CAE Techniques Investigation of Rocket Parts Malfunction

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Abstract: In this paper, an investigation of possible causes which could lead to firig incidents is presented. The subject submitted to this analysis is an romanian portable antiaircraft rocket, self-guided in IR radiation. Once the causes identified, some design corrections are required. In order to carry out this work, highly use of FEM software is needed. Thus, the problems formulation using COSMOS, LS-DYNA and FLUENT were very useful. Also, a series of experimental tests were developed in laboratory and in real firing situation in order to validate the simulation results.

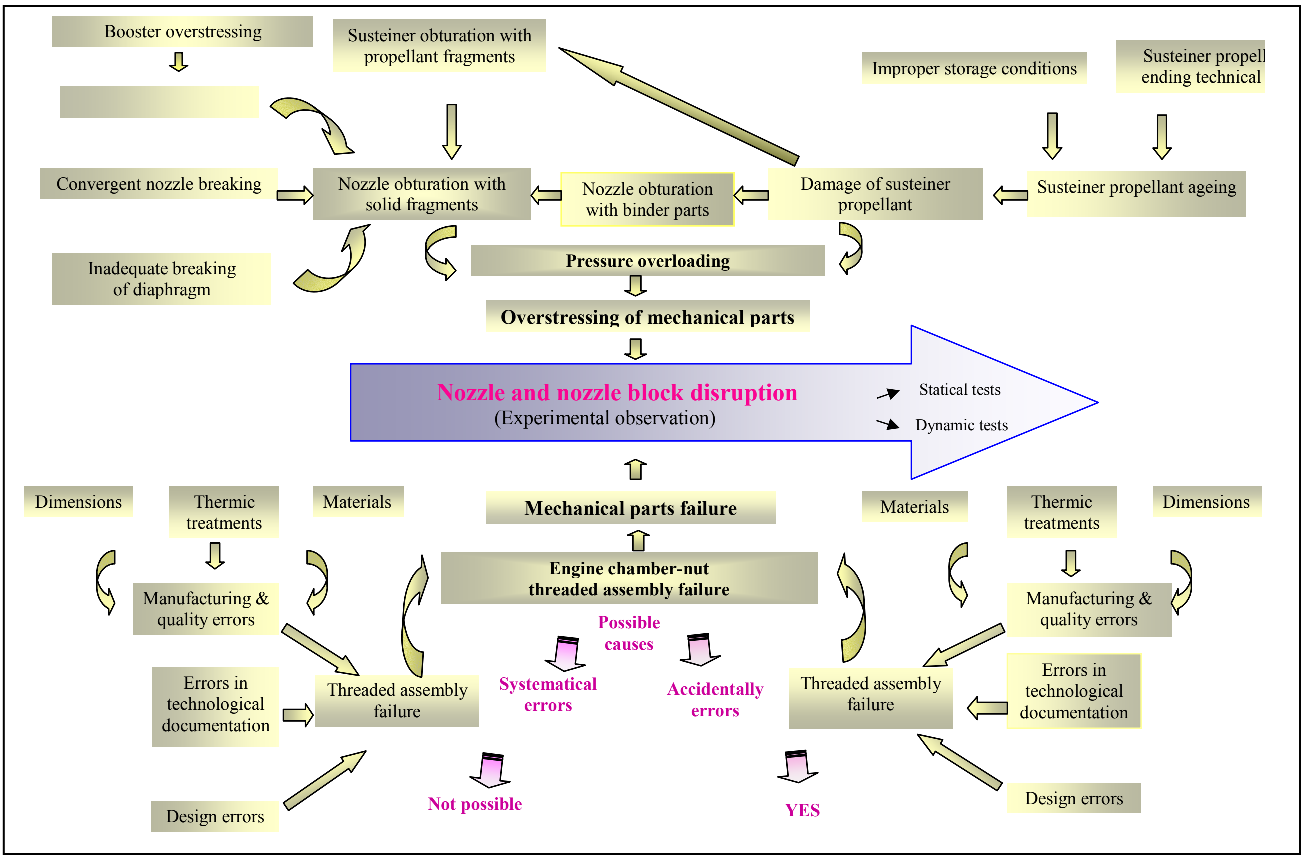
Key-Words: - Rocket engine, FEM simulation, COSMOS, LS-DYNA, Failure Analysis

1 Introduction

During time service of this kind of rockets with short range action were accidentally reported three abnormal functioning situations. Based on statistics, there are less than 0,5% incidents from the total number of fired rockets, which is up to requirements imposed by military standards.

