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Reliability Demonstration of Safety Actuating Mechanism

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ABSTRACT

Development of high technology and high cost weapons system is a difficult task in view of high reliability goals. It is further compounded in the case of single-shot airborne systems. Overall reliability of weapons system depends upon the reliability of systems and sub-systems used. Design of each system and sub-system is finalised after preliminary design review, critical design review, etc. and final reliability is demonstrated by subjecting to functional tests.

Warhead is the only sub-system responsible for inflicting damage to the target and all the other sub-systems assist in delivering the warhead on or near the target. Safety actuating mechanism (SAM) sub-system is a single-shot device which provides safety during handling, launch and flight of a missile and actuates the warhead, whenever desired on receipt of firing pulse from radio altitude switch. SAM being critical for successful detonation of the warhead, it is desired that this unit should have very high reliability. SAM units are subjected to reliability tests and a reliability factor of 0.84 at 90 per cent confidence level is achieved which further increases to 0.98 due to redundancy.

1. INTRODUCTION

Prediction, assessment and evaluation of reliability must be based on relevant and credible data. Unfortunately for most applications, collection of data on reliability is expensive and time consuming. As a result, many manufacturers simply design and build their products, as best as they can, and hope for their reliability in service. In some cases, concurrent engineering methods are used to develop product designs and manufacturing processes with good quality and sometimes, reliability tests are conducted on the resulting products.

Aerospace technology applications, such as guided weapons, launch vehicles, etc. need highly reliable and consistently good quality systems. Missile being a weapon system, no user would like to use if it does not perform as expected. Under the circumstances, paramount need and conflicting demands of today are on the product design like high reliability, less complexity low-cost, and easy to maintain and use.

Reliability has to be introduced right from the design stage so that the end product is reliable. In large weapons systems like missiles, the required reliability values are allocated to various sub-systems, based on the system configuration. These allocated values become targets for sub-system designers. Based on the realised reliabilities of sub-systems, flight trials with integration of various sub-systems can be carried

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out. However, classical approach for reliability measurements require a relatively large number of tests for long periods to generate large amount of test data to produce estimates with reasonable confidence levels. Moreover, design and development cycle is shortening as the technology becomes obsolete very fast. Indeed, under the demands for time and cost-effectiveness Bayesian technique which takes into account both subjective test data (i.e. past experience, engineering judgement, reliability prediction etc.) and objective (actual) test data is one of the methods for estimating probability of success of a particular system, The data could be either attributive or continuous type. SAM being the most critical system for detonation of warhead and to achieve mission, it was decided to demonstrate reliability to the users by conducting functional tests using classical approach.

2. CASE STUDY

SAM is located at the base of a warhead which actuates the warhead on receipt of firing pulse form RAS. It provides the following safeties.

2.1 Minimum Time Safety

Minimum time safety is provided by clockwork mechanism. This isolates the circuit of the pyrotechnic device (the firing of which subsequently aligns detonator with main explosive train) on receiving the command.

2.2 Igniter Shorting

When the missile is at predetermined distance from the target, Command II generates a pulse which removes shorting of igniter by firing of a squib. The shorting of the igniter cannot be removed by spurious signals before the clockwork completes its set time.

2.3 Detonator Mis-alignment

The detonator is mis-aligned from the explosive train during a coarse of a missile flight. When the missile is at pre-determined distance from its target, Command II generates a pulse to fire the squib to align detonator with explosive train.

2.4 Radio Altitude Switch-Power Supply

Power supply to RAS is made available only after removal of the above safeties and on receipt of Command III, hence effective only after this stage.

