OPTIMISATION STUDY OF HYBRID ELECTRIC DRIVETRAIN FOR 8X8 ARMOURED VEHICLE

Ong Rui Ting[1], Wu Tongyu Belinda[2], Ernie Ang[3], Ng Yi Yang[3], Titus Yeo[3]
[1] CHIJ St Nicholas Girls' School, Ang Mo Kio Street 13, Singapore 569405
[2] Dunman High School, 10 Tanjong Rhu Rd, Singapore 436895
[3] Defence Science and Technology Agency, 1 Depot Rd, Singapore 109679

ABSTRACT

Hybridization of military vehicles has become imperative due to the industrial shift from conventional Internal Combustion Engine Vehicles (ICEV) to Hybrid Electric Vehicles (HEV) and Electric Vehicles (EVs). The Series Hybrid-Electric Drivetrains (HED) offers a solution to the increasing demand for onboard power, fuel economy and silent watch operations. The report aims to propose an engine-generator module to replace the existing ICE and investigate the arrangement of the HED components through the use of model-based engineering on a generic 8x8 armoured vehicle as a reference. Factors such as crew communication, movement, visibility and weight distribution were considered. The report also recommends future considerations such as evolving battery technologies and adaptive space utilisation.

INTRODUCTION

Global market projections indicate that the market for HEV and EV market will reach a size of approximately USD 444.4 billion by 2032 [1] and emphasises on the trend that the automotive industry is moving away from traditional ICEV to meet the increasing demand for HEV and EV. In addition, the advancements in battery technology have improved the battery lifespan, battery capacity, reliability and lowered the cost of battery over the years [2].

Therefore, military have begun attempts to adopt HED in their platforms to exploit tangible benefits to meet its escalating demand for onboard power in military vehicles while enhancing its warfighting capabilities, mobility, lethality, and survivability [3]. In the United States' HMMWV program, notable improvements reported over 3% enhanced fuel economy per 100 km [4], a 10% to 20% fuel economy savings, freeing up of interior space for auxiliary weapons and also reducing logistical burdens [5]. Moreover, military HEV excel in silent watch and mobility missions as its electric-only propulsion mode significantly reduces thermal and acoustic signatures in adversarial territories [6].

AIM

The report aims to propose an engine-generator module to replace the existing ICE and investigate the arrangement of the Series HED components through the use of model-based engineering on an existing generic 8x8 armoured vehicle as a reference.

APPROACH

Selection of Series HED

The key reason for selecting the Series HED is because it has the least system complexity as compared to other existing configurations (such as parallel, series-parallel, complex hybrid) as shown in Figure 1. Series HED also offers an edge in terms of maintainability, flexibility in system configuration and space optimisation which is crucial in decreasing logistics burden on the battlefield. The advantages and disadvantages of the different HED configurations are also evaluated as supporting literature review. Therefore, the Series HED will be used in this study.

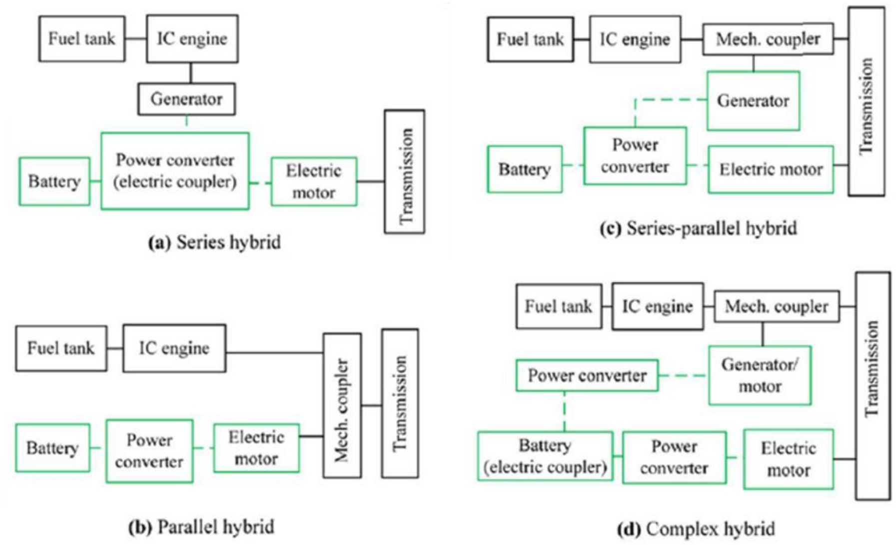

Figure 1: Simplified HED Architectures

Other reasons for the selection of Series HED over other configurations are also tabulated in Table 1.

Table 1: Pros and Cons of Different HED Configurations

S/N	HED Type	Advantages	Disadvantages
1	Series	• Downsized combustion engines reduce space taken up by drivetrains [7]. • Charges batteries while on the move [8]. • Enhances lethality directly [8]. • Batteries can easily size up to fulfil higher demands for power [8].	• The use of larger, more complicated battery packs and motor fulfil vehicle power demands incurs higher costs [7].
2	Parallel	• Automatic change between electric and gasoline power [9]. • Improved fuel economy [10] as electric motors can be used at low power over short distances.	• Complex design of parallel HEDs [10] causes positioning constraints. • Batteries used are too small to allow vehicles to travel over long distances [8].
3	Series Parallel	• Engine operates at near optimum efficiency more often. [7] • More suitable for various driving conditions [11].	• Requires more components to manufacture [7].