Despite it, these situations are subjected to multiple and complex interpretations which result could arise new technical solutions. Back to the paper subject, the incidents consist in an abnormal function of rocket engine, short time after launching, when the nozzle block were separated from the rest of the engine. Due to gas pressure in engine chamber, over this block was acting a force pointed to the fire man. If hit by this engine piece, serious injuries are possible to the personnel.

Fig.1 Ishikawa diagram



2 Possible Causes

All possible causes were identified, investigated and synthesized in an cause – effect diagram, known as Ishikawa diagram, in combination with an multiple causes diagram, as shown in Fig.1.

The possible causes were separated in three major groups, as follow:

- Causes related to the design process, which could be errors in calculus and execution documentation, or errors in technological documentation;
- Causes related to the fabrication process, which could consist in dimensional (measuring) errors, thermic treatments errors or material errors (hide structure errors);
- Causes related to manipulation, transport, storage conditions or maintenance, etc.

2.1 Causes analysis

For causes verification and confirmation, three sets of activities were pointed out:

- Inspection of a number of rockets;
- Virtual simulations of rocket engine functioning;
- Experimental work for causes validation.

For a better understanding of terms in use and functional principle, the engine scheme is presented in Fig.2. First of all, after a minutious inspection focused on possible wrong exploitation, manufacturing, assembling and testing errors and which inspection included parts and subassemblies analysis, nothing bad were discovered.

Further, during the analysis of rocket fragments after engine functioning, an interesting observation appeared. It was the idea that nozzle block separation was caused due to elastoplastic failure of threaded assembly between nozzle block and engine chamber. The hypothesis confirmation raised from several findings after the dimensional analyze of deformed fragment's shape, as follow:

- In threaded assembly parts the material failure limit was not reached. The material kept it's continuity and integrity and no cracks observed;
- The thread does not look as failed by shearing;
- The thread shows local plastic deformations, due to relative displacements, which consist in edge's rotunding and modification of thread side's angle;
- The engine chamber shows remanent radial deformations in threaded assembly area, which values are the upper limit in the ending section. Thus, the exterior diameter of engine chamber reached an increasing values of 0,4 mm / diameter;
- None thermic influence in threaded assembly area was identified, due to burning gases action.

