Research on the System Safety Assessment of Aero Engine based on the Monte Carlo

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Abstract. The process of research and development on the aero engine is complicate and iterative. Essentially system safety assessment is an indispensable part of the development process. Taking safety assessment of "Extinguishing lapsing when Request" as an example, this paper develops a Monte Carlo calculation model which calculates the probability combination of basic events as the security requirements from top event change. The Monte Carlo model offers a method to calculate from top events request to the basic events.

1. Introduction

The process of research and development on the aero engine is complicate and iterative. Essentially safety assessment is an indispensable part of the development process. In the aero engine research and development process, systematic and standardized analysis, design and verification prevent the occurrence of disaster or accident effectively, reduce the accident losses and the risk of engine operation and improve the safety of aero engine [1,2].

Based on the result of reference 1 and 3, this paper applies the Monte Carlo calculation model to the safety assessment of aero engine as a study. Reference 3 manually iterates the change of top event probability as the basic events failure rate changes by several orders of magnitude, and shows several basic event failure rate combinations that meet the probability changing requirements of top event. In Reference 3 the modified top event probability requirement is 1E-11 per engine flight hour, but the probability calculation result is between 4.32E-12 and 9.91E-12 per engine flight hours, which is still stricter than the request. If the basic event failure rate combination, which exactly meet the top event probability of 1E-11 per engine flight hour, is able to be calculated or predicted, there will be some chance to reduce the technical requirements for engine development from safety requirements [1,3].

If we manually iterate the basic event failure rate combinations that meet 1E-11 per engine flight hour, there will be multiple iterations and a lot of computation. In this paper, the Monte Carlo method is introduced to reduce the computing workload and the optimal solution of basic event failure rate combination is obtained.

2. Monte Carlo method

Monte Carlo method is random simulation calculation methodology, which also called statistical simulation method and random sampling technique. It is a kind of calculation method that based on the theory of probability and statistics. Monte Carlo model establishes the relationship between the problem need solving and the probability model, proceeds statistical simulation or sampling by computer and obtains the approximate solution of the problem.
The basic steps of using Monte Carlo method to solve practical problems are showing as below.

1. According to the characteristics of practical problems, the researchers construct a simple and convenient probabilistic statistical model, ensure the solution is exactly the probability distribution or mathematical expectation of the problem.
   2. The researchers describe the sampling methods of random variables with different distribution in the model.
   3. The researchers summarize statistic or process simulation results and predict the estimate solution of the problem.

In the aero engine system safety assessment process, the basic event failure rate is a random variable value. Based on the established fault tree (Extinguishing lapsing when Request) [3], the Monte Carlo method can be used to calculate different combinations of basic event failure rates corresponding to the top event probability.

### 3. Application of Monte Carlo method

Based on the established fault tree (Extinguishing lapsing when Request) from Reference 3, the paper calculates the top events probability distribution and the trend as the failure rate of basic events continuous variation and proves the relationships between top events probability and the failure rate of the basic events by ORIGIN, and finds out the optimal combination of the basic event failure rate corresponding to the requirements from the top event.

According to reference 3, when both of event 1 and event 2 failure rate are 5.00E-06, the probability of top event is 8.43E-12 that can meet the modified top event probability. When the failure rate of event 1 and event 2 are 1.00E-05 and 1.00E-06 respectively, the probability of top event is 9.28E-12 that can meet the modified top event probability. Event 1 and event 2 respectively fetch 10000 values randomly from 1.00E-06 to 1.00E-04 according to uniform distribution to calculate the probability of top event. And the probability range of top event is distributed from 2.34E-12 to 1.67E-10, the grouping result is shown in Figure 1. The figure shows that most of the top event probability calculation results are between 8.00E-11 and 1.00E-12, the exact result quantity is 2236 in this range.

