END/MMOD: A SYNERGIC COMBINATION OF A LEO SPACECRAFT AERO-BRAKING DEORBITING MODULE WITH A LEO SPACE DEBRIS AD MICRO-METEOROIDS DETECTION AND CHARACTERIZATION SYSTEM

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Abstract

In this paper it is proposed the combination of the End-of-life Natural Deorbiting (END) module (an inflatable aerobreaking device already under development in AVIO and aimed to accelerate the orbital decay of inoperative spacecraft) with a sub-system called MMOD (Micro-Meteoroids and Orbital Debris) consisting of a hypervelocity impacts detector capable of collecting data relevant to the type and the distribution of space debris and micro-meteoroids in the LEO region.

1 END-MMOD Concept and Mission Objective

The END module concept is based on the idea of an inflatable and deployable shield that, increasing the aerodynamic drag area of the entire vehicle, would be capable of accelerating the S/C orbital decay by mean of the consequent enhanced aero-braking effect. This would allow the compliance with the 25 years orbital lifetime constraint.

The MMOD section, instead, would provide the capability of acquiring data on the flux of micro-particles (natural andartificial) potentially dangerous for spacecraft in Low Earth Orbit (LEO) through piezoelectric and vibro-acoustic sensors fully integrated into the END shield, and independent from the other S/C subsystems, including the power supply.

The End-of-life Natural Deorbiting module (END) equipped whit the Micrometeoroids and Orbital Debris (MMOD) detector would give a technical answer to both procedures and methods to the disposal of space debris with reduction of the lifetime in orbit after the end of the operative life of the satellite and to the possibility of acquiring data on the flux of micro-particles (natural and artificial) potentially dangerous for satellites and, in general, for spacecraft in LEO.

2 END-MMOD System Architecture

The surface of the aero-breaking shield provides the opportunity for the installation of a MMOD detector system (piezoelectric sensor), the power source (solar array) and the thermal protection. Moreover there are electrical devices (cable, connector) and electronics system required to initialize the aero-breaking shield deployment, to interface piezoelectric sensor and solar array, and to elaborate the relevant data.

Therefore, the END/MMOD architecture consists of the following components:

- Metallic Cylindrical Case
- Aero-breaking Shield
- Deployment Systems
- Power Sub-System
- ISIDE Sub-System (Described Later)
- AOC Sub-System
- GPS Sub-System
- Telemetry Sub-System
- On Board PC
- Multifunctional Unit

3 END-MMOD Mission Description

As a matter of fact a large fraction of space objects are so small that cannot be easily detected by ground instruments. Therefore it is necessary an in-situ detection to have a closer prediction of micro-particles flux and the relative single particle energy, since with these data it is possible to have a quite accurate prediction about the potential damage that a particle can produce on a spacecraft.

The entire system (END/MMOD) will start its operative life after completion of the spacecraft operational life, when the END/MMOD will be deployed and inflated.

Thanks to the shield shape and size, there is an increase of the spacecraft aerodynamic reference area that reduces the ballistic coefficient, defined by the relationship:

$$BC = m/\left(A_{REF} C_D\right) \quad (1)$$

Obviously, at LEO altitudes the lower is the value of the ballistic coefficient, the shorter turns out to be the orbital lifetime. For this reason the spacecraft orbital decay evolution depends on both the ballistic coefficient and the initial altitude.

During the orbital decay evolution, the module is supposed to detect and record data about micro particles impacts by means of the shield sensor and its dedicated sub-systems.

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The impact data (kinetic energy, time of impact, size and trajectory) are processed and stored on a specific electronic unit and on-board computer in order to be sent to the ground station with a dedicated transmission unit.

In accordance with the re-entry analysis reported in [1] and with the results obtained with Nasa DAS (Debris Assessment Software) software, based on the common technical datasheet of the main electronic device, we can assert that the module should detect particles up to 300 km of altitude without breakups caused by aero-thermal stress.

