COMPREHENSIVE APPROACH FOR ASSESSMENT OF SOLID-PROPELLANT ROCKET MOTORS

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Abstract. In this article, we propose a comprehensive approach for the assessment of solid-propellant rocket motors. The comprehensive approach is based on the mix between standardized (chemical stability, live fire, etc.) and non-destructive methods. This approach is needed to precisely calculate reliability and to compensate for mixed results obtained from different parts of lots. Long-term in-service is the main prerequisite of these mixed results. The main challenge for implementing NDT remains the lack of standardization in this area, and non-destructive methods applications provide only additional information for "transfer" precisely the results obtained from destructive standardized methods over the whole lot.

Keywords: ammunition life cycle, ammunition service life, solid propellant rocket motor, non-destructive testing

1. INTRODUCTION

Nowadays, the emphasis in military understanding is on the provision of military capability, to which the weapon systems and effectors probably are the most significant and directly referred add of the materiel. From a quality assurance perspective, the need for the establishment of large stockpiles in order to ensure current and future operational or training activities and the need to keep the characteristics for long periods are critical [17, 18].

The reliability usually depends on the following:

- Design, materials, and used technologies;
- Reaction of energetics to real environmental and service handling loads;
- Service factors – overall climatic profile, service loads, storage period, etc.

These suggestions are very valid for tactical missiles. The majority of them use solid rocket motors, and the focus is on energetic materials as one of the critical important subsystems of tactical missiles, which represent between 40 and 65% of the total missile mass [12]. The combination of these factors could lead to irreversible

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changes, which compromise normal engine performance – in chemical composition and mechanical properties, cracking, and other damages. As a result, unstable combustion may occur [12, 28, 29, 30, 31], and worse – destruction or even explosion of the rocket engine. However, rocket motors, by design, function within narrow performance boundaries. In order to guarantee safety and performance, we must be able to predict their behavior, as well as determine their residual life span after the system has been subject to handling and storage under varying conditions, which are not always fully recorded.

2. COMPREHENSIVE APPROACH FOR SERVICE LIFE ASSESSMENT OF SOLID ROCKET MOTORS

2.1 Sample selection and grouping

AOP-63 [3] gives general guidance for In-Service Surveillance (ISS) of munitions – for the selection and examination of items from the service inventory. A well-planned surveillance program and the information gained provide evidence to support a life estimation of particular munitions and also allow the early detection of degradation in energetic materials and, therefore, prevent accidents. The surveillance program will identify which energetic and non-energetic components of the munitions are to be examined based typically on the breakdown of the munitions and destructive testing.

Table 1. Expected service life for different tactical missile components

<table>
<tr><th>Components</th><th>Expected service life, years</th><th>Possible degradation</th></tr>
<tr><td>Pyrotechnics</td><td>20</td><td rowspan="2">- Destruction of pressed/glued joints;
- Depletion of chemical precursors;
- Diffusion;
- Micro and macrocracks generation;
- Moisture.</td></tr>
<tr><td>Composite, one or two components propellants (sealed)</td><td>20÷35</td></tr>
<tr><td>Electronic components</td><td>25-30</td><td>- “Electronic” aging;
- Damages after service loads.</td></tr>
<tr><td>Optical components</td><td>>50</td><td>- Damages after service loads;
- Moisture.</td></tr>
<tr><td>Power units</td><td>10-20</td><td></td></tr>
<tr><td>Contact surfaces</td><td></td><td>- Damages of seals;
- Contact corrosion.</td></tr>
<tr><td>Rubber and plastic components</td><td>10-20</td><td>- Damages after service loads;
- Thermal degradation.</td></tr>
<tr><td>Metal components</td><td>>50</td><td>- Damages after service loads;
- Thermal degradation.</td></tr>
</table>

Being one-shot devices, the most important issue is the safety and suitability for service. Starting in the very early phase (in the design and development stages) and continuing during service life, safety and performance lie on the munitions system reliability. To ensure it, the tests and monitoring during service life, predominantly destructive ones, play a significant role.

