Procedures for Integrating, Testing and Operating Advanced Microsatellites

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Abstract: The costs involved in building and launching standard big satellites are very high. Due to the miniaturization of electronic and mechanical devices, smaller and cheaper satellites, also known as microsatellites, are becoming more capable, and thus, more important in space exploration. In other words, microsatellites can unite simplicity with capacity to carry more sophisticated payloads. This paper details practical aspects of microsatellites ranging from integrating process, vibration tests and vacuum chamber tests to its operation.

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1. INTRODUCTION

Currently the fabrication and launching costs involving small satellites ranges from US10^5 to US10^6, while costs of standard satellites ranges from US10^6 to US10^8. On the other hand, with the development of microelectronics, the small satellites are becoming able to develop similar tasks to the standard satellites.

Microsatellites are key for the easy access to space and can be used for almost all kinds of applications by trading off both the advantages of having a simple and small system, yet still having enough capacity for a variety of applications suitable for commercial exploration. Microsatellites weight from 10 kg to 100 kg. Their typical dimensions, although not fixed and excluding protrusions, are 50 × 50 × 50 cm. Since they are similar, microsatellites can also benefit from cubesat technologies, specially from the workforce that can now be trained in the university environment.

Microsatellites usually contain, saving its proportion, most of the standard satellite subsystems. The most important are the structures subsystem, power subsystem, attitude control subsystem with reaction wheels (Wertz (2012)), payload communications subsystem, command and telemetry communications subsystem and the payload. Thermal control on such spacecraft is mostly passive by means of finished surfaces Gilmore (2002), however, heaters might also be placed on more sensible parts.

Advanced microsatellite integration and testing is proposed from a project managers point of view in Silva (2011). In Gao (2011), the usage of computer assisted design tools to plan advanced satellites integration is shown. This paper shows the integration testing and operations of an advanced microsatellite from a practical point view. This gives insight to technicians and spacecraft designers planning integration, testing and operations of their future missions.

The remainder of this paper is divided as follows. In Section 2, we show the process of assembling a microsatellite. In Section 3, the environmental tests are detailed and its results are shown. Section 4 makes an overview of how the spacecraft is operated. Finally, Section 5 draws the conclusions.

2. MICROSATELITE INTEGRATION

The satellite integration starts with the setup of an adequate environment. In a micro gravity environment

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dust imposes a big problem. The dust can be electrically charged and harm electrical systems while floating towards static sensitive components. Therefore, a clean booth is usually the preferred choice for setting the microsatellite integration so that the satellite is almost dust free when launched to space. In a clean booth, filtered air is blown from the top towards the ground to force dust particles to settle on the floor and keep the air with a small particle density elsewhere. Also, clean-wear equipment is necessary to avoid the contamination by the technicians and the anti-static protection, since electronic equipment will be handled. The equipment should always be handled with gloves.

Before any procedure is taken, the one executing it should say out loud what he is about to do so that the colleagues can verify if the step is correct and if it is being done correctly. We shall remember that once in space, the equipment cannot be repaired or have any physical connection redone.

As depicted in Fig. 1, the integration of a microsatellite starts with the preparation of the external plates that form the structure of the spacecraft.

![Fig. 1. Preparation of the satellite’s inner and outer plates](image)

The preparation includes removing shipment protection, labeling, applying thermal insulators and harness organizers to the plates. Figure 2 shows a sideview of a thermal insulator installation.

![Fig. 2. Thermal insulators set up](image)

The thermal insulators are present to mitigate undesirable heat transfer between plates and are positioned at the fixing points. They usually have a square shape and hole in the middle where the bolts pass through and can be fixed in position using polyimide double sided tape. Polyimide tape is popular in space applications due to its good temperature characteristics.

Another example of component attached to the plates is a panel board as illustrated in Figure 3. In this case, the panel boards collect the energy from their respective solar panel and, as a plus, measures the temperature of the associated plate. As illustrated in Figure 3, the temperature sensor is glued to the plate using epoxy glue. To help keeping it in place, Polyimide tape may also be applied. The glue is then left to harden for a couple hours before the plate can be further handled.