A single-shot device, i.e. SAM under development is considered for reliability demonstration. Assuming the test data follows binomial distribution, reliability is estimated as the proportion of success to the total trials conducted. Upper and lower limit of reliability for a given confidence is estimated by the following equation:

$$R = P \pm Z_a \frac{P_q}{n}$$

where

p = Point reliability

q = Failure probability

n = No. of units tested

Confidence intervals are obtained with assumption of normality which is not valid for small sample sizes. In case of small samples, exact method of estimation of lower and upper confidence bound of the limit is obtained by

Confidence value = $1-R_L-(n)(1-R_L)$ --- $(n)\, R_L (1-R_L)^{n-f}$

1–Confidence value = $1-R_U-(n)R_U(1-R_U)$ --- $(n)\, R_U$ $(1-R_U)^f$

3. DESIGN QUALIFICATION & LOT ACCEPTANCE

SAM design was qualified by subjecting sample units to qualification level tests for detonation proof. Sealing proof test was also carried out after subjecting the sample unit to all qualification level tests. Subsequently, production lots were accepted by subjecting the sample units for acceptance and functional level tests. Samples were picked up randomly from accepted lot for reliability demonstration.

4. RELIABILITY TARGET

Reliability target for SAM is 0.95 with 90 per cent confidence level in dual SAM mode. Towards achieving this, it is required to test 45 dual SAM with zero failure.

4.1 Reliability Test

Figures 1 and 2 show functional and reliability block diagrams respectively. Various blocks in the diagram are independently testable for their performance. However, hot tests using squibs are not conducted in all cases. Only a few of them are hot tested for evaluation of the design of that particular sub-systems. The details of sub-system tests are given in Tables 1 and 2, wherein sub-system

