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A COMPARISON OF STRUCTURAL APPROACHES FOR COMBAT VEHICLES

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ABSTRACT

Since the development of combat vehicles for military use, such as tanks, infantry carriers, gun transports, etc. the main approach has been a monolithic structure that has been described as monocoque. This approach has been the standard-bearer since the inception of modern combat vehicles.

Since the end of the Cold War, the world has become a much more "Multi-Polar" world. The U.S. is not locked in a static, monotonic engagement against the Soviet Union and its allies. The nature of the threat has changed. The U.S. Army is looking to make its Combat Vehicle fleet lighter and more adaptable to new technology and changing environments. By doing so the U.S. will be better able to project forces where they are needed. Lighter weight means more flexibility in transportation of equipment to various locations. In addition, the U.S. Army will be better able to deploy forces that have the latest and/or the most desirable protection required for the specific engagement they may encounter.

The U.S. Army would like to investigate the uses of a space frame, if and where appropriate on their combat vehicle systems. This would be a definite paradigm shift in the development of combat vehicle systems.

This article talks about the misconception that space frames are a "parasitic weight" to the system. The belief is that a monocoque approach is efficient because the material thickness is driven by survivability requirements and not structural requirements. It is said that once you meet the survivability requirement you will have enough structure. Therefore, adding a space frame structure is just adding weight. This article looks to dispel this belief.

Over the last fifteen years, the Army has done several programs that have been able to shed more light on this issue. While it is true in some cases that a space frame would not be efficient, and therefore be adding weight. It is not always true. This article shows the studies and development programs that drive that conclusion.

Space frames offer a potential to reduce weight and increase modular flexibility. By taking a look at studies and developments that, have been done over the last fifteen years we hope to begin the dispelling of the "parasitic" weight myth, and to be able to engage in a more in-depth look at exactly how to use monocoque and space frame structures in a judicious way to make our future vehicles better.

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INTRODUCTION

This article talks about the misconception that space frames are a "parasitic weight" to a military Combat/Tactical vehicle system. The belief is that a monocoque approach is always the most efficient design approach. This understanding is driven by the understanding that the Armor material will provide both the survivability requirements and structural requirements. It is said that once you meet the survivability requirement you will have material to meet the structural requirements. Therefore, adding a space frame structure to address the structural requirements separately is adding weight. This article will explore this debate.

Over the last fifteen years, the Army has done several programs that have been able to shed more light on this issue. While it is true in some cases that a space frame would not be efficient, and therefore be adding weight. It is not always true. This article shows the studies and development programs that drive that conclusion.

Space frames offer a potential to reduce weight and increase modular flexibility. By taking a look at studies and developments that, have been done over the last fifteen years we hope to begin the dispelling of the "parasitic" weight myth, and to be able to engage in a more in-depth look at exactly how to use monocoque and space frame structures in a judicious way to make our future vehicles better.

This paper has a modest goal of presenting evidence that a space frame approach, judiciously used can help increase weight savings on military ground vehicles. By showing cases where the weight savings might occur and providing a convincing rationale, it is the intention to open a discussion. The possibility that space frames can save weight needs to be able to be entertained if the topic is to be properly explored. We will study a detailed trade study that was performed for the Army's Future Combat System (FCS) that looked at this very topic. We will also look at an example of some of the latest armor designs. We will then discuss the scenarios where space frames may make sense.

The trade study, which is the primary focus of this report, was performed under a follow-on effort to the Composite Armored Vehicle (CAV) program. This trade study investigated three types of combat vehicles: an infantry carrier, a Non Line-of-Sight (NLOS) vehicle (indirect fire), and a Beyond Line-of-Sight/Line-of-Sight (BLOS/LOS) (direct fire) vehicle system.

The armor systems that are investigated are composite ceramic armor systems that were first proposed during the CAV program and then further developed as both a monocoque structure and as an appliqué system up until current times.

DISCUSSION

Trade Study Background

The trade study was developed primarily by BAE (formerly, United Defense LP). There were significant contribution by TARDEC and Boeing as well to develop the concepts, the threats, and the decision tree to be used. The significant value of the effort was that it investigated four different design strategies that were to perform to the same requirements. Typically, we have different design philosophies for different vehicles that have different requirements and that requires that any comparison involve a significant amount of interpolation. This study is the closest thing we have to an "apples-to-Apples" comparison. The Army does not have the resources to perform this type of comparison on physical hardware, at least not to the level of fidelity that was performed in this study. The four designs that were studied are as follows:

Monocoque: This approach uses an integrated Structure Armor approach on the entire vehicle platform. The vehicle uses plates to handle the structural loads and provide the base Roll-on/Roll-off (RO/RO) required protection level (Heavy Machine gun).

Space frame: The Space frame approach is a complete space frame for the entire vehicle. The vehicle is armored to the base RO/RO required protection level (Heavy Machine Gun).

Hybrid: The hybrid structure has both monocoque and space frame elements. The lower hull and front upper glacis area is monocoque and the rear upper hull is a space frame. This vehicle is armored to the base RO/RO required protection level (Heavy Machine Gun).

Med. Cannon: A second hybrid structure was also done. This structure is identical to the first hybrid structure, except that the base RO/RO required protection level is increased to a Med. Cannon on the front glacis.

