MEDET IN-FLIGHT EXPERIMENT (MATERIALS EXPOSURE AND DEGRADATION EXPERIMENT) DESCRIPTION AND FIRST RESULTS

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1. Introduction

MEDET is a material experiment on board EuTEF/Columbus. It is a fruitful collaboration between ONERA, ESA, CNES and the University of Southampton. It combines seven sub-experiments devoted to the combined measure of the radiative space environment in low earth orbit and its associated effects on materials. It allows for real time characterization of the local ISS environment (radiation and contamination) and for the evaluation of material degradation such as thermal coatings, polymers for inflatable structures....
The mission is planned to start on February 2007 (Atlantis launch) and to last 1.5 years before the equipment return for post-flight investigation.

2. Objectives

The three main MEDET scientific objectives are:
a) Evaluate the effect of the complex space environment on the optical and thermo-optical properties of materials to be considered for utilisation on LEO spacecraft. This includes the active measurement of thermo-optical properties (and more exactly, their variation as a function of space exposure) for a number of proposed spacecraft materials. Among these materials are anodizations, second surface mirrors (SSM) and new thermal paints externally used onboard the Space Station and LEO satellites.
b) Assessment of the effects of the ISS environment on optical windows. Special emphasis will be placed upon the part of degradation that is due to molecular contamination. Contamination results from various sources, including outgassing and degradation of materials, manoeuvres of service vehicles, re-boost operations, firings of attitude control systems, dumps and EVA.
c) Investigation of micro-particle and debris fluxes (especially their variation as a function of time) and, after retrieval, the origin of the debris and the detectors' behaviour.

In support of the above objectives, the local environment will have to be characterised in terms of local pressure, contamination rate, Atomic Oxygen (AO), X rays and UV flux.

The experiment results are expected to give essential information to the spacecraft designer on:
- the mechanisms of space damage, discriminating between the effects of the individual components of the spacecraft environment, and detecting also possible synergistic effects,
- the long-term characteristics of these materials with the aim to indicate if they are appropriate for use in future space station applications or other missions,
- the validity of laboratory simulation results from comparison to the space data, laboratory simulation being considered as imperative for prediction of materials degradation in space.

3. Description

A schematic view of MEDET is given in figure 1 and a summary description of the experiments and systems in the flight segment is given in table 1. More detailed descriptions and diagrams are given in the following sections.

