# Proposal of method to estimate of the probability to fulfillment product's functional requirements

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**Abstract.** This work proposes a method to estimate the probability of meeting functional requirements of complex products. The method uses concepts and techniques from Systems Engineering and from Reliability. Functional interactions represented in the Functional Flow Block Diagrams (FFBD) are translated into a correspondent configuration of the reliability block diagram (RBD), according to the method's conventions. After that, a reliability value is attributed to each component block, and using reliability evaluation methods the probability of meeting a particular functional requirement is estimated. An application example is presented by missile's subsystem.

Keywords: Systems Engineering, Functional Analysis, Functional Flow Block Diagram, Functional Requirements, Reliability, Reliability Block Diagram.

## 1 Introduction

Customers' requirements have become more complex, sophisticated and difficult to achieve. In addition, there is much lower risk tolerance and the budget is much smaller. As a result, the development of the complex system is more challenging than ever.

In response, Systems Engineering has developed several techniques to reduce risk. In particular, Requirement Analysis has become standard practice, with logical and physical decomposition being performed at very early stages of the development.

At the same time, verification and validation have evolved and several simulation, analytical and testing techniques, guidelines and standards are available for the designers. Up to now, these tools comprise most of requirement validation strategies.

Unfortunately, some systems are too expensive to perform extensive testing and others are too complex to perform meaningful analytical or simulation validation. In some cases, the system is a one-of-a-kind, and being able to verify some requirements only after the system is fully developed can lead to major disputes, rework and losses. It is clear that new techniques are needed to deal with such cases.

Requirements can be divided into several classes, but functional requirements are of special interest in this work. They usually are related to the use and the performance that the user expects from the new system. They are also some of the hardest to validate without having the system fully developed.

But, if the client had an indication of the probability of each functional requirement to be successfully achieved, this information could be used for several purposes, ranging from risk mitigation to validation and verification.
This paper presents a technique to achieve just that: estimate the probability of a functional requirement to be successfully achieved. By combining Systems Engineering techniques with Reliability theory, the probability can be estimated at very early stages of development and refined with the progresses of the project. In order to do that, only the Functional Flow Block Diagram, Product Tree and the reliability for each item represented by a leaf of the Product Tree are needed.
The mechanism that combines the Functional Flow Block Diagram, Product Tree and the reliability of each Product Tree leaf in the probability of a functional requirement being achieved is explained in the next sections. Section 2 provides the user with the minimum background needed to understand the remaining of the text. The actual method is presented in Section 3, where the concepts presented in Section 2 are linked together in order to lead the reader to trough the method. In order to provide the user with a meaningful application example, Section 4 applies the method to a functional requirement of a missile actuator. Finally, Section 5 presents some interesting conclusions and some hints where the concepts presented here can be applied to some other knowledge domains.

# 2 Background

A functional requirement is a special type of requirement that states what the system is supposed to do. This is very important from the client's perspective, where strong emphasis is put on the system's functions.

The analysis of functional requirements is done using the Functional Flow Block Diagram, which is a set of diagrams that contains information of how a system is supposed to perform a specific function. These diagrams will latter be converted into reliability diagrams.

The reliability diagram is not in the knowledge domain of the Systems Engineering, but in the domain of the Reliability. Its main use in this work is to estimate the probability of a system to perform its function from its subsystems and manner how they are interconnect. Standard tools are available in order to work with these diagrams and ultimately to generate a reliability number.

In order to actually populate the reliability diagram with the success probability of each subsystem/box, the method relies on the Product Tree. Actually, the Product Tree has to be populated with the reliability figure of each of its leaves.

The next subsection will give a partial overview of the System Engineering tools that need to be understood in order to use the method.

## *2.1 Systems Engineering*

Systems Engineering is an approach to engineering. It helps practitioners to cope with complexity by using a structured approach for the entire life cycle, from identification of the client's need to the disposal of the final product.

As a result, the development process is more structured, with higher quality, lower risks and much more predictable. Much of the success of the Systems Engineering is due to its emphasis on Requirement Analysis, which is performed in a top-down approach, enabling the understanding of how the components of the systems interact with each other (BLANCHARD and FABRYCKY, 1998).

### 2.1.1. Requirements Analysis

The requirement analysis is the first step of the Systems Engineering process. Through its application the requirements of customers are translated into a set of requirements that define what the product should do and how well it must perform (DoD - System Engineering Fundamentals, 2001).

### 2.1.2. Functional Analysis

Blanchard and Fabrycky (1998) stated that the entire process of functional analysis begins with the identification of the functions that the proposed product must perform. In wide sense, the functional analysis describes what the product must to do.

NASA states that the Functional Analysis is: “a systematic process for identifying, describing and linking the functions that a system must perform in order to achieve its goals and objectives.” This process aims to identify the functions and sub-functions in a “top-down” fashion (NASA - Systems Engineering Handbook, 1995).

