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Methods for Analyzing the Reliability of Electrical Systems Used Inside Aircrafts

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1. Introduction

This chapter presents two solutions to perform reliability analysis of electrical systems installed on aircrafts. The first method for determining the reliability of electrical networks is based on an analogy between electrical impedance and reliability. The second method is based on application of Boolean algebra to the study of reliability in electrical circuits. By using these research methods we obtain information on operational safety of the electrical systems on board of an airplane, either for the entire system or for each of its components (Jula, 1986). The results allow further optimization of the construction of electrical system used on aircrafts (Aron et al., 1980), (Jula et al., 2008).

2. Calculating electrical impedance and reliability – an analogy

Establishing the reliability of structures resulting from the analysis of electrical systems installed on board of aircrafts can be achieved by direct calculations, but involves a long working time as a result of taking into account all possible situations that can occur during system operation (Reus, 1971), (Hoang Pham ,2003), (Levitin, G. et al., 1997).

A more efficient calculation method for complex structures can be achieved by applying equivalent transformation methods in terms of reliability, similar to the transformation theorems for electrical circuits applied to determine the equivalent impedance between two nodes (Moisil, 1979), (Drujinin,1977), (Billinton, 1996).

2.1 Short presentation of the analogy method

To highlight the approximations introduced by this method of calculation consider a group of elements connected in series, with the likelihood of downtime q_1, q_2, ..., q_n. Using transformation theorem for elements in series, these elements can be replaced with a resultant, a single item that has a probability of downtime q, (Drujinin,1977), given by:

- The exact formula

$$q = 1 - \prod_{i=1}^{n}(1 - q_i) \tag{1}$$

- The approximation of order 1

$$q = \sum_{i=1}^{n} q_i \tag{2}$$

- The approximation of order 2

$$q = \sum_{i=1}^{n} q_i - \frac{1}{2}\sum_{i=1}^{n} \sum_{j=1}^{n} q_i q_j \tag{3}$$

For the approximation of order 1, the error made is of the order of magnitude q_i^2, while for 2nd order the approximation error is q_i^3, etc.

Therefore for order 1 approximation, the probabilities of downtimes q_1, q_2, ..., q_n of elements connected in series are added together as if determining the equivalent impedance of a circuit with electrical components connected in series.

A group of elements connected in parallel with the probability of downtimes q_1, q_2, ..., q_n can be replaced by one single element that has a probability of downtime:

$$q = \prod_{i=1}^{n} q_i \tag{4}$$

In this case, the equivalent probability of downtime is achieved as a product of individual probabilities; therefore the result in this case is different from the equivalent impedance of an electrical circuit made of components in parallel.

A group of elements with delta connection, with the likelihood of downtime q_{12}, q_{23}, q_{31} may be replaced by another group of elements connected in star with the probability of downtime q_1, q_2, q_3. The relations for transformation are:

$$\begin{aligned} q_1 &= q_{12} q_{31} \\ q_2 &= q_{23} q_{12} \\ q_3 &= q_{31} q_{23} \end{aligned} \tag{5}$$

with an approximation error proportional with $q_{12} \cdot q_{23} \cdot q_{31}$.

Relation (5) was deducted under the assumption that the reliability of the circuit between two points, for example between point 1 and point 2 - Figure 1 - is the same for both connections in two borderline cases, namely:

- The third point is offline,
- The third point is connected to one of the first two.

Under these conditions the following relationships are obtained:

$$\begin{aligned} q_1 + q_2 - q_1 q_2 &= q_{12}(q_{23} + q_{31} - q_{23} q_{31}) \\ q_2 + q_3 - q_2 q_3 &= q_{23}(q_{31} + q_{12} - q_{31} q_{12}) \\ q_3 + q_1 - q_3 q_1 &= q_{31}(q_{12} + q_{23} - q_{12} q_{23}) \end{aligned} \tag{6}$$

$$\begin{aligned} q_1 + q_{23} - q_1 q_2 q_3 &= q_{12} q_{31} \\ q_2 + q_{31} - q_2 q_3 q_1 &= q_{23} q_{12} \\ q_3 + q_{12} - q_3 q_1 q_2 &= q_{31} q_{23} \end{aligned} \tag{7}$$

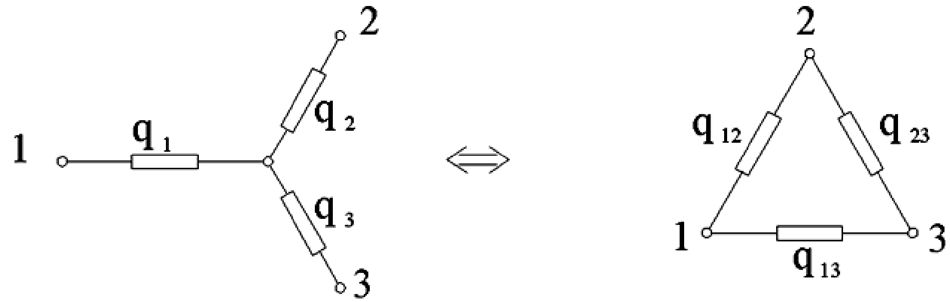


Fig. 1. Star-Delta and Delta - Star transformation for reliability.

It can be seen that the two systems described in (6) and (7) are incompatible. But if you take into account that the components used in electrical circuits on board of an aircraft are characterized by $q << 1$, approximate solutions can be utilized (Aron & Paun, 1980).

Neglecting the smaller higher-order terms of the transformation delta-star, in this case the third order component, equations in (6) become:

$$\begin{aligned} q_1 + q_2 &= q_{12} q_{23} + q_{12} q_{31} \\ q_2 + q_3 &= q_{23} q_{31} + q_{23} q_{12} \\ q_3 + q_1 &= q_{31} q_{12} + q_{31} q_{23} \end{aligned} \tag{8}$$

If the second equation is multiplied by (-1) and all the system equations are added, equation (9) is obtained:

$$q_1 = q_{12} q_{31} \tag{9}$$

Applying the same methodology for the other two remaining equations in (8) results the below equivalence for delta-star transformation:

$$\begin{aligned} q_1 &= q_{12} q_{31} \\ q_2 &= q_{23} q_{12} \\ q_3 &= q_{31} q_{23} \end{aligned} \tag{10}$$

From (7) and using the same methodology, relationships for star-delta transformation are obtained (Hohan, 1982):

$$q_{12} = \sqrt{\frac{q_1 q_2}{q_3}} \quad q_{23} = \sqrt{\frac{q_2 q_3}{q_1}} \quad q_{31} = \sqrt{\frac{q_3 q_1}{q_1}} \tag{11}$$

2.2 The analogy method applied for electrical circuits used in aircrafts

Example 1. The diagram presented in Figure 2.a corresponds to a three-phase electrical generator, part of the airplane power system, powered by a three-phase electric motor, both having their stators with delta connection. The transformed version of the diagram according to the analogy method is shown in Figure 2.b.

