ABSTRACT

Armoured fighting vehicles (AFV) and military aircrafts (MAC) are the key mechanical systems which are used in field force and air force, respectively for maintaining the security of our country and to train the personnel for the purpose. Since these systems are very costly, attempts have been made to keep their most effective performance and fullest utilization. Also, in order to make the prompt availability of these systems in the field at the time of war, research studies need to be carried out to determine the exact number of spares to be kept in the stock for their replacement and overhauling so that the entire exercise of maintenance becomes cost effective and least time consuming.

The present investigation has been carried out on the above said field and air systems for estimating their life expectancy and for estimating their annual replacement to ensure their high state of availability so that the management decisions in regard to provisions of spares and planning of overhaul of failed engines of AFV and failed subsystems of MAC could be facilitated.

The engine of AFV is considered as a single component on which depends its mobility. Therefore, it is supposed to be the most critical subsystem because it has comparatively less life as compared to other subsystems of AFV. On the other hand, a military aircraft is a complex repairable system consisting of a number of subsystems of varying characteristics. Keeping these facts in mind, the engines of AFV and 13 major subsystems of MAC have been chosen as mechanical systems for the purpose of reliability analysis. The AFV engines population has been grouped into five different categories, e.g. Category-1 (Overall population of engines), Category-2 (Population of original engines), Category-3 (Population of overhauled engines), Category-4 (Population of model-A engines), and Category-5 (Population of model-B engines). While, the
13 different subsystems identified in case of military aircraft have been as: aircraft structure (1), flying control (2), hydraulic control (3), air conditioning (4), power plant (5), fuel plant (6), canopy operation (7), under-carriage (8), brake operation (9), electrical control (10), instruments (11), wireless (12), and radio compass (13). The failure data pertaining to these mechanical systems have been arranged category-wise as well as subsystems-wise and have been presented in tabular forms.

The estimation of life expectancy of AFV engines and subsystems of MAC has been made based on the 2-parameter Weibull distribution. The annual spares requirements for each of these systems have also been determined. A generalized computer software package has been developed to determine shape and scale parameters of Weibull distribution analytically fitted to the data available, using maximum likelihood method and Newton- Raphson’s algorithm. Life characteristics, e.g. mean life, standard deviation etc. of these systems have also been computed with the help of above software package.

Following are the research findings of the present investigation carried out:

1. The reliability of AFV engines $R(T)$ varies from 1 at 0 km and approaches 0 at 5000 km for all different categories of engine population. Further, it is revealed that during a life span of 0-3000 km, engines belonging to category-5 are the most reliable and engines belonging to category-3 are the least reliable among all different categories of engine population. Engine population of category-2 shows the value of reliability next to the value as that of category-5 population of engines. For example, at life time of 1500 km, the values of $R(T)$ are 0.601157, 0.578065, 0.528217, 0.472750 & 0.363565 for model-B, original, overall, model-A & overhauled engine populations, respectively.
2. The failure distribution $F(T)$ varies in a reverse fashion to that of $R(T)$ because it is a complement function of $R(T)$.

3. Failure density $f(T)$ for all different categories of engine population increases from 0 at 0 km and reaches maximum at certain value of lifetime and then decreases to reach 0 at about 5000 km. All curves of $f(T)$ are positively skewed toward right. The maximum values of $f(T)$ for different categories of engine population are about 0.000494 at 500 km for category-3 engine population, 0.000480 at 1500 km for category-2 engine population, 0.000466 at 1500 km for category-5 engine population, 0.000438 at 1100 km for category-4 engine population, & 0.000437 at 1300 km for category-1 engine population. This reveals that engine failures take place most frequently at their mode values of life times. Category-5 engines exhibit longest life because the value of failure density is found to be the minimum in comparison to other population of engines. While, overhauled engine population (Category-3) shows the shortest life at which failures take place most frequently. It indicates that model-B engine population is exhibiting superior life as compared to the lives of all different categories of engine population.

