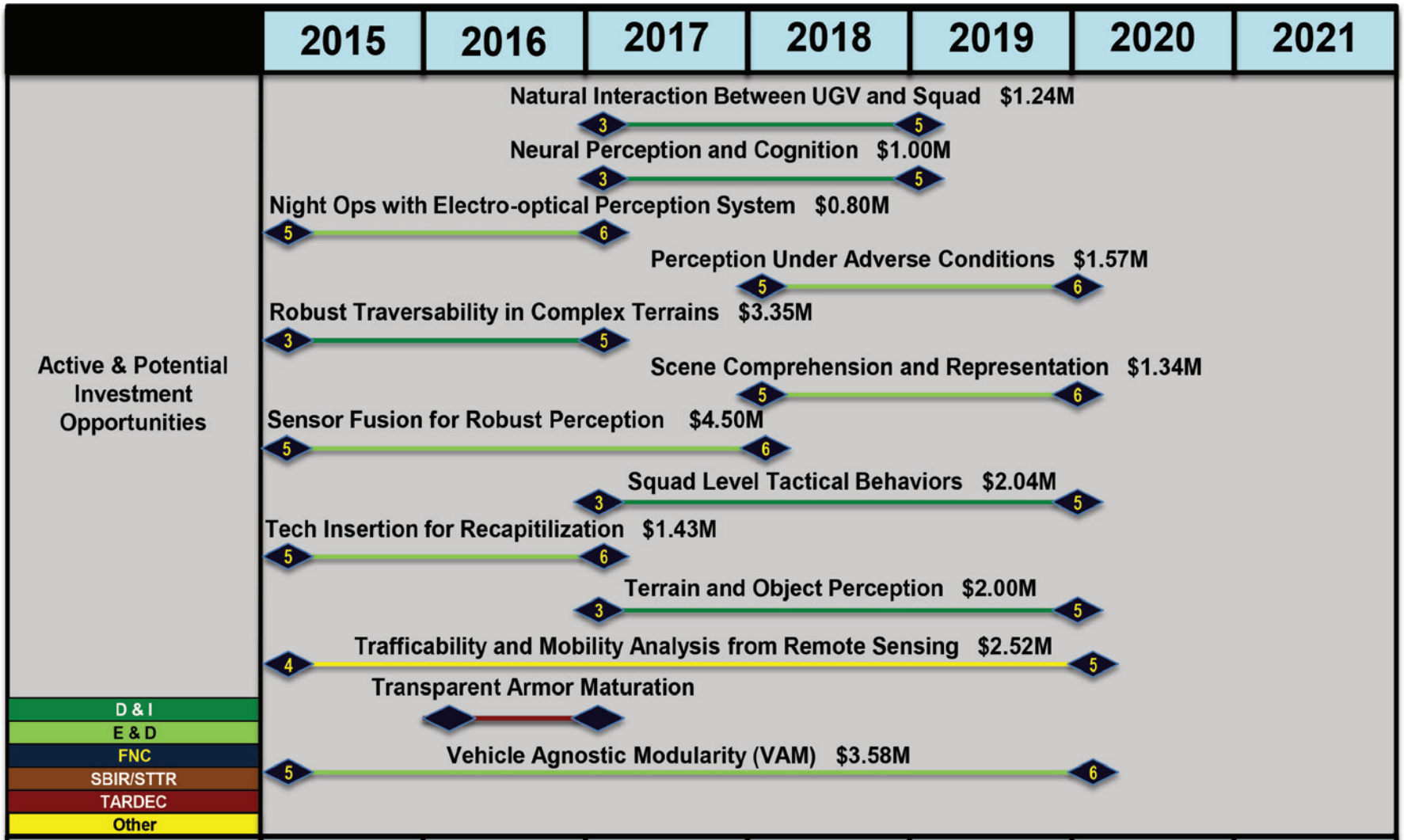
Mobility



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	3.84	18.93	24.38	29.77	28.43		