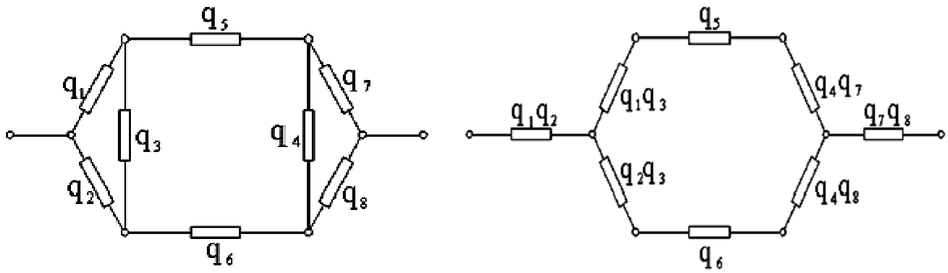


Fig. 2. Delta-star transformation – example 1.

The transformation delta – star applied to q_1, q_2, q_3 and q_4, q_7, q_8 becomes a simple network configuration for which downtime can be established with the specific probability when applying the previously derived relations:

$$Q = q_1 q_2 + q_7 q_8 + (q_1 q_3 + q_5 + q_4 q_7)(q_2 q_3 + q_6 + q_4 q_8)$$

$$Q = q_1 q_2 + q_5 q_6 + q_7 q_8 + q_1 q_3 q_6 + q_1 q_3 q_5 + q_4 q_6 q_7 + q_4 q_5 q_8$$

If the components have the same probability q, then the probability of downtime Q is:

$$Q = 3q^2 + 4q^3$$

Example 2. Figure 3 shows the diagram of a measurement instrument based on logometric principle, used to measure engine temperature or quantity of existing fuel in the plane tanks (Jula, 1986).

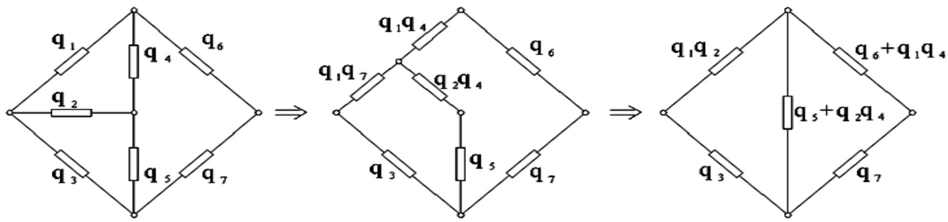


Fig. 3. Transformations for the measurement instrument – example 2.

The relations obtained for the probability of downtime Q after two transformations are:

$$Q = q_1q_2q_3 + q_7(q_6 + q_1q_4) + q_1q_2q_7(q_5+q_2q_4) + q_3(q_6 + q_1q_4)(q_5 + q_2q_4)$$

$$Q \cong q_6q_7 + q_1q_2q_3 + q_1q_4q_7 + q_3q_5q_6$$

If the components have the same probability of downtime q, it results:

$$Q \cong q^2 + 3q^3$$

Example 3. The diagram in Figure 4 corresponds to an aircraft specific electromagnetic system powered by multiple nodes.

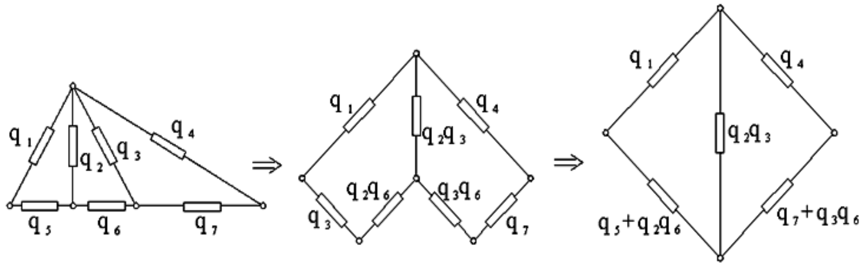


Fig. 4. Successive transformation of the electromagnetic system – example 3.

The downtime probability Q, resulting from the transformations illustrated above is:

$$Q = q_1(q_5 + q_2q_6) + q_4(q_7 + q_3q_6) + q_1q_2q_3(q_7 + q_3q_6) + q_7 + q_2q_3q_4(q_5 + q_2q_6)$$

$$Q \cong q_1q_5 + q_4q_7 + q_1q_2q_6 + q_3q_4q_6$$

If the components have the same probability q of downtime, it results:

$$Q \cong 2q^2 + 3q^3$$

Alternatively, a more efficient transformation is presented in Figure 5.

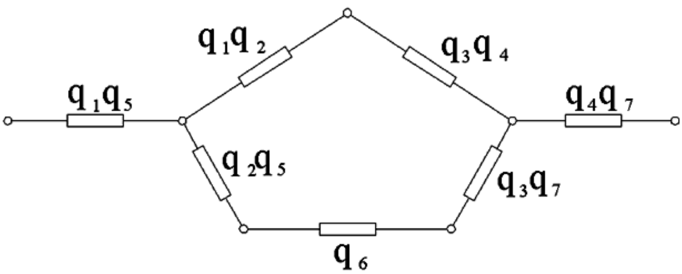


Fig. 5. A version of the final state after the transformation.

A relation for this state is:

$$Q = q_1 q_5 + q_4 q_7 + (q_6 + q_2 q_5 + q_3 q_7)(q_1 q_2 + q_3 q_4)$$

$$Q \cong q_1 q_5 + q_4 q_7 + q_1 q_2 q_6 + q_1 q_4 q_6$$

Whereby the result is identical to the one previously obtained, the calculation time is significantly reduced.

2.3 Conclusions regarding the analogy method

The method draws on the similarity between the calculus for the electrical impedance and the reliability one, allowing the use of simple relationships and reducing the number of equations to be solved. In case of complex networks other methods would lead to difficulties in obtaining results in short time, while the analogy method, with its rather low number of calculations ensures a time efficient way of finding the downtime probability of any electrical circuit.

If one or more circuit elements are less reliable than other parts of the circuit, and therefore its downtime probability is high, the transformation can get more accurate approximations of the real state of the system than other methods, mainly due to the multiplier effect contained.

