Random Vibration Fatigue Analysis for a Gunner Platform Frame using Experimental Data

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Abstract

Remote controlled weapon systems have gained great importance in defense industry as they maximize crew safety with accurate shooting capabilities. On the other hand, vibration levels are of great consideration because of its effect on crew comfort and system reliability especially for tracked armored vehicles. In this study, vibrational evaluation is performed for a remote control gunner platform frame, which is mounted to the top plate of an armored tracked vehicle. Vibrational response of the gunner platform is critical for a successful completion of especially mobile missions. In order to perform random vibration fatigue evaluation, the experimental data obtained from the top plate of an armored tracked vehicle is used and random vibration analysis are performed using LS-DYNA®. Power Spectral Density (PSD) profiles provided in NATO AECTP 400 document are also included in the random vibration analysis with a degree of modification in order to make a comparison. Finally, random vibration analysis results from LS-DYNA® are compared with the results of another commercial software using similar analysis parameters.

Keywords: random vibration, PSD, experimental, fatigue

1 Introduction

Random vibration analysis can be defined as the probabilistic description of the response of a dynamic system, which is exposed to arbitrary levels of vibration through service time. Tracked vehicles are exposed significant levels of vibration while moving over a terrain due to interactions of tracks with ground and the irregularities on the terrain in addition to the contribution of power train components to the vibration levels. Another source of vibration is the tracks moving over the wheels, sprockets etc. and the vibration is transferred to the subsystems through suspension system and the hull geometry, which may cause catastrophic failures in sub systems at specific frequencies [1]. As there are many sources of vibration for a tracked vehicle, random vibration analysis is a strong tool to predict the vibrational response of the system.

Remote control systems allow military crew to operate remote controlled weapon stations with maximum protection. However, because of the high levels of vibration that the system may be exposed to, several cases have been reported about the deterioration of the vision from monitor during operations. In this study, a remote controlled gunner platform, which is mounted to the top plate of the hull, is analyzed using both experimental data and the PSD profiles given in AECTP 400 in order to increase the vision comfort while using the platform and predict the fatigue life for the system. Analysis are performed for both LS-DYNA® and another commercial software using the experimental data for two different velocities.

2 Model Information

Finite element model is created for 21 parts with same element size using linear solid elements but node to node coincidence is not considered for the opposing parts. Bolted joints are modeled with rigid elements and three inertia elements are defined to represent monitor, handle and control stick. For ANSYS similar modelling approach is implemented. Results for default element formulation (ELFORM=1) and ELFORM=-1 are compared initially.

It is seen that contact definition plays an important role on the results. Hence, several contact definitions are used and RMS of von-Mises stress and natural frequency results are compared with other commercial code. The list of compared contact keywords is given in
Table **1**.

	Contact Keyword
Case 1	***CONTACT_TIED_SURFACE_TO_SURFACE_OFFSET**
Case 2	***CONTACT_TIED_SURFACE_TO_SURFACE_CONSTRAINED_OFFSET**
Case 3	***CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_TIED**

Table 1: The list of contact definitions which are used for comparison

It is decided to start with ***CONTACT_TIED_SURFACE_TO_SURFACE_OFFSET** keyword as it is known to work sufficiently for explicit analysis. For a couple of runs of different types of master and slave and different values of MAXPAR parameter there was no significant increase in the accuracy when compared to ANSYS results. After that, it is seen that LS-DYNA® suggests ***CONTACT_TIED_SURFACE_TO_SURFACE_CONSTRAINED_OFFSET** for implicit analysis in output files. Grimes suggests use of _CONSTRAINED_OFFSET for a robust implicit solution as well [2]. _MORTAR option is said to work very well for nonlinear analysis so the tied version is tried as well.

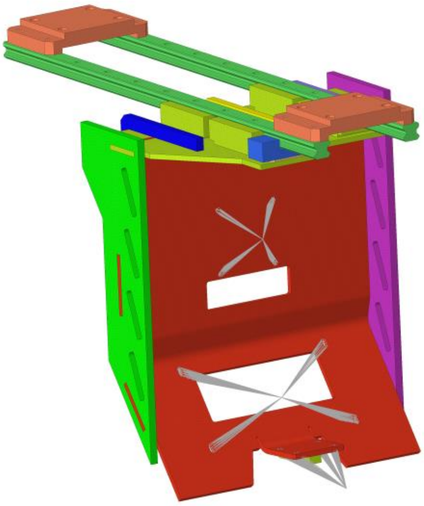

Figure 1 – Finite Element Model

2.1 Comparison of Element Formulation Option

For Case 1 and 2 element formulation "ELFORM" is left as default "1" and compared with results of ELFORM=-1 referencing the ANSYS natural frequencies and maximum 1-sigma von Mises stress result. Normalized results are given in **Error! Reference source not found.**.

