Defence Science Journal, Vol. 68, No. 1, January 2018, pp. 19-25, DOI : 10.14429/dsj.68.12182

A Design of Experiments Methodology for Evaluating Configuration for a Generation Next Main Battle Tank

A.H. Rahman*, S.A. Malik, J.R. Kumar, V. Balaguru, and P. Sivakumar

Main Battle Tank Division, DRDO-Combat Vehicles Research and Development Establishment, Chennai - 600 054, India
E-mail: hafeezurrahman.a@cvrde.drdo.in

ABSTRACT

Combat vehicles for generation next main battle tank requires state-of-the-art technologies to counter advanced threats both from conventional and un-conventional sources across various theatres of operation. In addition, they require strategic mobility by road, rail, air and sea. Under such conditions, the trend across the world has been to converge on configurations that are lethal, agile, modular systems and interchangeable mission based turret configurations along with higher survivability which imposes limitations on mobility as mass increases. To achieve all the user objectives as laid down in the qualitative requirements, it is prudent to focus the attention on weight management. The traditional approach of weight management is time consuming, for which an alternate approach using design of experiments is proposed in this paper. To carry out this study, two configurations are selected namely evolutionary and revolutionary design. Keeping the outer boundary as the constraint, a simple linear regression and analysis of variance are carried out with mass and volume data from various systems and sub-systems. Subsequently, the accuracy of the analysis is ascertained using a test of hypothesis using PHStat software. Although this study discusses configuration, the factors responsible for reduced system mass and volume namely technology, materials, intelligence etc have not been discussed. Finally, from the outcome of the study it is observed that the revolutionary design configuration fares better compared to the evolutionary design configuration with a combat mass of only 41 t.

Keywords: Configuration; Evolutionary design; Revolutionary design; Regression; Systems

1. INTRODUCTION

Armoured fighting vehicles (AFV) of which the Main Battle Tank (MBT) forms the mainstay, has to incorporate state-of-the-art technologies to counter futuristic threats for which present day weapon platforms do not suffice. These threats can be classified into two types namely traditional and non-traditional. Whereas traditional threats are those employed by conventional armies, the non-traditional ones are employed by non-state actors both of which are shown in Fig. 1.

To obviate the above threats, a variety of countermeasures both structural, electronic and special systems are required. Whereas, the structural part consists of armour, the electronic part consists of systems such as jammers, spoofers, laser retro-reflection, magnetic signature duplicator, soft-kill defence aide suite. Similarly, a host of special systems have evolved namely active protection system, adaptive camouflage, nuclear-biological-chemical warfare suites, advanced external fire detection and suppression systems, combat identification of friend-or-foe.

These technologies in addition to the ones that upgrade the firepower and mobility, bring the major challenge of volume and mass budgeting in arriving at an acceptable configuration. These factors become much more complex when external constraints are imposed on the configuration. One such constraint is the over dimensioned consignment (ODC) limits for rail and air transport. Whereas mass limits are met with easedue to superior wagon design for rail transportability, the same for air transportability is rigorous. This when coupled with the need for high altitude warfare i.e. above 15,000 ft, constrain the mass needed to much less than the limits as per air transport requirements.

To configure a generation next main battle tank (GNMBT), two design approaches are possible. The first approach is to consider an in-service MBT retrofitted with technology upgrades which is called an evolutionary design. Such an approach is dealt in detail by Kurpas & Holota[1]. In this paper, the authors have considered the modernisation and modification or conversion of existing T-72 platforms into engineering vehicles. It is also proposed that such an approach has the distinct twin advantages of constructing new tracked vehicles at low cost and extending product life cycle.

The other approach is an ab-initio design for an altogether new MBT which is called a revolutionary design. Both these approaches follow laid out traditional design methodologies which consist of configuring within the outer boundary as defined by ODC limits. Since, the volume and mass estimates are known for individual systems, surface models are created for the structural and add-on armour, armament, ammunition, power pack, crew and other systems.