Selection of Engine-Generator Module

The engine is then selected based on theoretical calculation of the minimum power rating required of an ICE. The governing power equation to determine the tractive effort for a typical propulsion drivetrain is defined below [12].

$$P_{Peak\ Tractive} = (P_{Series\ ICE} \times E_{Generator} \times E_{Inverter} \times E_{AC\ motor}) + (P_{Battery} \times E_{Inverter} \times E_{AC\ motor})$$

Based on public information available online, the ICE of an existing generic 8x8 armoured vehicle [13] features a Caterpillar Inc. C9 inline-six diesel engine which supplies 450 horsepower [14]. After substituting the conservative efficiency values, the peak tractive power of the vehicle is calculated to be:

$$\begin{aligned} P_{Peak\ Tractive} &= P_{Conventional\ ICE} \times E_{Transmission} \times E_{Driveline} \\ &= 450 \times 0.75 \times 0.99 \\ &= 334.13\ hp \end{aligned}$$

The maximum power rating of the batteries used in our design of 8x8 armoured vehicle is estimated by referencing the power requirement of an All-Electric Combat Vehicle (ACEV) [6]. Assuming a silent watch and silent mobility requirement of 80 kW (in battery mode):

$$\begin{aligned} P_{Battery} &= P_{silent\ watch\ requirement}\ x\ Weight\ Ratio\ of\ ACEV\ \&\ 8x8\ armoured\ vehicle\ Battery \\ &= 80 \times 30000 / 17000 \\ &= 141.18\ \text{kW} \approx 142\ kW\ (rounded\ up) \end{aligned}$$

The calculated power rating and estimated energy storage capacity of the battery for the 8x8 armoured vehicle is 142 kW and 72 kWh [6] respectively.

Upon substitution of the values above together with the conservative efficiency values [15] of respective components,

$$\begin{aligned} P_{Peak\ tractive} &= (P_{Series\ ICE} \times E_{Generator} \times E_{Inverter} \times E_{AC\ motor}) + (P_{Battery} \times E_{Inverter} \times E_{AC\ motor}) \\ 334.13^{1} &= P_{Series\ ICE} \times 0.90 \times 0.95 \times 0.85 + 190.43 \times 0.95 \times 0.85 \\ &= P_{Series\ ICE} \times 0.72675 + 153.77 \\ P_{Series\ ICE} &= 248.17\ hp \\ &\approx 249\ hp\ (rounded\ up) \end{aligned}$$

Therefore, the minimum power rating required of an ICE is calculated to be 249 hp. Premised on power rating requirement and size, the Caterpillar series engines were assessed to be

---

[1] Assumed an efficiency factor of 0.75 and 0.99 for transmission efficiency and driveline efficiency respectively on the existing engine power output of 450hp.

unsuitable. The Cummins ISB6 engine was then chosen over the Cummins QSM engine due to its smaller size while still meeting the required horsepower rating of 249hp.

Based on compatibility [16][17] and having the highest power rating than that of the engine, the Dana TM4 SUMO HP (HV2500-6P) generator is then selected to provision for potential future growth in power demand. Refer to Appendix A for the list of engine and generators considered. The final engine-generator module configuration selected is the Cummins ISB6 engine coupled with Dana TM4 SUMO HP (HV2500-6P) generator.

Selection of Battery System

The battery is selected largely based on energy density and the securing method used. Figure 2 illustrates how multiple batteries can be secured together. After comparing various commercially available Li-ion batteries manufactured by top global brands, a cylindrical type Li-ion battery (Panasonic's NCR18650GA) is selected as it has the highest energy density of 0.70758 kWh/L amongst 83 other battery models. By theoretical calculation, a minimum of 5798 of these cylindrical cells are needed in order to meet the 72-kWh energy requirement. Refer to the Appendix B the list of Li-ion batteries considered.

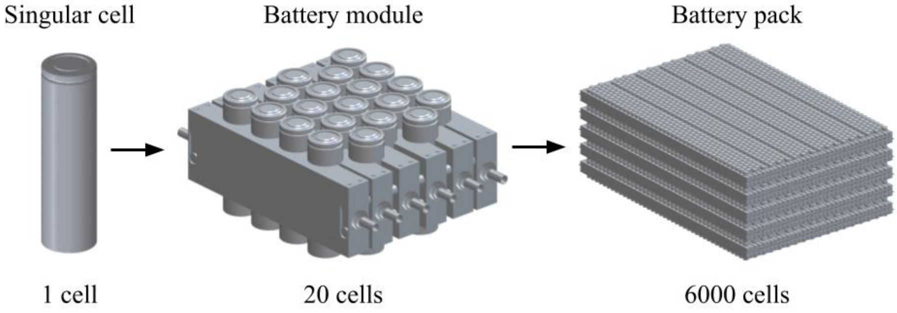

Figure 2: Securing Method for Multiple Batteries

Optimization of Space and Configuration

The SOLIDWORKS 2021 CAD is employed to generate the models of selected engine-generator module and batteries. The model of a typical 8x8 vehicle hull is also used as the baseline boundary for the rest of the sub-systems components.

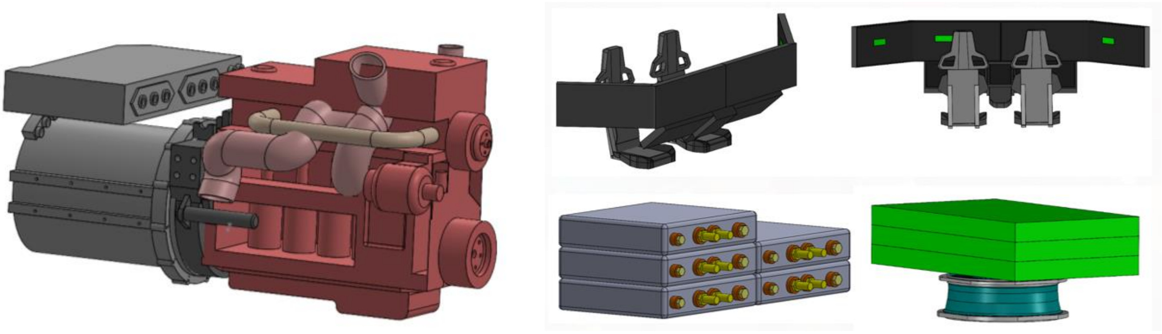

Figure 3: Isometric Model View of Assembled Cummins ISB6 with Dana HV2500 (left) and other sub-systems such as Vehicle Cockpit Monitors, Battery Management System and Radiators

