FAILURE ANALYSIS AND SYSTEM DESIGNING WITH RELIABILITY AND SAFETY TAKEN INTO CONSIDERATION

Prof. D.Sc. Eng. Jan BORGOŃ, Prof. D.Sc. Eng. Jerzy JAŹWIŃSKI,
Prof. D.Sc. Eng. Maciej WOROPAY, D.Sc Józef ŻUREK

INSTYTUT TECHNICZNY WOJSK LOTNICZYCH
(Air Force Institute of Technology)
Warsaw, Poland

Abstract. Our considerations are to be focused on the process of upgrading the aeronautical products, as conditioned by undesirable tendencies in reliability and safety coefficients. Modern aircraft (SP) are featured with high level of complexity. In practice, there is no chance to secure the required reliability and safety characteristics in the course of design and manufacturing processes. The situation calls for applying special strategy of controlling these properties. The strategy is based upon relations between the aircraft manufacturing system and the system of operating the aircraft. The paper deals with a selected portion of such a strategy. Every aircraft is composed of subassemblies of high level of reliability. Reliability structure of an aircarft is of a redundant type (structural, functional, parametric, time, and informational redundancies); what is more, there are many safeguarding/fail-safe provisions in the aircraft. For the above-mentioned reasons the likelihood of various events to occur in the aircraft is rather small. In practice, a number of various events (failrues, air accidents) can be equal to zero. Therefore, a special algorithm to determine reliability of subassemblies has been discussed herein. The tendencies in some selected coefficients have been dealt with, as well. On the basis of the tendencies found the aeronautical products are upgraded. Some modernization methods have been suggested.

Stating the Problem

It is input information that is absolutely necessary in the course of manufacturing the aeronautical engineering products (aircraft, aircraft assemblies and subassemblies). The information includes coefficients of reliability, maintainability (repairability) and safety of aeronautical products, information on weak points, (sub)assemblies of poor quality, etc. The information is used to match assemblies and subassemblies for designing the aeronautical engineering products as well as to analyse the products with computer simulation methods or using a tree of events.

Another significant field of utilizing the operational information is the process of upgrading the aeronautical products. The upgrading procedures result in various alternative designs of the aeronautical products. Our considerations are to be focused on the process of upgrading the aeronautical products, as conditioned by undesirable tendencies in reliability and safety coefficients. Taking into account also a correspondence factor - apart from the above-mentioned coefficients - the algorithm under consideration should include modernization of the operational type, as well.

Algorithm of Controlling the Upgrading Process

Modern aircraft (SP) are featured with high level of complexity. In practice, there is no chance to secure the required reliability and safety characteristics in the course of design and manufacturing processes. The situation calls for applying special strategy of controlling these properties. The strategy is based upon relations between the aircraft manufacturing system and the system of operating the aircraft. Fig. 1 shows a fraction of the relation.

A decision of dividing the events into the dangerous ones (eg. an air accident) and other events is taken within the algorithm (Fig. 1).
The dangerous events enforce some specific, provided by regulations, procedures. There is no room in this paper to deal with the relation 'manufacturer - operating process' with reference to individual events.

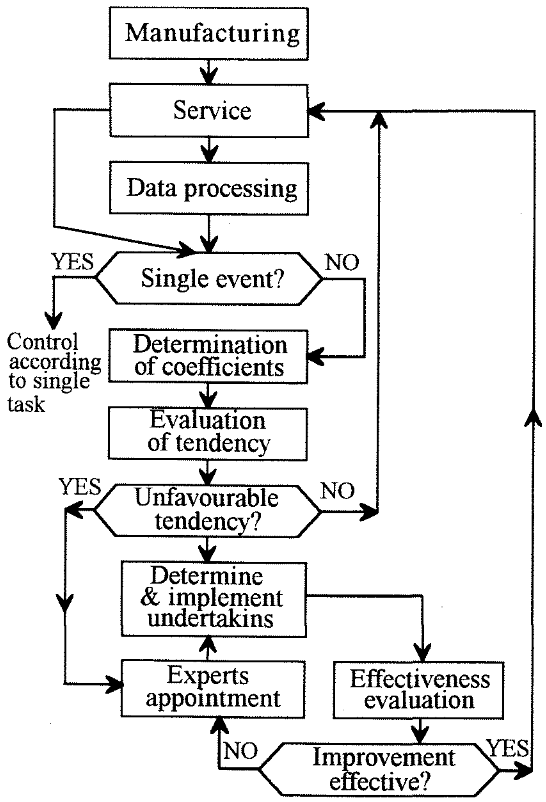

Fig. 1. Fragment of 'manufacturing vs requirements' interdependence.

