A Summary on the 2018 Update to Lightweight Combat Vehicle S&T Campaign (LCVSTC)

Robert Hart[1], Ravi Thyagarajan[2], Daniel O'Brien[3], Andrew Littlefield[4], Mark Robeson[5]

[1]US Army Combat Capabilities Development Command Ground Vehicle Systems Center

[2]US Army Futures Command Directorate of Systems Integration

[3]US Army Combat Capabilities Development Command Army Research Laboratory

[4]US Army Combat Capabilities Development Command Armaments Center

[5]US Army Combat Capabilities Development Command Aviation and Missile Center

Abstract

The need of the Army to be more lethal, expeditionary, and agile, with greater capability to conduct operations that are decentralized, distributed, and integrated is as critical today as ever. The impact of weight on its ability to achieve a combat vehicle force with smaller deployment, employment and sustainment footprints is a well-recognized and accepted fact. Threats continue to grow at a fast pace, and advanced capabilities like Active Protection Systems are being added to combat vehicles to counter them. Today, there is an urgent need to add performance at the lightest weight possible, as well as find weight reduction opportunities elsewhere in the vehicle to counter the weight added by these new countermeasures. Lightweighting is a cross-cutting competency across all of the Army's six modernization priorities, including the Next Generation Combat Vehicle's objectives in close combat capabilities in manned, unmanned and optionally-manned variants, and ability to fight and win against any foe.

Motivation:

The Lightweight Combat Vehicle Science & Technology (S&T) Campaign (LCVSTC), originally published in Oct 2014 [1, 2], and the recommendations therein, have been re-visited considering the current Army priorities and the ensuing progress of the different Army technology programs over the past 4 years. A core team of Combat Capabilities Development Command (CCDC) subject matter experts, including some of the contributors to the original campaign, convened in 2QFY18 with the primary objective to address the following six essential focus areas:

1. The Relevance of Lightweighting With Respect to New Army Priorities
2. Barriers to Army ground vehicle lightweighting
3. Progress updates to the 92 lightweighting-relevant S&T programs listed in 2014
4. Discussion on recent technologies, both in materials science and non-materials science areas
5. Updates to the weight projections of the 2030 MBT and IFV combat vehicles
6. Revisiting the recommendations and making modifications/additions, as necessary

Section 1: Relevance of Lightweighting With Respect to New Army Priorities

The need of the Army to be more lethal, expeditionary, and agile, with greater capability to conduct operations that are decentralized, distributed, and integrated is as critical today as ever. As the Army modernizes, S&T programs focus on supporting the following six modernization priorities, shown in Figure 1.

Figure 1: Army Modernization Priorities [3]

Lightweighting is a cross-cutting competency across all of the Army's six modernization priorities, including the Next Generation Combat Vehicle's (NGCV) objectives in close combat capabilities in manned, unmanned and optionally-manned variants, and ability to fight and win against any foe. The impact of weight on its ability to achieve a combat vehicle force with smaller deployment, employment and sustainment footprints is a well-recognized and accepted fact. Threats continue to grow at a fast pace, and advanced capabilities like Active Protection Systems (APS) are being added to combat vehicles to counter them. Today, there is an urgent need to add performance at the lightest weight possible, as well as find weight reduction opportunities elsewhere in the vehicle to counter the weight added by these new countermeasures.

While it has always been understood that weight impacts mobility, and in turn survivability and combat effectiveness, the Combat Capabilities Development Command Ground Vehicle Systems Center recently published a study that successfully quantified the magnitude of its effect [4]. This study demonstrated that vehicle weight has a far greater impact on combat effectiveness than previously known. The Chief of Staff of the Army (CSA) also released a time-based approach for all the 6 priorities, including NGCV, which addresses combat readiness and selective upgrades, continuous S&T/Research and fielding new family of combat systems in the Future Army. *Readiness initiatives*, *Selective upgrades* (Abrams – Rolled Homogenous Armor replacement by lightweight steel alloy, Active Protection), *S&T* (Advanced Materials, Manned-Unmanned Teaming (MUM-T) experimental prototypes, Protection for autonomous vehicles), and *Research* (Beyond Novel Materials, Integrated Computational Materials Engineering (ICME)/Machine Learning methodologies to develop "Materials-by-design") play a crucial role to play in

every aspect of the NGCV, and is integral to the underlying objectives of that and other Army modernization priorities:

Specifically in reference to the NGCV, lightweighting is a critical enabler to achieve the aggressive objectives of the program in a shortened timeframe. This was echoed by LTG Murray in a meeting with lawmakers on the Senate Armed Services Committee's Airland subcommittee in Feb 2018 [5], where he said: **"Integrated active protection, enhanced lethality and lighter weight would also be highly valued in the NGCV."**

While the original LCVSTC campaign was kicked off initially to respond to a Training and Doctrine Command (TRADOC) challenge of a 35 ton MBT / 30 ton IFV combat vehicle by 2030, the strategy developed therein and the ensuing recommendations are equally well aligned with the Army's latest modernization priorities.