These models are then assembled within the boundary to

Received: 26 October 2017, Revised: 07 December 2017
Accepted: 11 December 2017, Online published: 18 December 2017

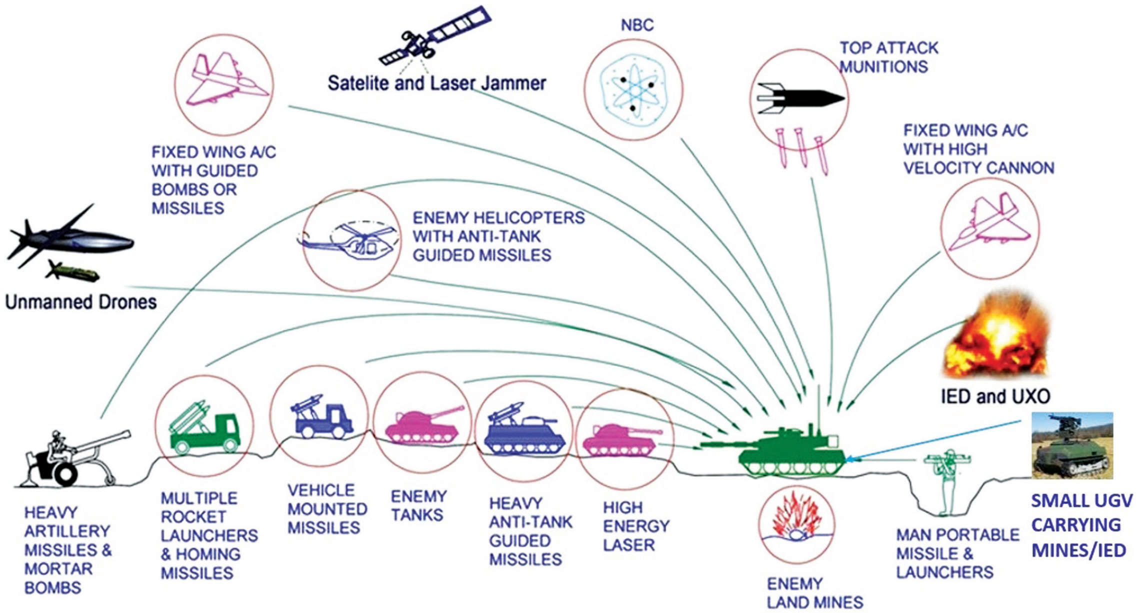

Figure 1. Survivability threat spectrum for Main Battle Tank.

estimate the available space or volume[2]. This approach is time consuming as exact volume, mass and location details are not available for CAD assembly as some technologies are not matured enough which leads to trial and error approach. On the other hand, if mathematical models are created for the above problem, a large time saving for the project will accrue, which forms the objective of this study.

Such a mathematical approach for tank armament along with its stabilisation is dealt by Purdy[3]. In addition, some complex mathematical models are also proposed[4]. In this work, authors stress on an integrated evaluation of MBT based on Topsis method. Finally, another noteworthy model developed is the one by Kurpas & Holota[5]. In this work, parametric analysis is considered as a key tool for meeting future user's expectations along with the effect of this solution on general structural arrangement or configuration.

2. PROPOSED DOE METHODOLOGY

The steps involved in the DOE methodology for the present study is shown in Fig. 2. The first step in the DOE methodology is the decision regarding the input (variables) and output (responses)[6]. Since, an optimised mass with state-of-the-art technologies seems to be the key for GNMBT, mass of the platform is considered as the output. Similarly, the individual system volume is considered as the input. Once, this cause and effect analysis is established, the next step is the collection of volume and mass data for the individual systems for both evolutionary