A procedure regarding events being the basis for determining statistical coefficients of reliability and safety is to be taken into account in this paper.

The algorithm in its outline takes the following course:

An aircraft (SP) taken from a manufacturer is introduced into service. Information on various events that occur in course of aircraft operation, eg. a failure, an air accident, etc. is transferred to a data collecting and processing system. A decision on the way(s) of analysing the event is taken, as well. The selected event is analysed according to some special procedure. On the basis of the comprehensive information gathered the reliability and safety coefficients are determined and tendencies in the aircraft (SP) characteristics (described by these coefficients) examined. If significant statistical unfavourable tendencies are found, eg. deterioration in reliability of the selected subassemblies of the selected aircraft, the problem is reported to the manufacturer that sets up a team of experts. The experts are supposed to evolve a method of counteracting the unfavourable tendencies.

Having introduced the improvements the manufacturer and the operator analyse the effectiveness of the countermeasures taken. If the result of an improvement is unfavourable, the problem is handed over to the experts again. The paper deals with algorithms to determine reliability and safety coefficients, to infer on tendencies in specific aircraft (SP) characteristics, and to select improvements to be made.

Aircraft Reliability and Safety Coefficients

Every aircraft is composed of subassemblies of high level of reliability. Reliability structure of an aircarft is of a redundant type (structural, functional, parametric, time, and informational redundancies); what is more, there are many safeguarding/fail-safe provisions in the aircraft. For the above-mentioned reasons the likelihood of various events to occur in the aircraft is rather small. In practice, a number of various events (failrues, air accidents) can be equal to m = 0.

Rates of events have been accepted as measures of their occurrences. Algorithm described in [5], that takes the case m=0 into account, has been used.

Following rates of events are considered:

- λ_u - rate of failures,
- λ_{pw} - rate of prerequisites for an accident,
- λ_w - rate of air accidents,
- λ_{nz} - rate of unperformed missions,
- λ_g - rate of unpunctual proceeding to perform a task,
- λ_{ul} - rate of in-flight damages.

In practice, quite a large number of such factors can be originated.

The expected value and variance of occurrence of the events are described with the following equations:

$$E[\lambda] = \frac{m+1}{t_s} \quad (1)$$

$$V[\lambda] = \frac{m+1}{t_s^2} \quad (2)$$

where: t_s - total service time of SP (aircraft) set under consideration, or its subassemblies, m - observed number of events of SP set under consideration, or its subassemblies.

Confidence intervals for the rate of events on the confidence level β_g and β_d are determined from the solution of the following system of equations:

$$1-\sum_{k=0}^{m}\frac{(\lambda_g t_s)^k \exp[-\lambda_g t_s]}{k!} = P(\lambda \le \lambda_g) = \beta_g \qquad (3)$$

$$\sum_{k=0}^{m}\frac{(\lambda_d t_s)^k \exp[-\lambda_d t_s]}{k!} = P(\lambda \le \lambda_d) = \beta_d \qquad (4)$$

By way of example, for m=0 we have:

$$\lambda = \frac{1}{t_s} \qquad (5)$$

$$\lambda_g = \frac{1}{t_s}\ln\frac{1}{1-\beta_g} \qquad (6)$$

$$\lambda_d = \frac{1}{t_s}\ln\frac{1}{\beta_d} \qquad (7)$$

Observing various events all the time we can use the previously collected information to increase accuracy of successive estimations. If we have information of the type $\lambda \subset [\lambda_1, \lambda_2]$ from the previously collected data, then the confidence interval is determined from the solution of the following system of equations:

$$F(\lambda_g, t_s, m) = \beta_g F(\lambda_2, t_s, m) + (1-\beta_g)F(\lambda_1, t_s m) \quad (8)$$

$$F(\lambda_d, t_s, m) = \beta_d F(\lambda_1, t_s, m) + (1-\beta_d)F(\lambda_2, t_s m) \quad (9)$$

$$F(\lambda, t_s m) = 1-\sum\frac{(\lambda\, t_s)^k \exp[-\lambda\, t_s]}{k!} \qquad (10)$$

By way of example again, for m=0, $\lambda \subset [0\lambda_2]$ we have:

$$\lambda_g = -\frac{1}{t_s}\ln\{1-\beta_g[1-\exp(-\lambda_2\, t_s)]\} \qquad (11)$$

$$\lambda_d = -\frac{1}{t_s}\ln\{1-(1-\beta_d)[1-\exp(-\lambda_2\, t_s)]\} \quad (12)$$

Having determined the reliability and safety coefficients and confidence intervals we can make a bar chart (Fig. 2).