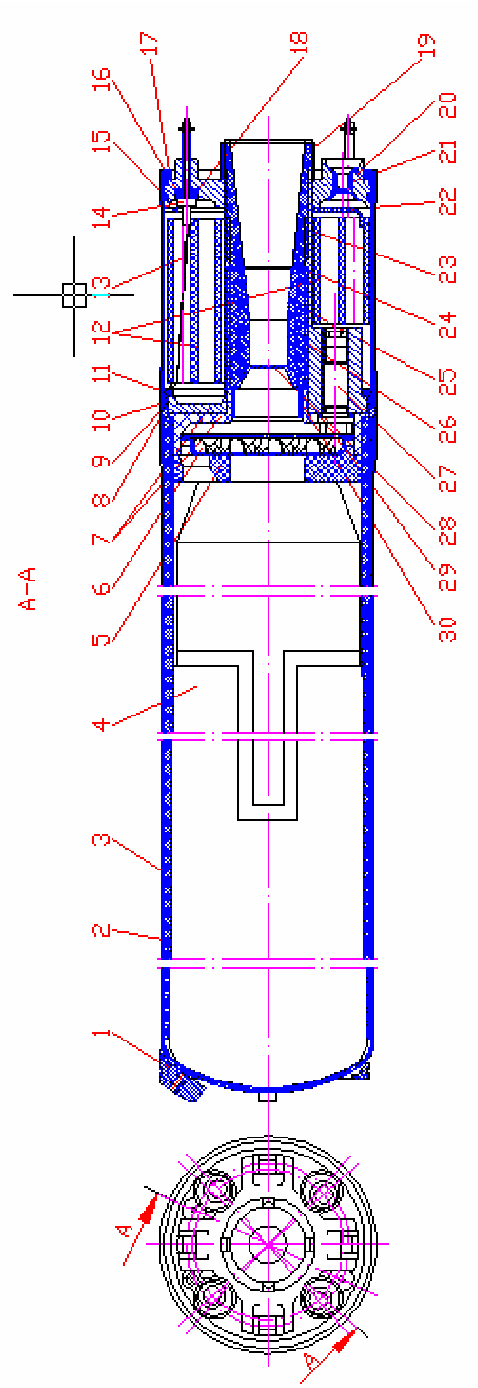


Fig.2 Rocket engine scheme

1 – linking part, 2 – engine chamber, 3 – thermic protection, 4 – susteiner propellant, 5 – sustainer grill, 6 – susteiner igniter, 7 – nozzle, 8 – elastic retainer, 9 – ring, 10,29 – fitting, 11 – booster igniter, 12 – booster propellant, 13 – rheophore, 14,18 – electric isolator, 15,16 – fitting, 17,19 – nut, 20 – nozzle block, 21 – diaphragm, 22 – booster grill, 23 – sustainer jet exhaust, 24 – absorber ring, 25 – central nozzle part, 26 – thermic protection, 27 – pyrotechnic delaytor, 28 – diaphragm, 30 – nozzle entry ring.

3 Causes FEM Analysis

By the interpretation of fore mentioned facts, a few causes which could contribute to rocket malfunction are suggested. There are, again, three categories:

- Form and dimensional deviation of assembly's parts, over the limit imposed by design requirements;
- Changes in material properties due to inconformity in fabrication process toward the fabrication technology or caused by structural modifications while in storage;
- Improper functioning of sustainer during early moments of propellant burning.

The virtual simulation program using FEM software is conceived in such a manner to cover as much as possible from the determinative possible causes. A few directions in analyzing the causes which could increase the incidents occurring risk were drawn up:

- Simulation of threaded assembly which combines the nozzle block with the rocket chamber;
- Simulation of nozzle – diaphragm assembly functioning;
- Analysis of what happens in engine functioning if accidentally obturations of nozzle critical section occur.

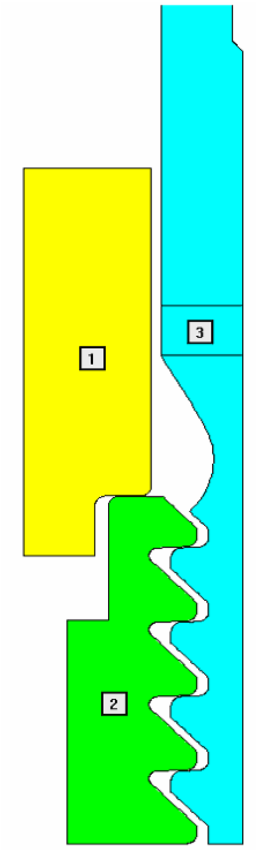


Fig.3 Nozzle block – rocket chamber assembly
1 – nozzle block, 2 – nut, 3 –burning chamber

4 Simulation Results

Concomitantly with FEM simulation program, a flow analysis using FLUENT was developed. This must point out the gas flow through the engine and parts heating with function of time in different functioning situations.

For the threaded assembly functioning, 9 dimensional cases were assigned. One of them are in concordance with the product technical documentation, while the others were altered with shape and dimension deviations. The threaded assembly is shown in Fig.3, while the situations analyzed are presented in Fig.4. All these cases were submitted to normal, accidental and destructive loadings. The material properties were considered the same as in technical conditions from the execution drawings.