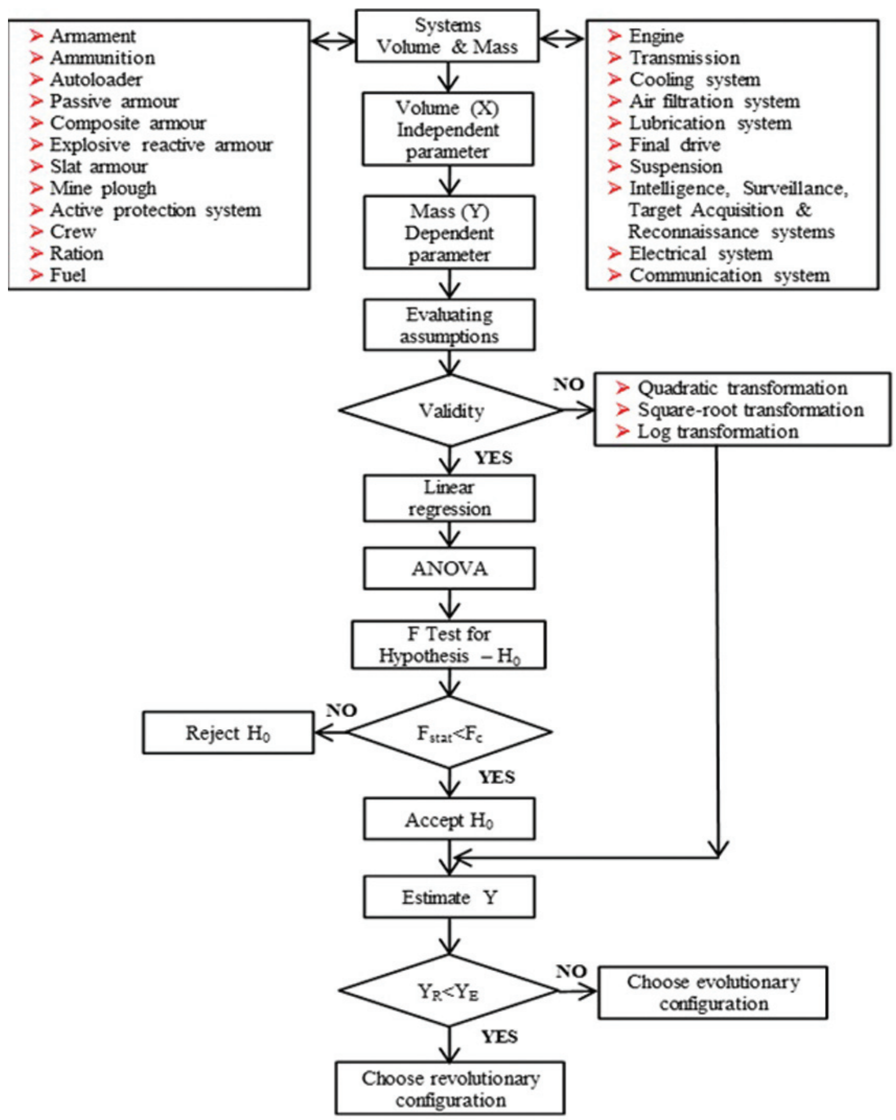

Figure 2. DOE Methodology for the proposed study.

and revolutionary configuration.

During system data analysis, the following inputs are considered.

Armament system: The armament system affects the volume data by means of its swept volume including recoil[7]. For this study, 120 mm, 125 mm, and 130 mm calibre smooth bore guns are considered.

Ammunition: The ammunition system data include the weight and volume of nine different types of ammunition namely fin stabilised armour piercing discarding sabot (FSAPDS), high energy anti-tank (HEAT), anti-tank guided missile (ATGM), high explosive (HE), HE (Fragmentation), kinetic energy multi-functional projectile (KEMP), anti-personnel anti-material (APAM), thermobaric (TB) and practice ammunition. Along with these ammunition data, the weight and volume of ammunition stowage's such as ammo racks or bins are also considered.

Autoloader: Carousel for two-piece ammunition and Bustle mounted autoloaders for single-piece ammunition are considered in this study. Whereas, the bustle mounted configuration adapts with ease for an un-manned configuration the same for carousel requires major modifications[8].

Gun Control System: The gun control system includes drives for gun elevation and rotation on the azimuth. For this system, the data considered include sub-systems such as azimuth drive, elevation drive along with their associated controls.

Passive armour: Rolled homogenous armour, high hardness steel, non-ferrous, composite and perforated armour weight and volume data for both configurations are considered.

Explosive reactive armour (ERA): Both existing ERA and Advanced ERA proposed for the revolutionary configuration are considered.

Mine plough: Since, the external boundary is fixed for this study, the effect of hydraulic systems and controllers along with the actual mine ploughing attachment are used.

Active Protection System: This system includes the sensors such as radar, launcher with counter grenades and controllers intended to protect theMBT against 360^o hemispherical protection.

Crew: Two, three and four crew configurations including both seating and standing positions are considered. The crew volume used for this study is based on 95th percentile man[9].

Ration: For 72 h combat duration ration such as food and drinking water are considered for the study. On the higher side, the requirements for a 4 men crew is taken as baseline.

Fuel: To cover 300 km range, the weight and volume of fuel required based on 80:20 ratio (80 per cent running and 20 per cent idling) for both the configurations is considered for the study.

Powerpack: The dry weight and volume of engine, transmission, cooling system, air filtration and lube system both as a stand-alone system and as a part of powerpack are taken for study. Similarly, the transmission also includes manual and auto transmission.

Running gear system: Includes both torsion bar (evolutionary) and hydro gas suspension (revolutionary) along with tracks, idlers and final drive respectively.

Intelligence-Surveillance-Target Acquisition and Reconnaissance: Includes systems and controllers namely, battlefield management system, software defined radio, automated target tracker, commander's panoramic sight, gunner's main sight, laser target designator, laser range finder, laser warning and countermeasure system, driver's sight with thermal imager and combat identification of friend-or-foe.

Electrical System: Controllers, rotary based junction, batteries and harnesses.

Communication System: Conventional Radio set with batteries.

