IN-ORBIT MEASUREMENT OF THE COLUMBUS LAB VACUUM ENVIRONMENT USING THE MEDET PRESSURE GAUGE

Adrian P.Tighe(1), Boris Iwanovsky(1), Marc van Eesbeek(1), Sophie Duzellier(2)

(1) *Materials Space Evaluation and Radiation Effects Section, ESA ESTEC, Keplerlaan 1 2200 AG Noordwijk, The Netherlands, E-mail : Adrian.Tighe@esa.int, Phone N°: (31) 71 565 4190*
(2) *ONERA/DESP, 2 Av. E. Belin 31055 Toulouse Cedex 4, France*

ABSTRACT

For the duration of the MEDET in-orbit mission from February 2008 - September 2009, the pressure gauge experiment has returned a wealth of high quality flight data, continuously monitoring the external vacuum environment with a frequency of 1 reading every 5 seconds. This is the first direct measurement of the pressure on the outside of the Columbus Laboratory. The data is supplemented with measurements from the MEDET temperature sensors, and other detectors (e.g. quartz crystal microbalances, atomic oxygen sensors). In this paper, we will describe the pressure gauge flight hardware and its qualification, before presenting a summary of the in-orbit pressure measurements to date, and a detailed analysis of some of the observed phenomena.

1 INTRODUCTION

The pressure gauge is one of the environmental monitoring instruments on the ram face of MEDET [1] which has operated throughout the 18 month mission. It has continuously monitored the external vacuum environment of ESA's Columbus Laboratory (Fig. 1, Fig. 2) with a frequency of 1 reading every 5 seconds. The data is supplemented with measurements from the MEDET temperature sensors and the illumination sensors. In this paper we describe the design, calibration and test of the hardware and we present a summary of the flight data up to July 2009, highlighting some of the key results to date.

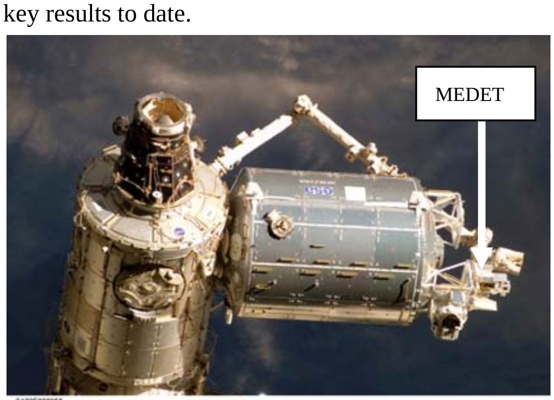

Fig. 1 MEDET in orbit on the outside of the Columbus Module (Photo Credit : NASA)

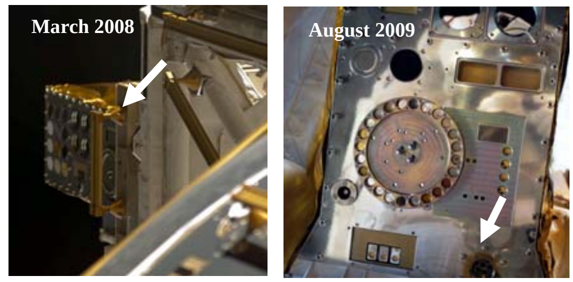

Fig. 2 Pressure gauge location on MEDET (Photo Credits : NASA)

2 DESIGN

The gauge is a cold cathode type, which works on the principle that a discharge current in a transverse magnetic field is dependent on the pressure of the gas. It is based on a commercial device (Pfeiffer Vacuum IKR 251) which was adapted for space use (Fig. 3). The plastic components (case and PCB supports) were replaced with metallic ones, some redundant components were removed (e.g. warning LEDs), and a conformal coating was applied over the internal electronics. In addition, a thermal tape was wrapped around the outside of the gauge for improved heat dissipation (Fig. 4). The operating range of the gauge is about 10^{-3} mbar to 5×10^{-10} mbar.