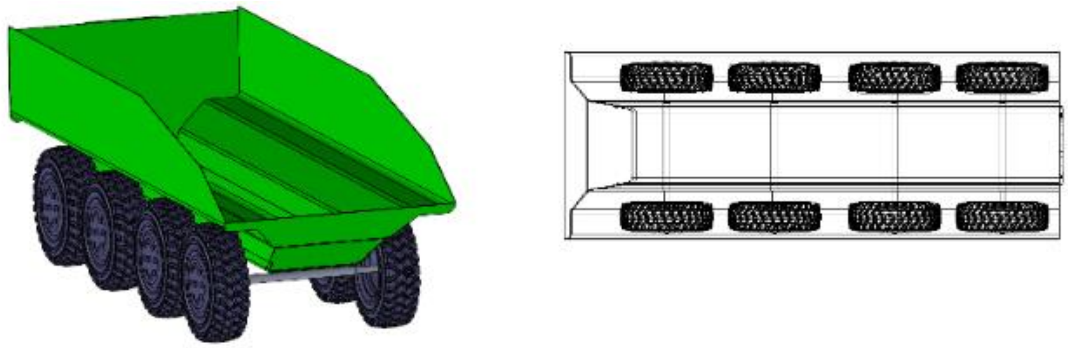

Figure 4: Isometric Model (left) and Top (right) View of Typical 8x8 Vehicle Hull

Some of the important considerations taken in the optimization of space and configurations include the convenience of communication between onboard crew, movement of crew in the cabin, visibility (dead ground) for commander and driver, vehicle weight distribution and safety.

RESULTS

Three main placements of engine-generator module and batteries are created and denoted by (F)ront, (M)iddle, (B)ack and (R)andom. The numeric labels (1 to 4) indicate the order in which the configuration is introduced and iterated.

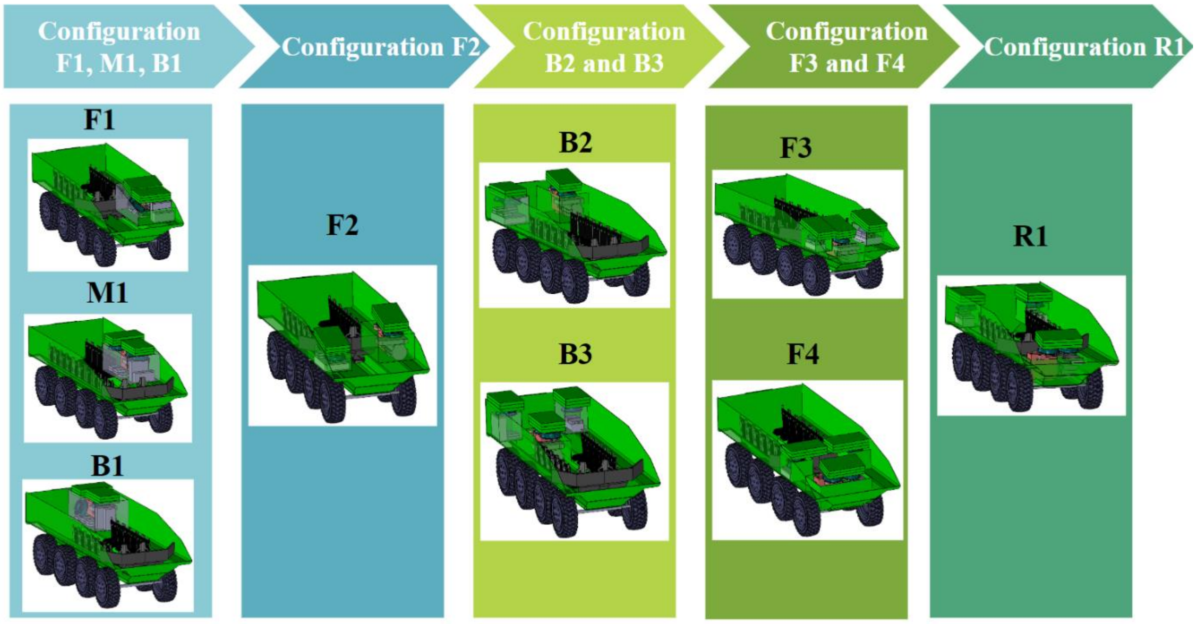

Figure 5: HED Configurations in the Order of Down-Selection (Left to Right)

Iteration 1

The first iteration explored the placement of the HED components in the Front-Left, Middle-Left and Back-Left regions. The locations of the driver and commander are placed side-by-side to improve crew communication in terms of proximity. However, it was assessed that such placement is not ideal. Having HED components installed predominantly on either left or right side of the vehicle can cause the vehicle to have an uneven weight distribution which adversely affect both the mobility performance and stability of the vehicle.

