Estimation of failure probability of B737 pneumatics system by fault tree analysis

H.MAHFOUD, A.ELBARKANY, A.ELBIYAALI

Abstract— in airline industry where reliability and safety are paramount and in such difficult economic environment today, it’s essential to adopt a strategy of mastery and rationalization of maintenance costs to perform the optimum level of capability. Fault tree analysis (FTA) is one of the most important logic and probabilistic techniques used in probabilistic risk assessment (PRA) and reliability analysis. It’s an effective decision support tool that helps to find operational weaknesses in complex systems and then uncover and prioritize safety improvements and maintainability cost optimization. The objective of this research is to develop an analytical method based on FTA to improve the reliability and maintainability of a large complex system of Boeing 737 next generation responsible for several key operations during flight, namely the pneumatic system; in order to optimize its preventive maintenance and availability of aircraft, intolerable thing in such us area where the lost of time means simply a waste of money.

Keywords—B737 aircraft, Fault tree analysis, Maintenance costs, PRA, reliability.

I. INTRODUCTION

FAULT TREE ANALYSIS has became the most important tool to evaluate safety and reliability of complex and large systems. It’s a logical and probabilistic approach for evaluating the possibility of an accident resulting from sequences and combinations of failure events. It’s simply a technique by which many events that interact to produce other events can be related using simple logical relationships. This method is a graphic model of the various parallel and sequential combinations of faults that will result in the occurrence of the predefined undesired event. The faults can be events that are associated with component hardware failures, human errors, or any other pertinent events which can lead to the undesired event. A fault tree thus depicts the logical interrelationships of basic events that lead to the undesired event—which is the top event of the fault tree [1].

II. ROLE OF FAULT TREES IN A PRA

Probabilistic risk assessment, or PRA, models sequences of events which are usually called an accident sequence that need to occur in order for undesired end states to occur. A model of a simple event sequence in PRA is shown below.

![Fig. 1 simple PRA events sequence](image)

If an event is independent of the others in the sequence and failure data exist, the probability can be directly estimated from the data. But form more complex events, the fault tree is developed to a level that encompasses the dependencies between systems or to a level where failure data exist for that basic events, whichever is lower [2].

III. GENERAL PROCEDURE FOR FTA CONSTRUCTION

To elaborate a comprehensive FTA, we follow these steps:
1) Define the system of interest
2) Define the top event for the analysis
3) Define the treetop structure
4) Explore each branch in successive levels of detail
5) Solve the fault tree for the combinations of events contributing to the top event
6) Identify important dependent failure potentials and adjust the model appropriately
7) Perform quantitative analysis
8) Use the results in the decision making [3]

IV. QUANTITATIVE FAULT TREE ANALYSIS

A. Boolean modeling

FTA is a mathematically Boolean tool for modeling a system’s unreliability. The conventional analysis, proposed by Vesely, determines the probability of failure (P0F) of a system from a set of components that make up that system. Boolean AND and OR gates are used to connect components with one another [4].

![Fig. 2 AND/OR gates](image)
For an AND gate, the probability of system failure, \( P_T \) can be calculated from:

\[
P_T = P_A \times P_B \quad (1)
\]

Where, \( P_A \) and \( P_B \) are the corresponding failure rates of each component, respectively.

In general, the top event probability for a set of \( N \) components through AND gates, is shown in Equation 2:

\[
P_T = \prod_{i=1}^{N} P(C_i) \quad (2)
\]

Likewise, top event failure for a simple OR gate is predicted by:

\[
P_T = P_A + P_B - (P_A \times P_B) \quad (3)
\]

In general, the top event probability for a set of \( N \) components through OR gates, is shown in Equation 4:

\[
P_T = \frac{\sum_{i=1}^{N} P(C_i) - \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} P(C_i \times C_j) + \sum_{i=1}^{N-2} \sum_{j=i+1}^{N-1} \sum_{k=j+1}^{N} P(C_i \times C_j \times C_k) \times \ldots \times (-1)^N P(C_1C_2C_3 \ldots C_N)}{\sum_{i=1}^{N}} \quad (4)
\]

The rare-event approximation is often used to simplify this equation.

\[
P_T = \sum_{i=1}^{N} P(C_i) \quad (5)
\]

B. Importance factors

The importance factors are used to quantify the contribution of each components failure to the top event occurrence probability [5].

