TECHNICAL ASPECTS REGARDING THE IMPROVEMENT OF AEROSPACE AIR DEFENSE VECTORS' PERFORMANCES

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Confronted with the spectacular evolution of the aircraft and other aerial vehicles, the systems destined to combat them, especially Surface-to-Air Missile Systems (SAMS), went through an accelerated loss of their performance. The financial crisis has forced an extension of the system operation even if the system is outdated. Therefore, a new modernized version has been designed. Many times, it is better to improve an existing system than to buy a new one. This article describes the diversity of SAMS's challenges, involving a decrease in time regarding their number. The types of challenges can be divided in two categories: technical and institutional ones. The technical challenges can be also divided in two categories: deterioration of material and obsolescence. The classes of material that present interest for us are aerodynamic vector structure, propulsion, and special systems. From an institutional point of view, the main problems are: cost versus performance and cost versus the remaining lifetime (technical resource) of the air defense system. The article finishes with conclusions that support the possibility and necessity of a SAMS upgrade, given the change of the threats characteristics.

Key words: *SAMS (Surface-to-Air Missile Systems), Technical and Institutional challenges, LCC (Life Cycle Cost).*

1. INTRODUCTION

Romanian military and other countries' armed forces use outdated air defense systems that had many years of service and still do not consider feasible to improve or update those systems in the next 20 years or more. The types of technical challenges that system operators will meet during operations can be separated into three categories:

- mobility and interoperability;
- material damage;
- obsolescence.

The components of integrated systems that can be subject to further improvements can be categorized as follows:

- aerodynamic component (the missile body);
- propulsion system;
- optoelectronic systems of guidance, navigation and control.

Missile aerodynamic structure is mainly composed of metals susceptible to wear (due to cracks, corrosion) and other components such as missile control systems (wing ailerons) which are based on honeycomb structures or carbon fiber.

The composite structure of the missile. Honeycomb structures.

Honeycomb structures served as the control surfaces of the missile, margins for the wings and stabilizers and entered into the composition of parts that make up the body of the rocket. A common arrangement for such structures includes a pair of outer plates made of a metal, such as aluminum or epoxy resin mixed with carbon fiber, a core of honeycomb structure made of aluminum or other materials being included glass fiber and an adhesive with the help of which the plates are glued to the honeycomb core.

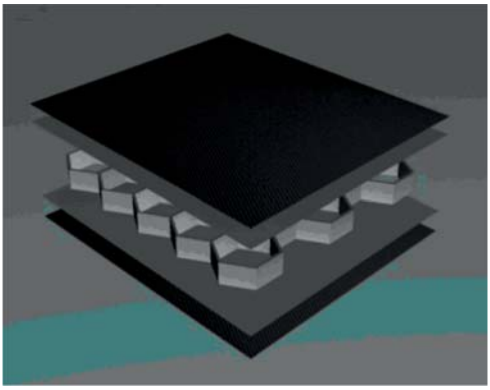

Figure 1. Composite honeycomb structure

Adhesive joining parts damage can be caused by moisture penetration, damage caused by impacts and premature aging of adhesive. Kernel vulnerability to damage depends on the material from which it was manufactured.

Carbon fiber structures

Carbon fiber structures were used to manufacture exterior panels for control surfaces and stabilizers. A common arrangement for such structures include carbon fiber layers oriented so as to match with the main directions in which tasks are acting on the missile body. Before placement, carbon fibers are combined with certain chemicals such as epoxy resin. After all the fibers are placed in position, the ensemble is placed in an autoclave where a program pressure and temperature causes the chemical interaction to form a strengthened structure with a system of fibers which are embedded. The role of the fibers is to distribute uniformly the forces acting on missile components (wings). The resin is used to prevent the collapse of the fibers. Structural damages can result from various problems, including manufacturing imperfections that expand when the missile performs various maneuvers or when moisture penetrates inside the structure which leads to exfoliation of the carbon fiber.

The evaluation of the assurance level to achieve a satisfactory return on a long-term investment in the purchase of new engines face a number of challenges which become increasingly severe with increasing time of using missiles.

Ancillary systems and board equipment

This category includes all components except the missile aerodynamic structure and propulsion system (engine and its accessories). Cables, hydraulic systems, pneumatic systems, fuel pumps, valves, electronic components, charge of explosives, missile components that communicate with ground control equipment and flight control elements, all these equipment are included in board equipment and ancillary systems of missiles.