Below this altitude, the residual orbital decay time is very low and consequently the functionality of the END/MMOD module becomes of irrelevant importance. Morevore, the simulation with this software assure the compliance with Nasa Technical Standard 8719 to limit risk from re-entry debris.

4 MMOD Sub-system: Characteristics and Performance

4.1 Detection Mechanism

In the present application, the piezoelectric property of the material is not exploited in conventional way, where the generated signal is proportional to the stress applied to its surface. Instead, in case of puncturing due to an hypervelocity impact, there is the destruction of the dipole in the point of impact and the generation of a number of electrons proportional to the removed volume from the piezoelectric material.

Thanks to the piezoelectric characteristic of the sensing material, it is possible to generate an electrical signal whenever an impact occurs, and then to elaborate this signal by a dedicated electronic circuit.

The output electrical signal is then a rapid charge pulse, and its amplitude depends on the mass and speed of the particle. In literature, there are many studies about the behaviour of PVDF (Poly-Vinylidene-Di-Fluoride) when a hypervelocity impact occurs: according to these works the quantity of released charge is proportional to the product of particle mass and velocity as defined by the follow relationship:

$$Q \propto m^a v^b \qquad (2)$$

where Q is the generated charge, m and v are mass and velocity respectively of the impacting particle; a and b are exponents (typically: $0.8<a<1.2$ and $1.8<b<2.6$) that depend on the kind of impact occurred (for example direction of impact or total/partial piercing events). The exact relationship (coefficients and exponents) between charge signal generated from the piezoelectric sensor and particle impact can be derived from suitable calibration procedures.

It is evident that accurate testing and validation analysis of the sensor, including hypervelocity impact tests, is a fundamental work to do before the flight in order to determine the range of particle size that the piezoelectric sensor can detect.

4.3 Piezoelectric sensor: geometry and characteristics

4.3.1 Geometry description

The type of shield sensor is a fundamental aspect of the conceptual design of END/MMOD module, since the signal readout and acquisition depend on its geometry and on the way the piezoelectric sensors are linked on the shield .

In addition, other important factors depend on the sensor geometry, such as the storage of the shield, the system robustness against failures and issues related to the mass budget of the entire system.
The entire sensing structure is composed of individual piezoelectric elements arranged in a bidimensional array and connected to each other in a way to realize a multilayer active structure (matrix) . The active layer is sandwiched between two layers that have a structural role to keep the PVDF tiles together and ensure the protection from the outer environment.

4.3.2 Matrix Structure Design

The matrix arrangement is motivated by considerations on different aspects. From the technological point of view the restrictions imposed by the fabrication process (e.g. the physical deposition of the sensor electrodes) limit the maximum size of the sensing elements, excluding the possibility to have one single sensor covering the entire inflatable shield.

From the electrical point of view, each piezoelectric sensor can be modeled as a capacitor combined with a current pulse generator that models the charge released by the impact. In order to read the signal a charge sensitive amplifier is connected to the sensor.

According to this consideration, the piezoelectric elements are connected to each other by row on one side and by columns on the opposite side. Each row and column connection is then connected to a separate readout circuit. In this way, despite the number of sensors is M x N displaced in M rows and N columns, only M+N read out channels are needed, so reducing the total mass and power consumption of the system.

From the electronic point of view, the proposed arrangement and interconnection scheme ensures the possibility to determine the position of the impact (in case of individual non-simultaneous events).

Whit this kind of connection, when an impact occurs, the charge generated by a piezoelectric sensor produces a signal in the circuits connected to the two channels (row and column) connected to that sensor.

Although the produced charge is shared with the other sensors connected in the same row and in the same column of the pierced capacitor, the signal induced in the neighboring channels is significantly smaller than that of the row and column connected to the pierced element.