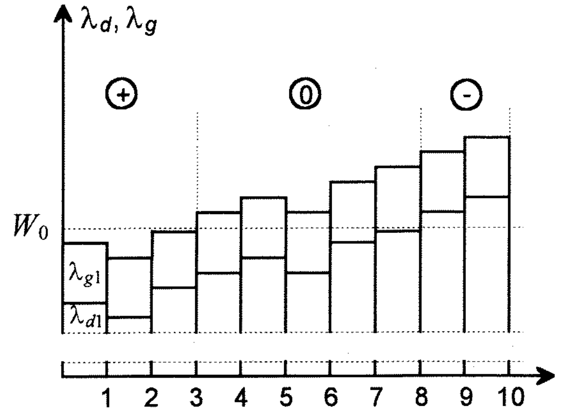

Fig. 2. Exemplary bar chart of ten-years' rate of events, with tendencies in W_0 requirements shown.

Inferring on Tendencies in Reliability and Safety

Tendency in rate of occurrences λ is evaluated by comparing it to the rate of standard events W_0; the following algorithm can be used:

$$w = \begin{cases} W_0 < \lambda_d & \text{- unfavourable tendency (-)} \\ W_0 \subset [\lambda_d, \lambda_g] & \text{- no tendency to change (0)} \\ W_0 > \lambda_g & \text{- favourable tendency (+)} \end{cases} \qquad (13)$$

Coefficient of reference W_0 can be either a reliability coefficient or a factor of safety, both determined by requirements; it can also be some other quantity accepted by experts in the operational process. If the reliability and safety cooefficients are determined monthly, quarterly or yearly, then the expected value of initial rate of events can be admitted as the coefficient of reference.

Fig. 2 shows various situations effected by eq. (13). The requirement on the rate of events has been admitted as the coefficient of reference W_0.

With eq. (13) as a basis a continuous measure of the tendencies can be originated. Introducing designations: $x_d = \lambda_d - W_0$; $x_g = W_0 - \lambda_g$; $y = \lambda_g - \lambda_d$ we can write down:

$$W = \begin{cases} 1-\frac{x_d}{y} & \text{for } x_d \le y; \quad W_0 < \lambda_d \\ 1 & \text{for} \quad W_0 \subset [\lambda_d, \lambda_g] \\ 1+\frac{x_g}{y} & \text{for } x_g \le y; \quad W_0 > \lambda_g \end{cases} \qquad (14)$$

In practice, in effect of investigations we arrive at estimates of tendencies in many coefficients, eg.:
$W[W(\lambda_u), W(\lambda_{pw}), W(\lambda_w), W(\lambda_{nz}), W(\lambda_g).....]$.
Evaluation of a complex tendency creates numerous difficulties.

Finding Reasons of Unfavourable Tendencies in Coefficients

A group of experts is appointed to find causes of unfavourable tendencies in coefficients that describe an aircraft.