### 2.1.3. Functional Flow Block Diagram (FFBD)

Many techniques are available to carry out a Functional Analysis, but the use of the Functional Flow Block Diagram (FFBD) is widespread. These diagrams decompose a main function into several steps, as well as their interdependence. Figure 1 presents a hypothetical decomposition of a sequence of tasks. The FFBD, ultimately, represents network of functional actions that lead to the fulfillment of a function of end-product.

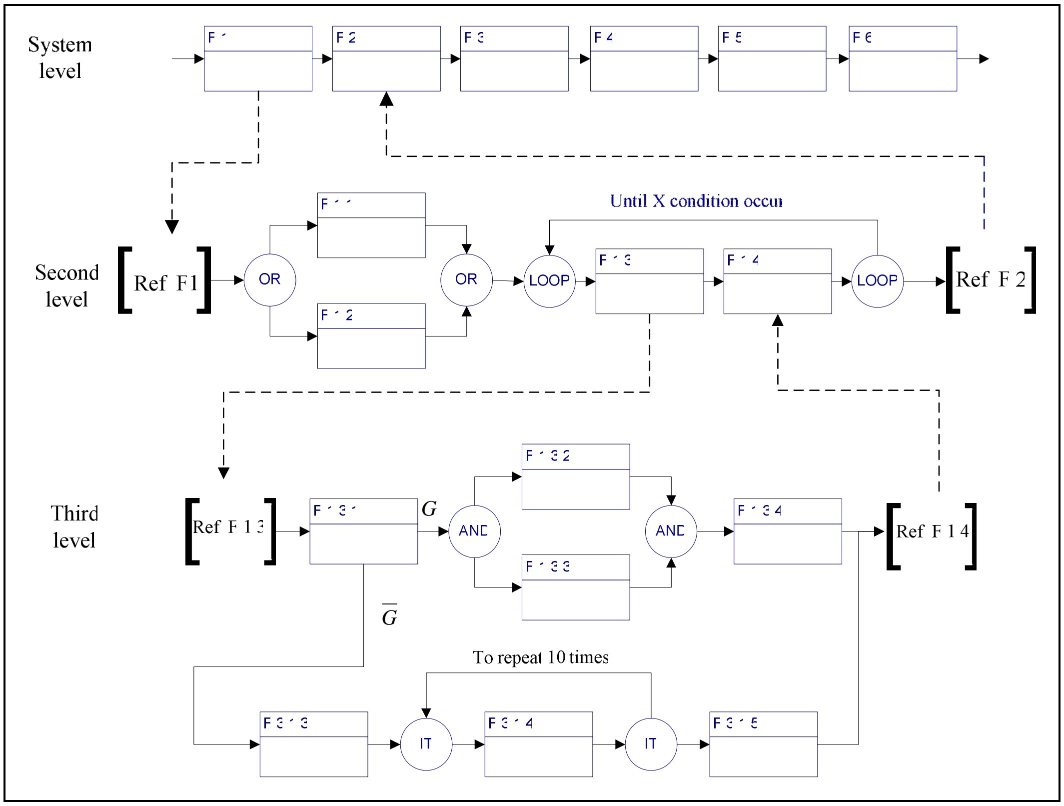


Figure 1. Example of Functional Flow Block Diagram (FFBD)

Functions are arranged in a logical sequence such that any use of specified system can be traced from the beginning to the end of the functional path. Some functions are more complex, and need to be decomposed. Therefore, a new FFBD is created for each decomposed function. Figure 1 shows the decompositions and some key symbology used in FFBDs.

### 2.1.4. Topologies

The representation of the FFBDs can use a very rich notation. Several authors propose some notation variants, with different degrees of richness. Since the FFBD will have to be translated to a reliability diagram, some restrictions on the types of topology had to be imposed. In particular, the topologies used in this work are the ones presented in Figure 2.

## *2.2 Product Structure*

The product Structure “links all parts and supplies used in the manufacture of a product” (Mutha, 1978 apud LOPES, 2007). In effect, it represents the hierarchical relationship of all parts, assemblies and materials that compose a system. As such, it provides also a very convenient way to attach relevant information to each system part. Figure 3 shows a simplified example of a simplified Product Tree for a bicycle.

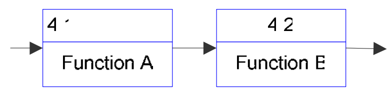
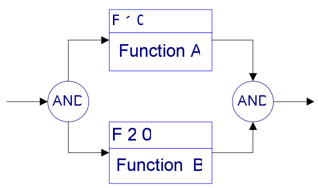
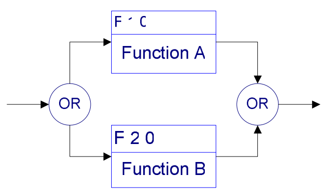
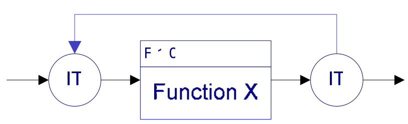
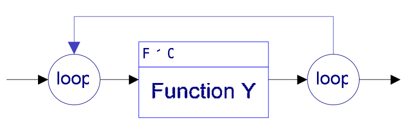
| Notations used in the elaboration of one DBFF | Description |
| --- | --- |
|  | Sequences of functions |
|  | <u>AND Gate</u> – it represents an interconnection where there will be simultaneity in the execution of the functions. |
|  | <u>OR Gate</u> - it represents an interconnection among functions where one or another function will be accomplished (mutual exclusiveness). |
|  | <u>Iteration Gate</u> – it represents the repetition of the function a defined number of times. |
|  | <u>LOOP Gate</u> - it represents the repetitive execution of the function until that a certain condition is satisfied. |
|  | <u>Reference</u> - it represents a connectivity to a certain function or interface of functions. |