It is important to notice that, despite its simplicity and limited number of readout channels, the proposed arrangement also ensures a certain degree of tolerance with respect to damages induced by big impacts. Indeed, if an element of the matrix is completely destroyed or its connections are heavy damaged, only a portion of the row and/or column will be disconnected from the sensor readout. In general the rest of the array will remain fully operative. The matrix arrangement proposed here is beneficial also in terms of system scalability, in the sense that it offers a certain degree of freedom in the design of the complete shield sensor. In particular, for a given total area value imposed by the deorbiting requirements, an optimal configuration in terms of number of sensing elements and their size can be found according to system specifications and constrains such as power consumption, weight or storability.

4.3.3 Single Piezoelectric Sensor Description

The piezoelectric sensor used in the present work is a 28μm-thick PVDF layer with thin film metal electrodes deposited on both faces. This sensor complies with the requirements of a deployable and inflatable structure and also with the other design constraints such as foldability.

4.4 Electronic readout circuits: block scheme

A single readout circuit is designed according to the modular scheme reported in the Fig. 1 and it is repeated for each channel of the module.

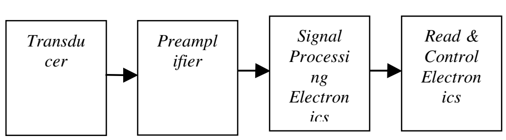

Figure 1: Block scheme of signal acquisition and processing

The firs block is always a preamplifier that converts a charge signal into a voltage signal.

The main specifications of this first stage are a good impedance coupling to the matrix output channel in order to reduce the losses and, as for any pre-amplifying stage, a low noise level.

The downward block, i.e. the signal processing electronics, depends on the type of information that has to be extracted from the charge signal. In the present work, the desired information are a timestamp for the impact, the total number of events and the size of each debris estimated from the amount of released charge.

4.5 ISIDE electronic board

The functions mentioned above have been implemented in an electronic board developed at the School of Aerospace Engineering of the University of Rome "La Sapienza". The board name ISIDE stands for In-Situ Impact Detection Electronics. The board has been designed taking into account both the results of previous satellite missions [8] and the characterization of PVDF sensors in hypervelocity impacts reported in literature. In particular, according to these sources, in case of hypervelocity piercing impacts on 28μm-thick PVDF sensor, a charge packet of about 5 $\mu C/cm^2$ is expected and the time duration of the charge packet can be estimated in the order of 10 ns. The combination of a relatively large charge packet delivered in a relatively short time, makes the design of the readout electronics challenging. This is particularly true if the additional system requirements of low power consumption and compactness are taken into account.

The approach used for ISIDE is that commonly used in pulse processing electronics such as that implemented for single-photon detectors used in high energy physics. ISIDE has been designed with eight identical channels in order to readout signals from a matrix of 4x4 piezoelectric tiles arranged in the way described in previous sections. The microcontroller, is one for the entire board and collects the data from all the channels.

4.5.1 The Charge Sensitive Amplifier

The charge created by the PVDF is collected by this pre-amplifier that acts as an interface between the transducer and the pulse processing electronics that follows. The main function of the amplifier is to extract the signal from the piezoelectric sensor without degrading the information it contains.

The preamplifier is based on an operational amplifier configured as a dumped charge integrator, with the values of the feedback capacitor and discharge resistor optimized according to the expected signal characteristics.

4.5.2 The Rectifier

The main function of this block is to ensure an always-positive signal to be fed in the following pulse processing circuits, thus simplifying their design. Indeed, when a sensor detects an impact, signals of opposite polarity appear on the two sensor electrodes (i.e. on the row and column connections) and both signals have to be processed in order to detect impact position and size.

4.5.3 The Shaper

The shaper has a fundamental role in the analogue processing of the incoming charge signal. Its primary role is to amplify the signal amplitude giving an output pulse with a pre-defined shape of finite duration, thus minimizing the risk o overlap of successive pulses. It also filters both low and high-frequency noise and therefore allows to optimize the resolution of the measurement of charge packet released by the impact.

4.5.4 The Peak Detect&Hold

The amplitude of the shaped pulse is proportional to the input charge and, therefore, to the size of the impacting particle, In order to extract this information a peak detect and hold circuit is used. The role of this block is to follow the shaper-output pulse and maintain the peak amplitude constant in order to allow its measurement by means of an analog-to-digital converter.