Any of these components present a high risk of vulnerability to wear caused by material aging leading to a number of problems such as increasing maintenance costs, low availability of spare parts and failure of safety devices when handling the missiles at ground. A unique system, unlike missile aerodynamic body, is unlikely to cause early exit of the resource. However, these types of problems can be solved without much difficulty unlike aerodynamic problems and propulsion. Of course, is required to consider that reliability, availability, cost and safety can become an issue if the missiles are too old.

Material damage

Materials from which are built ancillary systems and board equipment may be damaged in so many different ways than fatigue and corrosion. Some systems such as hydraulic and pneumatic systems may present leaks which may cause a change in the flight path of the missile. Fault caused by worn wires or damage of electronic components can also cause the missile explosion before reaching the target or make it no longer manage to initiate explosion charge near the target.

2. THE METAL STRUCTURE OF THE MISSILE SYSTEM

The main technical challenge regarding the wear of the missiles includes:

- small cracks caused by material fatigue;
- multiple cracks caused by material fatigue;
- various forms of corrosion.

Ironically, the success obtained in terms of solving small cracks occurrence (through careful selection of materials during design, through regular inspection and replacement of material presenting problems) open the way for more complex vulnerabilities. The success obtained in managing and preventing small cracks gave us the possibility of maintaining missiles in service for such a long period of time so they become vulnerable to multiple cracks spread on a specific portion or the entire surface of the missile. Damages caused by material fatigue represent a problem much more serious and harder to solve than damages caused by simple cracks.

2.1. Simple cracks caused by material fatigue

Simple cracks are the main factor in missile frazzle. These cracks can only occur if a part of the missile was exposed to cyclic stress, including stretching efforts. Crack initiation, their stable and subsequent propagation is governed by the intensity of the stress level of the material and initially appears as a flaw in the material, which then leads to the crack. Material stress intensity is determined by four factors:

- the size of the crack;
- peak magnitude of the voltage near the crack for reverse cycle;
- minimum stress for that cycle;
- details regarding the geometry of the affected area near the crack.

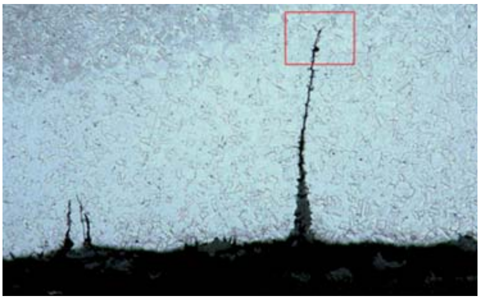

Figure 2. Simple crack

Regarding this aspect there are some questions such as:

1. Where could cracks appear, how quickly can they increase and when should inspectors begin their search in the material structure?
2. If they could develop undetected and lead to structural failure that would cause structural collapse of missile, will that part which caused the destruction ever be found?
3. How will inspectors know what to look for in the analysis to discover the malfunction which caused the failure?

These are the kind of problems facing air defense missile systems due to the use of outdated missiles and due to the extension of their resources way after their end of life cycle (because of financial reasons).

2.2. Multiple cracks caused by material fatigue

Another issue is the high concentration of simple cracks on a significant surface of missiles structure. Such concentration may appear in several places on one surface of the structure, such as a missile wing or might occur on multiple missile components (major damage). Regarding this aspect the questions that arise are mostly the same as in case of simple cracks. The understanding of this type of wear was made possible due to the study of fracture mechanics and through the management of aircraft components fatigue in general.

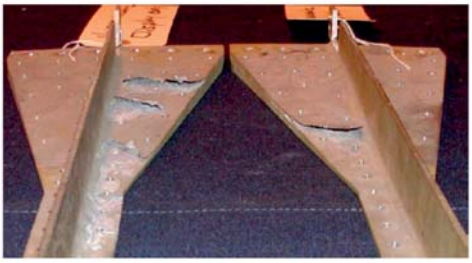

Figure 3. Multiple cracks due to material stress

Aviation community interest has been directed toward this type of problem only after the collapse of Aloha 737 flight in April 1988. However after 20 years the experts are still searching solutions for preventing the appearance of cracks in aerodynamic structure of aircrafts and missiles.

The crash of Aloha flight 737 showed how simple cracks join to form a large crack that leads to the failure of a large area of wings aerodynamic structure. Detection of this type of failures before determining the crack of o important missile parts is a major problem in the aviation industry because of inspection methods limitations. Even we know what missiles and which missiles parts must be inspected, the problem still remains due to the great variety of missiles and their large numbers. For all these reasons, the development rhythm of methods to provide protection against both simple and multiple fissures was slowed down both in aviation and air defense.