To reduce the number of resources, munitions can be classified into groups based on different criteria. The munitions in specific groups are to be similar – in age, manufacturing period (usually manufacture should be no more than 12 or 18 months apart), and environmental history. This provides relatively homogeneity and prerequisites for Probabilistic Sampling Strategy (PSS) application. Of course, a non-probabilistic sampling strategy is also possible in case no other approach is practical.

All the sampling approaches are well described in AOP-63 [3] (Fig. 1).

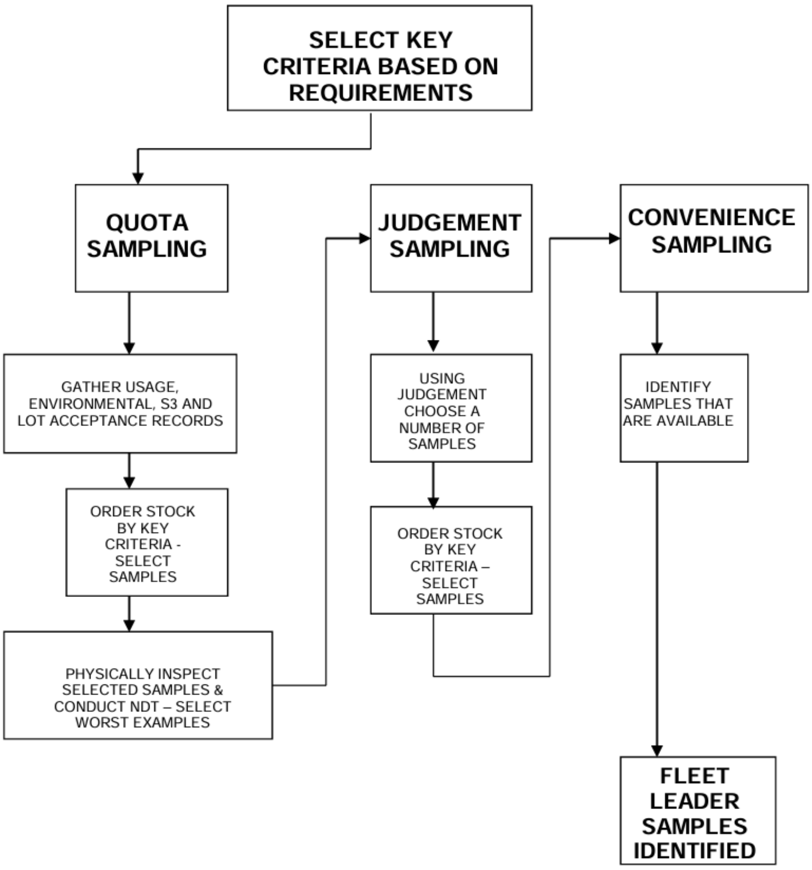

Fig. 1. Fleet Leader Identification (Adapted by [3])

2.2 Justification of combined use of classical and non-destructive methods for service life assessment of solid rocket motors

In [23], two interacting iterative paths to produce current service life estimates are used. One path is analytical, which assesses the rate of material aging, the effect of material aging on the system (i.e., stability, performance, integrity, etc.), and the statistical probability of system failure during service life. The typical approach is to specify a conservative service life period, determined under harsh environmental conditions and severe service loadings. Generally, the base for the service life period for the whole system is the non-replaceable part with energetic material with the shortest service life period. Nevertheless, the designed rocket motor can be used safely for longer (Table 1) [21].

The second path is system surveillance, which includes system observation and system trend analysis. As a result, the service life estimate may predict a minimum service life (safe interval) that will likely be extended on testing at a later period. All aspects of service life issues for solid rocket motors will be addressed, including chemical and physical aging mechanisms, methodology and techniques for determining service life, application of the service life methodology and techniques to systems, and non-destructive test methods. For these paths, except for non-destructive methods, existing system of standards and best practices [9].