4.5.5 The Trigger

The trigger circuit its of fundamental importance in the ISIDE circuit architecture. Its main tasks are:

- to wake up the microcontroller: indeed, since the expected impact rate is quite low, the microcontroller can be put in low-power operational mode to minimize the power consumption;
- to start the analog-to-digital conversion process for collecting the impact data;
- to generate a digital signal that increments the impact counter;

4.5.6 The Microcontroller

One single microcontroller supervises the operation of the entire board and handles the communication with the on-board computer. Thanks to the microcontroller and to the overall ISIDE architecture, the impact detection electronics is a stand-alone system that can be easily integrated in the END-MMOD system.

4.5.7 ISIDE first prototype and test results

A first prototype of the eight-channel ISIDE board has been successfully tested with a 4x4-element sensor matrix. The following figure reports the output signals of the main functional blocks when an impact is detected. In particular, the Fig. 2 shows the output of the dumped charge sensitive preamplifier that integrates the incoming charge packet leading to the negative-going step-like behaviour reported in a). The shaped pulse is reported in b) showing the designed peaking time of 500µs. The output of the constant fraction discriminator is reported in c) and the digital trigger signal (active low) is shown in d).

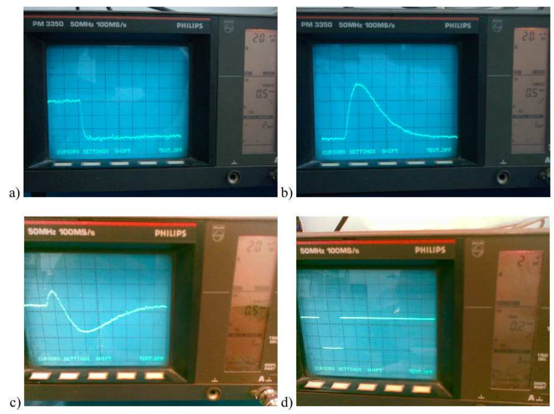

Figure 2: ISIDE otput signals: a) charge sensitive pre-amplifier output, b) CR-RC shaper output, c) constant fraction discriminator output and d) trigger output

4.6 ISIDE electronic limit and solutions

In any case, electronic readout circuits have a limit: saturation due to a large charge signal after a bigger impact.

Despite this problem, ISIDE has been designed to guarantee the impact counting, since the electronic circuits inside it are capable to count the number of impacts and their position on the shield.

Some possible solutions to prevent the saturation or to give another method to obtain information about bigger impacts are under investigation. At the present, three cases studies can be described:

- Obtain the law which the charge is distributed into the entire shield; this is the first step of signal detection and from this depends the correct signal readout. Our design introduce crosstalk that, on one hand, leads to a greater charge handling capability but on the other hand it entails a more complicated way in extrapolating the hole size information by the measured peak voltage. So a good dimensioning of the components and the value of time constants could improve the strength against electronic saturation but it is not sufficient because a precise knowledge of the charge sharing over the matrix which, however, is not easy to compute;

- Use the microcontroller for other measurement such as information about the static capacitance of the single pixel, or using a different sensor system compliant with the END/MMOD module and able to provide those information that the piezoelectric sensors cannot provide.

4.7 Vibro-Acoustic Sensor

In the detection systems for space debris based on PVDF sensors, the limit is given by electronics saturations, so the ability to detect particles having a mass and / or a speed out of the operational limits observed in both the calibration phase of the sensor and during the dimensioning of the electronic part (saturation of the amplifiers as a result of charge higher than detectable).

For this reason, given the peculiarities of the structure of the module END, we try to compensate these limitations through the use of acoustic sensors (quartz or piezoelectric) that should provide information on particles whose sizes are out of the operating limits and on their direction of impact.

For this subsystem it has been followed an approach similar to that one based on acoustic sensors used by missions that are designed to detect micrometeorite or space dust (such as the Stardust Mission), or based on some panels of the International Space Station to detect its structural health.