	Case 1 ELFORM=-1	Case 1 ELFORM=1	Case 2 ELFORM=-1	Case 2 ELFORM=1
Mode #1	0.91	0.88	0.96	0.92
Mode #2	0.96	0.93	0.98	0.95
Mode #3	0.93	0.89	0.97	0.93
Mode #4	0.93	0.90	0.97	0.94
Mode #5	0.95	0.93	0.98	0.96
Mode #6	0.93	0.89	0.97	0.93
Mode #7	0.95	0.91	0.99	0.95
Mode #8	0.95	0.92	0.98	0.94
Mode #9	0.96	0.94	0.99	0.96
Mode #10	0.95	0.91	0.98	0.94
von-Mises	1.66	1.97	1.20	1.55

Table 2 – Comparison of element formulation option

It is obvious that natural frequencies are under predicted and maximum RMS of von-Mises stress is higher for all results in LS-DYNA®. However, using the default element formulation option “1” increases the discrepancy between results of LS_DYNA® and ANSYS. For Case 1 maximum von-Mises stress difference increases from 66% to %97 and for Case 2, increases from 20% to 55%; thus, it is decided to continue with ELFORM=-1.

2.2 Comparison of Contact Options

Three different contact options and master/slave types for one option are compared. The comparison between ANSYS natural frequencies and 1-sigma von Mises stress results are given in Table 3.

	Case 1	Case 2	Case 3
Mode #1	0.91	0.96	0.89
Mode #2	0.96	0.98	0.95
Mode #3	0.93	0.97	0.91
Mode #4	0.93	0.97	0.90
Mode #5	0.95	0.98	0.94
Mode #6	0.93	0.97	0.90
Mode #7	0.95	0.99	0.93
Mode #8	0.95	0.98	0.94
Mode #9	0.96	0.99	0.95
Mode #10	0.94	0.98	0.93
von-Mises	1.65	1.20	1.87

Table 3 – Comparison of Contact Options

Natural frequencies of first ten modes for the contact keyword **`*CONTACT_TIED_SURFACE_TO_SURFACE_CONSTRAINED_OFFSET`** is almost the same of the ANSYS‘s. Maximum value for RMS of von Mises stress is close to 20% when compared to ANSYS.

Response PSD results are compared for _CONSTRAINED_OFFSET and ELFORM=-1 and it is observed that the results are in very good agreement in vertical, transverse and longitudinal directions as shown in Figure 2.

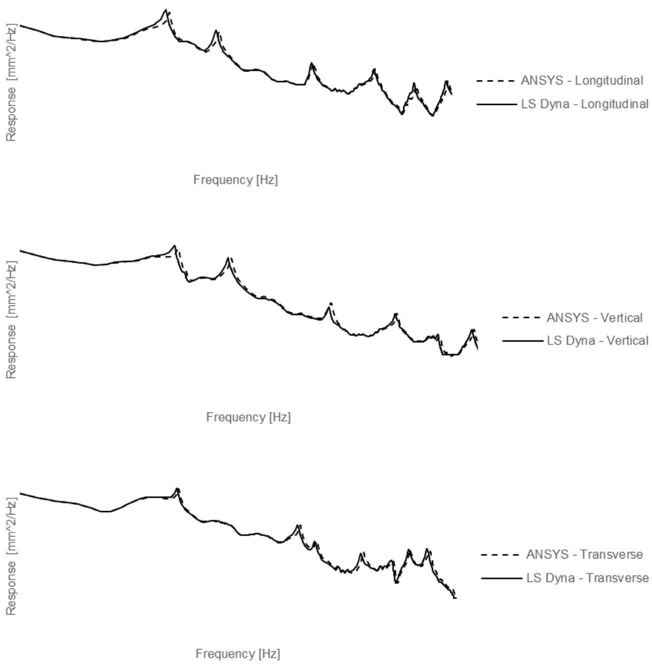

Figure 2 – Response PSD Comparison for _CONSTRAINED_OFFSET and ELFORM=-1

Random vibration fatigue analysis is performed with _CONSTRAINED_OFFSET contact keyword and element formulation ELFORM=-1.