Most of them are based on destructive methods – live firings, chemical analyses, aging, mechanical tests, etc. [21]. In turn, the non-destructive methods (NDT) methods are powerful tools for many industry areas, but due to their inherent limitations and the complementary nature of different types, many of them need to be applied depending on their suitability as a service life estimation tool [14].

Unfortunately, they aren't a popular tool (except the visual methods) in the service life of ammunitions (except the production phase) (see Fig. 2), following the main problems for implementing NDT for qualification of the ammunition – the scope and lack of standardization. For inspection at various stages of the production and service life of the rocket motors, for instance:

- NDT methods such as radiography, ultrasonic testing, and dye-penetrant testing are being employed for the inspection of hardware;
- Magnetic methods for shells and mortar bodies [36];
- Ultrasonic testing is applied to check the bond-line integrity of the case, ammunition elements, and insulation layer [10, 21] and
- X-ray radiography is employed for evaluating both the integrity of propellant mass and the bond-line integrity of propellant and insulation [4, 26].

It is well a fact that the input elements, units, and aggregates change their characteristics [4, 5, 27], and for munitions, producers tie the aggravated deadlines of the individual with the prescribed lifetime. The term aging is marked by the generalized change in mechanical and chemical factors as compared to properties immediately after production.

Usually, the associated problems during the service life are related to explosives in rocket motors (solid propellant and pyrotechnics). During the service life, they change their properties [10], the integrity of solid propellant is disturbed, the bond lines are disintegrated, and defects like cracks, voids, and depletion appear. Also, during the service life, continuing changes in chemical composition appear. In detail, the aging processes in different energetic materials and their displays are described in [20].

The pyrotechnics are even more vulnerable, mainly because of the trend to absorb moisture. To monitor these changes during service life in this study, we propose a comprehensive methodology for the evaluation of rocket motors of tactical missiles.

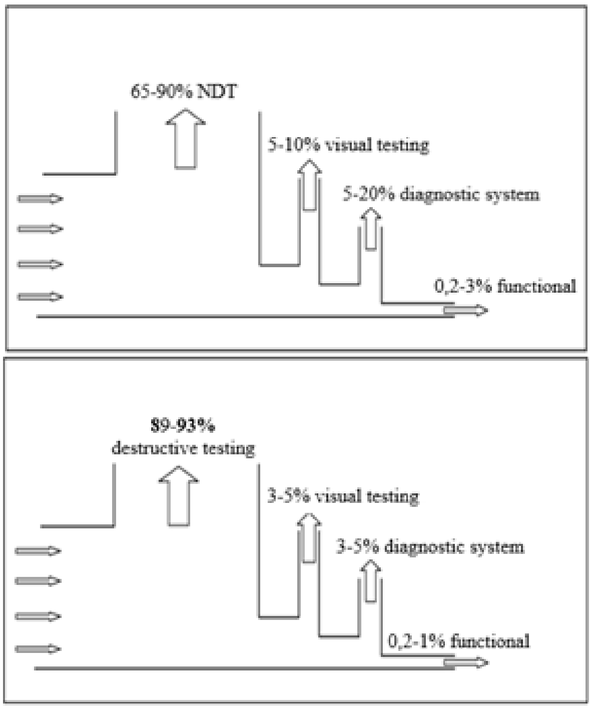

Fig. 2. Coverage of different methods in the industry (up) and ammunition life cycle (down) (Adapted by [21, 23])

2.3 Comprehensive approach for service life assessment of solid rocket motors

A schematic view of the methodology for the evaluation of rocket motors of tactical missiles that have been followed in this study is shown in Fig. 3. For expensive and complex systems, the number of sampled units for destructive full-system tests, which are considered the gold-standard measurements of the performance of the system, may necessarily be small, and it's a hard task to make conclusions for a whole lot of performance based on the full-system test result of several test samples [21].