On completing data collation, the next step is evaluating the assumptions[10]. Four assumptions have to be validated namely:

- *Linearity:* On plotting the residual errors with independent variable (X), no apparent pattern should be visible. If not, then linear regression is in-appropriate.
- *Independence:* If the plot of residuals shows a cyclic pattern then it establishes a relationship between consecutive residuals. Since the data analysed is time independent, this assumption is irrelevant to this study.
- *Normality:* The assumption of normality is central to this investigation which is carried out using a normality plot.
- *Equal variance:* The assumption of equal variance is established by the plot of same residuals as discussed above.

Once these assumptions are validated, an analysis of variance (ANOVA) table for single factor method is obtained. A sample ANOVA for both these configurations is given in Table 1.

Table 1. ANOVA Table for DOE study

Parameter	*df*	SS	MS	F
Regression	k-1	*SSR*	$MS_{regression}$	F_{stat}
Residual	n-k-1	*SSE*	$MS_{residual}$	--
Total	n	*SST*	--	--
	Coeff.	Std. error	t_{stat}	p_{value}
Intercept	β_0	e_1	t_1	p_1
Volume	β_1	e_2	t_2	p_2

In Table 1, total degrees of freedom (*df)* is the sample size of 29. Higher this value higher is the possibility of a normal distribution. However, determining values of mass and volume for such large number of data is cumbersome and it defeats the purpose of least time which is one of the objectives of this study. Similarly, k is the number of variables and for this study it is 2 (i.e. X and Y). The sum of squares regression difference between the actual and predicted Y values. Finally, the sum of squares total (SST) refer to the sum of squares error (SSE) and sum of squares regression (SSR). In the ANOVA tables, the mean sum of squares (MS) and F value are determined from the Eqns (1), (2), and (3).

$$MS_{regression} = \frac{SSR}{k-1} \tag{1}$$

$$MS_{residual} = \frac{SSE}{k-1} \tag{2}$$

$$F_{stat} = \frac{MS_{regression}}{MS_{residual}} \tag{3}$$

The two coefficients β_0 and β_1 given in the ANOVA table refer to the intercept value and slope of the liner regression equation. The intercept value refers to the value of Y when X i.e. internal volume is zero, which does not convey any meaning[11]. On the other hand, the slope refers to the change in mass (Y) per change in internal volume (X) which can be either positive or negative and for this study a positive value is practicable, as increase in internal volume increases overall mass. The standard error of estimate e_1 and e_2 measure variability of the observed Y from the predicted Y values around the sample mean. Finally, F test is used in this study to determine whether the slope is statistically significant[12]. Subsequently, a test of hypothesis (null and alternate hypothesis) is carried out as given in Eqns. (4) and (5). The objective of this DOE is to prove that the null hypothesis (H_0) is untrue.

$$\frac{H_0}{\beta_0} = 0 \text{ (No relationship between } X \text{ and } Y\text{)} \tag{4}$$

$$\frac{H_1}{\beta_1} \neq 0 \text{ (Linear relationship between } X \text{ and } Y\text{)} \tag{5}$$

On completion of the above hypothesis an estimate of mass (Y) is calculated for both evolutionary and revolutionary configuration and best of them chosen as the configuration for GNMBT.

3. EVALUATING ASSUMPTIONS FOR BOTH DESIGN CONFIGURATIONS

For both evolutionary and revolutionary configuration, the linearity and equal variance assumptions are validated as there are no apparent patterns visible in both plots as visible from Figs. 3 to 6.

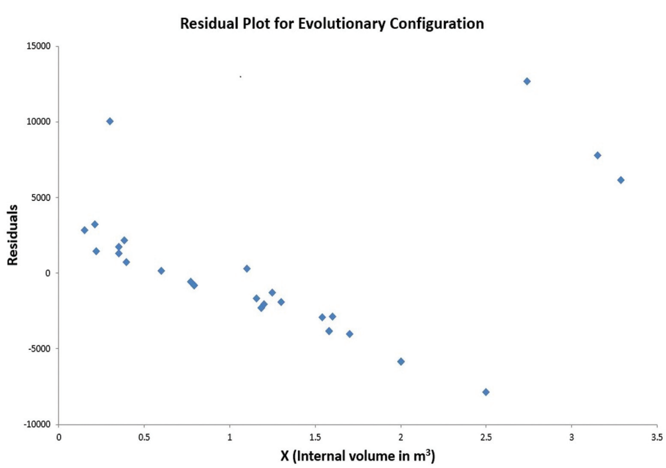

Figure 3. Residual plot – Evolutionary design configuration.