3 Input Data

Acceleration data near the gunner platform joints at 10 km/s and 50 km/s is recorded and Power Spectral Density (PSD) data generated for 300 seconds at 10 km/s and 50 km/s. In addition to the experimental data, AECTP 400 test PSD for "Light Vehicle-Materiel Installed in Hull" is used for comparison [3]. Narrowband definitions are not considered as swept [3]. But narrow bands are moved to the critical excitation frequencies to simulate the most severe situation for the structure. Frequencies with maximum effective mass are determined as critical. In addition, narrowband peak points are scaled to the maximum of experimental data. Experimental PSD data in vertical direction is presented in Figure 3.

S-N curve data provided in Eurocode 9 is implemented for plain castings [4].

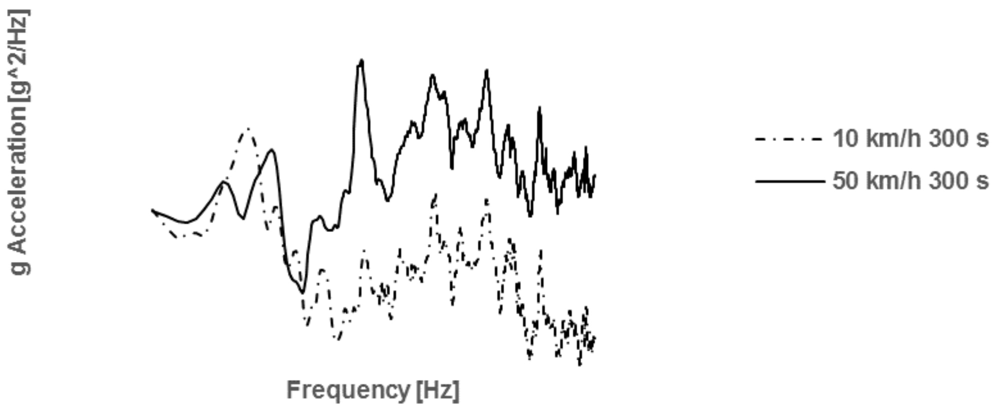

Figure 3 – Experimental Data

4 Random Vibration Fatigue Analysis

`*DOMAIN_RANDOM_VIBRATION_FATIGUE` card is implemented to perform random vibration fatigue analysis. Following options are defined in in the keyword:

- The last mode in modal superposition method "MDMAX"
- Maximum frequency "FNMAX"
- Damping factor "DAMPF"
- "VAFFLAG" to define loading type as base acceleration
- Unit system is chosen as "-1" and multiplier for g "UMLT" is defined as 9810 for consistency
- A part set is created to define the panel exposed to acoustic environment (SID) and PSD data is defined in vertical, transverse and longitudinal directions separately with the correct definition for "DOF".

  For fatigue calculations:

- Dirlik method is chosen
- Type of exposure is defined
- S-N curve ID
- Fatigue threshold value "STHRES" is defined for the material.

Response PSD is a significant indicator to evaluate the structure's behavior when subjected to random vibration. In order to get the results, **`*DATABASE_FREQUENCY_ASCII_NODOUT_PSD`** or **`*DATABASE_FREQUENCY_BINARY_DE3PSD`** keywords can be used. It is possible to define the frequency range and get data for a specific curve of the user's choice.

5 Results

Results are examined for 10 km/h and 50 km/h speeds to satisfy both service life and get a moderately low response for crew comfort.

Notch radius near the control stick mount is observed to be most critical as expected. RMS of von Mises stress results are given in Figure 4.