The data thus obtained may give a series of information which, used together the piezoelectric sensor, would allow to have a more complete view of what all the system goes to detect, especially the high-energy particles which are the mostdangerous for space systems.

In short, we can have with this system:

- Detection of high-energy impacts;
- Improved accuracy on the direction of impact;
- Improved accuracy of size and speed of the particle;
- Possibility to study the spectral characteristics of the pulse train generated as a result of the impact in such a way to understand the propagation of energy and the potential damage that would cause the particle under examination. The signal generated by this system depends both on the mass of the particle and on the impact position and, in any case, consists of a complex sinusoidal eventually decaying to zero.

4.7.1 Preliminary study of an acoustic sub-system

The principal key points of this preliminary design are:

- To know if the work frequency is appropriate for our purposes;
- To give an estimate of the geometric surface that a single sensor can cover and which can give an accurate measure;
- To understand if this type of system is compatible, by a mechanical and structural points of view, with the structure of the module END/MMOD;
- To understand if this type of system is compatible, by a mechanical and structural points of view, with the structure of the module END/MMOD;

Since, until now, we have no practical knowledge on how the shield can behave by a mechanical and acoustical point of view after an hypervelocity impact but we will provide to give an implementation on a possible acoustic sensor system in the END module.

Obviously, a sensor that features an higher frequency range can provide more impact information, and thus ensure higher accuracy.

5 END-MMOD System Budgets

5.1 Link Budget

The END/MMOD communication system design is based, as we said above, on S-band system with a PSK modulation. For this kind of transmission, a method to estimate the performance is the one of evaluating the Bit Error Rate (BER), that is the probability to receive a wrong bit every specific data flow.

According to signal theory, we consider a typical BER of 1E-5 (a wrong bit every 100000 transmitted) with the correspondent SNR (Signal Noise Ratio) of 10 dB (decibels). Referring to BPSK\QPSK curve for theoretic BER the exact point is at 9.6 dB, but in this case we take in consideration the value of 10 dB.

5.2 Memory Data Budget

In this section we preliminary compute the quantity of data both from the detector system, both from the housekeeping system.

5.2.1 Housekeeping Data and Impact Data

In order to compute the amount of data required to provide the information on the impacts and on the status (housekeeping) of the module, we performed dedicated computations with which we obtained:

- Total impacts data: 20 Bytes
- Total housekeeping data: 18 Bytes
- Number of measure per day: 11

Whit this evaluation we can compute the memory size required for the impact data during a 24 hours period:

Bytes per measure × Number of measure = 20×11=220 Bytes.

The number of measure are computed on [RD-1] using specific software (ie Master2005 and Ordem2000) and this data is referred on a statistical evaluation on the expected impacts per day on a specific surface area, in this case the shield area of END/MMOD module (80 m^2).

5.2.2 Sizing Evaluation of Total Data Memory

During 24 hours the total data memorized is:

Housekeeping Data + Impact Data = 18KB + 220B ≈ 19KB →20KB

The data amount is computed on [1] and it's compliant with the preliminary system design.

For a specific circular orbit altitude of 1000 Km and referred to Fucino Space Center, we find that, in the worst case, the satellite is not in view to ground station for about 12 hours (in this case we consider in interval of 24 hours to be conservative) followed by two passes every 1,75 hours. So the maximum offline time is set to:

$$T_{\max} = (24 + 1.75 \times 2) \times 5 \cong 137.5\,hours \qquad (3)$$

Where the factor "5" is an arbitrary safety margin.
Whit this value, it's necessary to have a memory with a size equal to:

$$Data\ size\ @\ 137.5\ hours = \frac{20K}{24} \times 137.5 \cong 115KB \qquad (4)$$

Once completed the link budget, we evaluate a signal rate budget to make an assessment about the time required by ground station to download data. We assume the follow values to compute the download time:

- Impact Signal Frequency: 5 MHz
- Sample Rate: 20 – 30 MHz
- Impact duration: 5 s
- Transmission Type: S-Band
- Download bit rate: 10 Kbit/s
- Download Time Required (worst case): ≈ 15 sec

5.4 Power Budget

The total power consumption of the module subsystem has to be assessed during both the sunlight and the eclipse periods. In this way it is possible to size solar array and battery dimension.

