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 **STUDY OF THE NANOSATC-BR1 MECHANICAL STRUCTURE BEHAVIOR THROUGH THE LAUNCH ENVIRONMENT**

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The NANOSATC-BR1 is the first Brazilian scientific university nanosatellite - first CubeSat from the NANOSATC-BR, CubeSats Development Program, Project originated from the agreement between National Institute of Space Research – INPE/MCTI – and the Santa Maria Federal University – UFSM, through the Santa Maria Space Science Laboratory – LACESM/UFSM. The NANOSATC-BR1 was launch on June 19th, 2014, at the Yasni launch base in Russia with a DNEPR launcher. Inl the first week of April the satellite was sent to Delft at ISIS - Innovative Solution In Space, a Dutch company that manufactured the NANOSATC-BR1 platforms. The CubeSat need to go ISIS to perform integration into the launcher interface, perform fit, other operational tests and final health check in ISL/ISIS, Delft – April/May, 2014. Before it was necessary to realize the mechanical-structure vibration, thermal and vacuum thermal tests in order to certificate the CubeSat for launch. The tests were realize between the last two weeks of March in the Laboratory of Integration and Tests (LIT), in INPE/MCTI, São José dos Campos, Brazil. One of the mechanical-structure tests required for qualification and certification of the CubeSat for Space Launch, for DNEPR Russian rocket, was the acceleration test, known as quasi-static test. LIT/INPE-MCTI has not the appropriated equipment for this test and the deadline to send the satellite for Netherlands was expiring. Because of that, it was necessary to make the NANOSATC-BR1 quasi-static test through computational analysis, which is acceptable by the launch company ISC Kosmotras. The computational structure analysis was made using the Finite Element Method (FEM), based on the Finite Element modeling of the NANOSATC-BR1 computational model. This way, all the CubeSat’s systems were modulated in finite element and the quasi-static analysis was realize on the three possible fixation axis of the satellite on the spacecraft. The gravity loads used on the analysis were based on the Environment Levels Auxiliary Payloads ISILAUNCH07, document from ISIS, being those loads required to fly on DNEPR. The results show that the stress found on the CubeSat’s systems on the three quasi-static analysis, on the three-reference axis of the satellite, were less than twenty five per cent of the material yield stress of the satellite system, which gives a large safety margin for the CubeSat. The work was utilize to certificate part of the vibration tests for the complete qualification of the first Brazilian CubeSat in space, the NANOSATC-BR1, aiming the DNEPR rocket. This gives the author the honor to be the first Brazilian undergraduate or graduate student to have a work accepted as part of the certification for launching a satellite.

1. Introduction to the NANOSATC-BR Program

According Schuch and Durão (2011), [1], The NANOSATC-BR, CubeSats Development Program consists of a Program of Human Resources Training for Brazilian Space research with development of Engineering and Space Technologies as CubeSats. This Program is developed in partnership between the National Institute for Space Research CRS/INPE-MCTI and the Federal University of Santa Maria - UFSM, through the Santa Maria Space Science Laboratory - LACESM/CT/UFSM.

The NANOSATC-BR Program began with the development of the first Brazilian scientific university nanosatellite, the NANOSATC-BR1, with the design of this satellite was obtained the training of several students at UFSM in various areas of engineering and space science. With the success of the first Project, the Program had follow-up with the creation of the NANOSATC-BR2.

The NANOSATC-BR1 was purchased from a specialized company - ISL-ISIS - Innovative Solutions in Space - being built in standard format in the 1U class of CubeSats.

Even with NANOSATC-BR1 being manufactured by a company specializing in CubeSats standard format and it was required to perform a structural mechanical analysis in the CubeSat by the fact that the orbital launching environment to which the satellite will be exposed at launch, can be harmful to satellite structure and its components, because this environment presents high gravitational loads, and vibrations. In addition, in according with Bürguer (2010) [2] for the launch it is necessary documents proving the satellite capability for space launch. Because of that it is needed at least computational analysis that confirms the satellite structural capacity, if it is not possible the performing a real laboratory quasi-static analysis with the real satellite.

1. **Introduction to the Quasi-Static Analysis**

The Quasi-Static Analysis was made to certificate that the NANOSATC-BR1 structure will support the loads that it will be subject on its launch to space.

The CubeSat numerical analysis was made in a Element Finite Modeling Software. The Quasi-Static Analysis was made in regarding to the three CubeSat axis. It was done because one do not know what will be the satellite position in the Spacecraft. After having done the three analysis, it was made the post processing of the tension data. It was made checking separately every CubeSat subsystems to be sure that the material allowable tension was not exceed.

1. **Finite Element Model**

 The Finite Element Model consist in a Numerical Modeling for the NANOSATC-BR1, in according with Bohrer (2011), [3]. Every subsystem was modeling and after all the subsystem was connected to form the numerical model for the CubeSat.

Some simplification was made on the numerical model, comparing with the real satellite, to perform the analysis. It was made for guarantee a good analysis, because if exist in the modeling many complex finite element, it will difficult the analysis, besides this, it can compromise the veracity of the analysis. All the simplification are based on the technologist’s instructions and guided for the document NX Nastran User’s Guide (2004) [4] when shows all the characteristics of witch finite element type. The Figure 1 shows the results of the NANOSATC-BR1's Finite Element Structure Model.

In regarding to CubeSat Design Specification (CDS) (2009) [5] all the 1U Cubesats are divided, including the NANOSATC-BR1 Finite Element Model, Figure 1, in: main frame; shear panels; internal components; antennas, external structure and screws. For identification of the NANOSATC-BR1's Finite Element Subsystems they were displayed in Table 1.