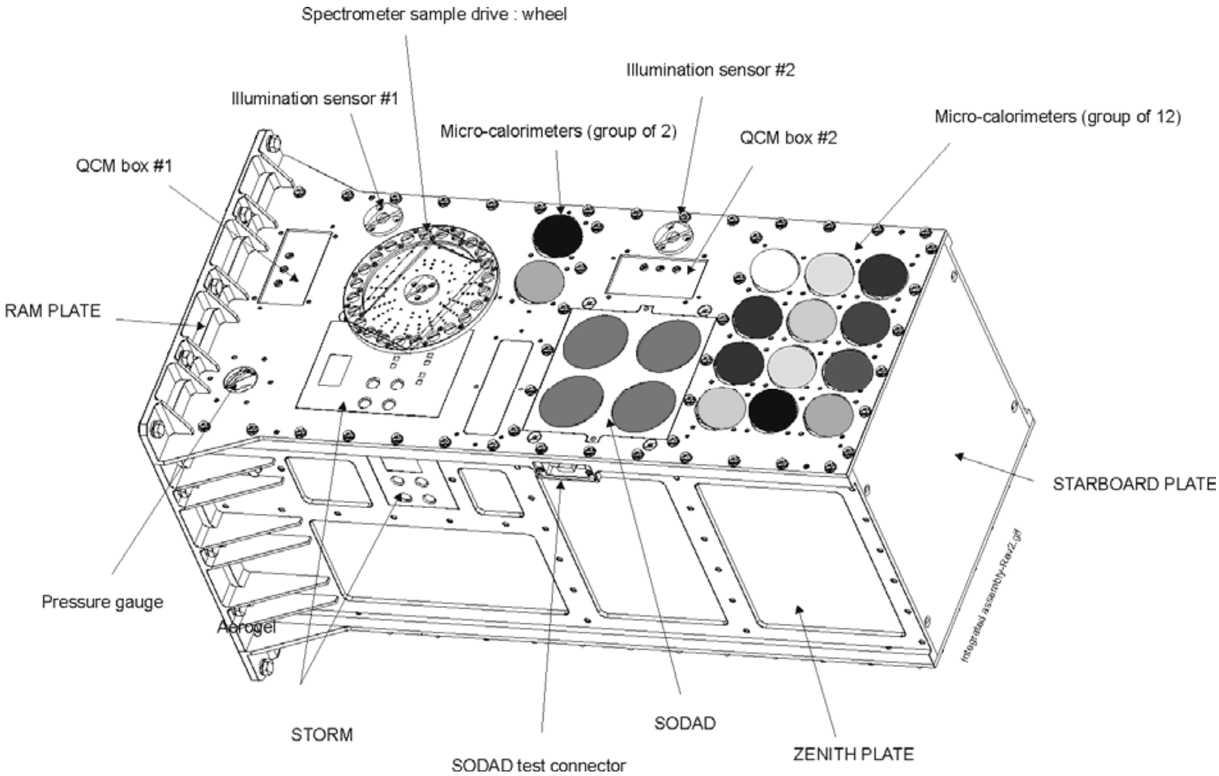

figure 1 : Schematics of MEDET experiment

Experiments	
SODAD	An active MOS type impact detector, to characterise the properties of micro meteoroids and orbital debris particles
Spectrometer	An active spectrometer system, to measure changes in the optical properties of transparent window materials.
QCM	A collection of active quartz crystal microbalances, to measure the atomic oxygen and contamination flux
Pressure Gauge	An active cold cathode type gauge, to measure the local pressure
AEROGEL	A passive detector, to capture micro meteoroid and orbital debris particles
MicroCalorimeters	A collection of active microcalorimeters, to measure the changes in the thermo-optical properties of thermal control coatings.
Southampton Experiments (STORM)	A collection of active detectors to measure the atomic oxygen, UV and X-ray flux

Sub-Systems	
Mechanical support structure	An aluminium box-type structure to provide the physical support for the sub-experiments and other sub-systems, and to attach MEDET to EuTEF.
Data Acquisition and power control unit (DAPC)	A central logic unit (LU), power supply (PDU) and associated electronics to control the operation of the sub-systems, store and transfer the data from the sub-systems to EuTEF and receive commands from the ground.
Thermal control and monitoring system	Used to keep the experiments and sub-systems within the specified temperature limits. Consists of radiators, multi layer insulation (MLI), thermal washers, temperature sensors, heaters and thermostats

Table 1 : Summary description of the MEDET sub-experiments and sub-system

3.1 SODAD

SODAD (Système Orbital de Détection Active de Débris) will be used to actively measure the micro meteoroid and debris flux in the vicinity of the ISS.

The detector works on the principle of monitoring the discharge of a parallel-plate capacitor containing a thin dielectric. The top electrode is made very thin and this surface is exposed to the impacting particles. The device is operated with an electrical potential (bias) applied across the capacitor plates : a charge is normally stored in the capacitor. When a high velocity particle impacts the exposed plate with enough energy, it can cause the dielectric to breakdown and results in a discharge of the capacitor.

The event is measured by monitoring the charge required to recharge the capacitor. After discharge the sensor is recharged to the nominal value within a short time. Evaporation of the electrode around the impact site usually prevents the occurrence of a permanent short. The sensitivity of the sensor depends mainly on the dielectric thickness, the top electrode material and thickness, the bias voltage, and also on the velocity of impacting particle. The device is best suited to the detection of particles with diameter ranging from 0.5 µm to 100 µm.

The electronics consists of a voltage doubler (providing the bias for the detector) and the circuits necessary for the detection of the discharge events and the monitoring of the detector status. The detection threshold is set at 95 % of the bias voltage. In the event of permanent short of the sensor, the measurement is automatically stopped if the leakage current is higher than 1100 µA. Standard mounting plates (120 x 120 x 50 mm) accommodate 4 sensors with integrated electronics. Each sensor is divided into two independent parts in order to increase the detection rate.

3.2 SPECTROMETER

The spectrometer experiment is being developed specifically for the MEDET project.