3. The method based on Boolean logical structures

Large-scale systems reliability analysis is based on the quantification of the failure process at the structural level. Thus, any system downtime is a result of a quantified sequence of states in the failure process. The quantification level can be chosen in accordance with the desired goal and probability, down even to individual components of the system. The more detailed the quantification, the more accurate would be the resulting probability (Reus, 1971) (Muzi, 2008).

The conceptual representation of an emergent downtime is formed by a series of primary events, interconnected through different Boolean logical structures, which indicate the possible combinations of those elements having as result a system failure (Denis-Papin& Malgrange, 1970), (Chern & Jan, 1986). Thus determining the reliability of an aircraft electrical system using Boolean algebra actually means calculating the probability of a “failure” event.

3.1 Principles of the Boolean method

From the structural point of view, for the reliability analysis, we will use the terms:

- Primary elements – components or blocks at the base level of the quantification,
- Primary failures – primary elements failures,
- Unwanted event – system failure state,
- Failure mode – the set of primary elements that when simultaneously in failure mode, drives to a system failure
- Minimal failure mode – the smallest set of primary components that when simultaneously in failure mode, drive to a system failure
- Hierarchic level – all elements that are structurally equivalent and having equivalent positions in the system failure representation.

The method is based on binary logic. Thus, a system function is equivalent to a binary function, which variables are the events (the failures).

This binary function:

$$Y = f\left(X_1, X_2, ..., X_n\right) \tag{12}$$

is synthesized with logical elements AND/OR, using the following symbols and states:

- $\bigcup$ (Reunion) for the function OR
- $\bigcap$ (Intersection) for the function AND

X_i is 1 if the primary element is good and 0 otherwise, and Y is 1 if the system is good and 0 otherwise.

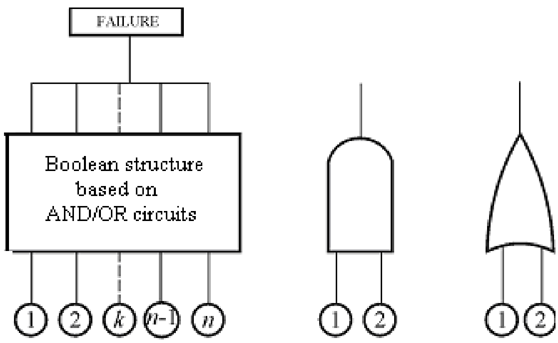
The method representation is depicted in Figure 6. For the reliability function indicators calculus, in the hypothesis of the failure intensity having an exponential distribution, we use the relations:

$$R(t) = \exp\left(-\sum_{i=1}^{n} \lambda_i t\right) = \exp\left(-\wedge t\right) \tag{13}$$

$$R(t) = 1 - \prod_{i=1}^{n}\left[1 - \exp\left(\lambda_i t\right)\right] \tag{14}$$

where: $\wedge = \sum_{i=1}^{n} \lambda_i$.

Relation (13) is used for the serial connection and relation (14) is used for the parallel connection of the elements.



a) b) c)

Fig. 6. a) The general concept of the method based on Boolean algebra (1, 2,..., n are independent primary events); b) the schematics of the logic function AND; c) the schematics of the logic function OR.

3.2 Method application for determining the reliability of the aircrafts electric circuits

In order to exemplify the method for the reliability indicators determination, we will focus on the DC electrical power supply system of an aircraft. Figure 7 depicts the electric power supply system of an aircraft.

In principle, this electric power supply system is present (as the main electric power supply system) in a large number of military aircrafts ranging from the MiG family (21, 23, 27, 29,31,35), Su (30,33,34,35,37) to Chengdu (J-10), Shenyang (J-11) and ORAO. The example refers only to a DC electric power supply system nevertheless the method can be used in alternative current and mixed systems set-ups. In Figure 7:

- 1E – starter-generator – startup time of several seconds (as a starter), after a successful start (three attempts permitted) it goes to a generator regime, supplying a 28V DC voltage
- 4E – accumulator switch
- 5E – inverse polarity protection diode
- 13E – accumulator
- 14E – accumulator to DC bar switch
- 24E – generator to DC bar coupler / de-coupler
- 47E – fuse
- 27E – voltage regulator.

The emerging failure state diagram using AND/OR elements is depicted in Figure 8. The failure event is the loss of voltage at the 28V bar.

For the failure intensity λ_i of the components we use the relation:

$$\lambda_i = k\lambda_0 \tag{15}$$

where: k – maintenance and way-of-use coefficient (for aircraft components the coefficient varies between 120 and 160); λ_0 – failure intensity – manufacturer specific data.

The data relative to the electric power supply system are presented in Table 1.

Symbol	Description	$\lambda_0\left[\text{h}^{-1}\right]$	No.	k	$\lambda_i = nk\lambda_0\left[\text{h}^{-1}\right]$	$F_i = 1 - e^{-\lambda_i t}$
4E	Switch	$0.12 \cdot 10^{-6}$	1	160	$\lambda_1 = 1.92 \cdot 10^{-5}$	$F_1 = 1 - e^{-1.92 \cdot 10^{-5} t}$
5E	Diode	$0.6 \cdot 10^{-6}$	1	160	$\lambda_1 = 9.6 \cdot 10^{-5}$	$F_2 = 1 - e^{-9.6 \cdot 10^{-5} t}$
13E	Accumulator	$1.4 \cdot 10^{-6}$	1	160	$\lambda_1 = 22.4 \cdot 10^{-5}$	$F_3 = 1 - e^{-22.4 \cdot 10^{-5} t}$
14E	Coupler	$0.4 \cdot 10^{-6}$	1	160	$\lambda_1 = 6.4 \cdot 10^{-5}$	$F_4 = 1 - e^{-6.4 \cdot 10^{-5} t}$
47E	Fuse	$2.75 \cdot 10^{-6}$	1	160	$\lambda_1 = 44 \cdot 10^{-5}$	$F_5 = 1 - e^{-44 \cdot 10^{-5} t}$
-	Contacts 1	$0.1 \cdot 10^{-6}$	1	160	$\lambda_1 = 16 \cdot 10^{-5}$	$F_6 = 1 - e^{-16 \cdot 10^{-5} t}$