Fig. 3 As-bought" cold cathode pressure gauge, showing the original casing and magnet

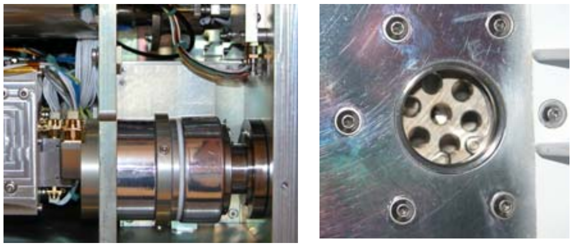

Fig. 4 Modified pressure gauge mounted on MEDET, showing external casing covered with thermal tape (left) and the cold cathode and grid exposed on the ram face (right)

3 CALIBRATION

The pressure gauge returns a 0-10V signal, and this was converted into an equivalent N_2 pressure in mbar using the manufacturer's calibration equation :

$$P = 10^{U-10.5}, \text{ where } U = \text{voltage (V)}.$$

The calibration is similar for O_2 and CO_2. However, we have used the gauge as a total pressure sensor only and the effect of gas composition has not been taken into account.

4 TEST

A series of functional tests under vacuum were performed at instrument level before the gauge was integrated onto MEDET, and flight qualification of the gauge was achieved during the MEDET system level tests (TB/TV, EMC, vibration). The TB/TV tests were used to assess the response of the gauge to temperature, and to validate its performance against another calibrated gauge attached to the thermal vacuum chamber. Over the temperature range -20^{O}C to +50^{O}C, the measurements from the two gauges differed by about 30% – 40%, which is within the measurement accuracy quoted by the manufacturer for this type of gauge (Fig. 5). No systematic influence of temperature on the gauge output voltage was observed. The gauge was not operated during any of the other ground based tests at atmospheric pressure, to avoid contamination of the cold cathode. After return to earth at the end of the mission, further functional testing will be performed to re-check the calibration, and the cold cathode will be inspected for signs of contamination.

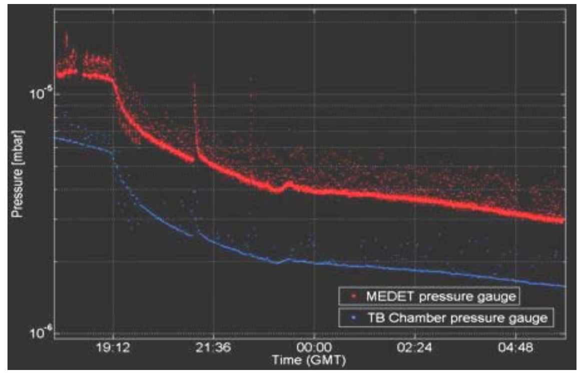

Fig. 5 Pressure measurements acquired during MEDET TB/TV tests

5 FLIGHT RESULTS

For the majority of the time, the pressure gauge was in the nominal ram direction, and it can be seen that the average pressure was around 5 x 10^{-6} to 10^{-7} mbar (Fig. 6). This is at least an order of magnitude greater than the ambient pressure of the neutral atmosphere for the Space Station orbit [2, 3] (as predicted by standard models such as the MSISE-90). This result can be explained by a ram pressure effect which has been observed previously [3]. Other significant features which are highlighted in the following figures (Fig. 7 - Fig. 13) are a diurnal variation in the pressure, thought to be related to solar heating effects [2,3], a ram-wake effect due to re-orientation of the Station, and "pressure spikes" observed during Shuttle water dumps.