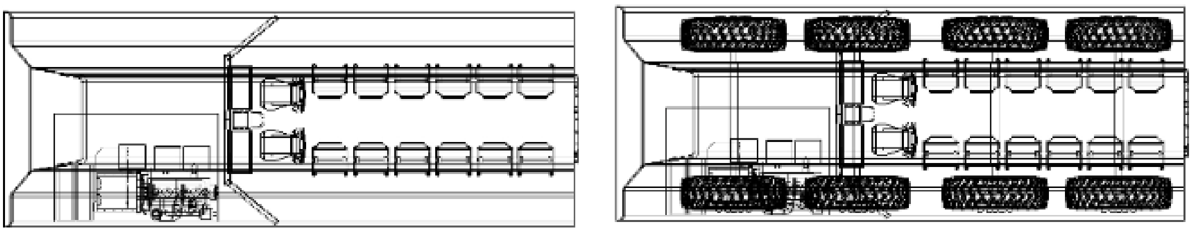

Figure 6: Configuration F1

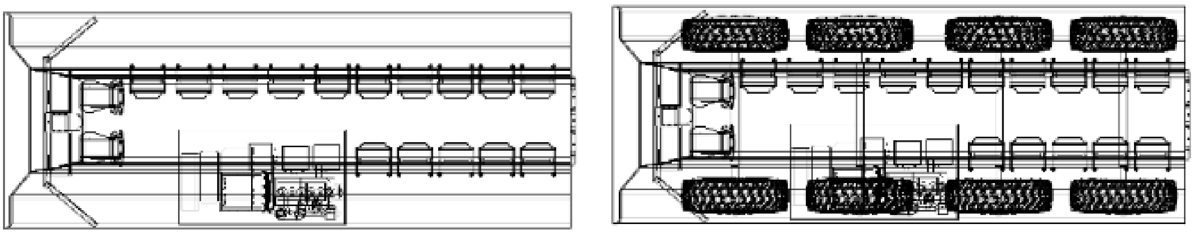

Figure 7: Configuration M1

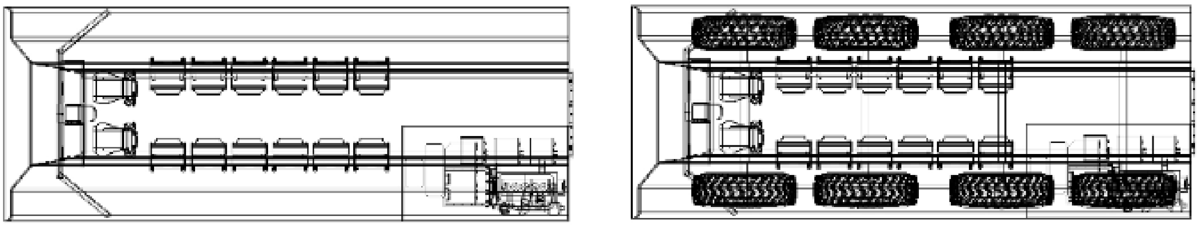

Figure 8: Configuration B1

Iteration 2

The second iteration separated the batteries from the engine-generator module in an attempt to improve the weight distribution as shown in Figure 10. However, the HED components are still occupying too much space which can be used to accommodate the 4 monitors and limited the visibility of the driver and commander.

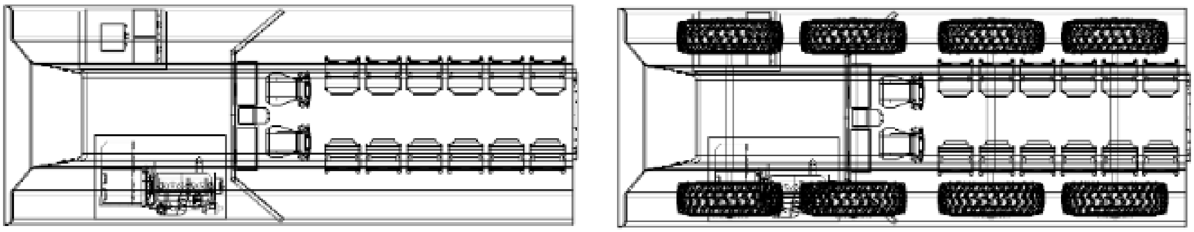

Figure 10: Configuration F2

Iteration 3

The third iteration placed all the HED components at the Back region. However, such configurations obstructed the ramp door which hinders quick crew entry and extrication from the vehicle. Therefore, such configurations are not viable for battlefield implementation.

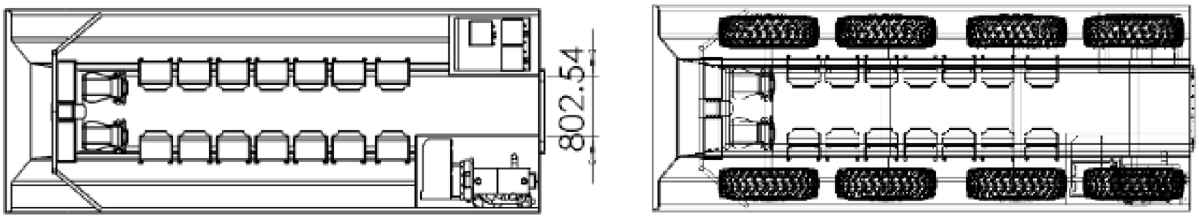

Figure 11: Configuration B2

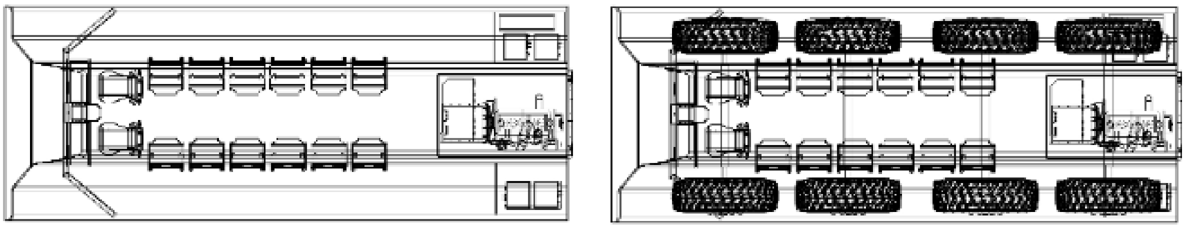

Figure 12: Configuration B3

Iteration 4

The fourth iteration placed the HED components at the Front, with the engine-generator module in the center and batteries on each side. The key difference between Configuration F3 and F4 is orientation of the engine-generator module (Figure 14b). It has been assessed that frontal placement of HED components ensures a balanced weight distribution, stability during acceleration, and optimal space utilisation which follows the design principles found in automotive engineering [18][19]. This is also aligned with the protective design practices seen in military tanks, enhancing crew safety against collisions and attacks [20]. However, the driver and commander are also placed along the second wheel axle of the vehicle which could be better improved in terms of ground visibility and deadground.