Cases to be analysed [mm]

Nr	D1	D2	D2i	D2fi	D2fe	D3f1	D3fe	D3	R
1	66.80	67.15	65.65	68.70	70.50	69.40	70.79	72.17	0.10
2	66.70	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.10
3	66.70	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.10
4	66.70	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.20
5	66.90	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.20
6	66.70	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.20
7	66.60	67.30	65.70	68.60	70.45	69.45	70.88	72.14	0.20
8	66.70	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.25
9	66.70	67.20	65.70	68.60	70.45	69.45	70.88	72.14	0.30

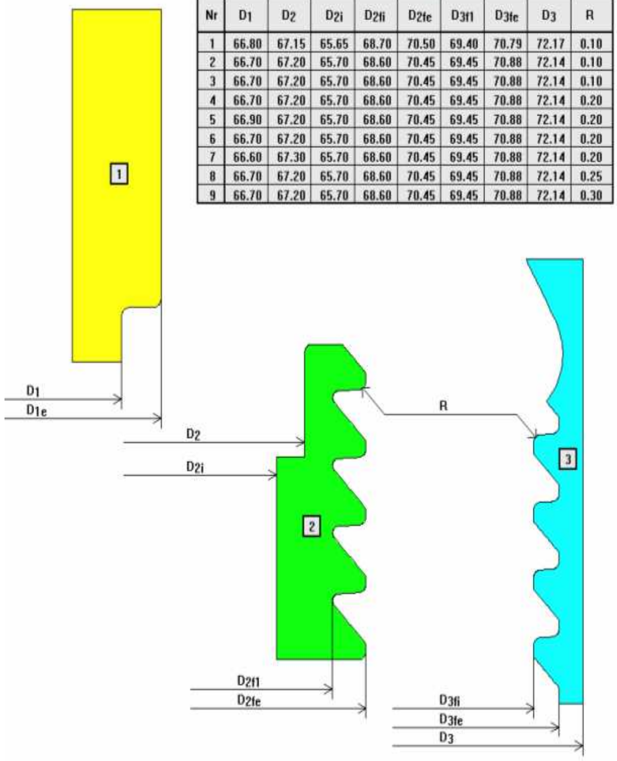


Fig.4 Assembly dimensional variants

4.1 Threaded Assembly Simulation Results

The detailed analysis of numerical simulation solutions raised the following aspects:

- If threaded assembly is made in accurate technical conditions, even it the worst pairing situation the engine withstands higher pressures than prescribed;
- The most important negative effect on assembly stability is represented by the top edge's rotunding or chamfering.

In Fig.5 and Fig.6 are further presented the effective stress fields in four of above mentioned situations.