Figure 2. Notations used in the FFBD.

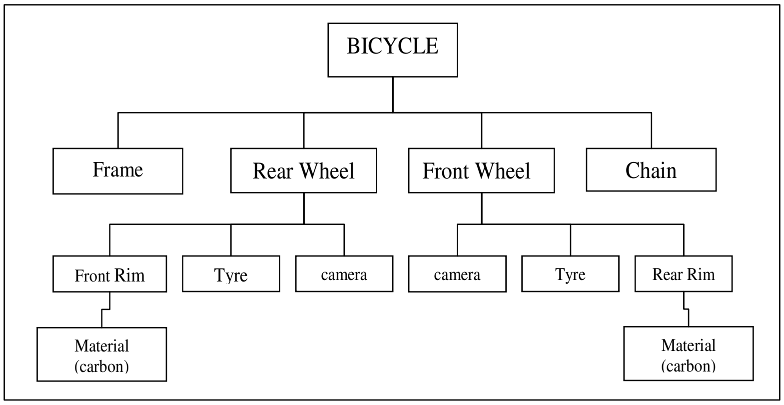


Figure 3. Bicycle's Product Structure.

## *2.3 Reliability*

Reliability, in Systems Engineering, is the field that studies the ability of a system to perform according to its requirements under a specified set of conditions. This ability is usually represented as a probability of success.

### 2.3.1. Reliability Block Diagram (RBD)

Azevedo (2005, pg. 82) defines the Reliability Block Diagram as "a way of representing the involvement of each system item in the overall reliability of the assembly". In order to create a RDB, is needed a good understanding of the mission of the system, how its various parts interoperate and how the system is to be used.
Figure 4 shows the most frequent topologies used to interconnect the various RDB blocks and how to reduce them to a single reliability value.

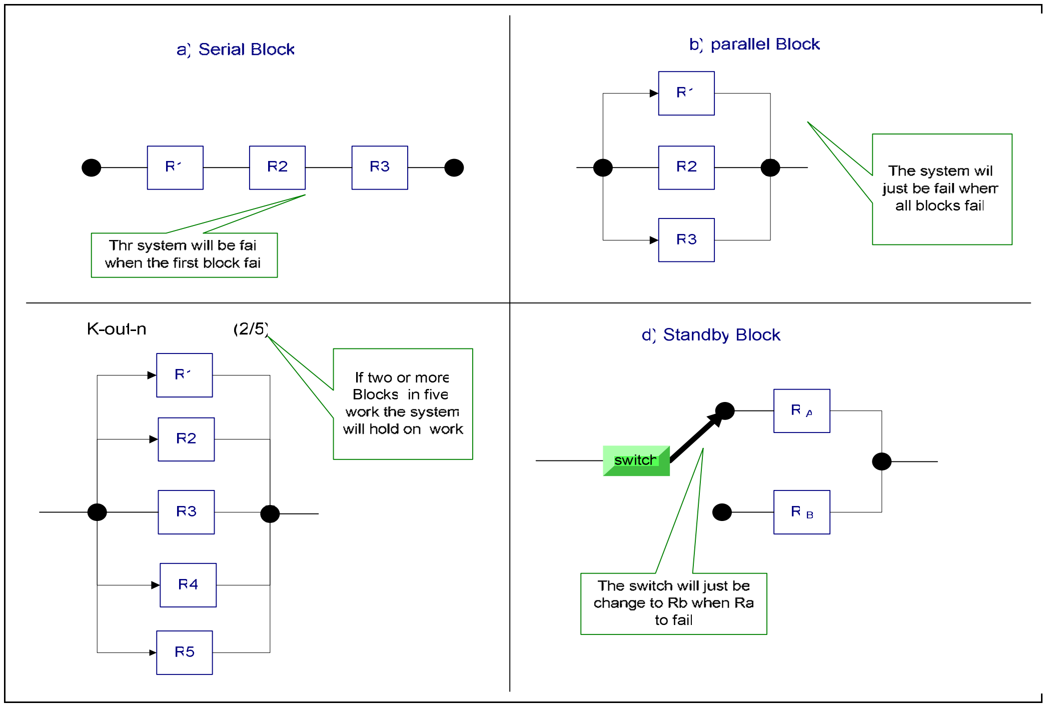



Figure 4. Main topologies of Reliability Block Diagram.

