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RELIABILITY PREDICTION OF MISSILE EJECTION SYSTEM BY FAULT TREE ANALYSIS

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Abstract: ***A Canisterised missile launch system is presented in this paper. The missile comes out of the canister and the main booster motor gets ignited in mid air. In this paper, Mean Time Between Failure (MTBF) is calculated for a sub systems involved in the ejection mechanism of a missile from the canister. The suitable distribution models were selected for estimating the reliability of each sub system. It appears that so far, in the literature Fault Tree Analysis for Canisterised Missile launch system has not been dealt with. The Fault tree is constructed using BlockSim software tool from Reliasoft for the top event "Booster motor not ignited". The MTBF values of sub systems are entered in fault tree and reliability for the defined event has been calculated. The advantages of canisterised missile system are also presented in this paper.***

Keywords: Distribution models, MTBF, Fault Tree Analysis, BlockSim.

1. Introduction:

Advantage of canister: 1. Better storage condition and makes operational flexibility 2. The launch clearance area is reduced 3. Quickly the vehicle can be launched along with added benefit is longer shelf-life.

The canister system consists of Electro explosive bolts, Auxiliary propulsion system, Exit sense mechanism, and Height sense mechanism. The missile is ejected out of canister through planned events. First, Electro explosive bolts will be fired and the missile will be released from the canister then the auxiliary propulsion will be fired which will develop enough pressure to take the missile out of the canister. These events are being executed by various sub systems. The missile ejection event is sensed by Exit sensor and height sense mechanism. The ejection system has been designed to tolerate single point failure.

Failure is considered due to software, as well as hardware [5]. Multiple breaks are introduced in missile and Ground control system to ensure the safe operation of explosive bolts. By using Fault Tree Analysis possible modes of failures and effects are studied, Test data is collected and MTBF value is calculated by using life distribution for each sub-system and the MTBF values of sub-system has been entered in fault tree and final unreliability is estimated for the top event which is in this case "Booster motor not ignited".

In section 2, Reliability, classification of sub systems, selection of distributions, confidence level is presented. In section 3, Fault Tree Analysis has been mentioned along with the symbols. In section 4, The Reliability is forecasted by using Fault Tree and Results are obtained by using Blocksim software tool. Finally, conclusions are given in section 5.

2. Reliability:

The reliability is the probability that the system should perform its intended functions for a specified period under specified conditions. [3] For missile system reliability prediction is important to identify the potential problem area and to verify whether missile system components met design requirements.

Following steps are required for reliability prediction:

- Identify the missile subsystem.
- Depending upon their functioning characteristics subsystem categorized as a discrete type and continuous type systems.
- For each type of system select suitable statistical distribution.
- Confidence level selection.

- Collect the test data.
- Forecast the reliability of subsystem and then unreliability of the system
- Enter the unreliability values of each subsystem into Fault Tree Analysis and find out the probability of failure of booster motor not ignited.

I. Classification of the subsystem:

Single-shot systems:

Electro explosive bolts, Exit sense mechanism, Auxiliary propulsion system are considered as single-shot systems. No. of tests and no. of failures are considered for reliability prediction.

Continuous systems:

The entire electronic subsystems like Relay Unit, Scheduler, Height sense mechanism, Redundancy relay unit, Local controller are considered as continuous systems that work continuously with respect to time. Mission time, total test time and no. of failures are considered for reliability prediction.

II. Selection of distributions:

For single shot systems:

For single-shot devices, the binomial distribution is used to find reliability.

The Binomial distribution is applicable only when there are two attainable outcomes i.e., success or failure

The probability density function,

$$f(x) = \binom{n}{k} q^{n-k} r^k \qquad (1)$$

where k is probability of failure

n-k is no. of success in n samples

r is probability of success

q is probability of failures

The following equation is the cumulative distribution function [4]:

$$F(x) = \sum_{k=0}^{n} \binom{n}{k} Q^k R^{n-k} = 1\text{-}C \qquad (2)$$

where C is confidence interval

Q is probability of failure

R is probability of success

n is no. of failures

For given confidence level, no. of failure is observed, by conducting the number of tests and reliability is to be calculated by using Eqn. (2)

For continuous type system:

For systems, whose survival depends on the time of operation and therefore the failure rate during useful life period is constant, the exponential distribution for time to failure is assumed and reliability calculated. The subsequent equation is employed for reliability estimation [4].

$$R = e^{-\lambda t}$$

$$R = e^{-(\frac{t}{m})} \qquad (3)$$

where, R is reliability

λ is failure rate

m is MTBF

m is calculated by using Eqn. [5]

$$m = \frac{2T}{\chi^2_{(1-C,2r+2)}} \qquad (4)$$

where T is total test time.