Lightweighting continues to be a critical enabler to achieve successful execution of the Army's priorities in the ground combat vehicle domain. If anything, based on senior Army leadership guidance, its role in the achievement of the near-term, mid-term, and far-term objectives of the NGCV and other modernization priority programs has only been bolstered in the current environment.

Independent of the NGCV program outcomes, including which combat vehicles in the current fleet the NGCV eventually replaces, there is no question that the overarching principles and science of lightweighting will be paramount in ensuring that the vehicle:

- is agile, expeditionary, more easily transportable, and lethal;
- has overmatch capabilities to conduct operations that are decentralized, distributed, and integrated;
- uses autonomous capabilities (full or autonomy-enabled), artificial intelligence and manned-unmanned teaming for decisive overmatch proficiency
- has smaller deployment, employment and sustainment footprints.

While lightweighting is an important competency across all of the six modernization priorities, pertaining to combat vehicles, lightweighting is most closely aligned with the Next-Generation Combat Vehicle.

Section 2: Barriers to Army Ground Vehicle Lightweighting

Significant effort and resources have been invested in S&T technologies in order to reduce weight [6]. Some of the examples of these are Abrams Weight Reduction Study (1986, 2017), Composite Infantry Fighting Vehicle – CIFV (1989-91), Composite Armored Vehicle – CAV (1995-1999), CAV-Integrated Hybrid Structure CAV-HIS (2000-2009), Advanced Reconfigurable Spaceframe – ARES (2004-09), Crusader Turret Material/Design Study (2004-08), Ultra-Light Vehicle – ULV (2012-15), Lightweight Vehicle Structure Multi-material Turret program (2012-17), etc. For a variety of reasons, in spite of demonstrating that significant weight savings could be achieved, most of these have not been able to cross the valley of death and transition into the acquisition world.

Some of the most pronounced barriers and impediments that have prevented transition into acquisition and to the actual realization of significant weight savings in combat vehicles are listed below.

- Costs associated with lightweighting technology insertion are not budgeted for
- Weight is not accorded the same primary focus as performance, payload and price, and often gets easily traded away in favor of the others
- Overall risk averseness and over-specification of requirements
- Reluctance to consider changes required in concept of operations/doctrine and over-reliance on materials technologies alone
- Physical testing required at the system level prior to fielding
- Lack of detailed Technical Design Package (TDP) data to allow for implementation of systematic modeling and simulation methodologies
- Lack of financial incentive for contractors/primes to reduce weight

Section 3: Progress of Lightweighting-Relevant Programs

Of the 70 funded programs considered in the original campaign, 16 programs actually saw an increase in funding since 2014, while 6 saw a reduction (Table 1). At the same time, 14 of the 22 unfunded programs remain unfunded, including some mature technologies as the XM360/XM360E1 gun program, which has significant potential in reducing the weight of the Abrams weapon system by 30%, or more than 2000 lb. Fully two-thirds of the funded programs are expected to either have measurable weight savings on an absolute or “performance-normalized” basis. The concept of performance-normalized weight savings is important in the lightweighting conversation, because it provides a constant benchmark that can be used for comparing technologies that have been developed based on different requirements. For example, the Advanced Combat Engine (ACE) will produce 1000 HP, compared a baseline Bradley engine at 675 HP. Though the ACE will weigh 38% more than the Bradley engine, the ACE provides 48% more power. On a performance normalized basis, the technology in the ACE provides an estimated 7% weight reduction over the older technology in the Bradley engine. This concept of weight-efficiency is crucial when implementing lightweighting technologies in an environment requiring constantly-increasing performance. In addition to the continued programs, 17 new lightweighting S&T programs have been initiated and funded since 2014, some of which were funded based on recommendations from the 2014 Campaign.