It will be used to follow the degradation with time of several types of optical windows (including synthetic ultra-pure SiO2 and other radiation stable materials). The optical spectral transmission of the samples will be measured by a system involving quartz optical fibres, two miniature spectrometer modules (to cover the solar spectrum from 200 to 1000 nm) and two illumination sensors.

The materials to be tested are placed on a rotating wheel, containing 24 apertures. A stepper motor is used to position each sample above the optical fibre entrance. The sun is used as the light source, so that measurements are allowed only when the sun is detected by the illumination sensor in a ± 40° acceptance angle. Only relative measurements are performed, comparing the spectra of the sunlight direct with the spectra of the sunlight observed through the tested materials. An encoder system, consisting of photodiodes positioned under the wheel, is used to identify the location of the wheel with respect to the fibre optic at any given instant (see Figure 2).

The miniature spectrometer modules consist of a grating, optics and CCD detector. These are all rigidly housed within the same case. The module is based on a standard laboratory device (Zeiss MMS), has been adapted for space flight use. However, in order to be operated safely on MEDET, which is an external payload, the miniature spectrometer modules are mounted in a pressurised cylinder. For redundancy, 2 sets of pressurised cylinders (with 2 spectrometers in each) are mounted behind the filter wheel .

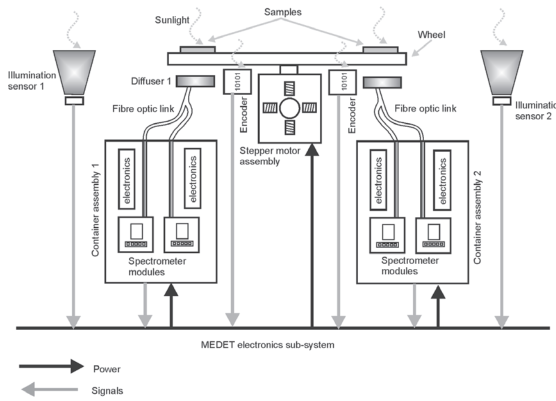

Figure 2 : Spectrometer experiment interface schematic

3.3 QCM

The Quartz Crystal Microbalance (QCM) experiment will be used to measure contamination levels and the atomic oxygen flux in the vicinity of the Space Station. The sensors are modified versions of commercially available miniature crystal oscillator packages. The package consists of a quartz crystal and an oscillator circuit contained within a metal housing. The quartz crystal is exposed to the space environment through a round hole in the housing directly above the crystal, and the oscillation frequency changes in relation to the changing mass and temperature of the crystal. The oscillator circuit provides an alternating voltage output.

To measure the contamination flux, a bare crystal is used, and the oscillation frequency decreases as contamination is deposited on the surface of the crystal and the mass of the crystal increases. To measure the atomic oxygen flux, a carbon coated crystal is used, and the oscillation frequency increases as the atomic oxygen erodes away the carbon layer and the mass of the crystal decreases. For both of these techniques, the relationship between the mass of the crystal and the oscillation frequency can depend on the temperature of the crystal. Therefore, a separate non coated crystal cut in the "Y-direction" is also used to independently monitor the crystal temperature, so that the mass data can be corrected for temperature dependent effects.

Three types of sensor will be flown on board MEDET :

- Type 1 : 10 MHz Crystal with Au electrode for contamination deposition measurements. The sensitivity is $4.4x10^{-9}gcm^{-2}Hz^{-1}$.

- Type 2 : 10 MHz Crystal with C-coating, to measure Atomic Oxygen. The sensitivity is $2.46x10^{15}$ O-atoms cm^{-2} Hz^{-1}.

- Type 3 : 11 MHz Crystal with Au electrode, for temperature measurements. The sensitivity is 600 Hz/K. The output of this type of crystal will be used to correct for temperature variations in Type 1 and Type 2.