$\chi^2_{(1-C,2r+2)}$ Ordinate with confidence level from a chi-square distribution, and

2r+2 is degree of freedom.

The value of m is calculated with Eqn. (4) and substitute in Eqn. (3) to calculate reliability.

III. Confidence level:

A Confidence level is the degree of confidence that may come with a conclusion drawn on the basis of sample data. Good amount of test data is available for many of the subsystems, hence 90% lower confidence level is taken into account for calculating reliability.

Test data:

The methodology of collection of the test data and grouping with block diagram representation is as shown in fig.1

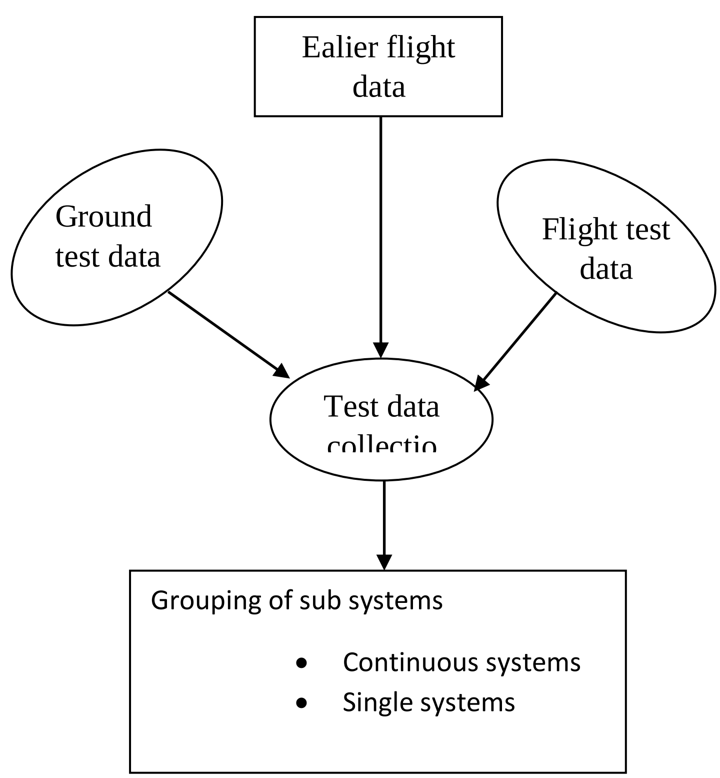


Fig. 1 block diagram of methodology of collection of test data and grouping

3. Fault Tree Analysis:

A fault tree is one of the methods for evaluating the failure probability of a sub system. Fault Tree Analysis is a top-bottom approach, it accustomed to determine potential causes of system failure and therefore logic diagram is to be found. Therefore, corrective action can be taken for the probability of system faults.

The main objective of Fault Tree Analysis is the identification of the causes leading to top events. It helps in improving system reliability. Fault Tree Analysis is also of particular value when applied to systems, comprising various components types and their interactions, which cannot be easily modeled with other techniques.

Events and Symbols:

Various events and symbols are used in the fault tree analysis [6] Presented in the appendix.

4. Analysis and Results:

Test data is collected for all subsystems and MTBF is to be found out from different distributions for these sub systems. The detail of the Fault Tree diagram of a top event is shown in Fig. 2. In the fault tree, two sub diagrams are to be introduced for "Auxiliary propulsion system not ignited" and "Electro explosive bolts not released" events. The details of sub diagrams are to be introduced in Fig. 2a and Fig. 2b respectively. The reliability test results are summarized in the table 1, 2, 3 respectively.