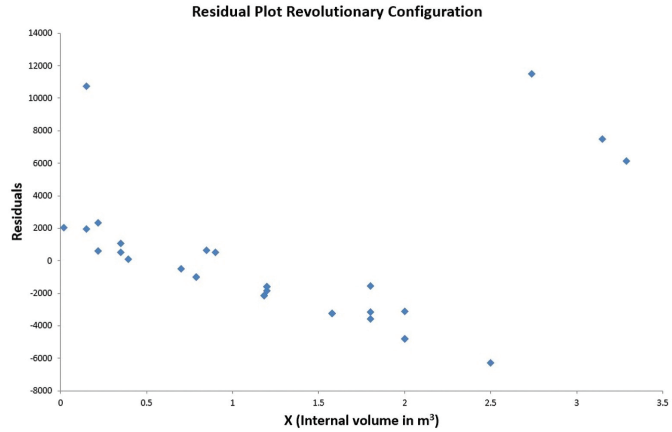

Figure 4. Residual plot – Revolutionary design configuration.

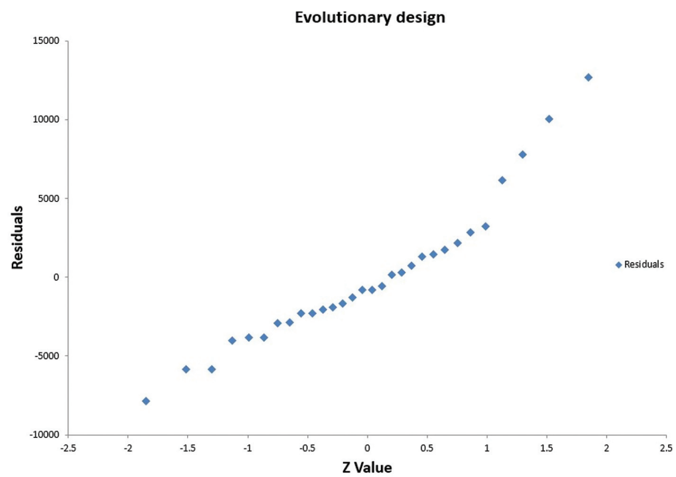

Figure 5. Normal probability plot – Evolutionary design configuration.

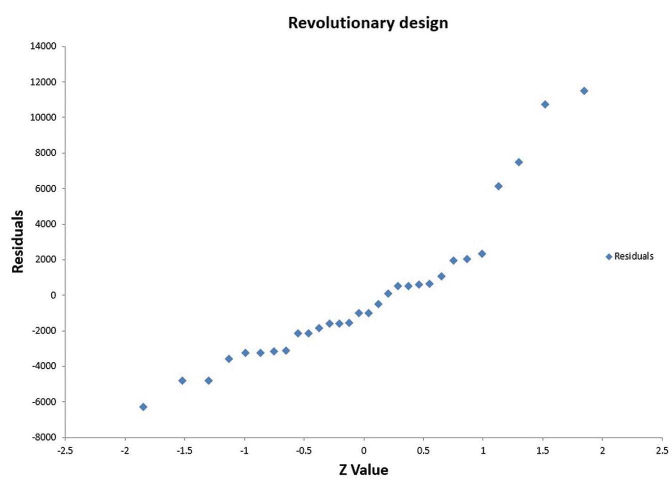

Figure 6. Normal probability plot – Revolutionary design configuration.

4. LINEAR REGRESSION AND ANOVA FOR BOTH CONFIGURATIONS

On confirming the validity of the assumptions, a linear regression and ANOVA table are derived as shown in Figs. 7 and 8 along with Tables 2 and 3 using PHStat. From the ANOVA for evolutionary design it is observed that for every increase in

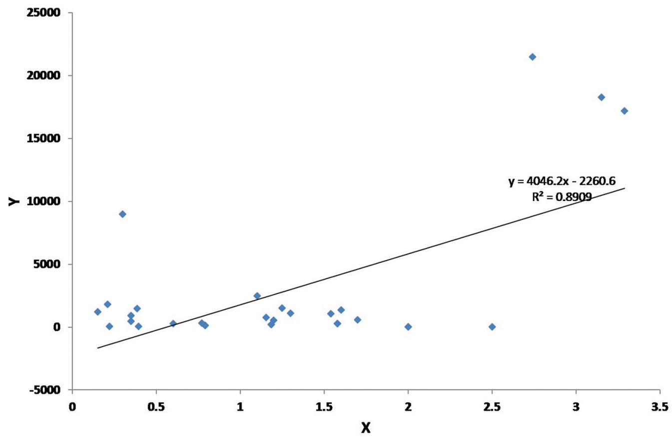

Figure 7. Scatter plot – Evolutionary design configuration.