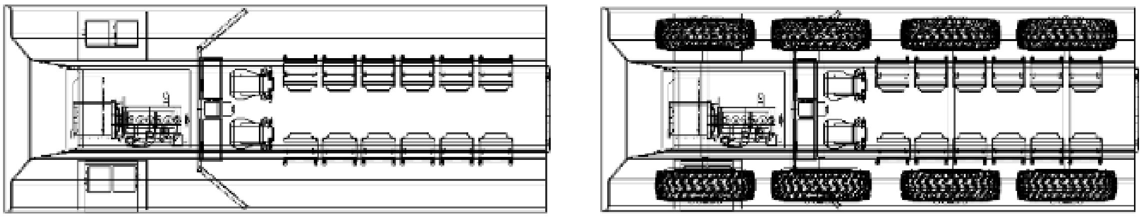

Figure 13: Configuration F3

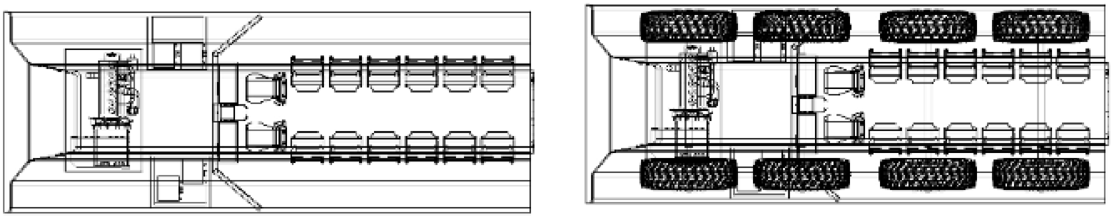

Figure 14: Configuration F4

Final Iteration

The final iteration improves on Configuration F4 by relocating the batteries to both sides of the rear. The driver and commander can now be placed towards the front first wheel axle. This configuration strikes a balance between improved visibility, enhanced driving convenience, and having a balanced weight distribution. This configuration also facilitates crew communication and mobility, while also strategically dispersing batteries minimises the risk of simultaneous damage by adversarial attacks.

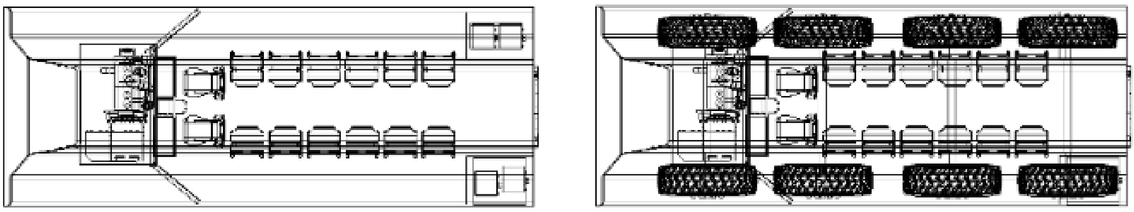

Figure 15: Configuration R1

DISCUSSION

The theoretical calculation which led to the selection of engine-generator module (Cummins ISB6 Engine with Dana HV2500 Generator) and battery system (CATL 116Ah batteries) are based on estimates and data obtained from online sources. Therefore, the choice of HED components can still influenced through the use of actual past field data or actual empirical/reliability data collected via testing and mobility trials.

Through the use of models and taking into consideration of important factors such as vehicle design engineering and human factor engineering, simplistic iterations were successfully performed and provided insights on the optimal series HED configuration in an 8x8 armoured vehicle. Incorporation of an extra cabin crew seats in the final configuration R1 can also be substituted by another payload or subsystem. However, the results should also be interpreted with caution due to the omittance of the rest of the sub-systems that may interfere with the proposed locations of the HED components.

CONCLUSION

It is concluded that the integration of HEDs into 8x8 armoured vehicles helps in optimizing the use of interior space. The final layout, with engine-generator module at the front and batteries flanking the rear, facilitated communication and crew movement in battlefield scenarios. In addition, this configuration allowed a balanced vehicle weight distribution which is important in vehicle mobility and stability. Distributed location of the battery at the rear also ensures resiliency against attacks, offering a win-win solution for both improved functionality and crew safety. The optimised layout allows scalability for increased battery size to meet growing power demands.

Future Considerations

Driven by technological advancements, high-energy-density batteries may be introduced. Evolving energy storage technologies may render alternative options viable for battlefield use. Integration of cutting-edge remote weapon systems for adaptive space utilisation could redefine interior design dynamics, prioritising functionality, and user-centric customisation. A forward-looking approach is crucial to align space optimisation strategies with evolving demands and technological landscapes, ensuring compatibility with combat capabilities.

ACKNOWLEDGEMENTS

We would like to thank Mr Ernie Ang, Mr Ng Yi Yang and Mr Titus Yeo for mentoring and guiding us throughout the research process. In addition, we would like to thank Ms Chua Hui Ru and Ms Esther Chew for their assistance in the administrative portion of this project, as well as DSTA for providing us with the opportunity to participate in Research@YDSP 2023.