One such example is the Operational Metrics program which has started quantifying the effects of combat weights on operational effectiveness [4], to directly answer the question “Why Lightweight?” Similar to the Metrics program, the Ground Vehicle Loads program was funded and spawned entirely as a result of the 2014 Campaign. The purpose of this program is to acquire design loads for combat vehicles in order to develop design guides and a generic vehicle design model for design optimization. The Combat Vehicle Prototype (CVP) Armor, Blast and Hull programs are designed with a 10-20% weight reduction over current technology, while also providing a significant increase in survivability. The Advanced Lightweight Running Gear program, another program funded

after the 2014 campaign, is projected to reduce weight by 950 lb in the Abrams running gear, using shape optimization and other methodologies recommended by the campaign.

Table 1: Lightweighting Program Statistics as of March 2018

Total Programs from 2014 LCVSTC	**92**
# of 2014 programs with increased funding, and lengthened schedules	16
# of 2014 programs with reduced funding	6
Unfunded Programs that were never funded	14
Unfunded Programs that were later funded	8
New Programs since 2014 LCVSTC	**17**
Total 2014 LCVSTC + New	**109**
% estimate of programs with measurable weight savings	58%
% estimate for programs with performance-normalized weight savings (Weight efficient)	9%
% enabling technologies/other	33%
% with planned transition to S&T	24%
% with planned transition to POR	42%

Section 4: Discussion on Recent Technologies

Of the different advanced technologies in the recent past, Additive Manufacturing (AM), by virtue of its innate ability to produce designs that cannot be manufactured by traditional methods, offers unique advantages from a lightweighting aspect. AM further enhances and offers enormous leverage to the design/topology optimization methodology toolset in its ability to perform an upfront, integrated design and manufacturing approach. For this reason, it is important for Army lightweighting activities to be closely connected and leveraged with the Army's Additive Manufacturing campaign currently in progress. Figure 2 displays a broad vision for the future of AM in the Army.

Autonomous vehicles, crew augmentation/reduced task loading, fire team vehicles, and advanced armament systems offer distinct advantages with non-material science related technologies to reduce combat vehicle weights. Combined with complementary technologies such as advanced sensors, modular and active protection etc., non-material science technologies offer some of the most promising opportunities for the lightweight combat vehicles of the future, with the understanding that some accompanying changes in concepts of operations will also be necessary to enable a holistic implementation. One such non-material science approach is the Mission Enabling Technologies – Demonstrator (MET-D).

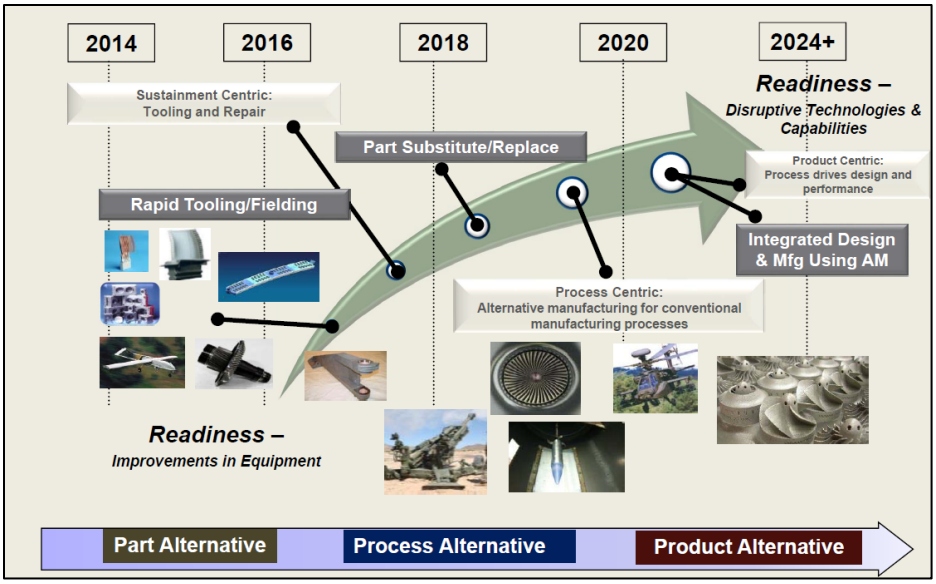

Figure 2: Broad vision / Roadmap for AM in the Army

This concept represents a paradigm shift in IFV concept of operations by using fire team vehicle designs. It embraces a networked two-vehicle concept, leveraging existing communication technologies enabling the Squad Leader to effectively communicate and interact with both fire teams virtually. This allows the squad to operate mounted as it does dismounted, by fire team, augmenting overall squad freedom of maneuver and fires capabilities. The initial concept (Phase 0) was demonstrated successfully in June 2015 in Fort Hood, TX on both the interconnected communications and 360 situational awareness aspects. In Phase 1, the technical demonstration will also include improved closed hatch operations (driving, target detection), integrated unmanned/remote turret, as well as reduced crew task loading (2 man crew objective) arising from innovative crew station designs. In this Phase 1 operational experiment, soldiers will be able to evaluate these upgraded technologies and compare their effects against current concept of operations.