4. The failure rates $\lambda(T)$ for all different categories of engine population are approximately 0 at 0 km and are maximum at 4900 km. For engine populations of Category-2 & Category-5, the values of $\lambda(T)$ increase very fast with the life time and reach the maximum values of 0.003740 fr/km & 0.003561 fr/km at 4900 km, respectively. While, values of $\lambda(T)$ increase with life time slowly for engine populations of Category 4 & 3 and reach the maximum value of 0.01920 fr/km and 0.001315 fr/km, at 4900 km, respectively. On the other hand, the variation of $\lambda(T)$ with lifetime is found to be almost
linear for engine population of Category-1 and attains the maximum value of 0.002339 fr/km at 4900km. The plots of $\lambda(T)$ are intersecting at the value of 1700 km of life time.

5. Since shape parameter $\beta$ values are greater than 1 for all categories of engine population so all kinds of engines are in wear-out life. Further, it is observed that the value of $\beta$ is 2.287 for Category-5 engine population and is the maximum among all categories of engine population. However, the value of $\beta$ is 1.326 for Category-3 engine population, which is the minimum. This indicates that model-B engines are in aggressive wear out life, while overhauled engines are in the stage of start up of wear-out life.

6. The scale parameter $\theta$ gives the values of life at which 63.2% of engine population fails. The value of $\theta$ is found to be the largest (2015 km) for engine populations of Category-5 and the smallest (1487 km) for engine population of Category-3.

7. The average mean life $\bar{T}$ is the largest (1786 km) for engine population of category-5 and is the smallest (1366 km) for engine population Category-3.

8. Standard deviation $\sigma_T$ is the square root of the variance $\sigma_T^2$. It is observed that standard deviation is the largest (1043 km) for engine population Category-3 and is the smallest (823 km) for engine population Category-5. It reveals that lifetime spreads more closely about mean life in case of Category-5 engines as compared to Category-3 of overhauled engines.

9. The stabilised period $T_s$ is found to be the largest (1291 km) for engine population of Category-5 and the smallest (597 km) for engine population of Category-3.
10. The value of period at which 10% of population fails $T_{10}$ is seen to be 753 km for model-B engines. While, for overhauled engine population, this is found to be 272 km. Further, in the former case it turns out to be the maximum and the minimum in the later case.

11. The mean reliability $\overline{R}(T)$ is the least (0.272536) for overhauled engines and is the largest (0.357057) for Model B engines. This reveals that model-B engines are the most reliable and overhauled engines are the least reliable among all categories of engine population.

12. The mean failure distribution $\overline{F}(T)$ which varies in a reverse way to that of $\overline{R}(T)$ as it is complimentary function of $\overline{R}(T)$.

13. Mean failure density $\overline{j}(T)$ values are found to be the same (0.0002) for all categories of engine population.

14. The mean failure rates $\overline{\lambda}(T)$ are found to be the smallest (0.000999) for overhauled engines and the largest (0.001689) for overall engine population. This indicates that more maintenance facilities should be provided in case of overall engine population as compared to the other ones.

15. The number of spare engines required annually is the maximum (336) for overhauled engines category and the minimum (257) for model-B engines category. Hence, from spare engines requirement view point, Category-5 of model B engine population is the best one, while category-3 of overhauled engine population is the least desirable.

16. The reliability $R(T)$ varies from about 1 at 0 hr and 0 at 600 hr for all different subsystems of the military aircraft accept the subsystems 11 & 12. These two subsystems have 0 value of $R(T)$ at their respective life times of 540 and 300 hr. It is also revealed
that during a life span of 0-600 hr, the subsystem 4 is the most reliable because of its higher value of \( R(T) \), while the subsystems 12 is the least reliable because of its least reliability. The value of \( R(T) \) for other subsystems lies between those of the subsystems 12 & 4. For example, at the lifetime of 180 hr, the values of \( R(T) \) are found to be decreasing as 0.174668, 0.165949, 0.165866, 0.127750, 0.112950, 0.108436, 0.077121, 0.04822, 0.044136, 0.038994, 0.022777, 0.013070 & 0.000189 for sub systems 4,1,6,13,3,7,10,5,9,2,8,11 & 12, respectively.

17. The variation of \( F(T) \) with lifetime for all subsystems is as found in the reversed fashion to that of \( R(T) \) because it is a complement function of \( R(T) \).