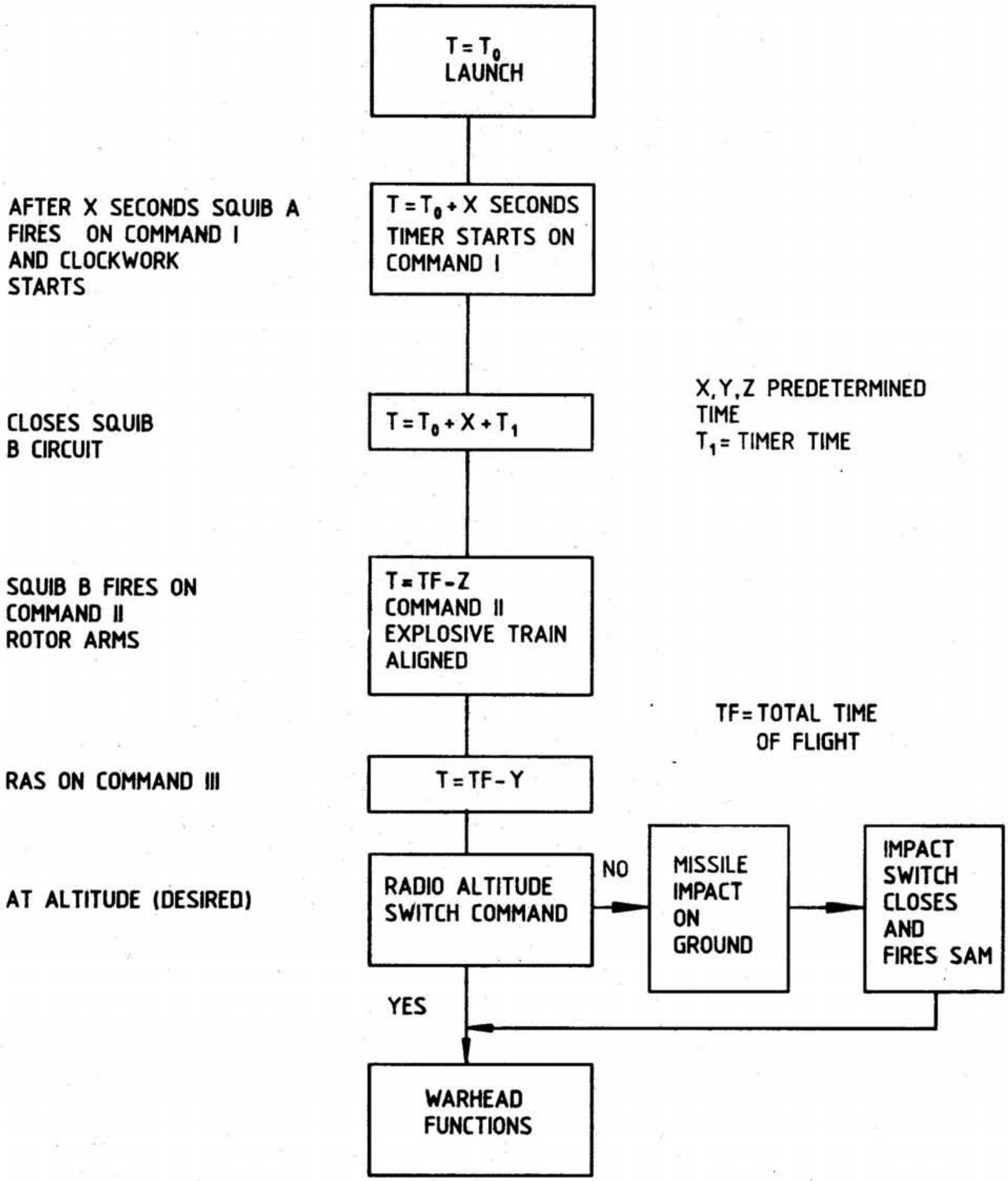

Figure 1. Functional block diagram of safety and arming mechanism

reliabilities are calculated by pooling data from different projects. Test results of full-scale SAM are also pooled from different production lots to get the overall reliability of the system.

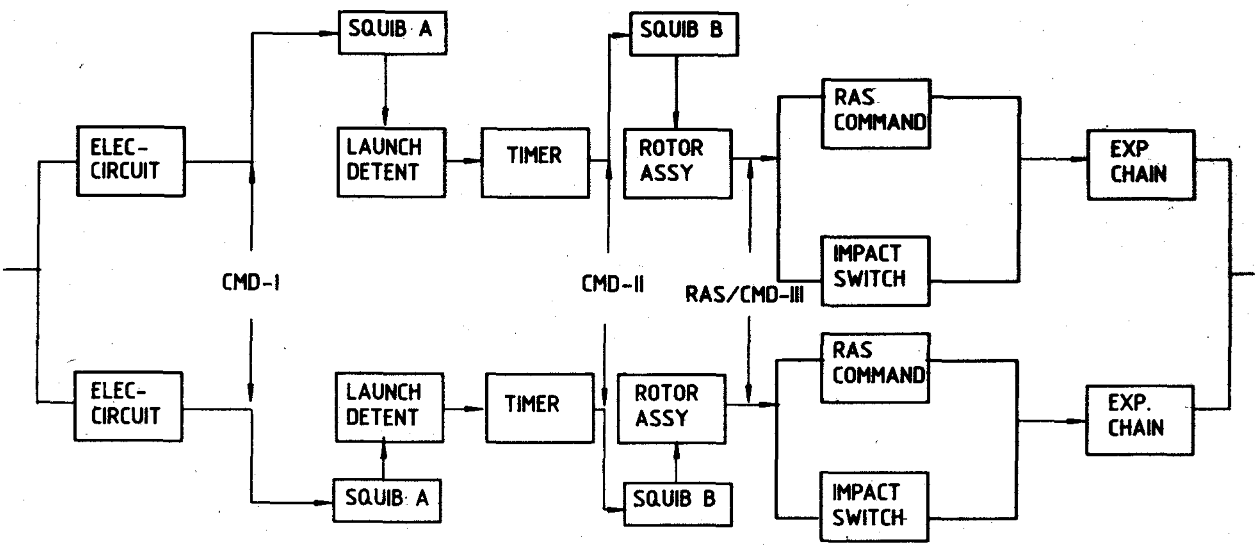

Figure 2. Reliability (mission) block diagram for SAM

5. RELIABILITY TEST ON FULL-SCALE SAM IN DUAL MODE

Ordnance factory, Ambhajari assembled 240 units of SAM pertaining to five different lots and these were filled at ordnance factory, Chanda. Sub-assemblies/components manufactured by VXL Ltd., Faridabad, were Inspected by local Inspection authority designated by Missile System Quality Assurance Agency (MSQAA), Hyderabad. Each lot was accepted as per laid down acceptance test plan which involved proof tests on seven units. Units for reliability demonstration were picked up at random from each accepted lot as per details given in Table 3 and subjected to functional test in dual mode. Individual units were also monitored for their performance. Two squibs used in the SAM are of the same specifications. The test data of squibs is presented in Table 2.