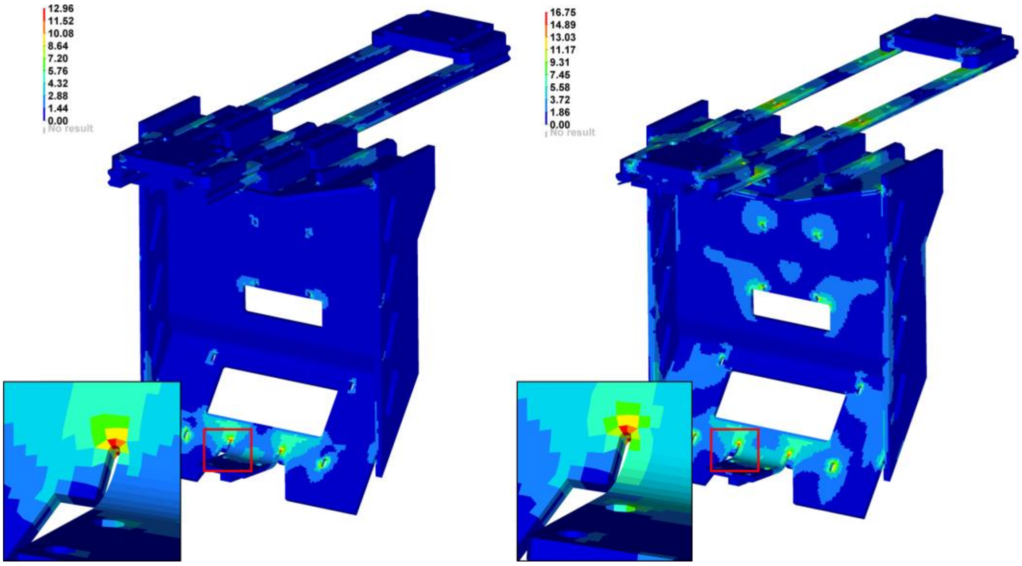

Figure 4 – RMS of von Mises Stress for 10 km/h and 50 km/h respectively

For 50 km/h, connection mounts and linear rails become critical considering the cumulative damage ratio as shown in Figure 5.

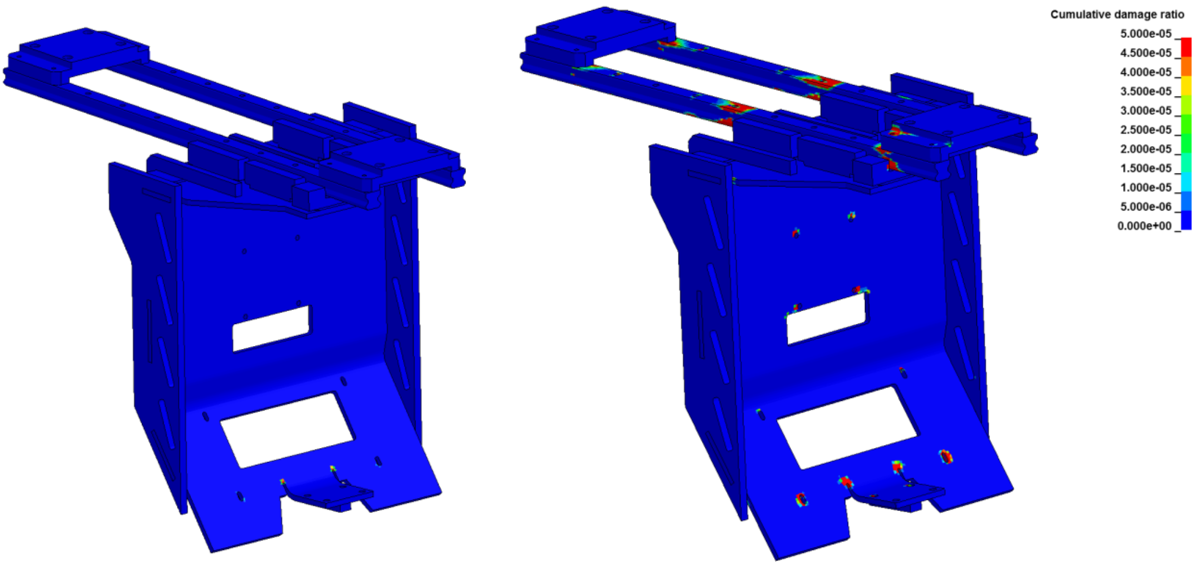

Figure 5 – Cumulative damage ratio for 10 km/h and 50 km/h respectively

In order to reduce the damage ratio for 50 km/h, analysis is conducted fixing the bolt holes assuming there is another mounting provision included in the design. Fixed nodes are given in Figure 6.