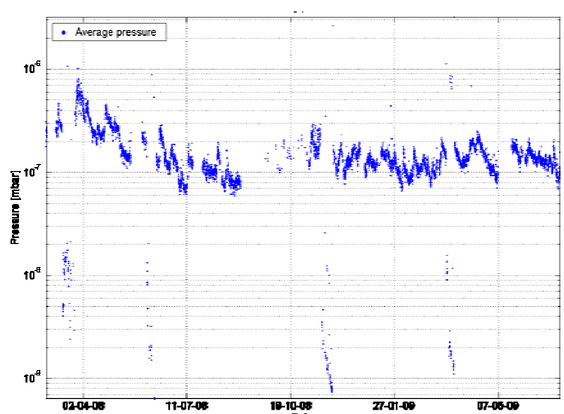

Fig. 6 Average pressure per orbit for the mission

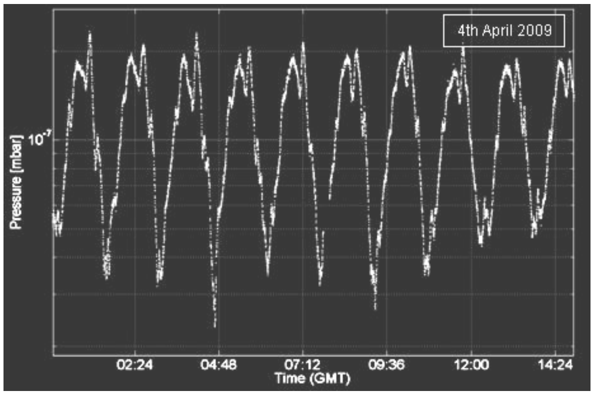

Fig. 7 Diurnal pressure variation observed throughout the mission, with a primary period equal to the ISS orbital period. This is consistent with solar heating effects [3]

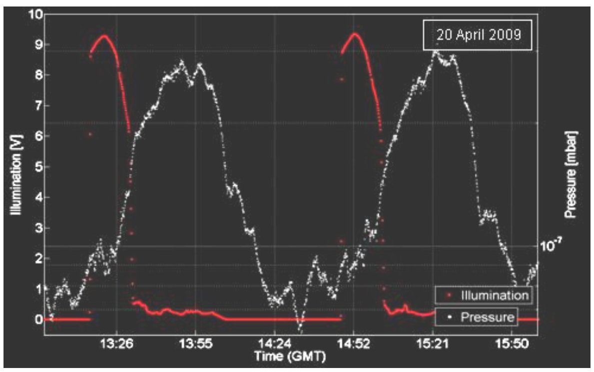

Fig. 8 By superimposing data from one of the MEDET Illumination Sensors on the pressure data, the diurnal pressure variation can be correlated with the solar illumination

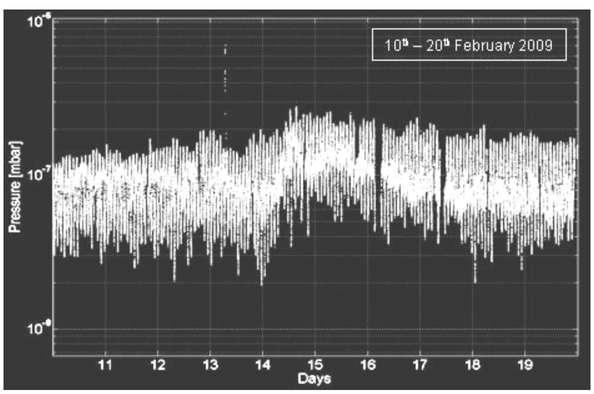

Fig. 9 Longer term variations in the pressure can also be observed, which are superimposed on the diurnal variation.

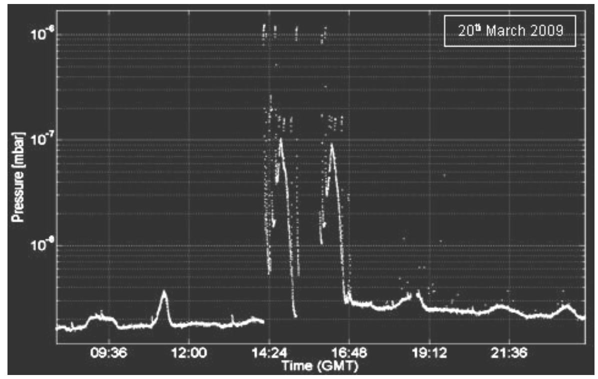

Fig. 10 Pressure variation due to reorientation of the Station by 90^{O} (from –XVV to +YPH) for solar array deployment during visit of Space Shuttle STS-119 in March 2009

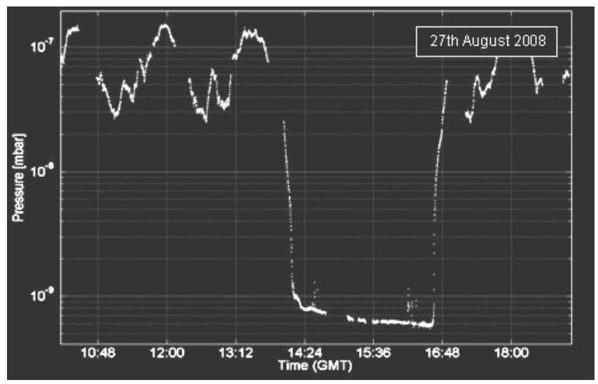

Fig. 11 Ram-wake effect due to reorientation of the Station by 180^{O} (from +XVV to –XVV) during ATV debris avoidance manoeuvre on 27th August 2008. The wake pressure is some 2-3 orders of magnitude less than the ram. The flat portion at the bottom of the graphs is due to the detection limit of the gauge