As before, in this concept of effective distributed operation centered around fire team vehicles, the number of crew and position directly impacts vehicle size and weight, with weight benefits due to the reduced under-armor volume effects. Just the armor weight reduction per foot of reduction in the length of the vehicle can lead to 1.5 tons of weight savings, not to mention other weight reductions due to smaller crew, engine/transmission size, etc.

Section 5: Updates to the 2030 Weight Projections

Clearly the original goals of the 35 ton Main Battle Tank (MBT) and 30 ton Infantry Fighting Vehicle (IFV) combat vehicles by 2030 were meant mostly to challenge the S&T community to develop tools, methodologies and processes for lightweighting ground vehicles. Today, it is not clear that the future combat vehicles will look at all like the ones

of today, and certainly will not be restricted to the performance capabilities of the 2014 benchmark Abrams and Bradley vehicles. Therefore, it must be recognized that these numerical weight goals, as defined, at best serve as benchmarks towards enabling a good projected comparison in the planning for lightweighting technologies, and tracking the progress towards those targets. Based on the progress and plans of the three main contributing factors, namely, (i) lightweighting S&T programs, (ii) ongoing materials research, and (iii) design/topology optimization efforts, with complementary support from additive manufacturing to further enable design optimization methodologies, the team believes that there is no need revise these estimates (Table 2) based on the data available at this time. Figure 3 shows an alternate breakdown of the project weight savings estimates, by general S&T category. **Over three-fourths of the projected weight savings would come from material science and design optimization.**

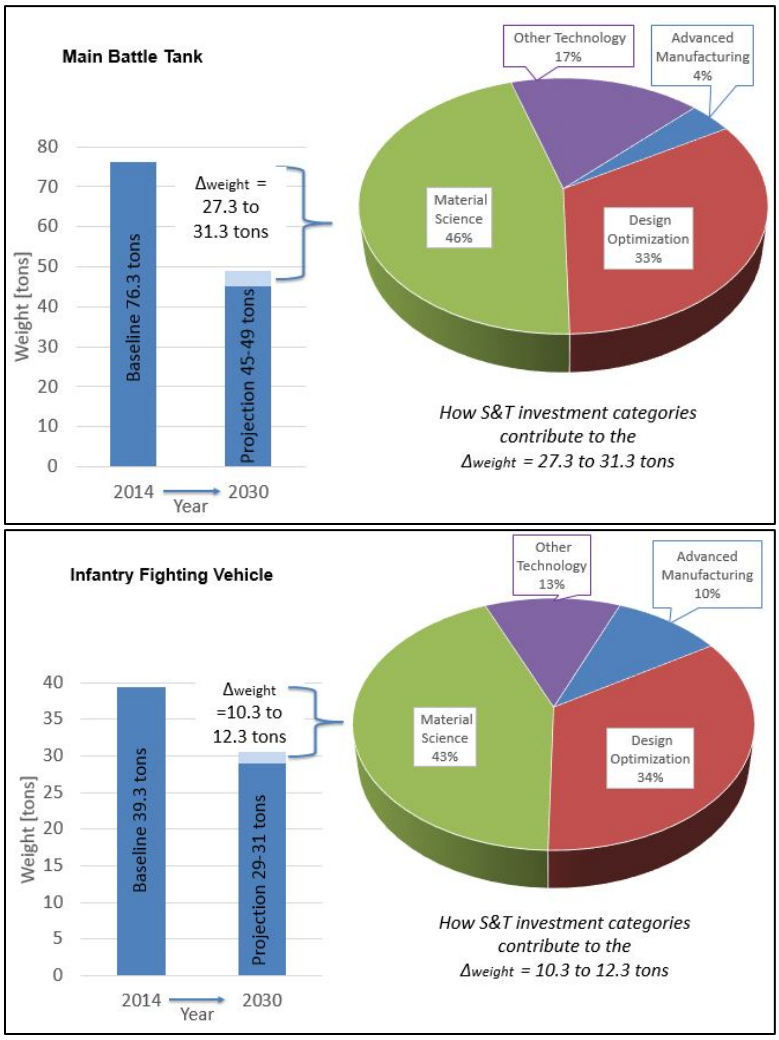

Figure 3: Contributions of Major Lightweighting S&T Investment Categories (Materials Science, Design Optimization, Advanced Manufacturing, and Other Technology) to Projected Weight Savings by 2030 (MBT, top), (IFV, bottom)