### 2.3.2. Topology Description

According to Azevedo (2005), the interconnection of the RDB blocks depends on its contribution in the product's reliability. Usually, the association is one of:

a) parallel (pure redundancy): the association will fail only if all its redundant blocks fail. The reliability value for the parallel association is:

$$R_s(t) = 1 - (1 - R_A)(1 - R_B) \tag{1}$$

b) series (also known as null redundancy): the association will fail if any of the blocks in the association fails. The computation of the association reliability is:

$$R_S = \prod_{i=1}^{n} R_i \Rightarrow R_{ABC} = R_A.R_B.R_C \tag{2}$$

c) “K-out of-n”: the association will not fail while at least K of the n blocks did not fail. The overall reliability is given by:

$$R_S(k;n;R) = \sum_{i=k}^{n} \binom{n}{i} R^i (1-R)^{n-i} \tag{3}$$

d) stand by blocks: a latent redundancy is present in this case, where a block is not in use, but will be activated if another block fails. This association will fail when all the latent redundant blocks fail (O´CONNOR, 2004).

$$P(2\,\text{stand by}) = e^{-\lambda t} + (\lambda t)e^{-\lambda t} + \frac{(\lambda t)^2 e^{-\lambda t}}{2!} \qquad (4)$$

## 3 The Method

The method is divided into six straightforward steps, as described below. In order to use it, one must have selected a single functional requisite.

**Step 1 – Identify the main function to be achieved under the selected functional requisite**

The objective of Step 1 is to identify the main function that has to be performed in order to meet the selected functional requisite.

**Step 2 – Create the FFDB**

Once the main function is selected, one must decompose it using an FFBD, which must be generated by means of a Functional Analysis. The FFBD will contain all the subfunctions, as well as will identify how they are logically interconnected. The FFBD may be decomposed into multiple levels, as in Figure 5.

It is very important that only the topologies described in section 2.1.2 are used.

**Step 3 – Create the Reliability Block Diagram (RBD)**

One RDB must be created for each level of the FFDB, as shown in Figure 5. The RDB is generated from the functional interactions among the several functions/subfunctions of a FFBD. Each FFDB association can be directly translated to a RBD association, as shown in section 3.1. One must realize that the resulting RDB is actually a multi-layered one, from the original FFDB multi-layered.

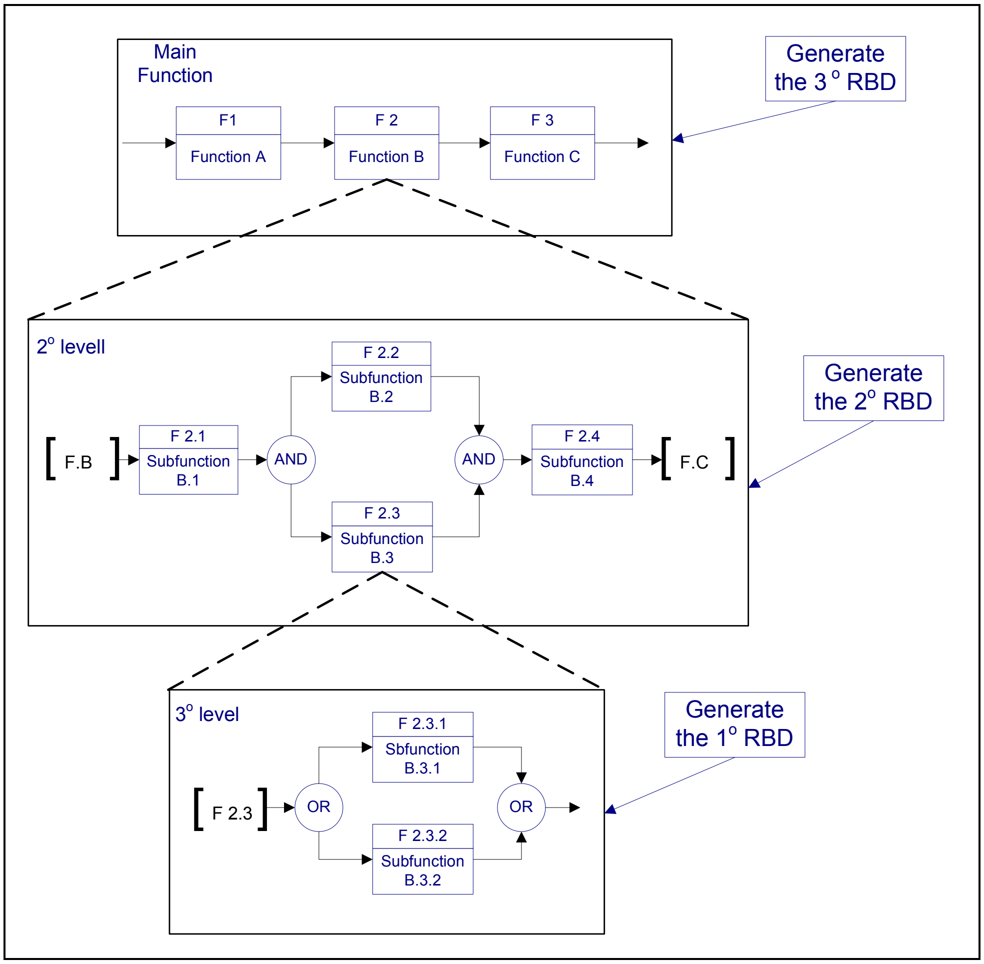



Figure 5. RBD's Sequence Resolution.