The response of each type of crystal is only linear within a limited frequency range. If a sudden large contamination deposit were to occur, perhaps due to a thruster firing in the local vicinity of MEDET, then the experiment would no longer be operable. Therefore, a heater and thermostat will also be placed directly underneath each crystal oscillator package, so that an attempt could be made to de-contaminate and regenerate the sensors by evaporating off the excess deposits (Figure 3 and Figure 4)

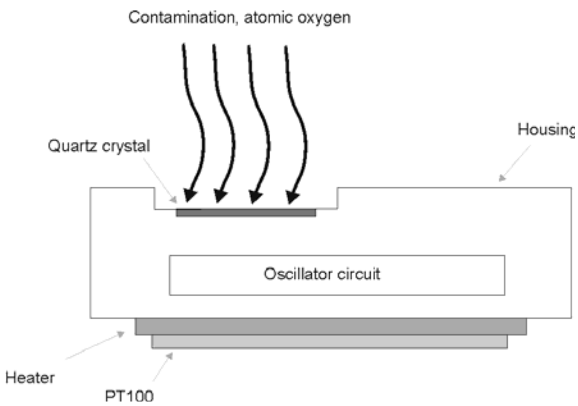

Figure 3 : QCM sensor in operational mode

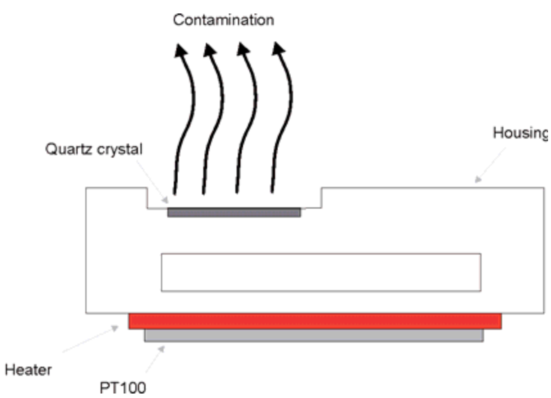

Figure 4 : QCM sensor in regenerate mode

3.4 Pressure Gauge

This sub-experiment will be used to actively measure changes in the concentration of gaseous products in the local vicinity of the Space Station. Gaseous products could be produced as a result of transient events such as extra vehicular activities, spacecraft docking and waste dumps, as well as general outgassing and degradation of materials. It may be possible to correlate the pressure data with the contamination experiments on board MEDET, and the data will also be made available to other instruments on board EuTEF.

The experiment consists of a standard commercially available cold-cathode type pressure gauge, which has been adapted and qualified for space use. The operation of the cold-cathode pressure gauge is based on the ionisation of the residual gas molecules in the vacuum by electrons emitted from a cold cathode. The ions are collected and the measured current can be correlated with the pressure. The probability of an electron hitting a gas molecule can be increased by trapping the electrons in a electromagnetic field of the correct geometry. This has the effect of increasing the sensitivity of the device

3.5 AEROGEL

The aim of the aerogel experiment is to capture, in an intact state, residue from micro-particles so that they can be returned to earth for chemical and physical analysis. This will provide information about the origin of the particles i.e. whether they are natural micro-meteoroids or orbital debris. Such information cannot be derived from the present generation of active detectors. The experiment is passive in nature and consists of a block of Silica aerogel exposed directly to the space environment. Silica aerogel is made up of amorphous grains of SiO_2, with diameters of 4 – 10nm. It is a transparent, highly porous material, with ultra low density (ranging from 0.05 to 0.15 gcm^{-3}). On colliding with silica aerogel, particles travelling at orbital impact velocities can be slowed down in the material without completely vaporising, leaving solid residue at the bottom of the track. On return to earth, the residue can be analysed using a sectioning technique. The porous aerogel is filled with an epoxy and cured, after which it can be sectioned along the length of the particle tracks to reveal the residue. The length and shape of the track can also give some information about the original collision velocity and direction of the particle.Aerogel has been used before in space applications, such as on the Stardust comet mission and various Space Shuttle science experiments.

3.6 Microcalorimeters

This sub-experiment will be used to actively measure the changes in the thermo-optical properties of spacecraft materials and coatings. The experiment consists of an array of space qualified micro-calorimeters mounted on the ram face of MEDET. The calorimeter technique is based on a comparison between the temperature of a thermally insulated sample and the temperature of a black-body reference sample. Using a heat balance equation, the total emissivity and solar absorptance of the sample can be deduced.