![Fig. 3. Integration of the panel boards containing temperature sensors](image)

Following, the components are bolted into place, for example, the gyroscope, radio transmitters and receivers, battery, reaction wheels, inner panels, on-board computer and power management board. One of the last steps in assembling a microsatellite is harness routing and connection. The high amount of components and cables may cause clutter, therefore, the harness should be properly labeled in the case it needs maintenance during the tests. The harness connection procedure is shown in Figure 4.

![Fig. 4. Installation and verification of the harness connections](image)

All the integration steps should be previously carefully detailed in a manual. All the steps should be clearly marked so that any missing step can be clearly identified.

## 3. MICROSATELLITE ENVIRONMENTAL TESTS

Environmental tests serve two basic purposes: validate if the spacecraft can withstand the forces at launch and guarantee that it can operate in its specified parameters in the harsh conditions of space. These conditions include near vacuum, implying poor heat exchange, and high temperature gradients. Satellites usually have a ground interface connection. Through this interface, that is connected via cable, the technician can acquire more detailed data and more often than if the satellite is in space.

The remainder of this section is divided into two subsections. In Subsection 3.1, the vibration tests is detailed and...
in Subsection 3.2, the setup and procedures for the vacuum test are shown.

3.1 Vibration Tests

To get to space, spacecraft need to flight on the top of a rocket. During launch, rocket payloads are typically subject to high levels of vibration. To verify that satellite can withstand such forces, the spacecraft put to vibration tests. To check the impact of the vibration on the satellite and its components, accelerometers are placed on each plate that form the main structure of the satellite and major components. The accelerometer cables should be organized and routed to an external computer that will record the data. Also, all the external bolts are marked as shown in Figure 5.

![Fig. 5. Upper view representation of a bolt and markings; (a) tight bolt; (b) unscrewed bolt](image)

Figure 5a shows the markings made using a marker pen over the bolt head and on the surface of the satellite to indicate the bolt original position. If the markings have shifted, Figure 5b, the bolt has been unscrewed and a solution measure should be taken.

Then, the satellite is mounted on top of a Jig. A jig is shown in Figure 6 and its function is to adapt the satellite onto the shaker machine. The test is performed in all the dimensions X, Y and Z, each at a time. For the first two tests, the shaker is set horizontally and the satellite is shaken over the X dimension. Then, the satellite is rotated 90° and the test is repeated so that the satellite’s response on the Y axis is measured. The test starts with a low intensity vibrations (modal test) and then the vibration intensity is gradually increased.

![Fig. 6. Jig ready for the vibration test](image)

The response of the satellite (accelerometer measurements) is compared with the modal test measurements. Also, the sensors are compared between each other and any big gaps are searched. Big gaps suggest that the natural frequency of the satellite is in the range of the launch stress and action might be taken to avoid structure damage. Such action might include the addition of supports to reduce unwanted low frequency responses and absorbers to reduce unwanted high frequency responses. Finally, the shaker machine is rotated 90° upwards and the test is repeated so that the Z axis is tested.

Finally, the bolts are checked for unaligned markings as shown in Figure 5. A photo of the procedure is shown in Figure 7.

![Fig. 7. Bolt inspection procedure](image)

3.2 Vacuum Tests

The vacuum tests have the purpose of simulating the absence of pressure and air of the space environment and the temperature differences. To simulate the vacuum of space, the satellite is placed inside a vacuum chamber as shown in Figure 8. The chamber is able to remove the air and cool it down by the use of liquid nitrogen. Before placing the satellite into the chamber, various temperature sensors, known as thermocouple, are positioned on almost all satellite components. To increase heat conductivity, the thermocouples are fixed using metallic aluminum tape. The wires of the thermocouples are routed to a computer outside the chamber through the chamber’s electrical interface. Also, heater panels are placed surrounding the satellite so that the spacecraft can be heated up and also have a better temperature control in the process of cooling. One thermocouple is also placed on each heater panel. An illustration of the “cage” formed by the heater is shown in Figure 9.