2.3. Damages caused by generalized fatigue

While fatigue cracks reach a significant size in several areas of the structure, the maintenance and modification costs increase inevitably. Because their impact on the economy is major:

- the economic viability of continuing operations decreased (under limited resources conditions), or
- the risk of failure increases - because is required to execute a large set of inspections using available resources, without allocating additional resources.

The existence of a significant number of cracks requires an increasing number of inspections (or changes) at some levels that may be considered unacceptable, this level of the wear could be referred as *generalized* or *fatigue damage*. This type of wear may be the result of multiple cracks that have developed in different parts of the structure. The dismantlement of an aerospace system (missile, airplane) depends on the material and the geometrical characteristics, and also on operating conditions. Figure 3 presents a summary of the main causes and forms of deterioration which leads to the appearance of wear particles.

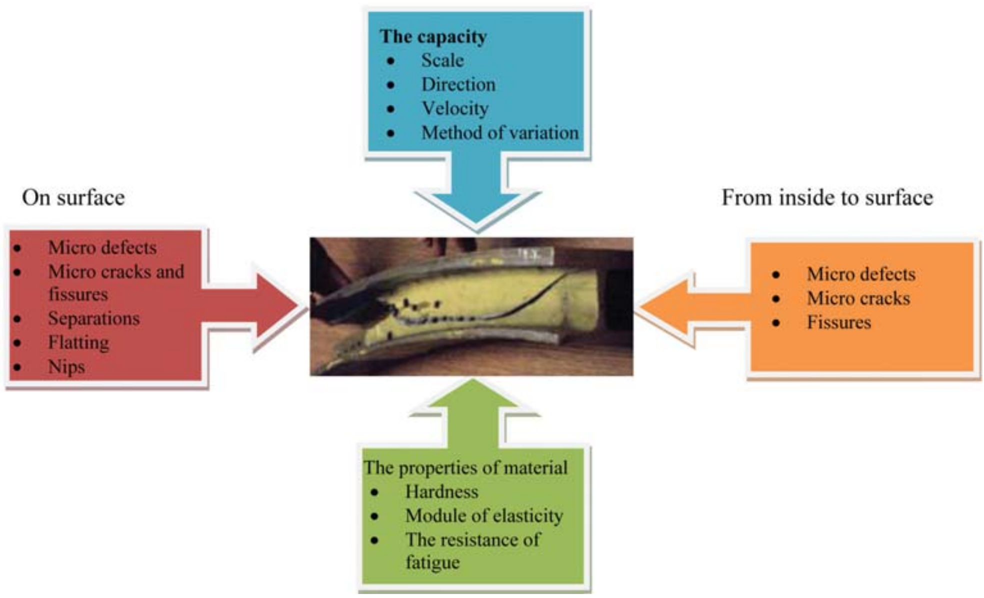

Figure 4. Causes which lead at the appearance of wear particles

2.4. Cracks caused by corrosion

The class of issues caused by corrosion of the material can take a variety of forms. A common cause attributed to this type of problems includes the presence of both the corrosion process and the stress level applied on the material perpendicular to the direction of the greatest strength of the material. This type of stress that applies transverse across the resistance structure can be developed in the ways described below.

1. Exposure of the fibers – Cracks caused by corrosion can grow on a part of the material (at the edge) where the longitudinal fiber of the material (parallel to the direction of the fibers which assure the highest resistance) is exposed to the action of corrosive agents. Those agents are acting as a feather (used to split wood) spacing the parallel fibers of the material on a transverse direction. Such behaviour is a consequence of the fact that corrosion products require a greater volume of material than the one which is consumed during the corrosion process.

2. *Residual stress* – Also known as internal stress, may occur when the material is laminated, extruded or forged in order to obtain different parts of the missile (fuselage, wings, ailerons, resistance structures). The corrosion that occurs in an area affected by residual stress may lead to the formation of cracks caused by corrosion.

3. *The stress that occurs during the manufacturing process* - When the parts of the rocket are assembled to form the final product, fitting them together can create transverse tensions or the phenomenon of stress due to merge. Again, if an area that presents such a phenomenon is subject to corrosion rises the risk of corrosive cracks appearance.

Certain alloys of aluminum, some thermal treatments and some methods for materials processing were found as causing this type of damages.

2.5. Corrosions made through exfoliation

This type of corrosion is characterized by the formation of small bumps which appear on the surface of the affected material or by peeling it similarly to wood which has been attacked by bugs. In general, this type of corrosion does not include a stress mechanism.