The calorimeters which will be used on MEDET are based on a standard design which has been flown on many previous missions. The samples are attached to an insulated thin plate using adhesive, painting or another form of bonding. The sample plate is held within a guard ring which has the same area and is coated with the same material as the sample. This minimises heat losses from the sample plate to the surrounding casing of the calorimeter. In addition, the sample plate and guard ring rest on thin Kapton cylinders, and layers of MLI are placed between the guard ring and the casing. The temperature of the sample is measured using a resistance thermometer mounted on the rear side of the sample plate (see Figure 6)

The black body reference calorimeter is of the same dimensions and basic construction as the standard calorimeters. However, the sample plate is covered by an array of thin edged blades packed tightly together, and the guard ring is painted with a black silicate based paint, to give the surface of the calorimeter an α/ε ratio close to 1.

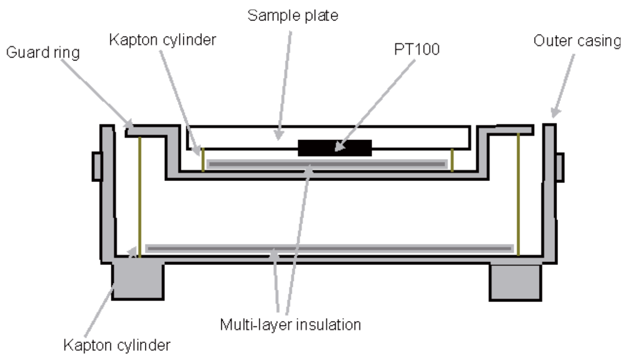

Figure 6 Micro-calorimeter schematic

3.7 STORM

The Southampton University Transient Oxygen and Radiation Monitor (STORM) consists of a package of sensors which will be used to measure Atomic Oxygen, UV and X-ray fluxes. STORM is being developed specifically for the MEDET experiment.

- AO sensors

Two AO sensor types are incorporated into STORM, based on carbon film actinometers and thin-film zinc oxide (ZnO) detectors. Both are located on the ram-face of MEDET in an area close to the rotating spectrometer wheel. The carbon actinometer instrument comprises four thin carbon films and an AD590 temperature sensor, all mounted on an alumina substrate. Incorporated onto the substrate is a low power heater element that will be used to stabilise the film temperature since carbon exhibits a temperature dependent erosion rate.

Zinc oxide is an n-type semiconductor material that is sensitive to adsorbed atomic oxygen. Analysis of the non-steady response indicates that the initial rate of decrease of the conductivity of a fresh ZnO film exposed to atomic oxygen is proportional to the incident AO flux. However, after a relatively short exposure to AO the sensor becomes saturated and its response ceases. Nevertheless, the sensor offers the great advantage that, by heating to modest temperatures, the sensor can be refreshed (or "regenerated") and is then able to take further AO measurements. The ZnO sensor comprises four thin films, two of which will be shielded from AO attack by a thin overcoat of silicon monoxide (silica).

The carbon actinometer elements are fully exposed on the ram face, whereas the ZnO film array are partially covered by the spectrometer wheel. One sensor is permanently shadowed from direct exposure to AO by the wheel, whilst another is periodically covered/uncovered by the wheel. The other two sensors are fully exposed on the ram face. ZnO sensor regeneration will take place whilst the wheel covers two of the four sensors.

- X ray sensors

Four x-ray sensors are mounted on STORM. Two are located on the zenith face of MEDET and two placed on the ram face with one active and one redundant active sensor on each of the faces. The x-ray sensors consist of silicon PIN diodes. A beryllium window is placed over the diodes to filter out the signal from lower energy photons. X-ray fluxes will be measured continuously, but the most important data will be gathered during Solar x-ray flare events when the x-ray flux is at its highest and most damaging levels.

- UV sensors

Eight UV sensors are mounted on STORM, four on the MEDET ram face and four on the zenith. The UV sensors consist of solar-visible blind aluminium gallium nitride photodetectors. These detectors are sensitive to an UV light range from 120nm to 285nm, and this lower limit of the wavelength range is important to be able to detect the Lyman-alpha hydrogen line half the sensors (two on each face) are fitted with sapphire windows to cut out the UV spectrum below approximately 130nm.

4. Perspectives

At the time this paper is written, only MEDET commissioning was performed and the experiment has been working for only 3 days. The first sets of data are being acquired and will be analysed soon. The total duration of the mission is expected to be of 18 months.