Table 2: Weight estimates by 2030 of MBT and IFV based on full funding of all recommended programs

Description	Tank Capabilities	IFV Capabilities
Hull	29,988 – 32,422	26,139 – 28,016
Suspension	6,081 – 7,283	9,219 – 9,833
Power Plant & Drivetrain	8,261 – 8,813	5,262 – 5,606
Auxiliary Automotive	3,360 – 3,601	3,474 – 3,695
Turret	31,738 – 34,195	5,033 – 5,408
Fire Control	1,835 – 2,024	2,490 – 2,538
Ammunition	3,218 – 3,407	2,185 – 2,313
Other Vehicle Equipment (OVE)	3,076 – 3,251	1,267 – 1,335
Crew	836	2,200
Fuel	2,286 – 2,438	995 – 1,061
Gross Vehicle Weight (lb)	**90,679 – 98,270**	**58,264 – 62,005**
(Tons)	**45.3 – 49.1**	**29.1 – 31.0**

Section 6: Revisiting the Recommendations of the 2014 Campaign

Generally speaking, after a detailed analysis of all the available data described in this report, the consensus from the core CCDC team is that, by and large, the original recommendations stated in the 2014 Campaign remain valid and applicable. Some of the more relevant recommendations from this update are as follows:

- Funding shortfalls to the originally proposed investments must be made up, or else the estimated long-term potential savings targets will not be met.
- The well-known barriers to lightweighting continue to persist, and need to be overcome both from a cultural and technical viewpoint in order to make the required large strides in lightweighting.
- The Army should continue to identify and evaluate disruptive technologies and philosophies involving potential changes to concept of operations such as remotely controlled autonomy-enabled vehicles, fire team vehicles, 2-man crew/task augmentation, etc. These and other non-material science approaches hold great potential, and it is as true today as ever that weight reduction of combat vehicles is not just a material science issue.
- Computational lightweighting methodologies need to be enforced and implemented at the lowest component design levels (usually contractor) in acquisition, not just in Army S&T programs, demonstrators and experimental prototypes.
- Special efforts should be taken to coordinate with the AM Campaign and implementation. AM provides an expanded dimension to designing and producing unique lightweight geometries, which were not previously producible by conventional manufacturing means.
- Like the aerospace and automotive industries, the government should either own the Tech Data Package (TDP) or at the very minimum, have full access to it for

performing systematic lightweighting activities. This includes full knowledge of the part geometry, materials and if possible, the maximum design loads that each component is required to withstand. A thorough business case of owning the TDPs vs the increased cost needs to be undertaken.

- Efforts to include lightweighting as a disciplined, simultaneous process in clean-sheet S&T programs should be improved. Anecdotal data from program surveys indicate that lightweighting continues to take a back seat to Performance/Schedule, even in S&T programs. For this reason, it is recommended that each CCDC Center have a central engineering activity focused on monitoring implementation and progress of lightweighting in S&T programs, providing guidance and expertise in lightweighting, with team members ideally collocated with the S&T activities.
- The different phases of the NGCV prototyping effort should be used as a golden opportunity to assess material science, design/optimization methodologies as well as non-material science approaches to design lighter weight combat vehicles, with appropriate technologies being incorporated in a spiral manner based on the experimental prototype timeline.

Conclusions

The original Lightweight Combat Vehicle S&T Campaign from 2014 and this current update provide a strategy for a holistic, system-level approach to lightweighting combat vehicles. The Army is fundamentally on the right track consistent with lightweighting methodologies in industry and academia, and the 2014 programs are progressing, but only at a rate consistent with funding. It is necessary to exploit both material science/design as well as non-material science approaches to develop a future combat fleet that is more lethal, expeditionary and agile, capable of fighting and winning against any foe, retaining the mobility to maneuver while protecting our forces. Lightweighting is one of the critical enablers to achieve the objectives of the Next Generation Combat Vehicle as well as other combat vehicles of the future.

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