REFERENCES

[1] Precedence Research. (2023, September). *Hybrid Electric Vehicle Market Size, Share, Growth, Report 2032*. Precedence Research. Retrieved January 3, 2024, from https://www.precedenceresearch.com/hybrid-electric-vehicle-market

[2] Raftery, T. (2022, August 30). *Seven Reasons Why The Internal Combustion Engine Is A Dead Man Walking [Updated]*. Forbes. Retrieved January 3, 2024, from https://www.forbes.com/sites/sap/2018/09/06/seven-reasons-why-the-internal-combustion-engine-is-a-dead-man-walking-updated/?sh=db36536603fe

[3] G. Khalil, "Challenges of hybrid electric vehicles for military applications," *2009 IEEE Vehicle Power and Propulsion Conference*, Dearborn, MI, USA, 2009, pp. 1-3, doi: 10.1109/VPPC.2009.5289878.

[4] Wang, X., Ji, W., & Gao, Y. (n.d.). Energy Consumption Optimization Strategy of Hybrid Vehicle Based on NSGA-II Genetic Algorithm. *Processes 2023*, *11*(6), 1735. https://doi.org/10.3390/pr11061735

[5] FFI Norwegian Defence Research Establishment. (2008). *Hybrid electric propulsion for military vehicles - overview and status of the technology*. Retrieved January 3, 2024, from https://www.ffi.no/en/publications-archive/hybrid-electric-propulsion-for-military-vehicles-overview-and-status-of-the-technology

[6] North Atlantic Treaty Organisation (NATO). (2004, July). *All Electric Combat Vehicles (AECV) for Future Applications*. DTIC. Retrieved January 3, 2024, from https://apps.dtic.mil/sti/pdfs/ADA426538.pdf

[7] Union of Concerned Scientists. (2015, February 25). *All About Drivetrains*. Union of Concerned Scientists. Retrieved January 3, 2024, from https://www.ucsusa.org/resources/all-about-drivetrains

[8] Mills, W., & Wiechens, R. (2022, December 1). *The Lethality Case for Electric Military Vehicles - Modern War Institute*. Modern War Institute -. Retrieved January 3, 2024, from https://mwi.westpoint.edu/the-lethality-case-for-electric-military-vehicles/

[9] Oscaly Academy. (2023, March 19). *Three Types of Hybrid Vehicles: Advantages and Disadvantages*. OCSALY Academy. Retrieved January 3, 2024, from https://ocsaly.com/three-types-of-hybrid-vehicles-advantages-and-disadvantages/

[10] Bartleby Research. (n.d.). *Advantages And Disadvantages Of Using A Parallel Over A.*.. Bartleby. Retrieved January 3, 2024, from https://www.bartleby.com/essay/Advantages-And-Disadvantages-Of-Using-A-Parallel-FCGS6EZQ3G

[11] Xiong, W., Yong, Z., & Yin, C. (2009). Optimal energy management for a series–parallel hybrid electric bus. *Energy Conversion and Management*, *50*(7), 1730-1738. https://doi.org/10.1016/j.enconman.2009.03.015

[12] Electrical Deck. (2022, April 26). *Tractive Effort For Propulsion Of Train - Definition & Equation*. Electrical Deck. Retrieved January 5, 2024, from https://www.electricaldeck.com/2022/04/tractive-effort-for-propulsion-of-train.html#google_vignette

[13] MINDEF Singapore. (2012, October 10). *Fact Sheet: Terrex Infantry Carrier Vehicle*. MINDEF Singapore. Retrieved January 3, 2024, from https://www.mindef.gov.sg/web/portal/mindef/news-and-events/latest-releases/article-detail/2012/october/2012oct10-news-releases-00217

[14] Army Technology. (2022, August 30). Terrex Armoured Infantry Fighting Vehicle. https://www.army-technology.com/projects/terrex-8x8-vehicle/?cf-view

[15] Norwegian Defence Research Establishment (FFI). (2008, June 24). Hybrid electric propulsion for military vehicles. https://ffi-publikasjoner.archive.knowledgearc.net/bitstream/handle/20.500.12242/2151/08-01220.pdf

[16] Dana TM4 Inc. (2017, May 11). TM4 INC. and CUMMINS INC. announce a joint effort to develop a plug-in hybrid powertrain. *Dana TM4*. https://www.danatm4.com/news-events/tm4-inc-and-cummins-inc-announce-a-joint-effort-to-develop-a-plug-in-hybrid-powertrain/

[17] Daigneault, M., Prigge, F., & Tellier, B. (2016). From Paper to Product: Engineering a 27,000 kg Fully Electric Mobile Railcar Mover in 6 Months. *World Electric Vehicle Journal, 8*(1), 69-77. https://doi.org/10.3390/wevj8010069

[18] Leith Cars. (n.d.). *Front vs mid vs Rear Engines – Which Is the Best?* Leith Cars. Retrieved January 3, 2024, from https://www.leithcars.com/blogs/1421/lifestyle/front-vs-mid-vs-rear-engines/

[19] Engineering Explained. (2015, May 5). Engineering Explained: Why Engine Placement Is Important. *Car Throttle*. https://www.carthrottle.com/news/engineering-explained-why-engine-placement-important

[20] Mizokami, K. (2021, September 6). *This Is How Israel Developed Its Legendary Merkava Tank*. The National Interest. Retrieved January 3, 2024, from https://nationalinterest.org/blog/reboot/how-israel-developed-its-legendary-merkava-tank-192985

APPENDIX A

Table A-1: Horsepower rating and volume of engines.

Model Name	**Horsepower (hp)**	**Volume (mm^3)**
Caterpillar C4.4	201.15	376902734
Caterpillar 7.1	236.69	758892723
Caterpillar C13	520.32	1618499806
Caterpillar C11	388.00	1503802932
Caterpillar C1.5	34.00	189234120
Caterpillar C2.2	67.00	326005680
Caterpillar 3054C	99.85	332958600
Caterpillar 3.6	104.00	296503824
Caterpillar C9	450.00	923008911
Caterpillar C9.3	600.00	1552121208
Cummins ISB6	320.00	654076500
Cummins QSM	400.00	1527915520

Table A-2: Horsepower rating and volume of generators.