According to the uniform distribution from 4.15E-09 to 4.15E-07, 10,000 numerical values are randomly selected for event 3 and event 4 to calculate the probability of top event, the result of the calculation is distributed from 6.33E-12 to 1.67E-10, and top event probability group distribution is shown in Figure 2. The figure shows that most of the top event probability calculation results are between 8.00E-11 and 1.00E-12, the exact result quantity is 2243 in this range. When the event 1 and event 2 continuously varying from 1.00E-06 to 1.00E-04 respectively, the calculated probability distribution of top events is shown in Figure 3. When the event 3 and event 4 continuously varying from 4.15E-09 to 4.15E-07 respectively, the calculated probability distribution of top events is shown in Figure 4.

The figures shown that the top event probability is linearly related to the correlation among the four basic events. As the failure rate of the basic event increases, the probability of the top event also increases. According to the color icon in the figure, the blue direction is the decreasing direction of top event probability, and the red direction is the increasing direction of the top event probability. The oblique line in the figure is the contour line. All the combinations of event 1 and 2, or event 3 and 4 failure rates zone, which is lower than the contour line with the top event probability of 1.00E-011, is the group that the top event probability is less than 1.00E-011, and the basic events probability combination which located in this zone meets the modified top event probability.
Figure 1. The top event probability distribution diagram (According to uniform distribution, events 1 and 2 fetch random values between 1.00E-06 and 1.00E-04).

Figure 2. The top event probability distribution diagram (According to uniform distribution, events 3 and 4 fetch random values between 4.15E-09 and 4.15E-07).

Figure 3. The top event probability distribution diagram as event 1 and 2 changing between 1.00E-06 and 1.00E-04.
If both of event 1 and event 2 failure rate is 1.00E-05 while both event 3 and event 4 failure rate is 2.08E-07, the probability of top event is 8.57E-12. The result can meet the modified top event probability. Fixing event 1 and event 2 are uniformly distributed from 1.00E-06 to 1.00E-05 while event 3 and event 4 are uniformly distributed from 2.08E-07 to 4.15E-07 respectively, 100000 values in the zone are randomly selected to calculate the probability of top events and the results are distributed between 2.94E-12 and 1.67E-10, the probability group distribution of top event probability is shown in Figure 5. The figure shows that most of the results are between 4.00E-11 and 6.00E-11, the exact top event probability calculation result quantity is 30,245 in this range.

Figure 6 shows 26 combinations of events 1, 2, 3 and 4, which are from the random selected 100,000 values, corresponding to the top event probability between 9.90E-12 and 1.00E-11. Figure 7 shows 9 combinations of events 1, 2, 3 and 4, which are from the random selected 100,000 values, corresponding to the top event probability between 9.96E-12 and 1.00E-11. The combination of the basic events corresponding to top event probability within 1.00E-11 meet modified security requirement. The basic event combination of failure rates that meet the top event security requirements is iterated to the development process. In the development process, the components, systems and parts involved in the basic events are developed and re-developed according to failure rate combination. In the current development process the failure rate generally comes from ground test, operation statistics and simulation analysis. If the new failure rate is calculated and the security requirements of the top event are met, the iteration can be ended. If the security requirements of the top event are not met, the iteration work must be re-calculated again.
Figure 5. The top event probability distribution diagram (According to uniform distribution, events 1 and 2 fetch random values between 1.00E-06 and 1.00E-05, events 3 and 4 fetch random values between 4.15E-09 and 2.08E-07).

Figure 6. The relationship between the failure rate combination of events 1, 2, 3 and 4 and the probability of top events.
Figure 7. The relationship between the failure rate combination of events 1, 2, 3 and 4 and the top events probability. (TP is the probability of top event, and EV1, EV2, EV3, and EV4 are the failure rates of event 1, 2, 3, and 4 respectively.)

4. Conclusion

This paper develops a Monte Carlo calculation model that applies to calculate the probability combination of basic events as the security requirements of top events varying. Meanwhile the linearly relationship is proved that the top event probability changes as the basic event failure rate changes continuously. This paper finds out a way to predict the optimal combination of basic events with the condition that the sensitive basic event is in relief when the top event probability is given. Failure rate prediction is the input of research and development, and the paper provides the developer a way to conduct iteration.

References

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