### Step 4 – Assign probabilities to the Product Tree

Each block in the FFBD describes a function that is executed by one and only one item of the Product Tree or only one entity of the system. The FFDB has been translated to an equivalent RDB and, therefore, each block of the RDB is related to one item on the Product Tree or one entity of the system.
Each part or assembly of the system has a probability of performing a function according to the specification established for the lifespan of the system. This probability must be assigned to the proper items on the Product Tree.

The designer must make a sensible choice for the blocks that represent entities outside the system.

### Step 5 – Assign probabilities to Blocks in the RBD

Each item on de RBD must have assigned to it a probability drawn from the Product Tree appended with the proper reliabilities, or from the probabilities of the external entities.

### Step 6 – Evaluate the RBD

Once every block in the RBD has a probability of success assigned to it, one can use standard reliability techniques to evaluate the probability of success of each RBD. Note that the evaluation has to be performed in a bottom-up fashion.

By completing the evaluation of the top-most RBD, one will have an estimate of the probability of the function that satisfies the selected requirement to be successful.

## 3.1 Translating FFBD into RBD

This section shows how to translate the FFBD into a RBD. If the FFBD follows a standard structure, the translation from a FFBD into a RDB can be done automatically.

For every sequence of blocks connected in series, using ports AND or IT, the blocks will be connected in series in the RBD (Figure 6). The final probability of success will be given by Equation 2.

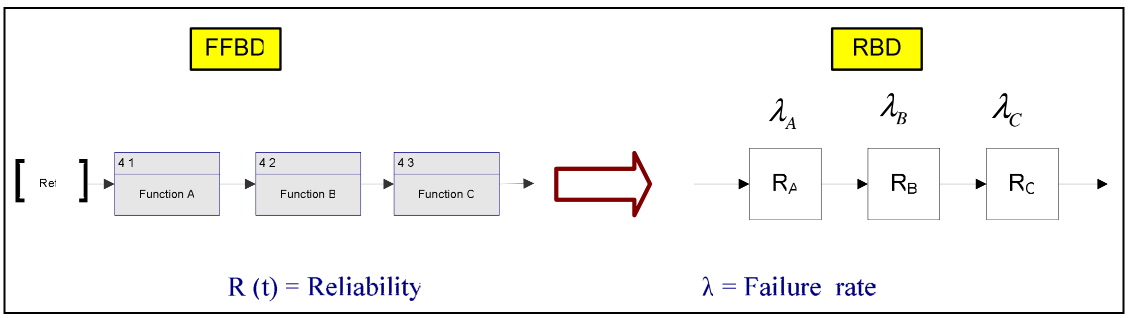



Figure 6. Equivalence of the functions connected in sequence.

The port loop (Figure 7) assumes that the maximum number of loops is known, or can be estimated, and then the treatment is the same as in the port IT.

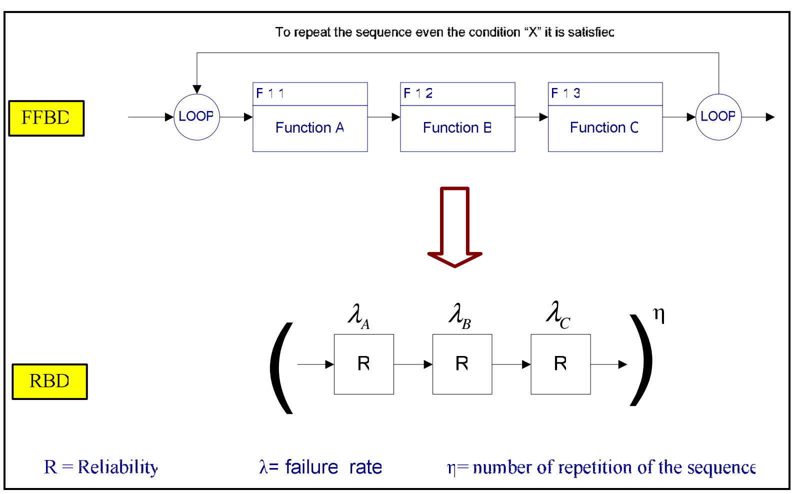



Figure 7. Equivalence of the functions connected by gate LOOP.

The parallel blocks interconnected by ports OR are converted to a parallel system in the RDB (Figure 8), and solved according to Equation 1.