Table 1. Part I

Symbol	Description	$\lambda_0\left[\mathrm{h}^{-1}\right]$	No.	k	$\lambda_i = nk\lambda_0\left[\mathrm{h}^{-1}\right]$	$F_i = 1 - e^{-\lambda_i t}$
1E	Starter-generator	$6 \cdot 10^{-6}$	1	160	$\lambda_1 = 96 \cdot 10^{-5}$	$F_8 = 1 - e^{-96 \cdot 10^{-5} t}$
24E	Coupler / Decoupler	$0.25 \cdot 10^{-6}$	1	160	$\lambda_1 = 4 \cdot 10^{-5}$	$F_9 = 1 - e^{-4 \cdot 10^{-5} t}$
27E	Voltage regulator	$13 \cdot 10^{-6}$	1	160	$\lambda_1 = 208 \cdot 10^{-5}$	$F_{10} = 1 - e^{-208 \cdot 10^{-5} t}$
-	Contacts 1	$0.1 \cdot 10^{-6}$	1	160	$\lambda_1 = 16 \cdot 10^{-5}$	$F_{11} = 1 - e^{-16 \cdot 10^{-5} t}$

Table 1. Part II

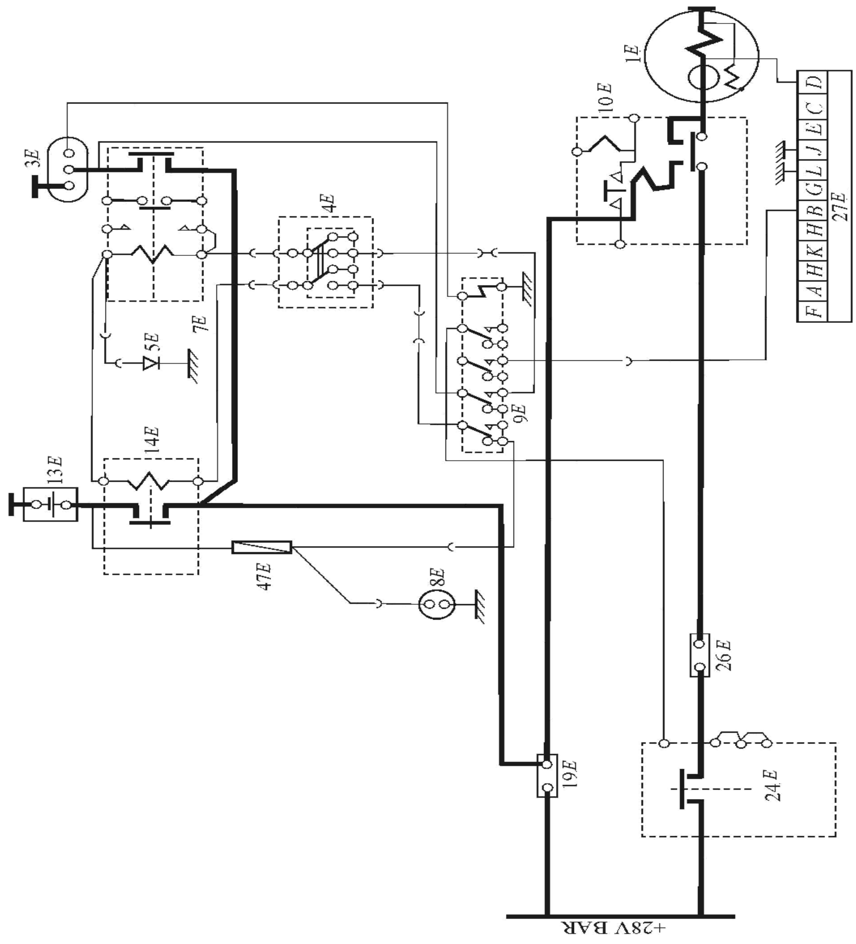


Fig. 7. The electric power supply diagram for a DC main electric supply system aircraft (fragment).

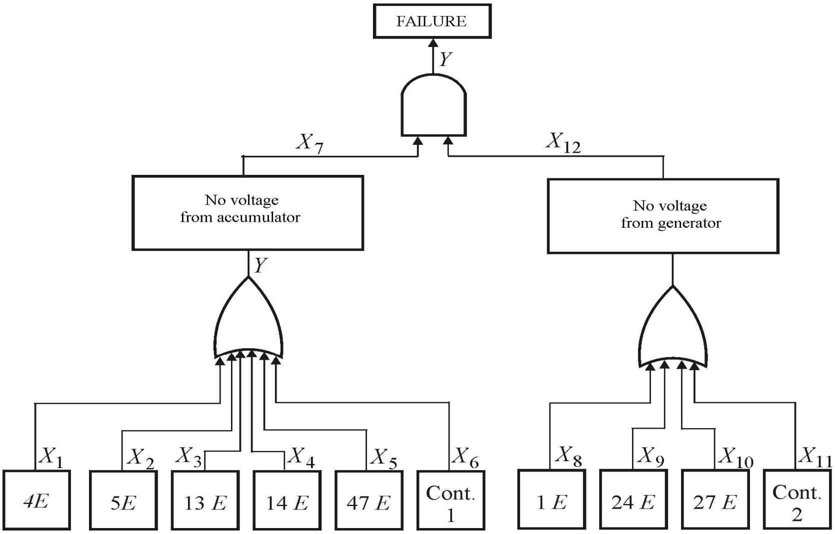


Fig. 8. The logic structure that drives to the system failure status.

In these conditions, the Boolean function associated to the logic structure depicted in Figure 8 has the following form:

$$Y = X_7 \cap X_{12} = \left(X_1 \cup X_2 \cup X_3 \cup X_4 \cup X_5 \cup X_6\right) \cap \left(X_8 \cup X_9 \cup X_{10} \cup X_{11}\right) \quad (16)$$

To transform the logic equation into algebraic form we use the following relations

$$X_1 \cap X_2 = X_1 \cdot X_2 \ ; X_1 \cup X_2 = X_1 + X_2 - X_1 X_2 \ ; \bigcup_{i=1}^{n} X_i = 1 - \prod_{i=1}^{n}\left(1 - X_i\right) \quad (17)$$

Thus, we have

$$Y = \left[1-(1-X_1)(1-X_2)(1-X_3)(1-X_4)(1-X_5)(1-X_6)\right] \cdot \left[1-(1-X_8)(1-X_9)(1-X_{10})(1-X_{11})\right] \quad (18)$$

which is similar to

$$Y = X_7 \cdot X_{12} = \left[1 - \prod_{i=1}^{6}\left(1 - X_i\right)\right] \cdot \left[1 - \prod_{k=8}^{11}\left(1 - X_k\right)\right] \quad (19)$$