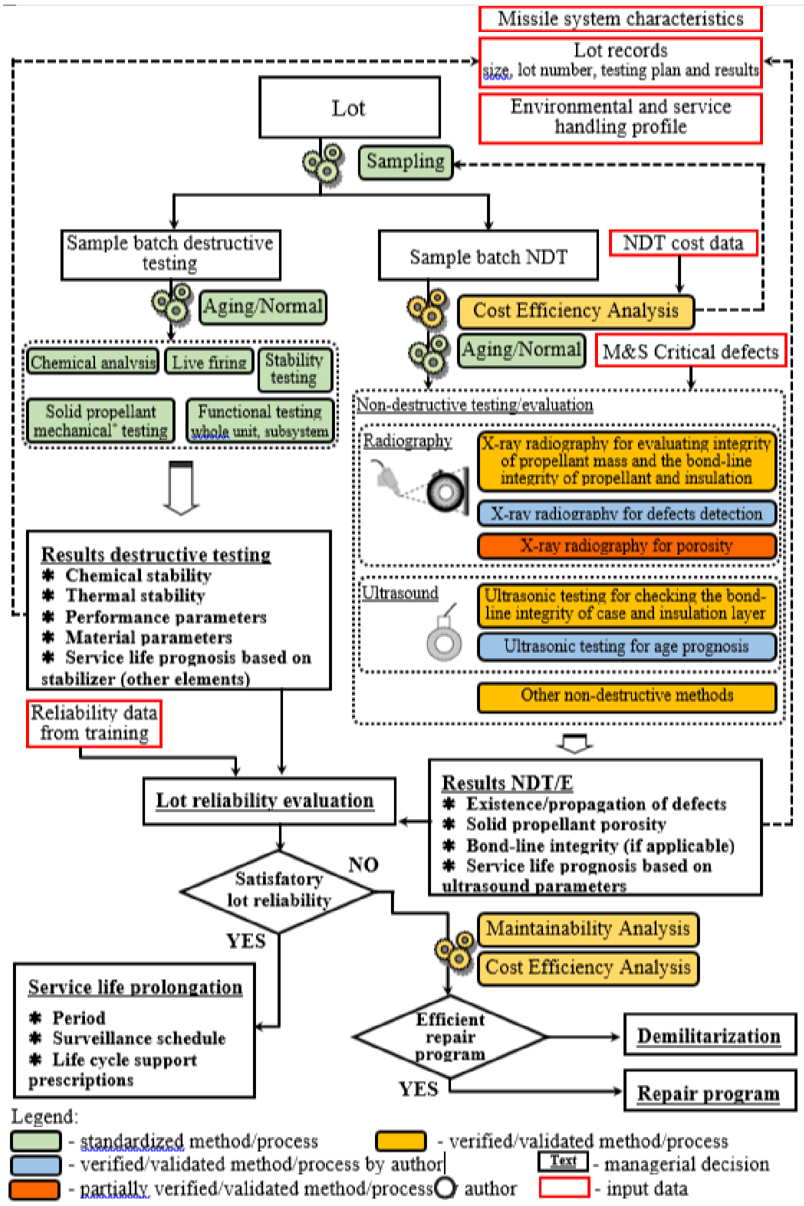

Fig. 3. Comprehensive approach for service life assessment of solid-propellant rocket (Copied from [21])

Fortunately, there are other sources of information on the system or component level, and in this methodology, we incorporate many other types as an alternate source of information – from functional tests on the component level to non-destructive testing that practically could be performed on the whole lot. Logically, the relative proportion of data available from these alternate sources may reduce the need for full-system and, in our case, subsystem tests and can enhance the precision of evaluation.