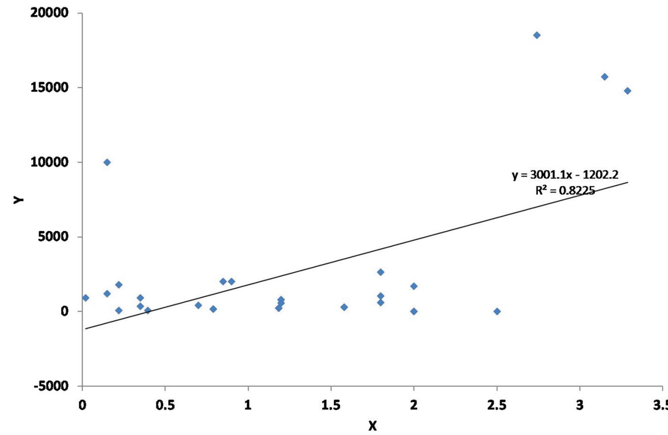

Figure 8. Scatter plot – Revolutionary design configuration.

internal volume by 1 m^3 the weight increases by 4046.2478 kg. Taking into account the intercept and coefficients, the weight equation for evolutionary design configuration is given in Eqn (6). From the ANOVA table, it is seen that the F_{stat} value of 16.44 is greater than the critical F_c value of 4.02 thus rejecting the null hypothesis H_0 and validating the mass volume relationship shown below.

$$Y = 4046.24 * X - 2260.5868 \quad (6)$$

Table 2. ANOVA table – Evolutionary design configuration

Parameter	*df*	SS	MS	*F*
Regression	1	356526742.80	356526742.80	16.44
Residual	28	607212404.12	21686157.29	--
Total	29	963739146.92	--	--
	Coeff	Std. error	t_{stat}	p_{value}
Intercept	-2260.58	1505.86	-1.5012	0.144
Volume	4046.24	997.92	4.0547	0.0004

Table 3. ANOVA table – Revolutionary design configuration

Parameter	*df*	SS	MS	*F*
Regression	1	214179609.01	214179609.01	11.57
Residual	28	518149414.30	18505336.22	--
Total	29	732329023.31	--	--
	Coeff	Std. error	t_{stat}	p_{value}
Intercept	-1202.23	1368.04	-0.8788	0.3870
Volume	3001.07	882.13	0.0020	0.0020

From the ANOVA for revolutionary design it is observed that for every increase in internal volume by 1 m^3 the weight increases by 3001.07 kg. Taking into account the intercept and coefficients, the weight equation for revolutionary design configuration is given in Eqn. (7). From the ANOVA table, it is seen that the F_{stat} value of 11.57 is greater than the critical F_c value of 4.02 thus rejecting the null hypothesis H_0 and validating the mass volume relationship shown below.

$$Y = 3001.07 * X - 1202.2327 \quad (7)$$

Another noteworthy factor to be considered is R^2 value which is around 89 per cent and 82 per cent for the evolutionary and revolutionary configurations respectively. This means that for the revolutionary configuration, 82 per cent variation in mass is due to system volume whereas 18 per cent is due to other unknown factors which is understandable. In order to obtain the overall combat mass for the given configuration the value of internal volume (X) is required. This value should satisfy all the requirements and from calculations it is found that 14 m^3 is the minimum volume required. For this minimum volume, the weight obtained for both the configurations is obtained by incorporating the volume i.e. X in Eqns. (6) and (7), respectively.

The low value of 41 t for the revolutionary as compared to 54 t for the evolutionary design is not surprising, considering the unique revolutionary configuration as shown in Fig. 9. The traditional method of housing the crew in the rotating turret is dispensed with, giving a considerable weight saving accruing due to the heavy frontal armour in the turret. Further, the turret is smaller compared to the evolutionary design as space required for crew ergonomics is dispensed and the three crew members being housed in a separate crew capsule in the frontal portion of the hull. One of the main reason for lesser mass is the three crew unlike four which imposes limitations due to survivability. This design which finally coupled with advanced technologies such as hybrid ERA and active protection system (APS) ensure that 41 t for this revolutionary configuration is practically possible.

5. CONCLUSIONS

A DOE based on regression with ANOVA for evaluating two different configurations namely evolutionary and revolutionary design for GNMBT is presented. This methodology saves considerable time during the configuration stage to arrive at weight estimates for the design. However, it is to be noted that the system weight and volume estimates used for the DOE evaluation are based on 95 per cent confidence level and hence there are always possibilities for the weight to be on the higher side which will still qualify it for a sub 50 t tank. Finally, this paper does agree that many approaches for the problem exists and this paper presents only an alternate approach to choose an acceptable configuration for both the designer and user.