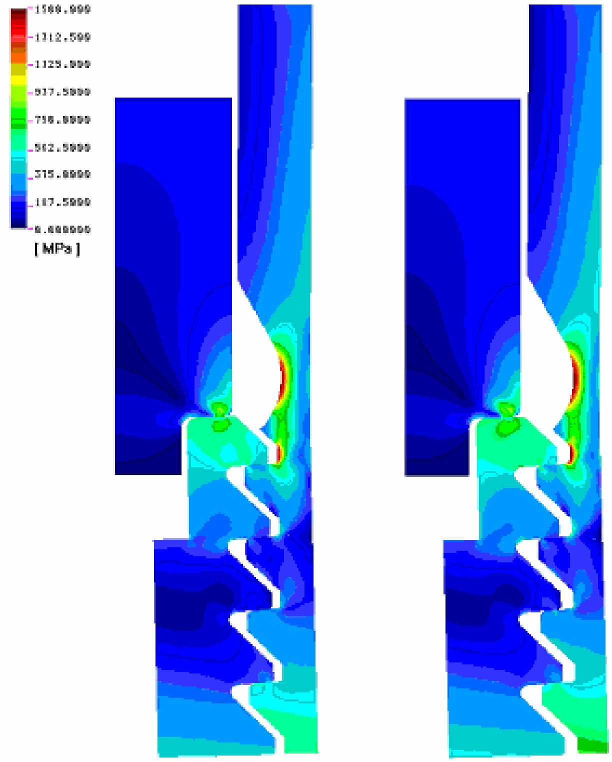


Fig.5 The effective stress threaded assembly for first and second variants

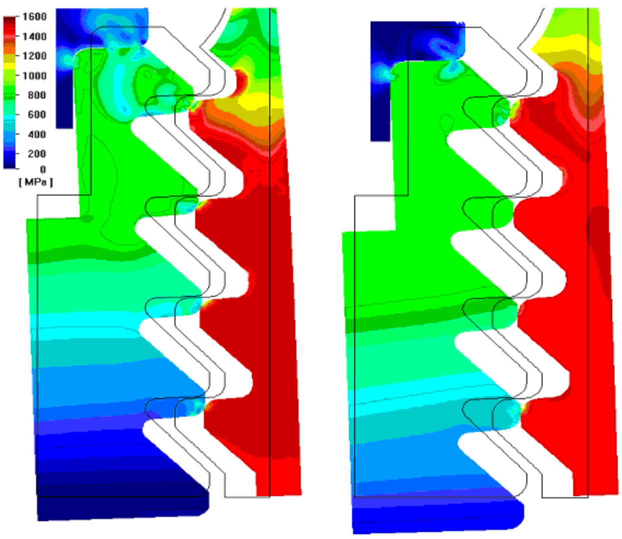


Fig.6 The effective stress threaded assembly for sixth and eighth variants

4.2 Nozzle – Diaphragm Assembly Results

The purpose of these simulations were discover the influences of nozzle opening manner over the pressure variation in the engine chamber. Two different types of diaphragms were analyzed, in two fastening conditions and two loading cases. In Fig.7 are presented the nozzle – diaphragm assembly and it's FEM model.

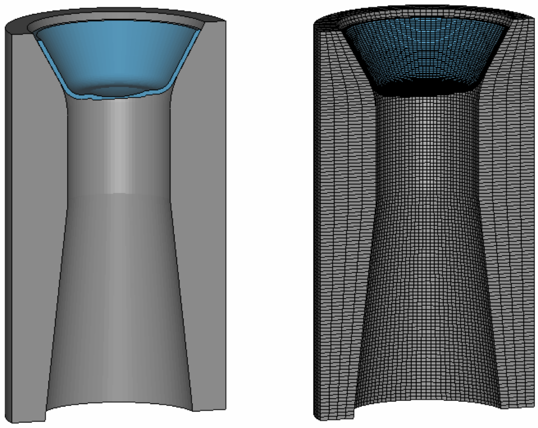


Fig.7 Nozzle – diaphragm assembly

All functional cases were submitted to an LS-DYNA analysis for all loading period, when the applied pressures varies from 0 to a maximum of 400 bar, even if in real tests the diaphragms gave up at lower pressure values. In all cases were observed the most important parameter which influences the pressure regime inside the engine. This parameter is the diaphragm breaking pressure. The deformed shapes are presented in form of breaking modes in Fig.8.

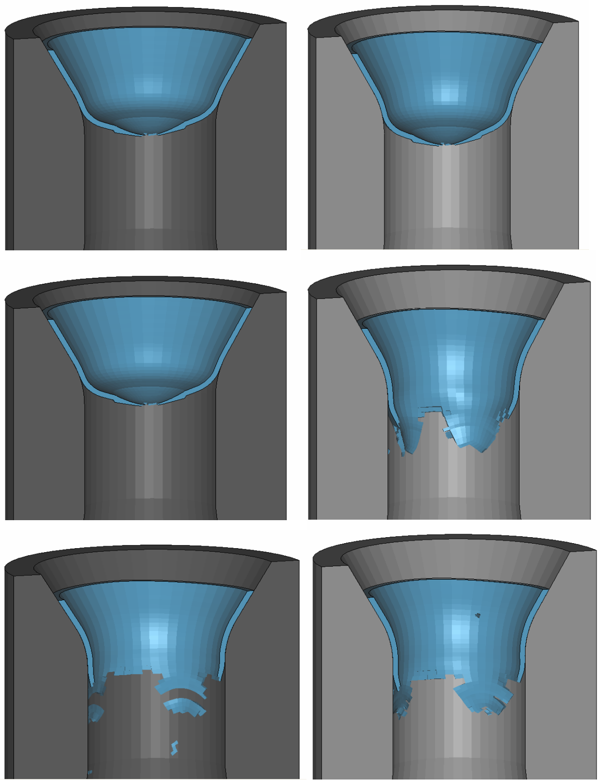


Fig.8 Breaking modes of free diaphragm

Left column represents different pressure loadings with quasi-static evolution, while in right column the same pressures are in dynamic evolution.