![Fig. 8. Satellite inside the heating “cage” prior to the thermal vacuum test](image)

As illustrated in Figure 9, two heater panels are positioned above each of the six sides of the satellite. First, with
the liquid nitrogen cooling system turned off, the panels are gradually heated. The temperature of the panels and satellite components are monitored and the battery temperature works as a reference. This reference is taken since the battery has a limited working temperature range from approximately 0\(^\degree\) to 40\(^\degree\) and the room temperature is around 25\(^\degree\).

First the satellite is heated to 40\(^\degree\), the heaters are turned off and the electrical functions are tested via telemetry data. Then, liquid nitrogen inject though the chamber walls and the chamber temperature starts to decreased. The heater panels are turned and gradually increased so that the temperature decrease can be controlled using the heater control. This is done since it is easier than controlling the liquid nitrogen flow. Once the battery temperature reaches 0\(^\degree\), the electrical test is performed again. Finally, the coolant flow is cut off and the satellite is heated back to room temperature for a final electrical test. In each electrical test, the telemetry shows the temperature of various components. A graphic showing the temperature of seven spacecraft components is shown in Figure 10.

Figure 10 shows the three temperature levels that the satellite was subject to, where the battery temperature is shown in light blue and labeled as TBAT. The temperature is seen close to 40 degree and starts decreasing once the heater panels are turned off. Due to different heat dissipation characteristics of each components, we can observe that the temperature change is different for each component. Then, the temperatures are shown for the 0\(^\degree\) and the room temperature tests. All temperatures recorded were as expected.

4. MICROSATELLITE OPERATIONS

Once launched into space, the satellite must be operated to perform its designed mission. A spacecraft contains many aspects that should be monitored and controlled such as temperature, attitude, reaction wheels saturation and the health of all the other systems. All these system components exist to support the payload that will provide the mission data that could be either images, scientific data or any other relevant to commercial usage including ice cover and soil moisture.

To collect all this data a command and telemetry software is needed. Figure 11 and 12 show the command and telemetry software user interface for the satellite operation. Figure 11 shows the commands list window and Figure 12 shows the temperature, current draw, magnetic field and other vital information. Also, Figure 12 shows the on/off status of all the satellite components.

Microsatellites are usually sent to low earth orbit (LEO). At LEO the spacecraft is only visible to the ground station for a few minutes during each passage that are typically less than a handful of passages per day, Wertz (2011). The commands that are sent to the satellite must be planned in advance so that all commands can be sent sent during the short periods of signal acquisition (typically 15 minutes or less). Also, the acquisition of telemetry and payload data should be fitted into this same time-frame.

5. CONCLUSION

Microsatellites are satellites that weights more than 10 kg and less than 100 kg and they are becoming an important
Microsatellites trade off the simplicity of smaller satellites, e.g., cubesats, yet being capable of hosting bigger and more capable payloads. This paper gives details on the tasks need to be executed to integrate, test and operate a microsatellite. The integration involves structure set up, component placement and harness connection. The test comprises vibration tests and vacuum chamber test. Finally, the operations show how command and telemetry should be dealt with in order to guarantee a mission success.

REFERENCES

Y. Gao, D. Yang, Z. Liu, “Using concurrent engineering technology to design a satellite assembly,” In proc. of the 2011 International Conference on Electronic and Mechanical Engineering and Information Technology (EMEIT), Harbin, 2011.

D. G. Gilmore, “Spacecraft Thermal Control Handbook Volume I: Fundamental Technologies” The Aerospace Press, 2002.

A. C. Silva, G. Loureiro, “Integrated development of space systems - design for AIT - design for assembly, Integration and Testing of satellites - D4AIT,” In proc. of the 2011 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, 2011.

J. R. Wertz, “Space Mission Engineering: The New SMAD,” Space Technology Library, Vol. 28, 2011.

J. R. Wertz, “Spacecraft Attitude Determination and Control,” Kluwer Academic Publishers, 2012.