It has been discovered that thick panels that form the upper surface of the missile body are vulnerable to corrosion made through exfoliation, beside the fixing holes where the aerodynamic body panels are attached to the missiles interior skeleton. The rockets are much more vulnerable to corrosion when exposed to moisture. One of the factors that lead to this type of wear is represented by peeling off the layer of cadmium from the joining bolts; this prevents the contact between steel and aluminum. This coverage is very important because steel and aluminum are very different in terms of electric potential.

Missiles are very vulnerable to atmospheric factors such as moisture. Pickling the paint and the base layer of material (in order to restore the barrier against the moisture) had the unintended effect of removing the layer of cadmium from the surface of the connecting bolts.

Figure 5. Corrosion around the joint pins

Because of this some panels need to be replaced and as the storage life of missiles in service increases, this would lead to higher costs in comparison to costs involved in modernizing certain types of missiles or the purchase of new types of air defense systems.

2.6. Corrosion due to cracks

The corrosion caused by the cracks may develop at the interface between two adjacent parts if every part is prone to corrosion and moisture makes contact with the surface of each side.

The application of one or more barriers against the moisture may also protect the material against corrosion caused by cracks, as follows:

- a coating applied in the area where the missiles body components are combined, to prevent moisture and to provide a conductive path of electricity between the parts in contact;
- apply a coat of primer and topcoat paint before joining the parts and after they were merged to prevent moisture to penetrate into areas where the parties are merged and applying a protective layer against corrosion.

However as time passes, the ability of paint to provide a barrier against the ingress of moisture can degrade.

3. MATHEMATICAL MODELING OF RELIABILITY GROWTH WITH A PONDERAL INFLUENCE OF THE ELEMENTS WHICH ARE PREDISPOSED AT DEFORMITY

Let us consider a new element (one aileron, from maximum 4), in a proper functional way at a moment $t = 0$. The deformity is produced at the moment *t*.

As defined, the reliability of the aileron at moment *t*, is given by the following formula of probability:

$$R(t) = P(T > t) \quad (1)$$

Applying this relationship is made by using the concepts for estimates, samples and probability laws for a period of life *T*. Considering a number n_0 - element in a proper functional way at the moment $t = 0$.

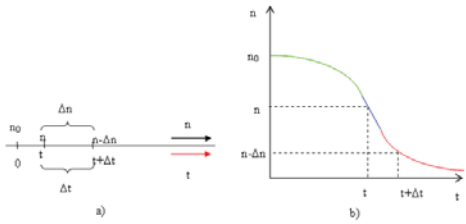

Figure 6. Variation of products number in a proper functional way

Observation:
a) The number of falls during Δt;
b) Decrease in time of elements number in a proper functional way.

At *t* moment there are still *n* elements in a proper functional way. During $(t, t+\Delta t)$, Δn elements fails. So *n* is the number of elements in a proper functional way before the $(t, t+\Delta t)$ range. The relation between Δn and Δt is realized considering that Δn is proportional with Δt:

$$\Delta n = -\lambda(t)\Delta t \quad (2)$$

Where: λ is a factor of proportionality, ($\lambda > 0$), and the minus sign takes account that *n* decreases when *t* increases.

Considering as a theoretical model, for continuous and differentiable function, which has the limit:

$$\lim_{\Delta t \to 0} \frac{\Delta n}{\Delta t} = \frac{dn}{dt} \quad (3)$$

we reach at the first order differential equation which can be also named „the differential equation of falls":

$$\frac{dn}{dt} + \lambda(t)n = 0 \quad (4)$$

This differential equation is the underlying for defining the relations of the fundamental identities of aileron reliability.

Specifying relation (3) in relation to *n*, obtain:

$$\frac{dn}{n} = -\lambda\, dt \qquad (5)$$

Considering following limit conditions:

$t = 0,\ n = n_0;$

$t = t,\ n = n;$

by integrating the relation (4) it becomes:

$$\ln \frac{n}{n_0} = \int_0^t \lambda(t)dt \qquad (6)$$

Proportionality factor λ is named "the rate (instantaneous) of failure". These can be considered constant, $\lambda=\lambda_0$=const. or variable $\lambda=\lambda(t)$.

The fraction $\frac{n}{n_0}$ represents the proportion of elements in a proper functional way or the frequency of the elements in a proper functional way at *t* moment.