Model Name	**Horsepower (hp)**	**Volume (mm^3)**
Cummins RV Generator Onan QG 2800i	3.75	79206400
DCA-25USIE	29.50	1224500000
EM-PME375-T150	53.64	31247225
DCA-60USI	70.81	3030500000
Rugged Mobile Power (60)*	80.46	2595215376
EM-PMI375-T200	84.48	10543542
DCA-100USI3	118.01	5394000000
Bosch Integrated Motor-Generator	120.69	84822930
EM-PMI300-T310	126.06	49289134
DCA-125ESK	148.05	4860000000
EM-PMI240-T180	152.88	23160528
ISG-100	194.45	55800000

Model Name	**Horsepower (hp)**	**Volume (mm^3)**
EM-PMI375-T500	211.88	58527822
TM4 SUMO MD (HV1500-3P)	217.25	35932206
ISG-200	268.20	55800000
TM4 SUMO MD (HV2200-3P)	288.32	40222590
TM4 SUMO MD (HV2400-6P)	321.85	62381816
EM-PMI375-T800	336.60	68070401
DCA-300SPK3	354.03	9450000000
TM4 SUMO MD (HV2600-6P)	355.37	66672200
EM-PMI375-T1100	396.94	87155561
ISG-300	402.31	57600000
EM-PMI540-T1500	445.22	175119314
TM4 SUMO HD (HV3500)	496.18	82758730
EM-PMI540-T2000	565.91	197215348
EM-PMI540-T3000	643.69	291750824
TM4 SUMO HP (HV2500-6P)	724.15	189757000

APPENDIX B

Table B-1: Comparison of the average specific energy, energy densities and power density of the different types of batteries, taking the median as the reference point.

Battery type	**Specific energy / Wh kg^{-1}**	**Energy density / Wh L^{-1}**	**Power density / W L^{-1}**
Lead acid	37.5	85	646
Nickel-based (NiMH, NiCd)	60	120	400
ZEBRA	100	160	272
Li-ion	175	325	482.86

Table B-2: Complete list of all the Li-ion batteries that were considered

Brand	**Packaging**	**Model**	**Ah**	**V**	**kWh**	**L**	**kWh/L**
Panasonic	Cylindrical	NCR18650GA	3.45	3.6	0.01242	0.01755280465	0.7075792301
Panasonic	Cylindrical	NCR18650BF	3.35	3.6	0.01206	0.01774307756	0.6797017009
Panasonic	Pouch	UPF4564124ZB	6	3.85	0.0231	0.0349272	0.6613756614
Panasonic	Cylindrical	NCR18650BD	3.18	3.6	0.011448	0.01755280465	0.6522034643
Panasonic	Pouch	UPF496171Z	3.55	3.85	0.0136675	0.02098866	0.6511849732
Panasonic	Cylindrical	NCR1850B	2.35	3.6	0.00846	0.01333260506	0.6345346585
Panasonic	Pouch	UPF359191Z	4.67	3.85	0.0179795	0.029053024	0.6188512425
CATL	Prismatic	116Ah	116	3.7	0.4292	0.72272655	0.5938622291
CATL	Prismatic	132Ah	132	3.7	0.4884	0.842128	0.5799593411
CATL	Prismatic	180Ah	180	3.7	0.666	1.157926	0.5751662887
Panasonic	Prismatic	NCA596080SA	4.53	3.6	0.016308	0.0286314	0.5695844423
CATL	Prismatic	62Ah	62	3.7	0.2294	0.414932	0.5528616737
Panasonic	Cylindrical	NCR18500A	2.04	3.6	0.007344	0.01330572481	0.5519428746
CATL	Prismatic	93Ah	93	3.7	0.3441	0.62475	0.5507803121

Brand	Packaging	Model	Ah	V	kWh	L	kWh/L
Panasonic	Prismatic	NCA653864SA	2.4	3.6	0.00864	0.01599819	0.5400610944
Panasonic	Prismatic	NCA903864A	3.28	3.6	0.011808	0.0219051	0.5390525494
Panasonic	Prismatic	NCA596080	4.17	3.6	0.015012	0.0281502	0.5332821792
Panasonic	Cylindrical	UR1865ZP	2.6	3.6	0.00936	0.01755280465	0.5332481155
Panasonic	Prismatic	NCA496080SA	3.49	3.6	0.012564	0.02383425	0.5271405645
Panasonic	Prismatic	NCA622944SA	1.17	3.6	0.004212	0.0080180625	0.5253139396
Panasonic	Cylindrical	UR1865ZM2	2.55	3.6	0.00918	0.01755280465	0.522993344
Panasonic	Prismatic	CGA463443XA	0.91	3.8	0.003458	0.006638996	0.5208618894
Panasonic	Prismatic	NCA593142SA	1.11	3.6	0.003996	0.00771506125	0.5179479294
Panasonic	Prismatic	CGA553450XA	1.31	3.8	0.004978	0.009613734	0.5178008878
Panasonic	Prismatic	CGA463450XA	1.03	3.8	0.003914	0.007643363	0.5120782567
Panasonic	Prismatic	NCA882936SA	1.31	3.6	0.004716	0.009231068	0.5108834644
Panasonic	Prismatic	NCA593446	1.3	3.6	0.00468	0.00917332	0.5101751601
Panasonic	Prismatic	NCA623535	1.1	3.6	0.00396	0.007783776	0.5087505088
Panasonic	Prismatic	NCA793540	1.57	3.6	0.005652	0.0113013225	0.5001184596
Panasonic	Prismatic	NCA653864	2.2	3.6	0.00792	0.01599819	0.4950560032
Panasonic	Prismatic	NCA673440	1.265	3.6	0.004554	0.0092058525	0.4946853102
Panasonic	Prismatic	NCA103450	2.35	3.6	0.00846	0.01721265	0.4914989848
Panasonic	Prismatic	NCA573544	1.19	3.6	0.004284	0.00888009	0.482427543
Panasonic	Prismatic	NCA523436	0.84	3.6	0.003024	0.0062708975	0.4822276237
Panasonic	Prismatic	NCA103443	2.01	3.6	0.007236	0.01515423	0.4774904433
Panasonic	Prismatic	UF463450FP	0.96	3.7	0.003552	0.007471372	0.4754146896