18. The value of \( f(T) \) is the maximum at the life of 20 hr and decreases monotonically and is convex as lifetime increases. The value of \( f(T) \) at 20 hr of life ranges from the maximum value of 0.19070 for subsystems 12 (wireless) and minimum value of 0.007859 for subsystems 4 (air conditioning). The value of \( f(T) \) for all subsystems reduces to almost 0 at 600 hr except the subsystems 2,8,11 and 12 for which the value of \( f(T) \) is 0 at 580, 500, 420 & 260 hr, respectively. These results again indicate that the subsystem 4 is having the longest life, while the subsystem 12 is having the shortest life as compared to the lives of all remaining subsystems of the aircraft.

19. The failure rate \( \lambda(T) \) at the 20 hr of lifetime varies from the minimum value (0.009460 \( \text{fr/km} \)) for subsystems 4 to the maximum value (0.029374 \( \text{fr/km} \)) for subsystem 12. As lifetime \( T \) increases, \( \lambda(T) \) also increases for all the subsystems except subsystems 6,7,9 & 13. Further, \( \lambda(T) \) increases with lifetime but with decreasing rate for subsystems 1,2,3,4,5,8,10,11 & 12. It indicates that subsystems 6,7,9 & 13 are exhibiting early life failures, while the remaining subsystems are in the wear-out life.
20. The value of shape parameter $\beta$ is greater than 1 for the subsystems 1,2,3,4,5,8,10,11 & 12 but its value is maximum (1.36) for the subsystems 12. Hence, these subsystems exhibit wear-out life. However, subsystem 12 is relatively more susceptible to wear-out life. On the other hand, the subsystems 6,7,9 & 13 are exhibiting early life failures because the values of $\beta$ are less than 1 for these subsystems.

21. The value of scale parameter $\theta$ is found to be the largest (104.3 hr) for the subsystem 4 and the smallest (37.07 hr) for the subsystem 12. It means that 63.2% of population of system 4 fails at lifetime of 104.3 hr and that of subsystem 12 fails at 37.07 hr.

22. The mean life $\bar{T}$ is the largest (103.43 hrs.) for subsystem 4 and the smallest (33.91 hr) for subsystem 12.

23. The $\sigma_T^2 & \sigma_T$ are found to be the maximum for subsystem 6, and their respective values are 11580 hr$^2$ & 107.61 hr. However, for subsystem 12 these values are 640.32 hr$^2$ & 25.3 hr respectively, and are seen to be the minimum. It reveals that the lifetime spreads more about the mean life in case of subsystem 6 as compared to subsystem 12.

24. The stabilized period $T_s$ of all subsystems during which they attain almost a constant failure rate is found to be the largest (35.17 hrs.) for subsystem 4 and the smallest (15.14 hr) for subsystem 12.

25. It is seen that 10% of population of subsystem 4 fails at the lifetime of 11.48 hr and is found to be the largest. While, for the subsystems 9, it is noticed to be 5.82 hr and is observed to be the minimum. The $T_{10}$ values of other systems lie between these maximum and minimum values.
26. Mean reliability \( \bar{R}(T) \) of all subsystems is the largest (0.170977) for subsystem 1 and is the least (0.054586) for subsystem 12. This means that the subsystem 1 is the most reliable and the subsystem 12 is the least reliable among all subsystems.

27. Mean failure distribution \( \bar{F}(T) \) also varies in a reverse fashion to that of \( \bar{R}(T) \) with lifetime for all subsystems because \( \bar{F}(T) \) is a complementary function of \( \bar{R}(T) \).

28. Mean failure density \( \bar{f}(T) \) is the largest (0.00178) for subsystem 12 and is the least (0.001608) for subsystem 7. This means that failure occurs more frequently in case of subsystem 12 as compared to subsystem 7 over the entire life span of 600 hr.

29. Mean failure rate \( \bar{\lambda}(T) \) is the largest (0.07361) for subsystem 12 and is the smallest (0.009067) for subsystem 6. This means that more maintenance facilities and spares should be arranged more rigorously for subsystem 12 as compared to other subsystems.

30. The spares required annually come out to be the maximum (116) for subsystem 12 and the minimum (38) for subsystem 4 for the desired availability of 0.95 and other requirements.