For this analysis we use data referring to the most common device used on micro and nano-satellite with three principal constraints: low power consumption, low mass and volume.

In this way we have estimated a total power required during the sunlight of 59 Watts.
Referring to a precise orbital parameter (the same used for link budget), it's possible to compute the power request during eclipse time for those devices that must be always turn on.

Orbital parameter:

- Altitude: 1000 km
- Max Eclipse time: tE = 35 min ; Max daylight time: tD = 70 min
- Period: 105 min

The following electrical devices are switched off during eclipse time:

- Transitter S-Band
- Receiver S-Band
- S-Band Patch Antenna
- 2_Axis Sensors (4 units)

So the amount of power required during the eclipse time is 21 Watts less than the power required during the sunlight.

The minimum electrical power available from solar panel:

$$P_{SA} = \frac{(P_S)_{NET}}{\eta_S} + \frac{(P_{BC})_{NET}}{\eta_{BC}} = \frac{59}{0.80} + \frac{22.55}{0.70} \cong 106W \qquad (5)$$

where:
η_S is the solar panel to loads average electrical path efficiency;
η_{BC} is the solar panel to battery average electrical path efficiency;

5.5 Battery selection and sizing

As said above, END/MMOD module needs a battery system for electronic devices that must be used during eclipse time. The data here used are referred to a standard battery system for space use.
The minimum electrical energy that is supposed to be absorbed by the battery during the sunlight period has been calculated as about 20 Wh.

Referred to the foollowing typical data for space used battery:

- Technology: NiCd (Nichel-Cadmio);
- DoD (Depth of Discharge): 10-20%;
- SED (Specific Electric Density): 30 Wh/kg;

the sizing of the battery capacity and the corresponding mass evaluation [1] are as follows:

- Battery capacity (Wh): 100 Wh.
- Battery mass: 3.34 kg.
- Minimum Battery Capacity (Ah) whit a 28 V standard discharge bus voltage: 3.7.

5.6 Solar Array Sizing

Now we evaluate the solar array dimension required to give the electrical power necessary for all END/MMOD subsystem.

As we said above, the use of a solar array technology fully integrated in inflatable and deployable structures is a design constraint. Besides, for a correct choice of the solar cell we must take in account ratio between weight and efficiency because we need a device not only flexible but also with a very low mass.

For a preliminary design of the solar arrays the following operational conditions have been into account:

- LEO Average Solar Flux: 1367.0 [W/m²] ([5])
- Solar Cell Conversion Efficiency η_C: 0.18
- Solar Panel Array Inherent Degradation ID: 0.77 ([5])
- Specific Solar Cell Power: 300 (W\kg) (To Be Defined)
- Mean Sunlight Incidence Angle θ_{mean}: 17.7°
- Minimum power required: 106 W.
- Mission life: 10 years.
- Degradation per year DD [1/year]: 0.0375 ([5]).

The value of the Mean Sunlight Incidence Angle θ_{mean}, during sunlight time has been derived for the case of an END/MMOD module having this properties:

- An aero-brake shield semi-vertex angle of 45°;
- Operational Orbit altitude: 1000 km circular;
- Operational Orbit Inclination: 90° (polar);
- RAAN value of 0°;
- Time of the year: vernal equinox (March 21);

With this data, the minimum area necessary to generate the minimum required power is 2.3 m^2.

5.7 Mass Budget

The masses of the END and of the MMOD modules have been assessed as 42 kg and 13 kg respectively. So, that the total mass of the END/MMOD assy turns out to be around 55 kg.