All of these structures are then up-armored to the vehicle's threshold protection level once they arrive at the battlefield. The analyses are done for the vehicle at the full protection level. The analyses involve Finite Element Analysis (FEA) to verify the integrity of each design. It may be important to note that the designs represent only one conceptual approach for each design philosophy. The first three design philosophies all used the same Add-on armor kits. This is due to the same base protection, and the same threshold requirement. This is an idealization. Different philosophies will require different attachment methods. However, keeping attachments equivalent is an excellent way to keep the comparison focused on strictly design philosophy.

Trade Study Results

The overall Trade study results were as follows:

Infantry Carrier Vehicle (ICV)	Hull Bolted Weight (lbs.)	Add-on Survivability Weight (lbs.)	Hull Bolted & Add-on Survivability Weight (lbs.)
Monocoque	10,789	15,966	24,905
Space Frame	11,356	15,966	25,472
Hybrid	10,989	15,966	25,105
Hybrid – Med. Cannon	12,638	14,827	25,615

Figure 1: The various Design weights for the Infantry Carrier Vehicle (ICV)

Non Line-of-Sight Cannon (NLOS - C)	Hull Bolted Weight (lbs.)	Add-on Survivability Weight (lbs.)	Hull Bolted & Add-on Survivability Weight (lbs.)
Monocoque	8,769	32,537	28,346
Space Frame	9,268	32,537	28,845
Hybrid	8,750	32,537	28,327
Hybrid – Med. Cannon	9,598	30,298	26,936

Figure 2: The various Design weights for the Non Line-of-Sight Cannon (NLOS - C)

Line-of-Sight/Beyond Line-of-Sight (LOS/BLOS)	Hull Bolted Weight (lbs.)	Add-on Survivability Weight (lbs.)	Hull Bolted & Add-on Survivability Weight (lbs.)
Monocoque	8,346	30,480	26,586
Space Frame	8,866	30,480	27,106
Hybrid	8,243	30,480	26,483
Hybrid – Med. Cannon	8,861	28,410	25,031

Figure 3: The various Design weights for the Line-of-Sight/Beyond Line-of-Sight (LOS/BLOS)

The hull bolted weight is the weight of the system in its transportability condition. The Hull Bolted & Add-on Survivability Weight is the weight in full fighting position. The Hybrid – Med. Cannon concepts were protected to a higher base level, which is why it is seen, in most cases, that the RO/RO weight is more than the other concepts. However, on the LOS/BLOS configuration the Hybrid – Med. Cannon was actually a lower weight than the more lightly protected complete space frame.

RESULTS

The most important observation is that all the weights are somewhat close across all the configurations. The ICV shows the largest differential at 1849 lbs. This was an increase of 17% from lightest to heaviest for Hull bolted weight. The LOS/BLOS had the lowest increase of weight at 7% of the hull bolted weight.

The important analyses are the areas that had the weight differences between the three similar configurations.

Infantry Carrier Vehicle (ICV)	Monocoque	Space Frame	Hybrid
Sponson (L&R)	304	26	304
Space frame Struts & Nodes	0	1215	200
Mobility Enhancement	252	12	252
Gun Firing Enhancement	0	0	0
Add-On Enhancement	193	62	193

Figure 4: The major weight deltas for the Infantry Carrier Vehicle (ICV)

Non Line-of-Sight Cannon (NLOS - C)	Monocoque	Space Frame	Hybrid
Sponson (L&R)	343	119	343
Space frame Struts & Nodes	0	1321	200
Mobility Enhancement	541	77	322
Gun Firing Enhancement	0	0	0
Add-On Enhancement	193	59	193

Figure 5: The major weight deltas for the Non Line-of-Sight Cannon (NLOS - C)

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Line-of-Sight/Beyond Line-of-Sight (LOS/BLOS)	Monocoque	Space Frame	Hybrid
Sponson (L&R)	336	117	336
Space frame Struts & Nodes	0	1243	206
Mobility Enhancement	135	55	135
Gun Firing Enhancement	309	0	0
Add-On Enhancement	116	2	116

Figure 6: The major weight deltas for the Line-of-Sight/Beyond Line-of-Sight (LOS/BLOS)

An important thing to note is that for the more severe load cases the monocoque required some sort of additional strengthening (such as the LOS/BLOS gun fire), but the space frame did not. However, the additional weight of the space frame was typically more than the monocoque strengthening. The one area where this was not the case was with the LOS/BLOS gunfire loads for the Monocoque compared to the hybrid. Also, There was a slight increase in the weight due to the significant weight enhancements due to the mobility loads of the NLOS-C vehicle, but the overall impact was less than 20 lbs.

CONCLUSIONS

What this study shows is that space frames can be the optimal structural design for handling some of the high impulse loads such as those seen in gunfire or mobility, especially as the loads increase. These concepts show a similar pattern to that seen in the commercial automotive field as well. Smaller road vehicles (with less impulse loads) tend towards the monocoque structure. However, vehicles like NASCAR, off-road, and Baja vehicles (with higher impulse loads) tend to utilize more space frame members. It is important to mention that it will be very unusual to see an actual vehicle system that is completely one design or the other. Each design has its distinct advantage. The designer can judiciously optimize each design methodology to a particular application that will achieve the lightest weight vehicle frame.

RECOMMENDATIONS

The modest goal of this paper was to show some examples of where a space frame design, or design components might be the optimal solution in a military vehicle system. We have shown that certain areas that are seeing high impulse loads, coupled with higher weight may see more benefits from a space frame. However, one area that has not been addressed is how well a space frame design handles a mine blast. This is still an unknown that will need to be investigated.

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