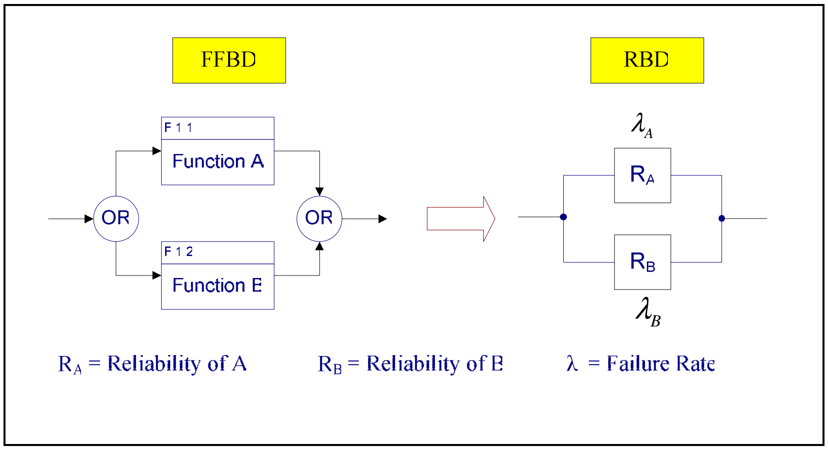



Figure 8. Equivalence of the functions connected by gate OR.

Finally, figure 9 represents a very common control structure in FFBD: the conditional path. This can be solved as shown in the figure, and the equivalent RDB block can be evaluated using Equation 5.

$$R_s = 1 - (1 - R_B R_C).(1 - R_K R_L) \qquad (5)$$

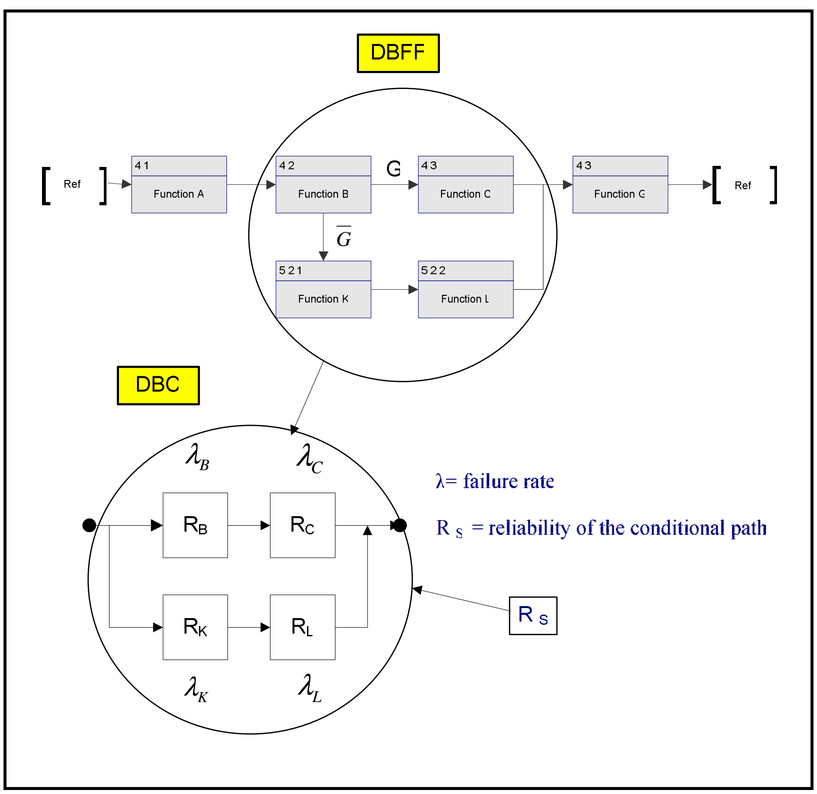



Figure 9. Equivalence of the paths Go - No Go.

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## 4 Case Study

In order to show the effectiveness of the method, it was applied to one functional requirement of a missile's actuator.
The functional requirement of the actuator was stated as follows:
**"The actuator must be capable of applying a torque at the canards, proportional to the electrical voltage sent by the missile's seeker, during the whole missile's free flight".**

Starting from this requirement, it was identified the main function to be performed:

**F1 – "Move the canards according to the seeker's commands during whole the missile's free flight."**

By following the steps described in this paper, the FFBD presented in Figure 10 was produced.