Considering the failure intensity as exponential distribution, the system failure probability is given by the following relations:

$$\begin{aligned} F(t) &= \left\{1 - \exp\left[-\left(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6\right)t\right]\right\} \cdot \left[1 - \exp\left(-\lambda_8 - \lambda_9 - \lambda_{10} - \lambda_{11}\right)t\right] = \\ &= 1 - \exp\left[-\sum_{i=8}^{11} \lambda_i t\right] - \exp\left[-\sum_{k=1}^{6} \lambda_k t\right] + \exp\left[-\sum_{\substack{p=1 \\ p \neq 7}}^{11} \lambda_p t\right] \end{aligned} \quad (20)$$

$$R(t) = 1 - F(t) = \exp\left[-\sum_{i=8}^{11} \lambda_i t\right] + \exp\left[-\sum_{k=1}^{6} \lambda_k t\right] - \exp\left[-\sum_{\substack{p=1\\p\neq 7}}^{11} \lambda_p t\right] \quad (21)$$

$$MTBF = \int_0^\infty R(t)\mathrm{d}t = \frac{1}{\sum_{i=8}^{11} \lambda_i t} + \frac{1}{\sum_{k=1}^{6} \lambda_k t} - \frac{1}{\sum_{\substack{p=1\\p\neq 7}}^{11} \lambda_p t} =$$

$$= \frac{1}{(96+4+208+16)\cdot 10^{-5}} + \frac{1}{(1.92+9.6+22.4+6.4+44+16)\cdot 10^{-5}} +$$

$$+ \frac{1}{(1.92+9.6+22.4+6.4+44+16+96+4+208+16)\cdot 10^{-5}}$$

On results $MTBF$ = 1069.79 hours.

Thus, mean time between failures in the non improved system may be approximated as follows $MTBF \cong 1070$ hours.

3.3 Reliability optimization of electric power supply in the aircraft industry

We can improve the electric power supply system reliability using a redundant (reserve) subsystem. The proposed improved electric power supply, including the back-up subsystem (dotted lines) is depicted in Figure 9.

Further on we will analyze the improved electric power supply system reliability, using the Boolean method presented in chapter 3.2. This analysis also allows a determination of a relation between the system reliability and the system weight. Such a relation is useful when emphasizing the variation of the system reliability with the total weight of system components.

Through a compared analysis of different reliability improving variants, imposing as minimum condition the component weight, we can obtain an optimal solution. The logic structure that drives to the system failure status (for the improved system schematics) is depicted in Figure 10.

Table 2 presents the values of the failure intensity for the supplementary components from the back-up system, in the exponential distribution hypothesis.

Symbol	Description	$\lambda_0\left[\mathrm{h}^{-1}\right]$	No.	k	$\lambda_i = nk\lambda_0\left[\mathrm{h}^{-1}\right]$	$F_i = 1 - e^{-\lambda_i t}$
60E	Coupler	$0.4\cdot 10^{-6}$	1	160	$\lambda_1 = 6.4\cdot 10^{-5}$	$F_1 = 1 - e^{-6.4\cdot 10^{-5}t}$
61E	Switch	$0.12\cdot 10^{-6}$	1	160	$\lambda_1 = 1.92\cdot 10^{-5}$	$F_2 = 1 - e^{-1.92\cdot 10^{-5}t}$
-	Contacts 3	$0.1\cdot 10^{-6}$	4	160	$\lambda_1 = 6.4\cdot 10^{-5}$	$F_3 = 1 - e^{-6.4\cdot 10^{-5}t}$

Table 2.

The Boolean function in this case is:

$$
\begin{aligned}
Y = (X_{16} \cap X_7) \cap X_{12} = (X_{13} \cup X_{14} \cup X_{15}) \cap \\
\cap (X_1 \cup X_2 \cup X_3 \cup X_4 \cup X_5 \cup X_6) \cap \\
\cap (X_8 \cup X_9 \cup X_{10} \cup X_{11}).
\end{aligned}
\tag{22}
$$

Transforming in algebraic form, we have:

$$
\begin{aligned}
Y = [1-(1-X_{13})(1-X_{14})(1-X_{15})] \cdot [1-(1-X_1)(1-X_2)(1-X_3)(1-X_4)(1-X_5)(1-X_6)] \cdot \\
\cdot [1-(1-X_8)(1-X_9)(1-X_{10})(1-X_{11})]
\end{aligned}
\tag{23}
$$

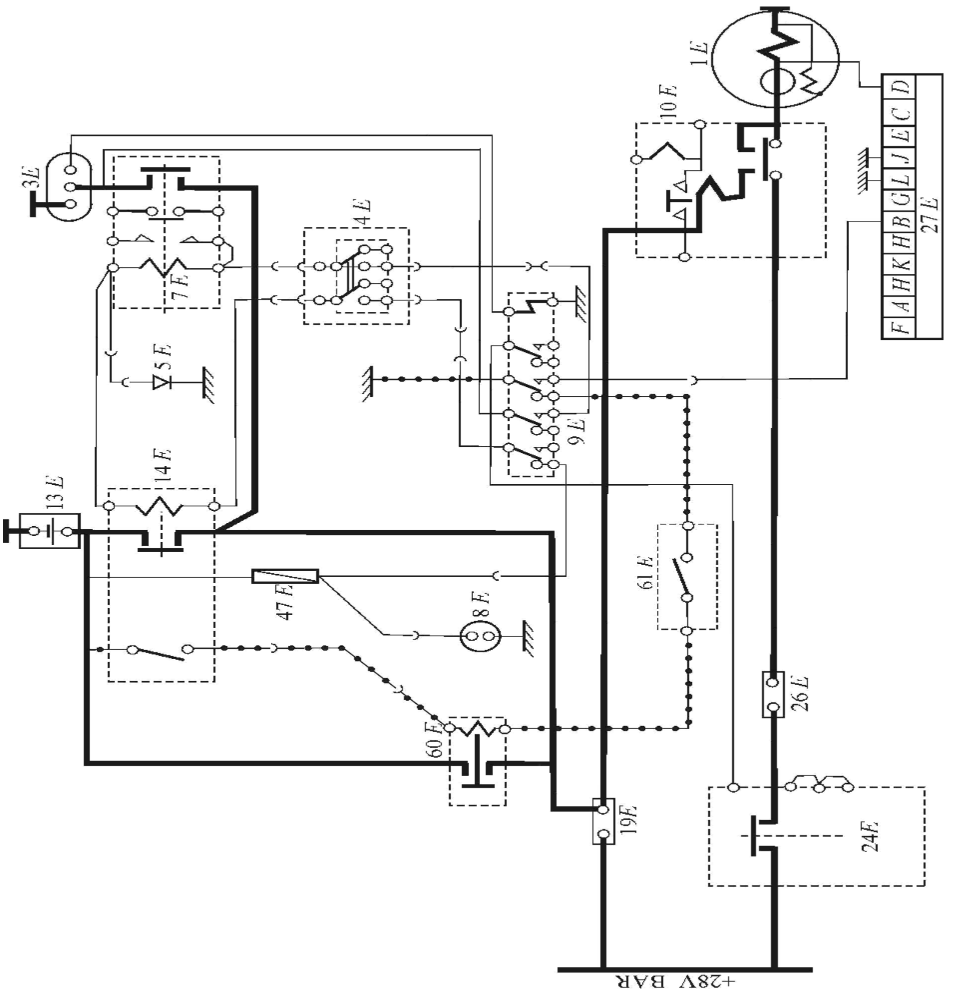


Fig. 9. Electric power supply system of an aircraft including the back-up subsystem (fragment).