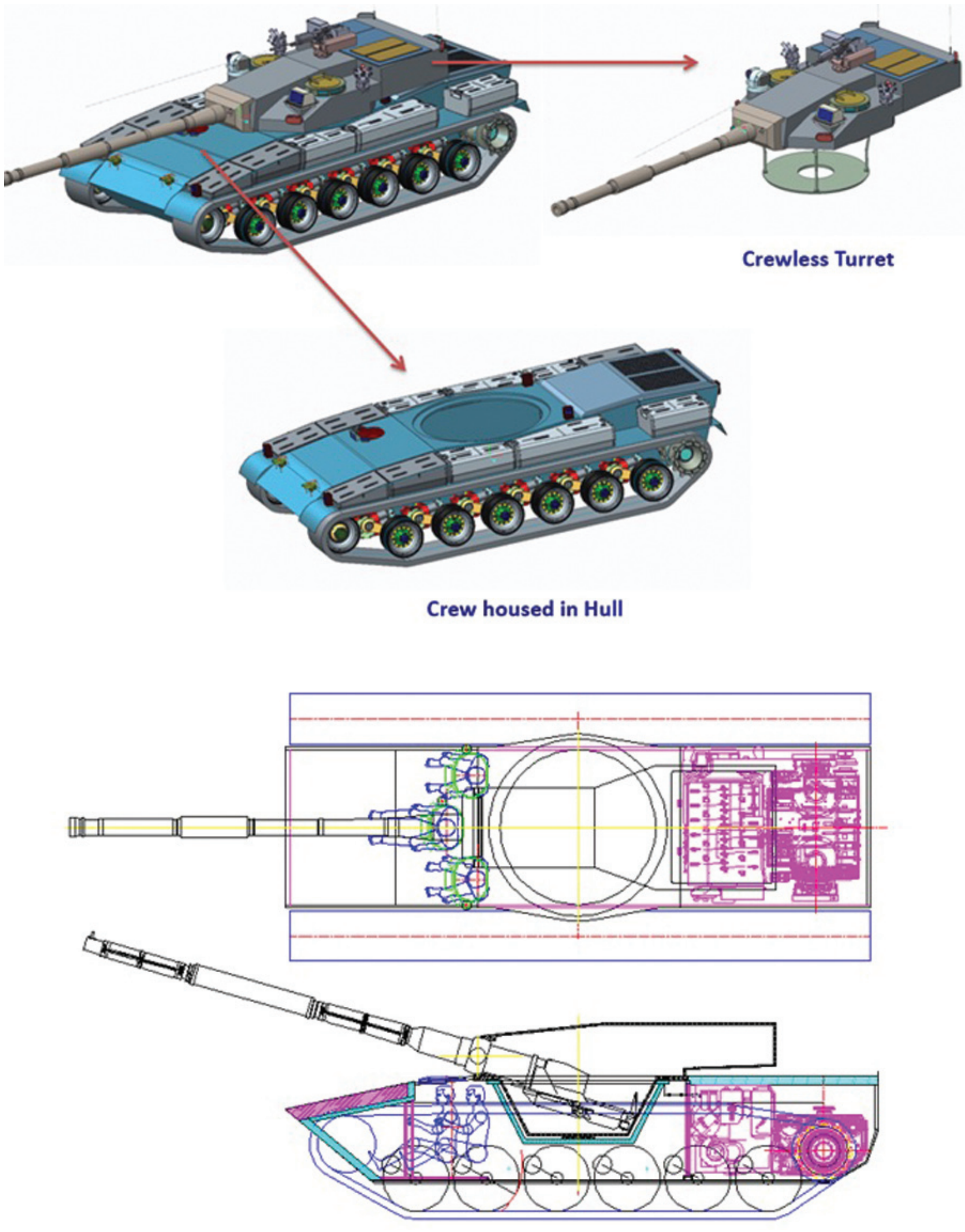

Figure 9. Revolutionary configuration design and layout.