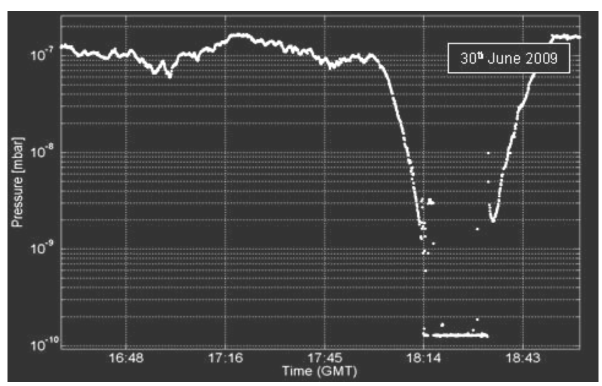

Fig. 12 Ram-wake effect due to reorientation of the Station by 180^{O} (from +XVV to –XVV) during Progress 33P undocking on 30th June 2009.

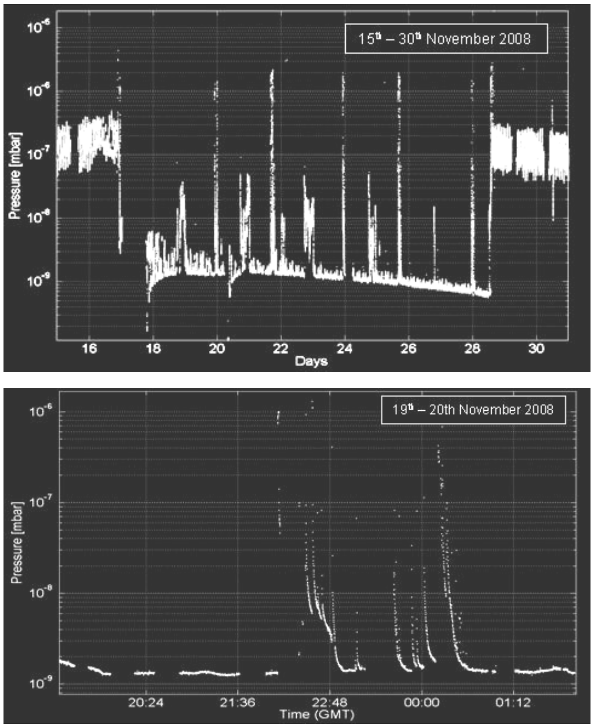

Fig. 13 Pressure variations observed during the visit of Space Shuttle STS-126 to the Station in November 2008. The ram-wake effect can be seen during the docking and undocking (above) and some of the pressure spikes coincide with the occurrence of the Shuttle water dumps (below).

6 CONCLUSIONS

The MEDET pressure gauge has operated successfully over the course of the mission, and it has provided a unique record of the pressure variations in the vicinity of the Columbus module. The measurements made in the ram direction show a pressure higher than that predicted from atmospheric models, and this is consistent with a ram pressure effect reported previously. Another key feature which has been observed is a diurnal pressure variation, which could be attributed to solar heating effects. It has also been shown that Space Station orbital manoeuvres have a significant influence on the measured pressure. In particular, a pressure difference of about 2-3 orders of magnitude has been seen between the ram and the wake.

7 ACKNOWLDEGMENTS

MEDET is one of the experiments on EuTEF, and it is a collaboration between CNES (Fr), ESA (NL), ONERA (Fr) and the University of Southampton (UK), The Principal Investigator is Sophie Duzellier (ONERA). The authors would like to acknowledge the support of the engineers in the TEC directorate at ESA ESTEC who helped to develop the pressure gauge experiment, including Jason Page, Bruno Sarti, Francesco Ratti, Roel Westera and Gianluca Gargiulo (formerly 3CSpace). We also thank the EuTEF team in ESA and industry, together with the NASA STS/ISS flight operations community and the flight crews for making the flight opportunity possible.

8 REFERENCES

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