Table 1. Sub-system test data

Sub-System	Project I	Project II	Only sub-system	Full-SAM	Failures	*RL* at 90 % confidence level
Launch dentent	90	50	62	147	0	0.9992
Timer	90	—	—	147	0	0.9991
Rotary arming	90	50	62	147	3	0.9851
Explosives chain	—	—	[illegible]	147	0	0.9988
Impact switch	90	—	—	147	0	0.9992
PCB (Electronics)	—	—	—	147	1*	0.9845
km_1 and km_2 contact	—	—	—	147	9	0.9135

* PCB broken due to pyro shock

Table 2. Squib test data

Lot size	Tested	Failed	Point reliability	Reliability at 90 % confidence level	Remarks
200	60	0			At HEMRL, Pune
	10	2	0.9918	0.9859	At OF, Chanda after 1 and 1/2 years
	63	0			At HEMRL after 2 years
200	60	0			At HEMRL, Pune
	48	1			PCB damage due to excessive pressure generated in one of the SAM firings
Others	123	0			At ARDE, Pune

For the success of SAM, two squibs have to work.

$$R^2 = 0.9859^2$$

$$= 0.9720$$

Overall reliability of unit at 90 per cent confidence level = 0.8580.

Table 3. Full-Scale SAM test data

Lot No.	Lot size	Lot proof (single SAM)		Reliability tests (dual SAM)		Remarks
		Unit	Results	Unit	Results	
1	37	7	All functioned	10	All functioned in dual mode, One SAM failed in one of the pairs	Squib B ckt did not close
2	57	7	All functioned	10	All functioned in dual mode. Two SAMs failed, one from each pair	Squib B ckt failed to close
3	57	7	All functioned	10	All functioned in dual mode. However, two SAMs failed, one from each pair	(a) Squib B ckt failed to close (b) Soldered connection from igniter pole to PCB disconnected
4	57	7	All functioned	10	8 functioned 2 pairs failed	(a) Rotor did not arm in one arm in one case and rotor armed but SAM not fired in other pair 1 (b) Squib B ckt did not close in both SAMs. (pair 2)
				4	All functioned. One SAM in one of the pairs failed	Squib B ckt did not close
5	32	7	6 functioned one failed	–	–	Squib B ckt did not close

6. ANALYSIS OF TEST DATA

The reliability tests were carried out in batches. Resultant data was analysed for mission reliability estimate. Even though, SAMs were tested in dual configuration, results were analysed as single SAM units for two reasons. Firstly, the status and end results of ignition were monitored separately and hence, the experiment could be treated as if two independent tests were conducted. Secondly, confidence on reliability estimates improved as the sample size increased. After obtaining the reliability estimate of single SAM, dual SAM configuration reliability was worked out.

Test results of full-scale SAM pertaining to all lots were pooled to get the reliability of the system. Nine failures observed in closing circuit of squib B and one failure observed in rotor arming units were considered as independent tests. However, mission failure was observed in two tests. Reliability estimate based on the above data, is reported as

Reliability of two parallel SAMs will be

$$R = 1 - (1-R_L)^2$$

Case I: Mission reliability (dual mode)

Units tested	=	44
Units failed	=	02
Units Succeed	=	42
Points Reliability	=	0.9545
Lower limit of Reliability at 90 per cent confidence level	=	0.9144

Case II: Unit reliability (single unit)

Units tested	=	88
Units failed	=	10
Units succeed	=	78
Points reliability	=	0.8864
Lower limit of reliability at 90 per cent confidence level	=	0.8431
Reliability in dual mode	=	0.9753

7. CONCLUSIONS

- Based on sub-system reliability estimate reliability of SAM unit was 0.8580
- Point reliability of unit was 0.8864 and lower level of unit reliability was 0.8431 at 90 per cent confidence level. However, the reliability of SAM was increased to 0.9753 by redundancy (i.e., by using two parallel SAMs)
- Point mission reliability in dual mode was 0.9545 and lower level of reliability was 0.9144 at 90 per cent confidence level. This being lesser than the desired reliability, it was therefore suggested to review the design and improve the quality and reliability by design improvement.

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Contributor

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