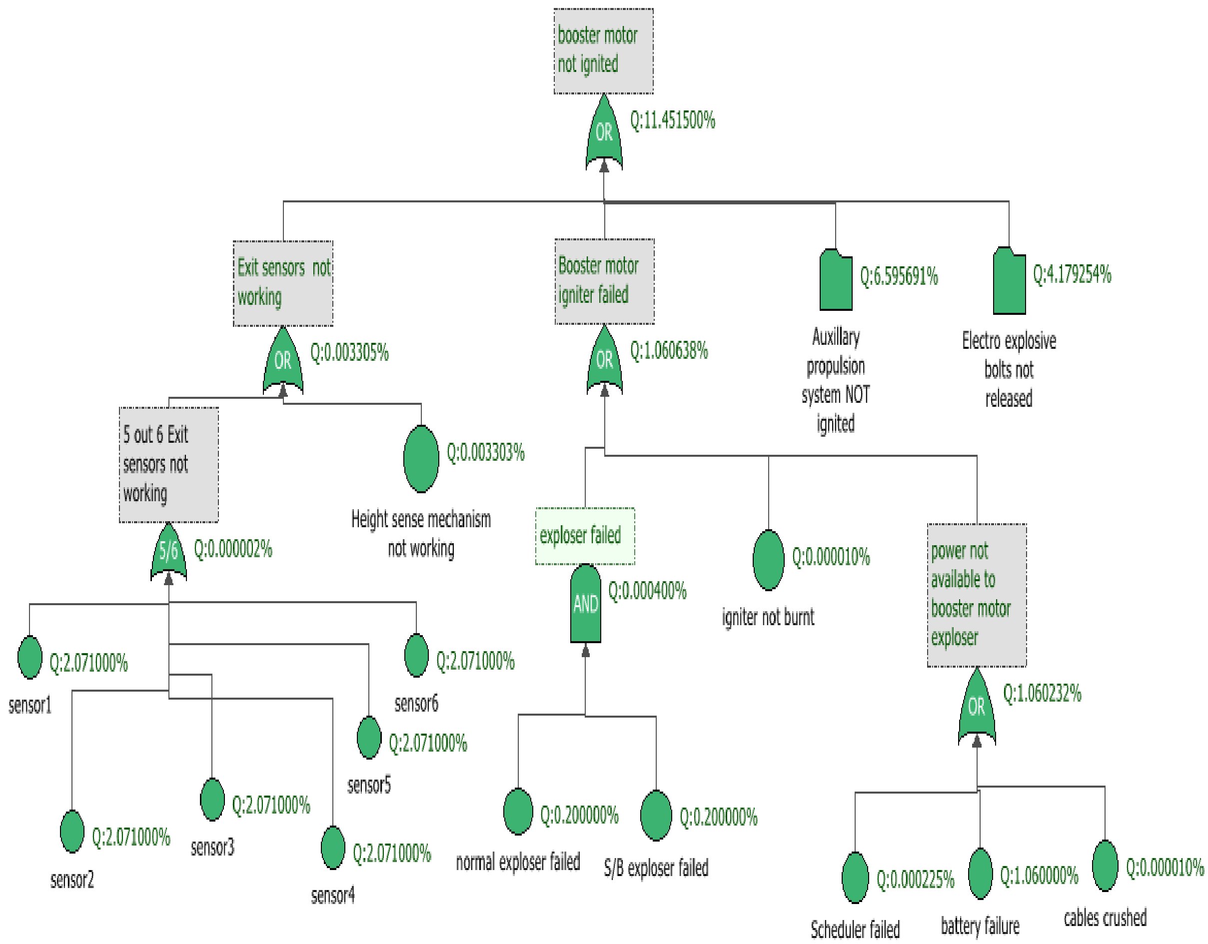


Fig. 2 FTA of Top event Booster motor not ignited

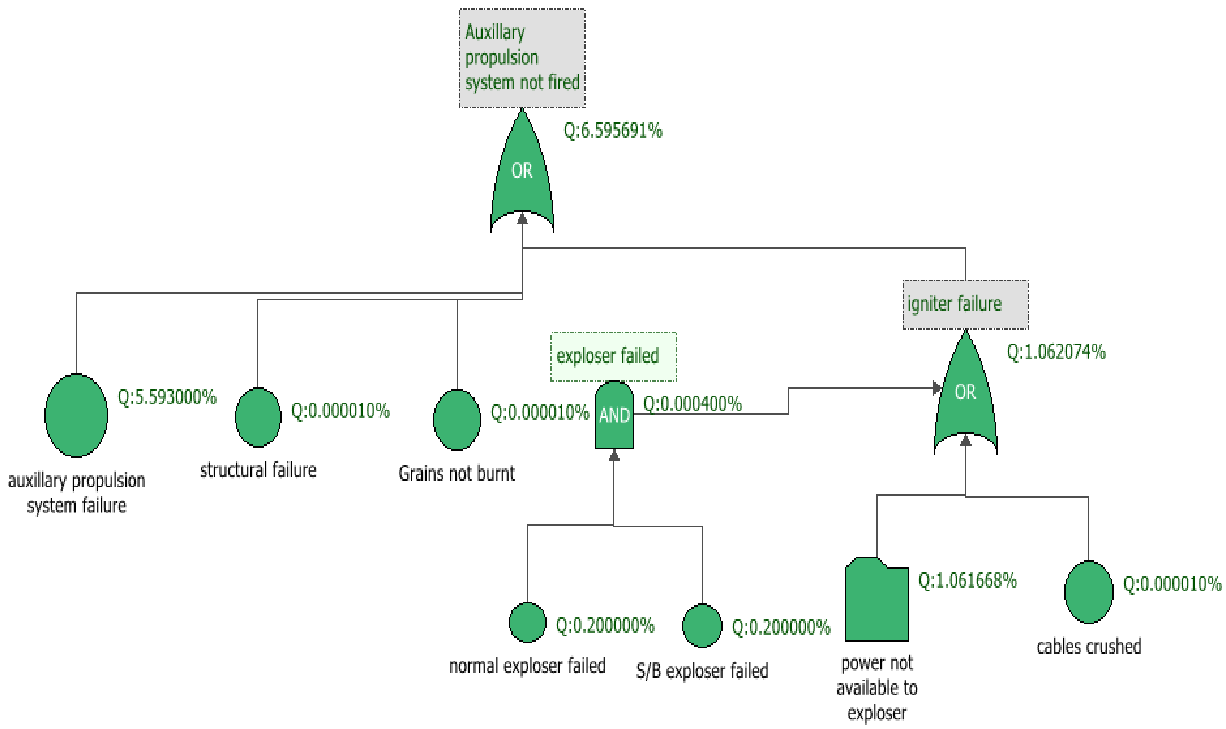


Fig. 2a subsystems of Auxiliary propulsion system not fired

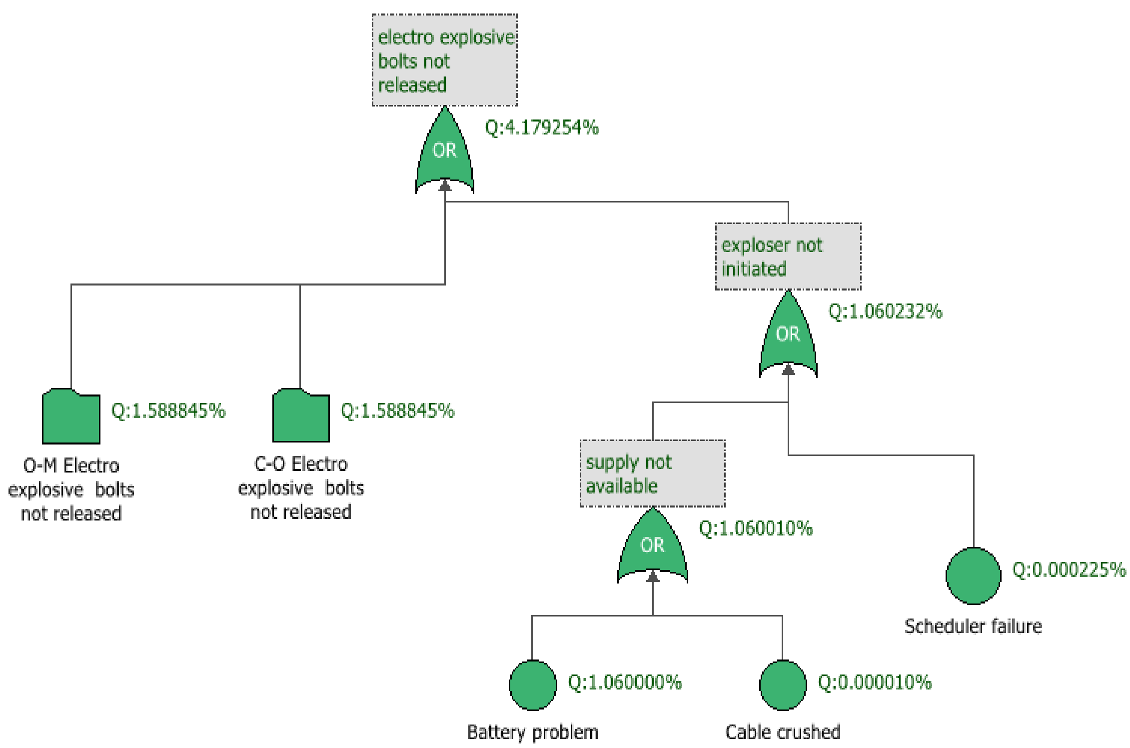


Fig. 2b subsystems of Electro explosive bolts not released

Table 1: Result of Booster Motor not ignited

Block Name	Unreliability (t=0.0011)
Booster motor not ignited	0.114514997
Exist sensors not working	3.305E-05
Height sense mechanism not working	3.30275E-05
5 out 6 Exit sensors not working	2.24642E-08
sensor1	0.02071
sensor2	0.02071
sensor3	0.02071
sensor4	0.02071
sensor5	0.02071
sensor6	0.02071
Booster motor igniter failed	0.010606381
igniter not burnt	0.0000001
power not available to booster motor exploser	0.010602325
battery failure	0.0106
cables crushed	0.0000001
Scheduler failed	2.24975E-06
exploser failed	0.000004
normal exploser failed	0.002
S/B exploser failed	0.002
Auxillary propulsion system NOT ignited	0.065956908
Electro explosive bolts not released	0.041792543

Table 2: Result of Auxiliary propulsion system not fired

Block Name	Unreliability (t=0.0011)
Auxilary propulsion system not fired	0.065956908
structural failure	0.0000001
Grains not burnt	0.0000001
auxillary propulsion system failure	0.05593
igniter failure	0.01062074
cables crushed	0.0000001