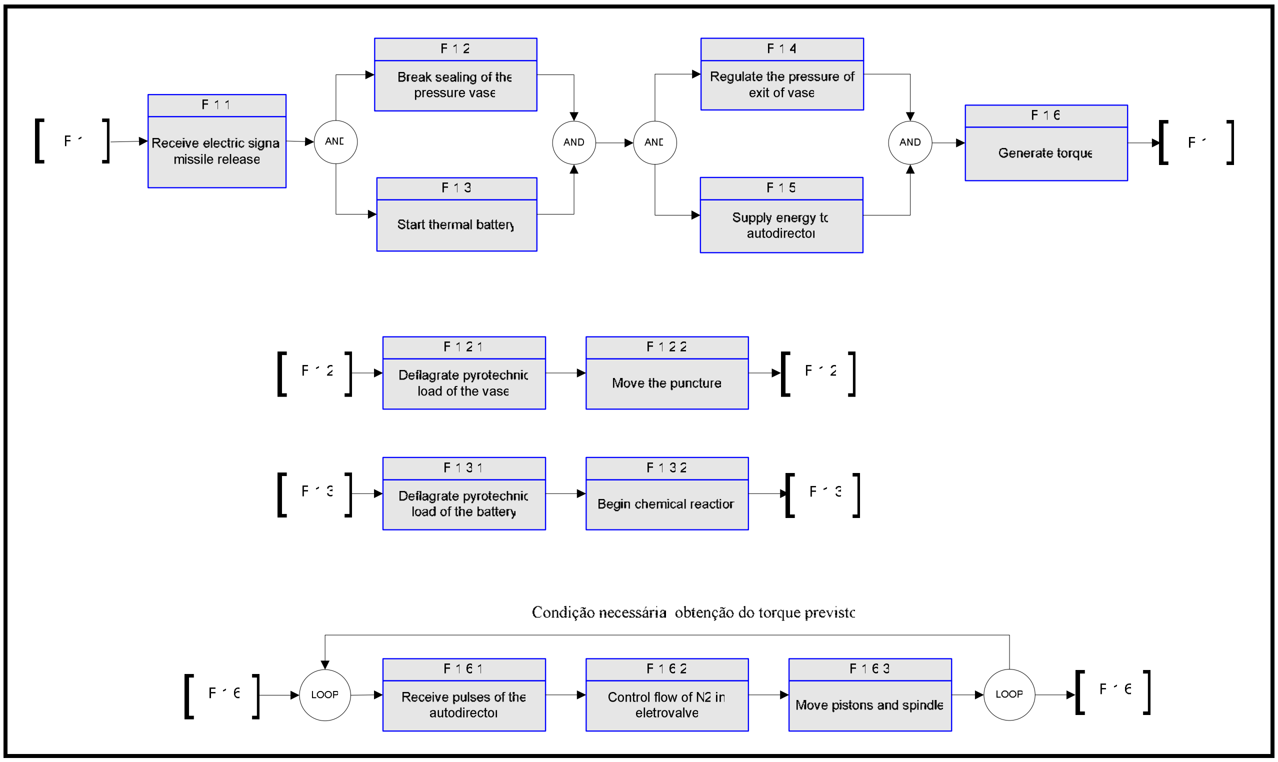


Figure 10. Actuator's FFBD.

As shown in Figure 10, four FFBDs were generated.

Table 1 shows the reliability of each function taking in account the way as each component participate of their accomplishment. This way means as the components are connected in the system (serial, parallel, stand by, K-out-n).

Table 1: reliability of each function

| function | Description of the function | Component(s) that participate of the accomplishment of the function | Reliability calculated for each function |
|---|---|---|---|
| F.1.1 | Receive electric signal missile release. | umbilical internal wiring | 0, 999995 |
| F.1.2 | Break the seal of the pressure vase. | F.1.2.1 (outbreak load) wiring of the actuator; umbilical internal wiring, pyrotechnic initiator of the vessel. | 0,995596 |
| | | F.1.2.2 moving puncture. | 1,0 |
| F.1.3 | Start thermal battery | F.1.3.1 (outbreak load) wiring of the actuator, and internal wiring umbilical pyrotechnic initiator of the battery. | 0,979607 |
| | | F.1.3.2 reaction of the fireworks start loading | 1,0 |
| F.1.4 | Regulate the output pressure of the vase. | Pressure regulator | 1,0 |
| F.1.5 | Supply energy to autodirector. | Battery and wiring of the actuator. | 0,979612 |
| F.1.6 | Generate torque | F.1.6.1 (receive signal) actuator wiring. | 0,999992 |
| | | F.1.6.2 (control of the flow) servovalve. | 0,999979 |
| | | F.1.6.3 spindle and pistons | 0,999966 |

The next step was to generate the RDB for each FFDB, as shown in Figure 11. The calculation of each RDB at the upper level can be performed only after all the lower level RDBs have been solved. Note that where several product items are used in a single block, a series association (worst case) was assumed.