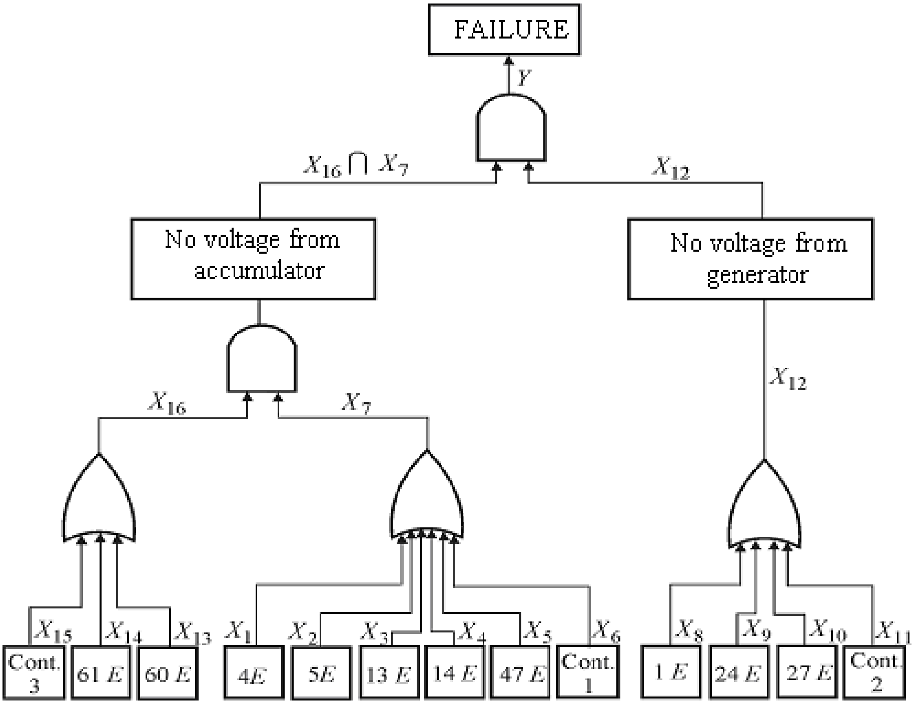


Fig. 10. The logic structure of the electric system presented in fig. 9.

$$Y = \left[1 - \prod_{i=13}^{15}(1 - X_i)\right] \cdot \left[1 - \prod_{k=1}^{6}(1 - X_k)\right] \cdot \left[1 - \prod_{p=8}^{11}(1 - X_p)\right] \tag{24}$$

From (24) we can determine the system failure probability $F(t)$:

$$F(t) = \left[1 - \exp\left(-\sum_{i=13}^{15}\lambda_i t\right)\right] \cdot \left[1 - \exp\left(-\sum_{k=1}^{6}\lambda_k t\right)\right] \cdot \left[1 - \exp\left(-\sum_{p=8}^{11}\lambda_p t\right)\right] = 1 - \exp\left(-\sum_{i=13}^{15}\lambda_i t\right) -$$
$$- \exp\left(-\sum_{k=1}^{6}\lambda_k t\right) - \exp\left(-\sum_{p=8}^{11}\lambda_p t\right) + \exp\left(-\sum_{\substack{i=1\\ i\neq 7}}^{11}\lambda_i t\right) + \tag{25}$$
$$+ \exp\left(-\sum_{\substack{i=1\\ i\neq 7,8,9,10,11,12}}^{15}\lambda_i t\right) - \exp\left(-\sum_{\substack{i=1\\ i\neq 7\\ i\neq 12}}^{15}\lambda_i t\right) + \exp\left(-\sum_{\substack{i=8\\ i\neq 12}}^{15}\lambda_i t\right)$$

$F(t)$ and $R(t)$ are complementary functions, thus, for the electric power supply system reliability $R(t)$ we will have the following relation:

$$R(t) = \exp\left(-\sum_{i=13}^{15}\lambda_i t\right) + \exp\left(-\sum_{k=1}^{6}\lambda_k t\right) + \\ +\exp\left(-\sum_{p=8}^{11}\lambda_p t\right) - \exp\left(-\sum_{\substack{i=1 \\ i\neq 7}}^{11}\lambda_i t\right) - \\ -\exp\left(-\sum_{\substack{i=1 \\ i\neq 7,8,9,10,11,12}}^{15}\lambda_i t\right) + \exp\left(-\sum_{\substack{i=1 \\ i\neq 7 \\ i\neq 12}}^{15}\lambda_i t\right) - -\exp\left(-\sum_{\substack{i=8 \\ i\neq 12}}^{15}\lambda_i t\right) \tag{26}$$

$$MTBF = \int_0^\infty R(t)\,\mathrm{d}t = \frac{1}{\sum_{i=13}^{15}\lambda_i} + \frac{1}{\sum_{k=1}^{6}\lambda_k} + \frac{1}{\sum_{p=8}^{11}\lambda_p} - \\ -\frac{1}{\sum_{\substack{i=1 \\ i\neq 7}}^{11}\lambda_i} - \frac{1}{\sum_{\substack{i=1 \\ i\neq 7,8,9,10,11,12}}^{15}\lambda_i} + \frac{1}{\sum_{\substack{i=1 \\ i\neq 7 \\ i\neq 12}}^{15}\lambda_i} - \frac{1}{\sum_{\substack{i=8 \\ i\neq 12}}^{15}\lambda_i} \cong 6926\,\text{hours} \tag{27}$$

3.4 Influence of the maintenance and way-of-use coefficient k on $MTBF$

Taking into account the characteristics of the system failure probability - $F(t)$ and reliability $R(t)$ as in Figure 7 and 9, a simulation was made using a Matlab program (Jula et. Al., 2008), which presents the time evolutions of the variables.