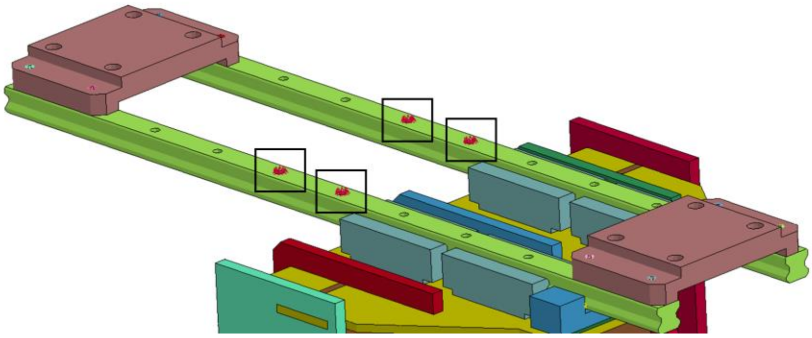

Figure 6 – Fixed nodes for extra analysis

There is %20 percent decrease in maximum RMS of of von Mises stress and damage rates decrease significantly as shown in Figure 7. High damage ratios observed at linear rails for two mounting provision case is eleminated when three is used.

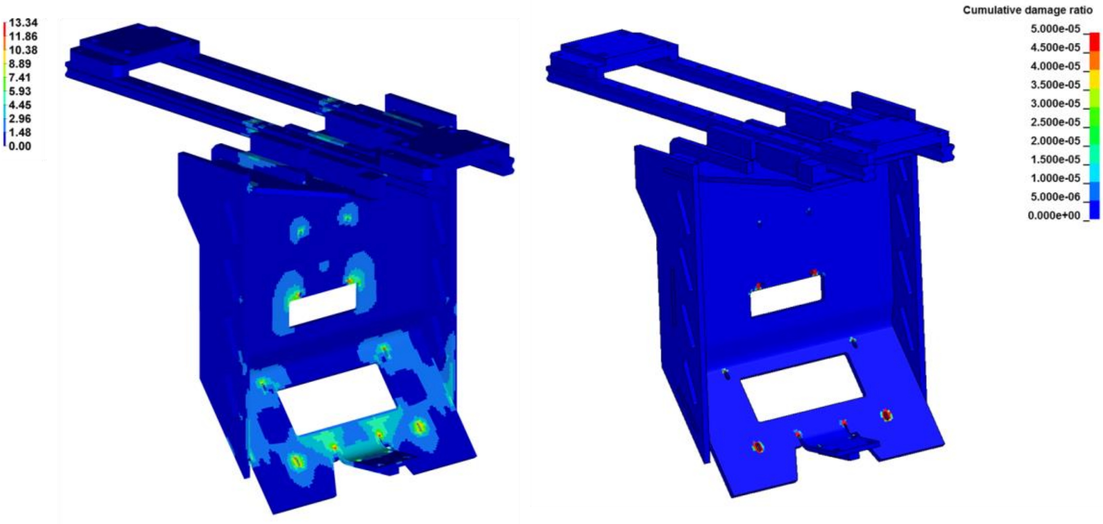

Figure 7 – RMS of von Mises stress and cumulative damage ratio results

AECTP 400 test PSD for “Light Vehicle-Materiel Installed in Hull” is seen to be very harsh when compared to the test data. RMS of von Mises stress results for non-modified and scaled PSD test data is shown in Figure 8.