1) Fussell-Vesely’s Factor

It’s a measure of a referred element contribution to the system failure. The mathematical definition of the importance of VF is as follows [6]:

\[
FV = \frac{P(T) - P(T/E=0)}{P(T)} \quad (6)
\]

Where

\( P(T) \): top event probability

\( P(T/E=0) \): conditional probability of the top event occurrence given that the occurrence of \( E=0 \).

2) Birnbaum’s Factor

It’s a measure of the difference between the value of a top event probability when \( E \) occur \( (P(E)=1) \) and when it doesn’t occur.

\[
BF = P(T/E=1) - P(T/E = 0) \quad (7)
\]

3) Risk achievement worth’s Factor

It’s a measure of the growth of a top event probability when the \( E \) is unavailable:

\[
RAW = \frac{P(T/E=1)}{P(T)} \quad (8)
\]

V. CASE STUDY: PNEUMATIC SYSTEM FAULT TREE ANALYSIS

A. System description

The pneumatic system supplies compressed air to the airplane user systems:

- These are the sources of pneumatic power [7]:
  - Engines bleed air system
  - Auxiliary power unit (APU) bleeds air system
  - Pneumatic ground air connection.

The pneumatic manifold collects the compressed air from the sources and supplies it to the user systems:

- Engine start systems
- Air conditioning and pressurization systems
- Engine inlet cowl anti-ice systems
- Wing thermal anti-ice systems
B. Structural analysis

Functional block diagram allows interconnecting different system functions.

![Fig. 5 Pneumatic functional bloc diagram](image)

C. The potential accident Top event

After mapping the system by establishing functional description, it was time to define the most penalizing equipment in terms of reliability. At this level, we based on the maintenance reports to better target the system potential failure that will be a little further subject of our study to overcome the problems of unavailability of 737/NG Boeing fleet RAM caused by an abnormality related to ATA 36.

Figure below show the distribution of unexpected failures related to our system that have led to interventions of maintenance just before the plane takes off, these abnormalities cause delays compared to pre flight schedules.

![Fig. 6 Pneumatic failures distribution](image)

Combining criteria of failure frequency, number of equipment removals, and consequences on availability and safety, we will consider in our study “Bleed Trip off” as a top event.

D. Treetop structure

At this stage we determine the events and conditions that most directly lead to the top event until the fault tree model is complete. We use PTC windchill quality solutions software.

![Fig. 7 Pneumatic fault tree](image)

E. Input data (MTBF)

Once the history is prepared and, Time Between failure is spotted, we determine by the weibull law the Mean Time Between Failure, which constitute the probability input data.

![Fig. 8 Events MTBF](image)

F. Quantitative assessment

For more precision, the software explicit for each event contributor to the potential accident it’s unreliability, unavailability and frequency in the first 1000 hours.
In the table below, “Precooler control valve” is the element which contribute first to the top failure analyzed with a fuzzel-Vesely factor=0.244 and high criticality that exceed 0.2.

### VI. MAINTENANCE COSTS OPTIMIZATION

According to the system tree analysis results, Precooler control valve is the defaulting element among the other events contributing to the general system failure. Thus the preventive maintenance is imperative to optimize its reliability.

### VII. CONCLUSION

This study deals with the pneumatic system reliability, by using the Fault tree Analysis. This method enables the estimation of the system breakdown probability, result of failure sequences that contribute to the top event. Thus the main result is the knowledge of the system characteristics to master maintenance costs.

### REFERENCES


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**A. Necessary expenses to control the Precooler control valve operation.**

This maintenance action must be done every 1234 (FH), which will take 6 hours of work and need the acquisition of some consumables and materials.

The cost of this operation is evaluated at 3924 DH.

**B. Damage caused in case of an unexpected failure**

An unexpected failure of the precooler control valve leads to its replacement by a new one and its expedition to a foreign subcontractor to be repaired.

- Reparation costs: 61550 DH
- Freight charges: 2500 DH
- Labor costs: 866 DH
- Immobilization: 2h

The cost of this failure is about 64 916 DH

Consequently, the inspection and control of precooler control valve provides gain of 94% over expenses of an unexpected failure.