power not available to exploser	0.010616683
exploser failed	0.000004
normal exploser failed	0.002
S/B exploser failed	0.002

Table 3: Result of electro explosive bolts not released

Block Name	Unreliability (t=0.0011)
electro explosive bolts not released	0.041792543
O-M Electro explosive bolts not released	0.015888447
C-O Electro explosive bolts not released	0.015888447
exploser not initiated	0.010602325
Scheduler failure	2.24975E-06
supply not available	0.010600099
Battery problem	0.0106
Cable crushed	0.0000001

5. Conclusion:

In this paper the Fault tree has been constructed for the top event i.e., ‘Booster motor not ignited’ using ‘Blocksim’ software of Reliasoft. The various potential failure modes in the system has been studied for the top event to happen and found out the weak links in the fault tree. The probability of failure of the top event was found for “Booster motor not ignited”. It is concluded that the reliability may be further improved if the probability of failure of the events ‘Auxiliary propulsion system’ and ‘Electro explosive bolts’ are reduced. The design may be optimized in future for the Auxiliary propulsion system and electro explosive bolts to reduce the chance of failure.

6. References:

[1] IEEE standard 2007: "Basic Fault Tree Analysis for Use in Protection Reliability" issue publication March 2007.

[2] IEEE standard 2018: "Fault Diagnosis System for Electric Vehicle Charging Device Based on Fault Tree Analysis".

[3] Roy Bilinton, Ronald N Allan, "*Reliability Evaluation of Engineering systems*", 2007 marketed by BS publications, Hyderabad.

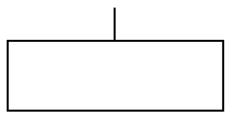
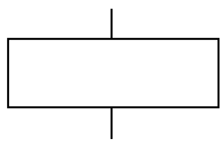
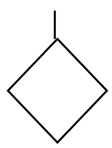
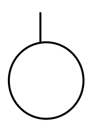
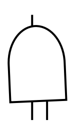
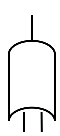
[4] V. Sankar, "*System Reliability Concepts*", published by Himalaya publishing House Pvt.Ltd., 2015.

[5] Clifton A Ericson II, "Fault Tree Analysis Primer". Create Space independent Publishing platform, 2011.

[6] Jeffrey W. Vincoil, "*Basic Guide to system safety*", Third Edition published in 2014.

Appendix:

Various events and symbols used in fault tree

Symbols	**Meaning of symbols**
	Top event: the most undesirable event of the system
	Intermediate event: caused by more primary events
	Undeveloped event: not developed any further because data is unavailable or it is not useful
	Basic event: A event which doesn't allow further development
	And Gate: The output of gate is high if and only if all the input fault events happens
	OR Gate: If any one of the input fault event happens the output of the gate is high