Figure 1 – NANOSATC-BR1 Finite Element Structure Model.

|  |  |  |  |
| --- | --- | --- | --- |
| Subsystems  |  |  | Number Identification range |
| Mainframe |  |  |  | 1 - 36983 \* |  |
| Shear panels |  |  |  | 40000- 47090 |  |
| Internal components |  |  | 50000 - 57023 |  |
| Antennas and External Structure |  | 60000 - 62999 |  |
| Screws M2,5x6 - antenna fixation |  | 2810 - 2817 |  |
| Screws M2,5x6 - mainframe fixation | 2818 - 2825 |  |
| Screws M2,5x6 - shear panels fixation | 2846 - 2861 |  |
| Screws M3 - subsystems spacers | 2826 - 2845 |  |
| RBE2 Element |  |  | 62986 - 62990 |  |

Table 1 – NANOSATC-BR1's Finite Element Subsystems and its respectively ID identification range.

The NANOSATC-BR1 mainframe was divided in parts which are displayed in Table 2.

|  |  |  |
| --- | --- | --- |
| Mainframe  |  | ID Elements |
| Rib 1 |  | 1 to 2809 |
| Rib 2 |  | 5000 to 7808 |
| Rib 3 |  | 10000 to 12808 |
| Rib 4 |  | 15000 to 17808 |
| Frame 1 |  | 20000 to 26983 |
| Frame 2 |  | 30000 to 36983 |

Table 2 – NANOSATC-BR1's Mainframe Subsystems Division.

1. **Analysis**

The Quasi-Static Analysis was made regarding to the document Environment Levels Auxiliary Payloads ISILAUNCH07 for ISIS [6]. In this document, Section two, the launch loads are shown to the three satellite axis. In order to do this three analysis for the NANOSATC-BR1 numerical model in each axis of the satellite were made. In this analysis it was applied the worst load for the launch on the three quasi-static analysis. The worst load shown in the document was 10,8 gravity acceleration on longitudinal axis and -3,4 gravity acceleration on transverse axis.

 The numerical analysis was performed using the software FEMAP/NASTRAN, and the tension data was obtained.

1. **Post Processing**

 After the Quasi-Static Analysis was run on the software it is also necessary to certificate that the tension on the CubeSat subsystems complies with the subsystems material allowable tensions. The Table 3 shows the subsystem and their respective material.

|  |  |
| --- | --- |
| Subsystems | Materials |
| Main Frame | Aluminum Al 6061-T6 |
| External Structure | Aluminum Al 6061-T6 |
| Internal Components | Fiberglass FR4 G-10 |
| Shear Panels | Aluminum Al 6061-T6 |

 Table 3 – Subsystem and its respective materials

For simplification reasons, the screws are considered manufacturing in Aluminum, but in fact, this parts are made for Stainless Steel. In fact, this simplification raises the certification of the post processing, because Stainless Steel is much more resistant than Aluminum. The ultimate tensions for the Aluminum Al 6061-T6 and Fiberglass FR4 G-10 are 262 MPa and 205 MPa, respectively.

For the three analysis made, the maximum tension in any subsystem was considered and compared with the material ultimate tension. Besides that, for any critical tension the safety margin was calculate. On the three Tables 4, 5 and 6, it is considered the three satellite axis, and it is shown the worst tension for any subsystem.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Tension Post-Processing - X Axis  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| Subsystem | ID Element with Maximum tension | Tension (Mpa) | Safety Margin |
| Main Frame  | 54553 |  |  |  | 6.48 |  | 39.43 |  |
| External Structure | 62973 |  |  |  | 9.08 |  | 27.84 |  |
| Internal Components | 62973 |  |  |  | 9.08 |  |  21.57 |  |
| Shear panels | 41102 |  |  |  | 30.48 |  |  7.59 |  |

Table 4 – NANOSATC-BR1's maximum tension and safety margin for the Finite Element in any Subsystem – X Axis Analysis.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Tension Post-Processing - Y Axis  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| Subsystem | ID Element with Maximum tension | Tension (Mpa) | Safety Margin |
| Main Frame  | 5675 |  |  |  | 47.51 |  |  4.51 |  |
| External Structure | 62973 |  |  |  | 11.17 |  |  22.44 |  |
| Internal Components | 54524 |  |  |  | 7.49 |  | 26.36 |  |
| Shear panels | 47049 |  |  |  | 39.15 |  |  4,23 |  |

Table 5 – NANOSATC-BR1's maximum tension and safety margin for the Finite Element in any Subsystem – Y Axis Analysis.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Tension Post-Processing - Z Axis  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| Subsystem | ID Element with Maximum tension | Tension (Mpa) | Safety Margin |
| Main Frame  | 5675 |  |  |  | 31.66 |  |  7.27 |  |
| External Structure | 62337 |  |  |  | 25.27 |  |  9.36 |  |
| Internal Components | 54549 |  |  |  | 20.58 |  |  11.72 |  |
| Shear panels | 45065 |  |  |  | 13.84 |  |  13,81 |  |

Table 6 – NANOSATC-BR1's maximum tension and safety margin for the Finite Element in any Subsystem – Z Axis Analysis.

1. **Conclusion**

In conclusion, it can be observed that all the NANOSATC-BR1's subsystems will support perfectly the load applied for the spacecraft acceleration in the space launching process. The worst safety margin obtained in the post processing shows that the worst tension that the NANOSATC-BR1 could be applied is less than twenty-five percent that the material allowable tension.

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