The key aspects of this approach are: (1) how non-destructive methods can be added to “classical” destructive methods to produce single informative platform and(2) a unified methodology for precisely evaluating solid propellant rocket motors system level that combines with prediction up from the component level data, but for clarity of presentation we will not go into details for incorporation of data because this process we described well before – in [17] the author demonstrate Bayesian approach to incorporate data from different sources and here we present only the results on sub-system level. Also, due to the same reasons, the sub-system decomposition process is not detailed here.

The proposed methodology is divided into two branches – “destructive” and “non-destructive.” “Destructive branch” includes performance tests, all applicable standardized and validated methods described in standardized documents (mainly STANAGs and allied publications), and specialized documentation – manuals, guidances, etc.

The “non-destructive branch” could combine different techniques. Two of them (Ultrasound technique implementation for aging characterization and X-ray technique for defects characterization) are validated by the author in [21], and here, only cursory notes for validation are added.

3. RESULTS AND WAY AHEAD

The results from reliability calculation on the sub-system level are shown in Fig. 4.

The Bayesian approach is used for reliability calculation based on the results from different testing results. The distinguished difference between prior and posterior reliability curves is observed, mainly due to the implementation of non-destructive techniques.

Performed cost-efficiency analysis (subject of another article) showed that the (expected) whole cost of the performed test X-ray and ultrasound test is between 0,01 and 0,1 times the price of one unit in dependence on the type of the rocket. Nevertheless, one of the directions for future development, as well as improving the sensitivity, precision, and productivity of the NDT methods) remains the cost reduction.

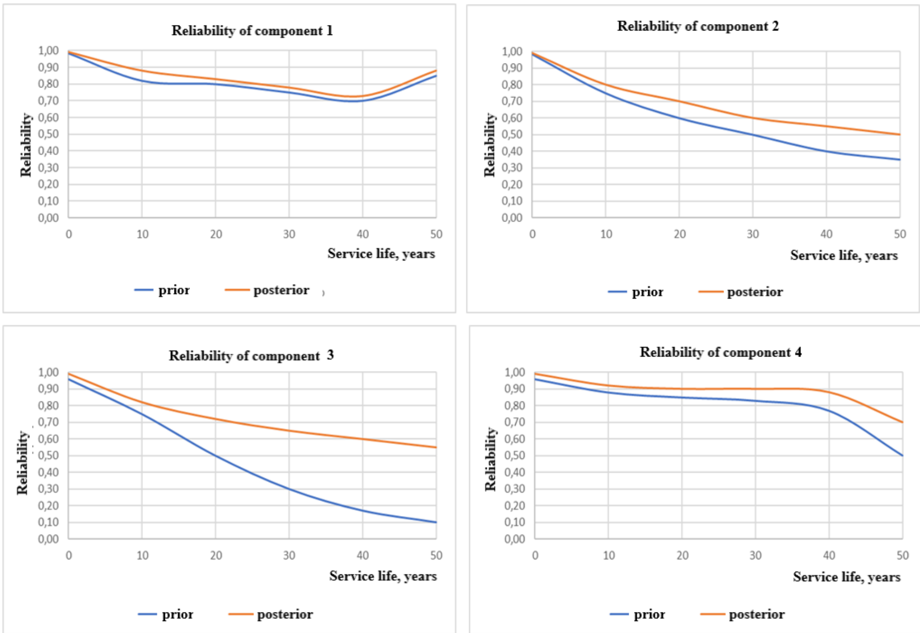

Fig. 4. Prior and posterior distributions for the reliability of the main elements of the rocket motor

4. SUMMARY

In this study, we propose a comprehensive approach for service life assessment of solid-propellant rocket motors based on the mix between traditional standardized (chemical stability, live-fire, etc.) and the non-destructive methods. Because of the lack of standardization of non-destructive methods in this neurological area, their usage is an additional tool, improving awareness.

The initial results are encouraging, and implementation of these methods definitely improved the accuracy of evaluation and practically could nullify the existence of mixed results obtained from different parts of lots in performance tests.

The efforts should be focused on validation and verification of NDT methods.

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