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

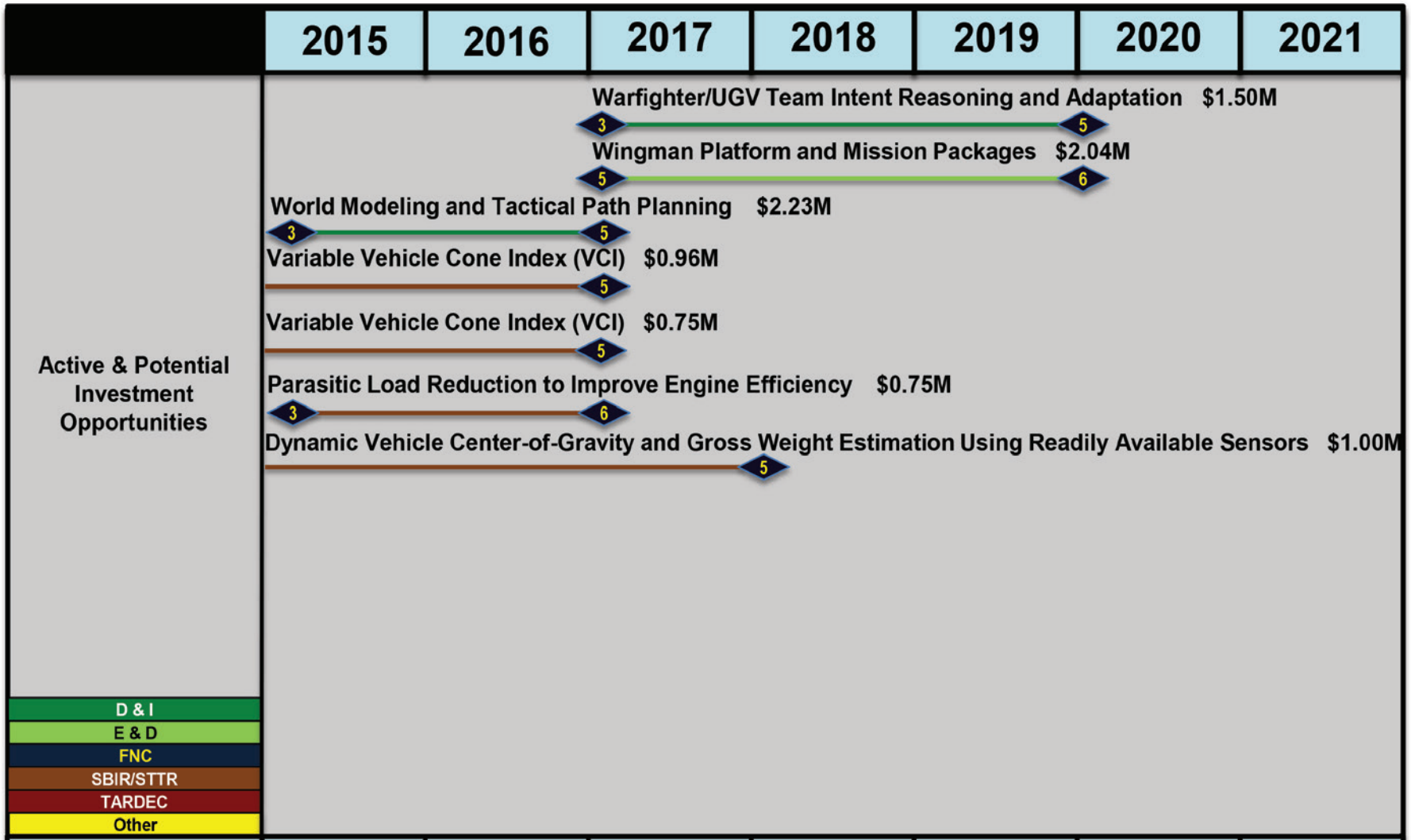
Mobility



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	4.40	5.89	4.35	4.41	4.21		

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7

Mobility



Funding Profiles ($M)	FY15	FY16	FY17	FY18	FY19	FY20	FY21
S&T (6.2/6.3)	1.92	1.71	1.38	1.18	1.18		

6.1 ⟷ Science & Technology ⟷ 6.3 6.4 ⟷ System & Development ⟷ 6.7