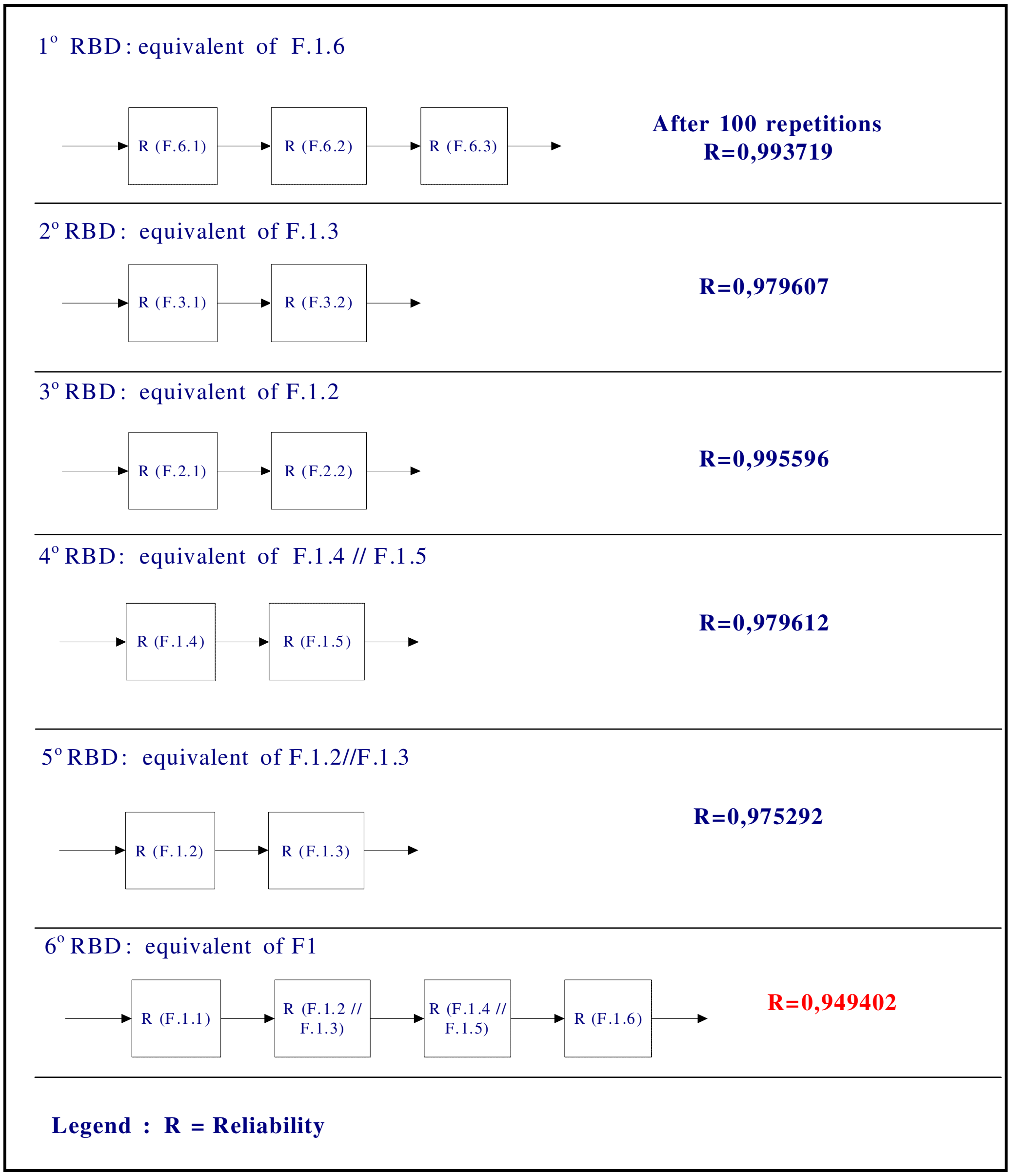


Figure 11. RBD of the subfunctions defined to actuator.

Using the method, the probability of the functional requirement to be met is of 95%. With this, it is possible to see that application of the proposed method allows to developer to identify which blocks of reliability could be improved in order to improve the fulfillment of the functional requirement.

## 5 Conclusion

The bibliographic review has shown that little work has been devoted to estimate the probability of functional requisite meeting. Most work has been done at prototype level and simulation, but those techniques can only be used much later than at requirement analysis phase. The method presented here enables the designers to estimate the probability in early development phases.

This figure can then be refined at later stages.
As shown in this work, one can combine standard Systems Engineering and Reliability techniques in order to estimate the probability to meeting a single functional requirement. This has strong implications where an estimation of the probability is needed in the initial phases of the design, or where standard techniques of requisite verification and validation are not practical or very expensive.
Essentially, the method starts from two derivatives of the Functional Block Diagram (FFBD) and the Product Tree. By assigning the probability of failure for each item in the Product Tree and converting the FFBD into an RDB, one can use standard techniques to reduce the RDB and get the desired probability of success of the selected requirement.

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## 7 Biography

José Damiani has PhD in Aerospace Engineering and Mechanics by the Technological Institute of Aeronautics (1995). He is currently a researcher at Technological Institute of Aeronautics (ITA).
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José de Paula is graduated en Mechanical Engineering and received his master degree in Mechanical-Aeronautical, from Technological Institute of Aeronautics (2008). Currently, he is acting in System Engineering in Institute of Aeronautics and Space.
The student Rosely Semabukuro is graduated in Mechanical Engineering and is working in hers master in system Engineering at the Technological Institute of Aeronautics. She is currently engaged in system Engineering work at the Institute of Aeronautics and Space.