Brand	Packaging	Model	Ah	V	kWh	L	kWh/L
Panasonic	Prismatic	UF553450ZP	1.2	3.7	0.00444	0.0093558015	0.4745718472
Panasonic	Prismatic	NCA752836A	1.01	3.6	0.003636	0.007823439	0.4647572506
CATL	Prismatic	234Ah	234	3.7	0.8658	1.87044	0.4628857381
Panasonic	Cylindrical	UR18650AA	2.25	3.6	0.0081	0.01749904414	0.4628824256
Panasonic	Prismatic	NCA463436A	0.72	3.6	0.002592	0.00560119	0.4627588066
Panasonic	Prismatic	UF653450SQ	1.3	3.7	0.00481	0.0107043855	0.4493485404
Panasonic	Prismatic	CGA573442	0.96	3.7	0.003552	0.007911904	0.4489437688
Panasonic	Prismatic	NCA843436	1.3	3.6	0.00468	0.010529001	0.4444866137
Panasonic	Prismatic	UF103450PN	2	3.7	0.0074	0.01731912	0.4272734411
Panasonic	Cylindrical	UR18650RX	2.05	3.6	0.00738	0.01755280465	0.4204456295
Panasonic	Prismatic	CGA103450	1.95	3.7	0.007215	0.017301375	0.4170188786
SVOLT	Prismatic	CBOMHW3NA-184Ah	184	3.2	0.5888	1.4927	0.3944530046
Panasonic	Cylindrical	UR14500P	0.84	3.7	0.03108	0.007950000486	0.3909433962
Panasonic	Prismatic	UF553443ZU	1.04	3	0.00312	0.008028852	0.3885985194
Panasonic	Cylindrical	UR14500AC	0.8	3.85	0.00308	0.007950000486	0.3874213599
Gotion	Prismatic	IFP81175200A-340Ah	340	3.2	1.088	2.8188	0.3859798496
CATL	Prismatic	173Ah	173	3.2	0.5536	1.44072	0.3842523183
EVE	Prismatic	LF304	304	3.2	0.9728	2.5533648	0.3809874719
EVE	Prismatic	LF173	173	3.2	0.5536	1.45877754	0.3794958346
EVE	Prismatic	LF230	230	3.2	0.736	1.94667138	0.3780812764
EVE	Prismatic	LF230	230	3.2	0.736	1.94667138	0.3780812764
CATL	Prismatic	MHH3L7	228	3.2	0.7296	1.944972	0.3751210814

Brand	Packaging	Model	Ah	V	kWh	L	kWh/L
CATL	Prismatic	LEP71H3L7	302	3.2	0.9664	2.582143908	0.3742626415
CATL	Prismatic	LFP6228082	161	3.2	0.5152	1.42352	0.3619197482
EVE	Prismatic	LF105	105	3.2	0.336	0.934882955	0.3594032795
Higee	Prismatic	LFP71173205E-280Ah	280	3.2	0.896	2.502948	0.3579778725
CATL	Prismatic	CB260	150	3.2	0.48	1.3464	0.3565062389
ETC	Prismatic	EC-AU277-CLH3LO	277	3.2	0.8864	2.50363728	0.3540448958
EVE	Prismatic	LF280K	280	3.2	0.896	2.54103993	0.3526115389
CATL	Prismatic	CB310	280	3.2	0.896	2.583500136	0.3468163162
REPT	Prismatic	CB71173200EA-280Ah	280	3.2	0.896	2.585811044	0.3465063706
Gotion	Prismatic	IFP28148115A-52Ah	52	3.2	0.1664	0.488992	0.3402918657
Lishen	Prismatic	LP71173207-272Ah	272	3.2	0.8704	2.576116175	0.3378729611
EVE	Prismatic	LF100L	100	3.2	0.32	0.948	0.3375527426
CATL	Prismatic	6LH3L8	271	3.2	0.8672	2.57560963	0.3366969862
Lishen	Prismatic	LP54173207-202Ah	202	3.2	0.6464	1.930186356	0.3348899437
Panasonic	Cylindrical	UR14500Y	0.71	3.7	0.002627	0.007950000486	0.3304402314
Lishen	Prismatic	LP54173207-190Ah	190	3.2	0.608	1.930186356	0.3149954916
CATL	Prismatic	176Ah	176	3.2	0.5632	1.8338	0.3071218235
EVE	Prismatic	LF90-73103	90	3.2	0.288	0.958793005	0.3003776608
CATL	Prismatic	6LH3L7	240	3.2	0.768	2.557278	0.3003193239
ETC	Prismatic	EC-AU176-NAH3L7	176	3.2	0.5632	1.937325234	0.2907100935
Ganfeng	Prismatic	FFH4D3	100	3.2	0.32	1.10349984	0.2899864489
Higee	Prismatic	HJLFP48173170E-120Ah	120	3.2	0.384	1.428714	0.2687731764

Brand	Packaging	Model	Ah	V	kWh	L	kWh/L
Lishen	Prismatic	LP44147272-130Ah	130	3.2	0.416	1.697658864	0.2450433411
EVE	Prismatic	LF50	50	3.2	0.16	0.729	0.219478738
ETP	Prismatic	EFP2714893WA	25	3.2	0.08	0.3759093	0.212817294
CATL	Prismatic	7Ah	7	3.7	0.0259	0.143276	0.1807699824