Coefficient k from the equation (15) has the starting value k =160. For this value MTBF was calculated both for the initial and the improved systems. The Matlab program helps conduct a complex analysis of the influence of coefficient k on system failure's probability, its reliability and *MTBF*.

Time characteristics $F(t)$ and $R(t)$, for different values of coefficient k are presented below (k = 120 (blue), k = 130 (red), k = 140 (black), k = 150 (magenta) and k = 130 (green)).

Figures 11 to 13 present the results for the initial system. As it can be seen, the increase of k is directly proportional with function $F(t)$ and inversely proportional with the reliability function $R(t)$. Mean time between failure (*MTBF*) is bigger for small values of the coefficient k.

The same analysis will be conducted for the improved system, in order to compare results. The graphic characteristics are the presented in Figures 14 to 16, while the obtained values both for initial system and improved system are presented in Table 3.

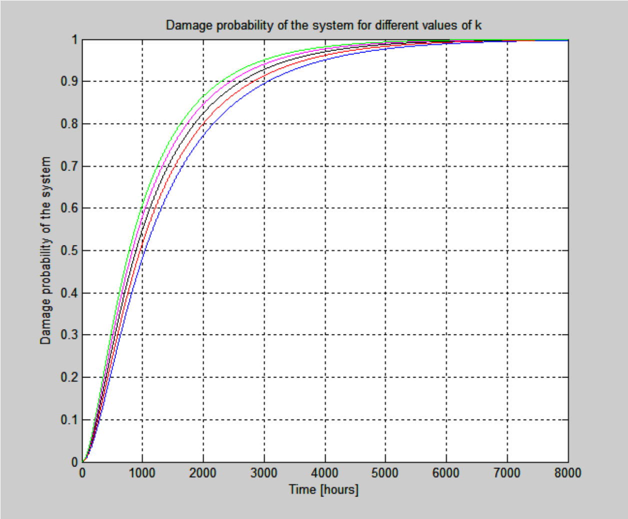


Fig. 11. System failure probability $F(t)$ for different values of k (initial system).

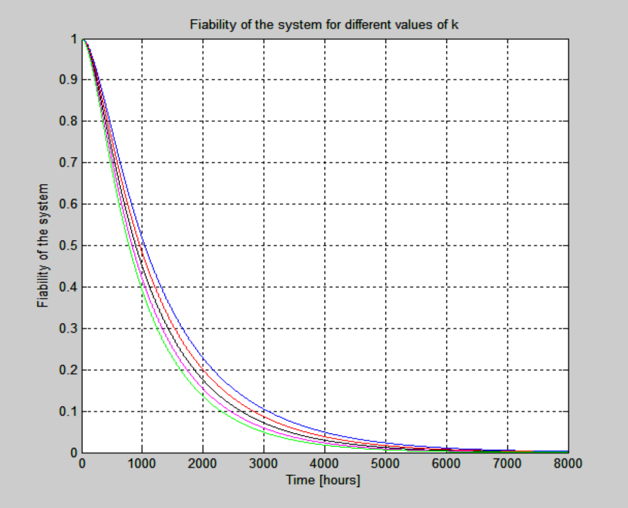


Fig. 12. System's reliability $R(t)$ for different values of k (initial system).

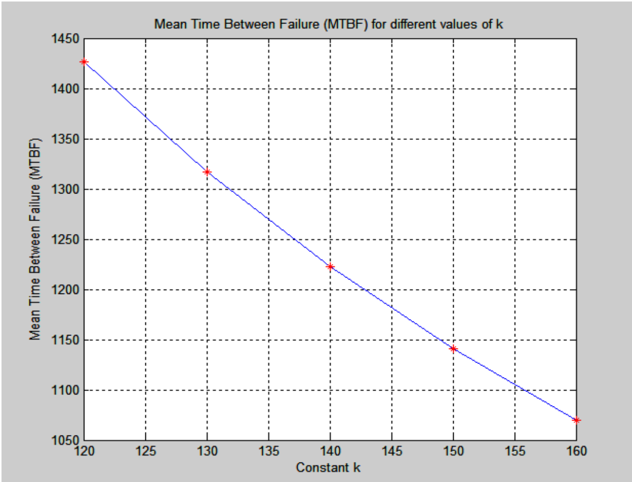


Fig. 13. *MTBF* for different values of k (initial system).

MTBF for different k	$k = 120$	$k = 130$	$k = 140$	$k = 150$	$k = 160$
Initial system (fig.3)	1426.4 hours	1316.7 hours	1222.6 hours	1141.1 hours	1069.8 hours
Improved system (fig.4)	9.2354 hours	8.5250 hours	7.9160 hours	7.3883 hours	6.9265 hours
$\gamma = \frac{(MTBF)_r}{(MTBF)_0}$	6.4746	6.4745	6.4747	6.4747	6.4746

Table 3.

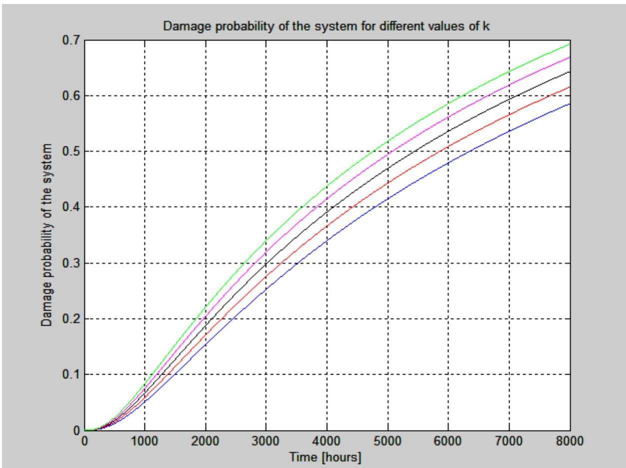


Fig. 14. System failure probability for different values of k (improved system).

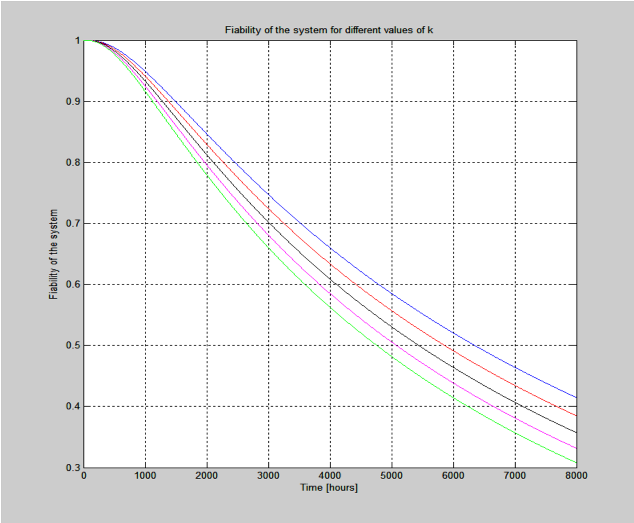


Fig. 15. System's reliability for different values of *k* (improved system).