Aileron's reliability during operability

In case we are interested on reliability only during a specific range (t_0, t_1), reliability is named „ mission's reliability" and it can be determined as follows:

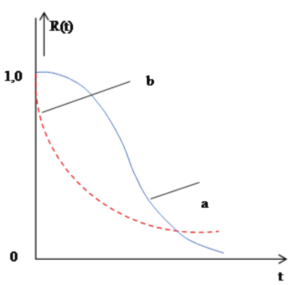

Figure 7. Variation of reliability:
a) reliability with λ variable;
b) reliability with λ constant

Considering the events:

A – Optimal operation during (0, t_0);

B – Operation during (t_0, t_1);

C = A∪B – good operation during (0, t_1).

The probability of these events represents the following reliabilities:

$$P(A) = R(t_0) = e^{-\int_0^{t_0} \lambda(t)dt}$$

$$P(C) = P(A \cup B) = P(A)\cdot P(B/A) = e^{-\int_0^{t_1} \lambda(t)dt} \qquad (7)$$

B event is conditioned by the fulfillment of A event. The conditioned probability of B event represents the mission's reliability, R (t_1/t_0) or conditioned probability:

$$P(B/A) = \frac{P(C)}{P(A)} = \frac{\exp[-\int_0^{t_1} \lambda(t)dt]}{\exp[-\int_0^{t_0} \lambda(t)dt]} = e^{-\int_{t_0}^{t_1} \lambda(t)dt} = R(t_1/t_0) \qquad (8)$$

In the particular case,

$\lambda=\lambda_0$=const.

$$R(t_1/t_0) = e^{-\lambda_0(t_1-t_0)} = e^{-\lambda_0 t} \qquad (9)$$

where $\theta=t_1-t_0$ represents the mission's time.

It is noticed that in all cases where $\lambda=\lambda_0$=const. The reliability depends only on θ range indifferent where it is that specific range on time scale.

So the element with λ=const. is the element "without memory" or without wear. The reliability on a specific range does not depend on the time of previous operation or the probability of operation without failure on a specific (t_0, t_1) does not depend of how much did this functioned before. Concluding, it does not depend on time, it depends on range.

4. INSTITUTIONAL CHALLENGES FOR OPERATORS OF INTEGRATED AIR DEFENSE SYSTEMS

Romania and other operators of outdated air defense systems can expect to encounter difficult institutional challenges. Air defense systems are outdated and become older. What is their real functionality? How much attention they need to keep maintenance costs as low as required? The main institutional challenge for such questions includes limitations on independent verification of operating status of missiles and limiting conditions for engineering analysis including risk assessments and also a decreased global resource that should be considered before making an investment no matter how insignificant in outdated air defense systems.

Independent verification of integrated air defense systems status and forecast of future conditions

Although objective assessment of the current and future conditions are fundamental to effective management of the life cycle of resources, only few operators seem to have the resources necessary for technical expertise. Thus, of necessity, most operators of integrated air defense systems depend largely of spares manufacturers and their suppliers.

Limitations regarding the information needed for material analysis

Achieving effective management of the lifecycle of the missile systems requires detailed analysis of the current status of the resource, forecasts of future conditions of integrated air defense systems and those options that could better correct any errors of evaluation, in order to reduce uncertainty and for mitigate some risks. Such analysis requires both objectivity and access to the information that can be used to analytical methods.

Structural fatigue

For this problem, achieving an efficient life-cycle for integrated air defense systems requires the following information: early detection of cracks caused by material fatigue, monitoring the severity of cracks of each air defense system, inspections planning and maintenance work to extend their life depending on the severity of wear and the decision to make a compromise between the remaining life of the system and the costs to eliminate the damage caused by material fatigue. Any delay in providing accurate and timely information on material fatigue help reduce life cycle of integrated air defense systems. For example, failure to detect an early stage of crack caused by material fatigue could cause more expensive repair or worse can reach a stage where there can be nothing to do, missile cannot be longer used. On the other hand, an inspection earlier than needed is a waste of economic resources.

5. CONCLUSIONS

As the cost of sustaining aging integrated systems continues to rise, and as the competition for scarce resources continues, getting each S.A.M.'s sustainment road map right will become increasingly important to controlling sustainment costs and protecting the operator from disruptions caused by unanticipated sustainment problems.

The new approach addresses the technical and institutional challenges of aging and the associated issues related to managing resources by using a total-systems paradigm that breaks a resource-management system into its principal domains to analyze how major challenges and issues relate to values that are important within each domain and to the customer. Connections to such a value structure can help the decision of makers set policy priorities for enhancing the resource-management system that must deal with the further aging of already-old Air Defense aerospace vectors.

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