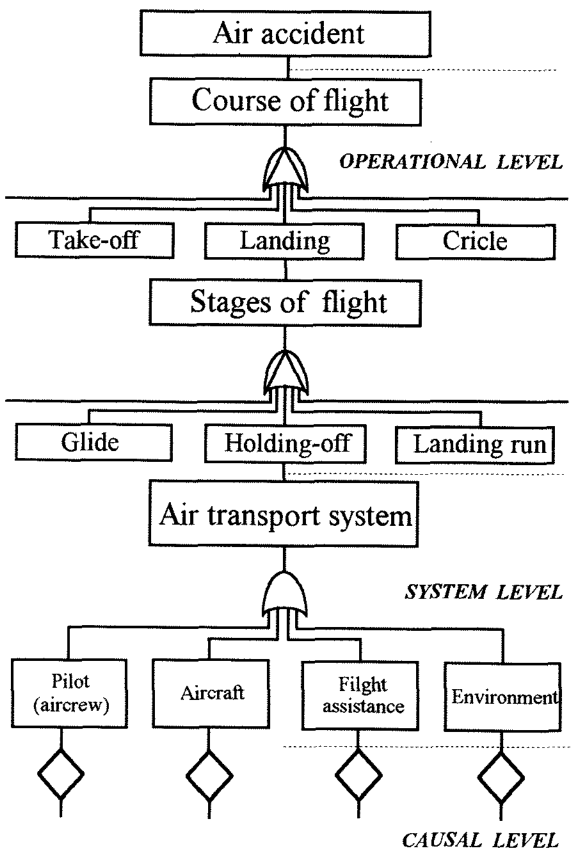

Fig.3. General-purpose tree of events.

The group includes:
- specialists in aircraft operating practice,
- researchers into problems of aeronautics,
- specialists in collecting and processing data on events that occur in course of aircraft operation,
- manufacturer's representatives.

As the statistical coefficients show the nature of a system, the appointed team often uses system methods in analyses. 'Tree of events' is such a method. In a given case the 'tree of events' serves the aim of ordering the course of a procedure. Fig. 3 shows fragments of such a tree of events aimed at analyzing the causes of the undesirable tendencies. The tree of events shown in this figure takes into account an air transport system in the course of performing a task. Effects of various components of the air transport system are given consideration.

System Upgrading

Having determined the potential causes of undesirable tendencies the team sets up to evolve a method to improve the situation. Depending on the nature of the causes found the operators or the manufacturer appoint an expert team to search for upgrading methods. Various heuristic methods can find their applications in this field. They are as follows:

1. **Autopsy method.** The team looks various similar systems through. Detailed analysis of collected data on events is carried out. With such a procedure as a basis, series of design and operational solutions are elaborated aimed at changing the unfavourable tendencies in coefficients

2. **Matrix-of-interactions method.** Matrix is generated with the elements $a_{ij}; ij = 1, 2, ..., n$, being weights that describe interactions between the elements.

	p	s	k
p	4 a_{pp}	5 a_{ps}	0 a_{pk}
s	3 a_{sp}	4 a_{ss}	0 a_{sk}
k	3 a_{kp}	3 a_{ks}	4 a_{kk}

Fig.4. Exemplary matrix of R relation (pilot, airplane, climate).

Let us consider a trivial example of a system that consists of three elements (Fig. 4): a pilot (p), an airplane (s), climatic conditions (k). Let us assume that $a_{ij} \subset [0, 5]$, where: 0 - no relation, 5 - close relation.

Numerical values $a_{ij}; ij = p, s, k$ are of illustrative nature. In practice, these are basic relations in aeronautics that show various values for various aircraft. Analysis of the matrix of relations allows effective solutions of upgrades to be found.

3. **Network-of-interactions method.** The method is similar to the matrix-of--interactions method; the difference is that we use the graph (Fig. 5).

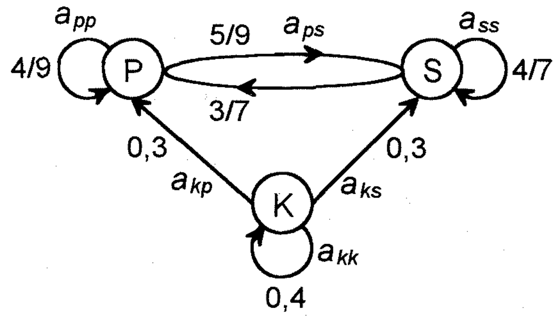

Fig.5. Exemplary graph of R relation (pilot, airplane, climate).

4. **Opposite-assumptions method.** Assumptions opposite to those creating the basis for system generation are introduced. The action allows the existing inconsistencies to be discovered and the system to be made more efficient.

5. **New-combinations method.** It consists in discovering new elements and features that allow a new improving solution to be found, eg.: the matrix in Fig. 4 can be enriched with various times of day or seasons of the year.

6. **Enforced-connections method.** The method consists in finding innovations by means of introducing certain unexisting relations to the matrix or the graph, eg.: the relation $a_{sk} > 0$ in Fig. 5.

Some exemplary methods of selecting this or that way of modification from a set of many and various formal and heuristic techniques have been mentioned. The efficiency of the upgrading process is selected depending on the tendency of a given coefficient.

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