REFERENCES

1. Kurpas, Monika & Holota, Marian. Transformation of the T-72 Main Battle Tanks. J. KONES Powertrain & Transport, 2015, **22** (1), 173-80. doi.org/10.5604/12314005.1161728
2. Stodola, J. Virtual Approach to Ground Armoured Vehicles Design. Advances in Military Technology, 2009, **4**(2), 13-25.
3. Purdy, David J. comparison of balance & out of balance Main Battle Tank Armaments. Shock & Vibration, 2001, **8**(3-4) , 167-74. doi.org/10.1155/2001/326219
4. Ma, Run Bo; Xu, Shi Meng; Dong, Yu Cai & Fan, Ge Hua. Comprehensive Evaluation on Weapon System of Main Battle Tank Based on Topsis Method. Adv Mat Res, 2012, **538-541**, 2949-52 doi: 10.4028/www.scientific.net/AMR.538-541.2949
5. Holota, Marian & Kurpas, Monika. Criteria and rules in the design of modern combat vehicles with large calibre armament, OBRUM , 2016 **39** (1), 126-46.
6. Levine, David M ; Stephen, David F & Szabat, Kathryn A. Statistics for managers, Ed 7 . Pearson Education India, New Delhi, Jan 2013.
7. Armoured fighting vehicles design. *In* Vol 3 Mobility, Cranfield University, Defence Academy, Shrivenham, UK, TSO 3.7.00, June 2005, pp. 349-397.
8. Hill, Gregory C . Automated ammunition magazine and projectile loader system. In 39th Annual Gun &

Ammunition Conference, USA, Apr 16 2004.

9. Angel, H. ; Brooks, J. ; Greenlay, M. & Kumagi, J. Human factor integration requirement for armoured fighting vehicles. Dept of National Defence, Ontario, Canada. Oct 1999.
10. Montgomery, Douglas C. Design and analysis of experiments, Ed 8. Wiley Publishers India, New Delhi, Feb 2013.
11. Freedman, David A. Statistical models: Theory & practice. Cambridge University Press, 2005. doi: 10.1017/CBO9781139165495
12. Gelman, Andrew. Analysis of variance. Ann Statist, 2005, **33** (1), 1-53. doi: 10.1214/009053604000001048

CONTRIBUTORS

Mr A. Hafeezur Rahman has completed his MSc (Military Vehicles Technology) from the Defence Academy, Cranfield University, United Kingdom, in 2013. He is currently serving as Scientist ‘E’ in Main Battle Tank Division, DRDO-Combat Vehicles Research and Development Establishment, Chennai. His research areas include: Design of structures, shock and vibration fixtures, structural and ballistic composites, honeycomb structures, weight optimisation of armoured fighting vehicles structures and design configuration for future combat vehicles.
His contribution to the current study include problem definition, complete DOE approach, DOE analysis using PH Stat, methodology used to compare the evolutionary and revolutionary configurationand full paper preparation.

Mr Ameer Malik Sheik has completed his MSc (Military Vehicles Technology) from the Defence Academy, Cranfield University, United Kingdom in 2014. He is currently serving as Scientist ‘C’ in Main Battle Tank Division, DRDO-Combat Vehicles Research and Development Establishment, Chennai. His research areas include indigenisation of louvres, development of weight reduced hull structure, composite cover plates, self-sealing fuel tanks and feasibility study for future combat vehicles.
His contribution to the present study include collation of data for both configurations.

Mr J. Rajesh Kumar has completed his MSc (Military Vehicles Technology) from the Defence Academy, Cranfield University, UK, in 2005 and MTech (Machine Design) from IIT, Madras, in 1999. Currently he is pursuing his PhD from IIT, Madras. He is currently serving as Scientist ‘G’, Addl Dir (Systems) in Main Battle Tank Division, DRDO-Combat Vehicles Research and Development Establishment, Chennai. His research areas include : System engineering, design, analysis, development, trial evaluation and productionisation of various mechanical sub-systems pertaining to armoured fighting vehicles.
His contribution in this study include arriving at the optimal parameters for the study, comparison of both configurations and overall guidance.

Mr V. Balaguru has completed his MTech (Machine Design) from IIT, Madras, in 1998 and currently pursuing his PhD from Annamalai University, Chidambaram. He is currently serving as Scientist ‘G’, Additional Director for the Main Battle Tank Division, DRDO-Combat Vehicles Research and Development Establishment, Chennai. His research areas include design, development and trial validation of systems that augment lethality, survivability and mobility for armoured fighting vehicles.
His contribution in this study include arriving at the optimal parameters for the study, comparison of both configurations and overall guidance.

Dr P. Sivakumar has completed his PhD in Machine Design from IIT, Madras, in 2011. He is currently serving as Distinguished Scientist and Director DRDO-Combat Vehicles Research and Development Establishment, Chennai. His research areas include design and development of AFV automatic transmission in the range of 150-1500 hp, combat aircraft transmission, conceptualisation of configuration for main battle tanks, infantry combat vehicles, armoured repair and recovery vehicles, self-propelled catapult vehicles, carrier command post, and unmanned ground vehicles.
His contribution in this study include revolutionary MBT configuration and overall guidance.