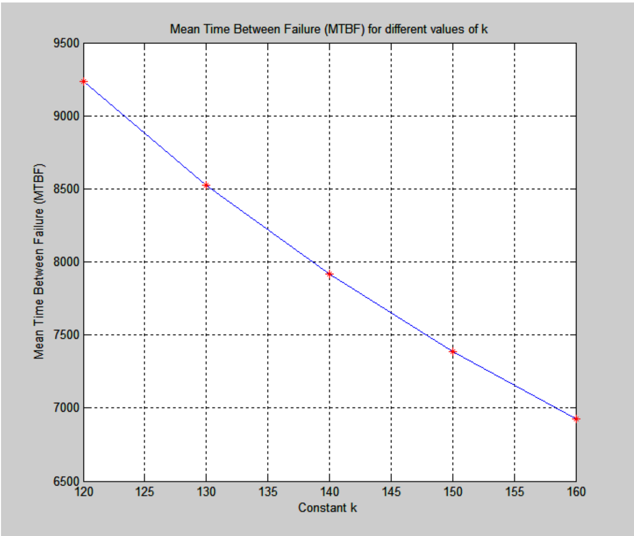


Fig. 16. *MTBF* for different values of *k* (improved system).

A comparative presentation of the two systems' reliability for different values of *k* is depicted in Figure 17 (for initial system with blue lines and red for the improved system).

For the five analyzed values of coefficient *k,* the improved electric supply with a redundant (reserve) subsystem is characterized by superior values of *MTBF* compared to the initial system (fig.18).

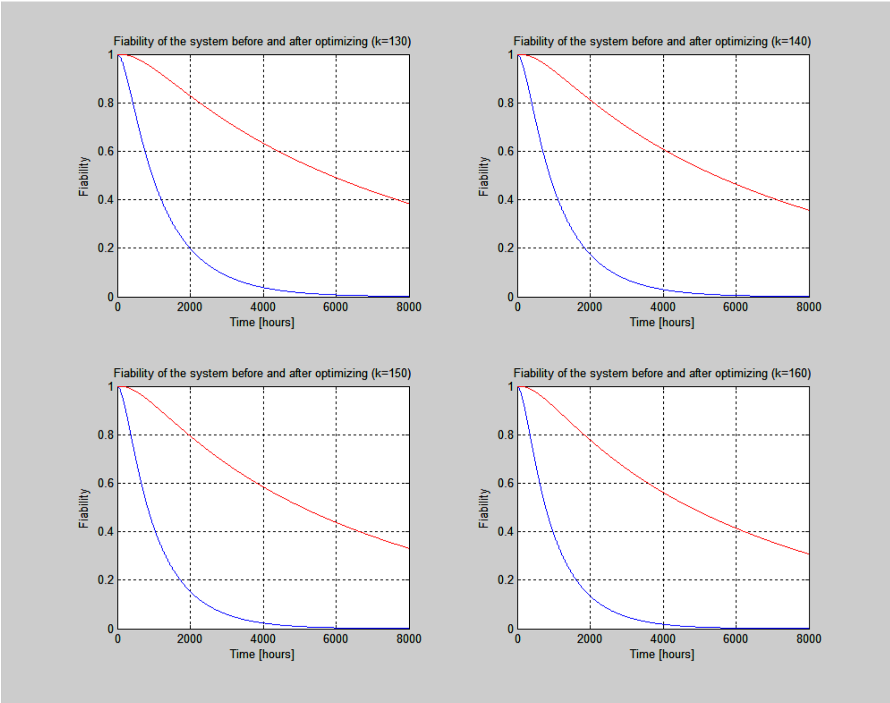


Fig. 17. Comparative analysis of the two systems' reliability for different values of *k*.

In Figure 18 the evolution of *MTBF* for the initial system is represented by a dashed line, while the evolution of *MTBF* for the improved system is represented by a continuous line.

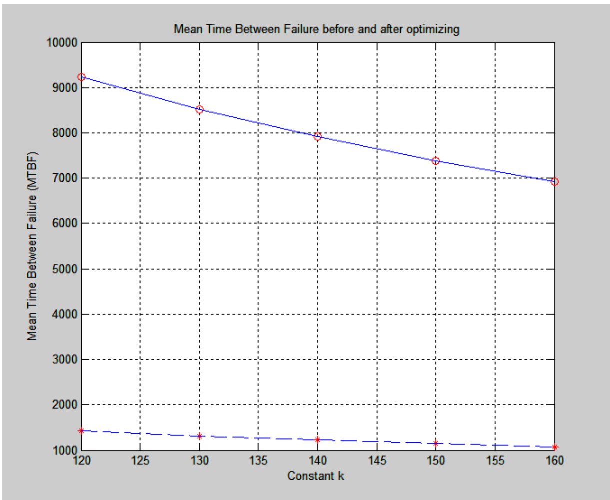


Fig. 18. Evolutions of *MTBF* for the two systems.

3.5 Conclusions regarding the Boolean method

From the analyzed examples and then results obtained for MTBF, we can conclude that the method can be successfully used in the aircraft industry for determining the reliability of the electrical systems. The *MTBF* influencing parameters in the main system nodes (power supply bars and distribution panels) can be calculated and compared.

Through the failure related logic function analysis we can determine the circuits that can improve the system reliability. In the case presented, through the introduction of the components 60E, 61E and corresponding contacts, substantial increase of the reliability (approximately 6 times higher) was obtained for the 28V DC power supply bar.

We have conducted a complex analysis of the influence of the maintenance and way-of-use coefficient *k* on system failure probability, system's reliability and *MTBF.*

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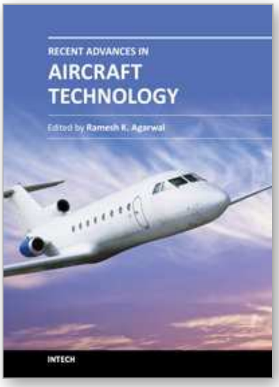

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The book describes the state of the art and latest advancements in technologies for various areas of aircraft systems. In particular it covers wide variety of topics in aircraft structures and advanced materials, control systems, electrical systems, inspection and maintenance, avionics and radar and some miscellaneous topics such as green aviation. The authors are leading experts in their fields. Both the researchers and the students should find the material useful in their work.