6 END-MMOD Testing Phase

From the mechanical point of view, the main concern is to prove that the structural properties of the shield are retained before the beginning of the END/MMOD mission (pre-launch packaging and storage inside the END case during launch and S/C payload mission) and during the orbital decay phase (i.e. after shield deployment and rigidization). So the most important aspects on which our testing activities must be focused are:

- Physical and mechanical properties in LEO environment.
- Structural properties retaining over a long period of storage.
- Deployment system of the entire module.

A first step along this path has been already carried out by AEROSEKUR (an Italian Company working in strict cooperation with AVIO on this project), that few months ago has succesfully completed, at its own factory plant in Aprilia (Italy), some deployment and inflation ground tests on a preliminary mechanical model of the END aerobraking shield, with the aim of starting to verify the mechanical feasibility of the concept from the operational point of view.

On the other hand, the testing phase of the electronic devices can be divided in two steps:

- The calibration of PVDF sensor, since this is necessary for a correct design and sizing of the detection electronic sub-system.
- The space flight qualification of electronic devices.

From the above considerations and since the prediction of the characteristics of inflatable structures are mainly based on experimental tests and not on mathematical models (very complicated and not very well developed yet), it is clear that a very well planned test activities is essential for the successful implementation of the END/MMOD concept.

7 END-MMOD Critical Aspects

7.1 Mechanical Critical Aspects:

About mechanical critical aspects we can define the follow tasks to be evaluated:

- Assure the reliability of the entire module after a long period of storage;
- Design and size the integration the END/MMOD sub-systems to be compliance with a deployable and inflatable structure;
- Selection a specific material and technology that can ensure a sufficient stiffness of the vessel after its deploy;
- Evaluate the aero-thermal loads of the entire structure in LEO environment to prevent the rapid degradation of the structure.

7.2 Electrical and Electronic Critical Aspects:

About Electrical and electronic critical aspects we take in consideration:

- Electronics circuits and devices must have low mass and volume to not interfere with the spacecraft;
- Determinate the range and magnitude of impact signal and also its correct processing method.
- Provide to know the strength of the electronic sub-system to know what happen after a long period of storage;
- Verify the electromagnetic compatibility with launch vehicle and spacecraft;

8 Conclusions

The combination of the END (End-of-life Natural Deorbiting) inflatable aerobreaking device, already under development in AVIO, with a sub-system called MMOD (Micro-Meteoroids and Orbital Debris), would result in a synergic module capable of both accelerating the orbital decay of an inoperative spacecraft and, at the same time, collecting data relevant to the type and distribution of space debris and micro-meteoroids in the LEO region by means of hypervelocity impacts detectors.

So, while the END enhanced aerobraking effect would allow the compliance with the 25 years orbital decay lifetime constraint relevant to dismissed spacecraft, on the other hand the MMOD module would acquire data on the flux of micro-particles (natural and artificial) potentially dangerous for spacecraft in Low Earth Orbit (LEO) through piezoelectric and vibro-acoustic sensors fully integrated into the END shield, and independent from the other S/C subsystems, including the power supply.

The entire system (END/MMOD) would be activated after the end of the spacecraft operational life, when the END shield would be deployed and inflated, detecting and recording data about micro particles impacts during the spacecraft orbital decay phase.

The impact data (kinetic energy, time of impact, size and trajectory, etc.) would be processed and stored on a dedicated on-board memory space, in order to be subsequently sent to the ground stations by means of a specific transmission unit.

Deployment and inflation ground tests on a preliminary model of the END aerobraking shield has been already carried out by the AEROSEKUR Company, in order to start the verification of the mechanical feasibility of the concept from the operational standpoint.

On the other hand, the School of Aerospace Engineering of the University of Rome "La Sapienza" has developed an electronic board called ISIDE (In-Situ Impact Detection Electronics), whose first eight-channel prototype has been successfully tested with a 4x4-element sensor matrix.

Cooperation among AVIO, AEROSEKUR and the University of Rome "La Sapienza" is supposed to go on with further ground tests and technological studies, for both the END and the MMOD modules, in order to find out the optimal compromise among performance, reliability and costs of the different components as well as the overall system configuration.

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