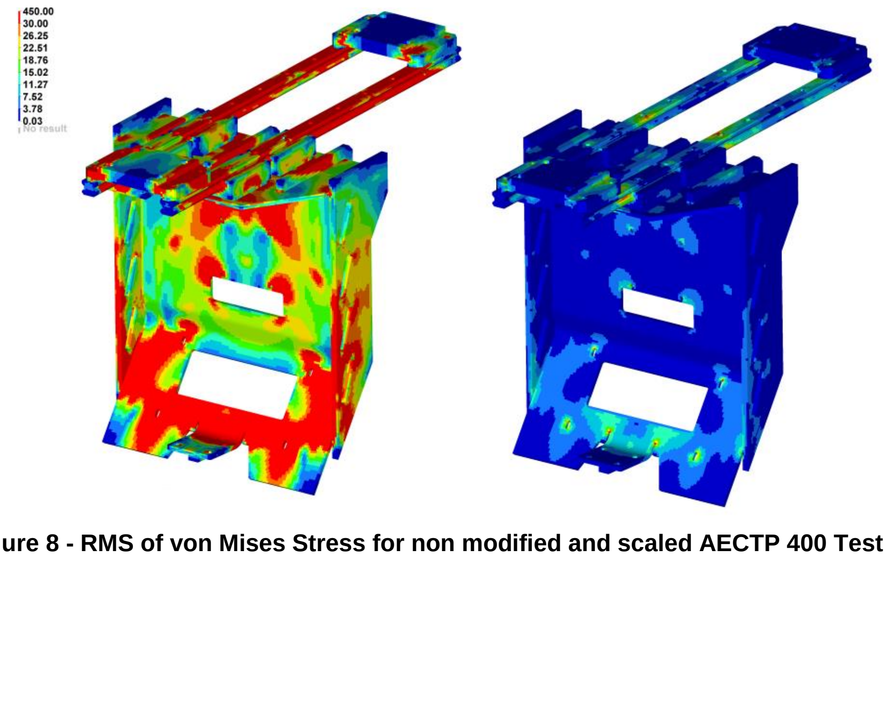

Figure 8 - RMS of von Mises Stress for non modified and scaled AECTP 400 Test PSD

Comparison in response PSD in vertical direction is given in Figure 9. It is suggested to use experimental data if available [1] and it is clear that provided test data over predicts the structural response.

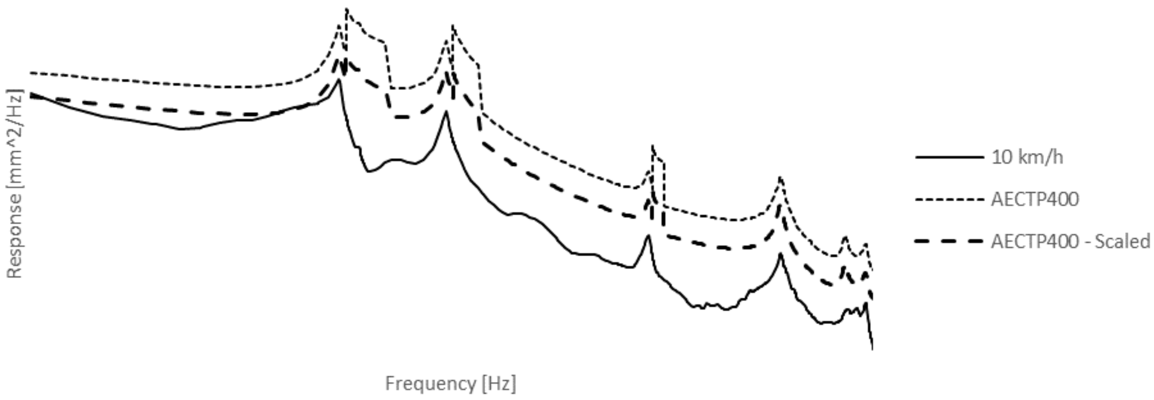

Figure 9 – Comparison of Response PSD

6 Summary

Random vibration fatigue analysis is performed for a gunner platform of remote controlled weapon station using LS-DYNA ® and general procedure and necessary cards are presented. At the beginning of the study, results of Eigen values, RMS of von Mises stress and response PSDs are compared with ANSYS results for several contact options and element formulation “1” and “-1” and it is decided to use _CONSTRAINED_OFFSET and ELFORM=-1.

Along with experimental data, AECTP 400 test PSD for “Light Vehicle-Materiel Installed in Hull” is used to perform analysis. Narrow band frequencies are moved to critical natural frequencies of the system. It is observed that AECTP PSD data over predicts stress results. The data may be used in the preliminary design phase as it gives an intuition for critical locations of the structures.

7 Bibliography

[1] *Allied Environmental Conditions and Test Publication, (AECTP 240), Edition 1,* NATO International Staff - Defence Investment Division, 2009.

[2] R. Grimes, „A Tutorial on How to Use Implicit LS-DYNA®,“ in *12th International LS-DYNA® Users Conference*, Detroit, 2012.

[3] *Allied Environmental Conditions and Test Publication, (AECTP 400), Edition 3,* NATO International Staff - Defence Investment Division, 2006.

[4] *Eurocode 9: Design of Aluminium Structures - Part 1-3: Structures susceptible to fatigue,* Brussels: European Committee for Standardization, 2011.

[5] *LS - DYNA® Keyword User's Manual,* Livermore Software Technology Corporation, 2018.