By results analyzing process, was pointed out that best functioning behavior is met when using a bold diagram, as shown in Fig.9.

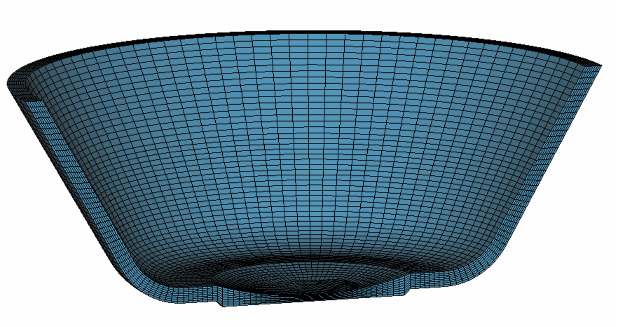


Fig.9 Detail of nozzle – diaphragm assembly

In the case of welding diaphragm, which means there is a firm contact between diaphragm and nozzle surface, it's behavior is totally different, as shown in Fig.10. Due to bold feature on the diaphragm, a cap is cut off when pressure reaches the proper value and rocket engine has a good functioning.

4.3 Accidentally Obturations of Nozzle Critical Section - Results

The conclusion in this cases is the accidentally obturation of nozzle critical section represents one of causes which increase the nozzle block separation risk. The pressure variations are highly sensitive at variations of nozzle critical section. This could lead to the critical regime of engine functioning. The situations considered to be critical were tested in real experiments. The measured parameters values were similar with the simulations results.

5 Conclusions

The whole simulation and experimental results helped to indicate a set of corrective actions in technical documentation and technology. Some of the are as bellow:

- Replacing the initial nozzle diaphragm with a bold one, including a bursting shape;
- More restrictive tolerance conditions are needed when fastening the engine chamber and assembling nut;
- More restrictive conditions when sticking diaphragm on the nozzle convergent surface.

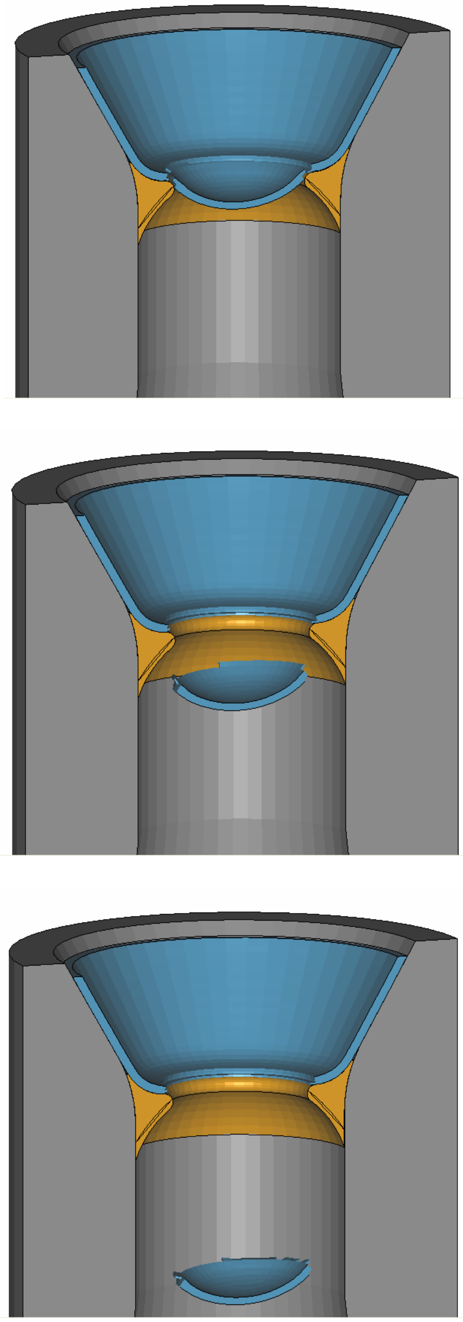


Fig.10 Cap forming from the diaphragm

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