国際宇宙ステーションにおけるダスト捕獲実験(MPAC)

PASSIVE MEASUREMENT OF DUST PARTICLES ON THE ISS (MPAC)

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Abstract

The Micro-Particles Capturer (MPAC) is a passive experiment designed to evaluate the micrometeoroid and space debris environment, and to capture particle residues for later chemical analysis. It is mounted on a frame about 1 m long, which it shares with the Space Environment Exposure Device (SEED), a materials exposure experiment. In this paper we focus on (1) Visual inspection of the whole surface of MPAC&SEED, and (2) Impact feature morphology and track analysis in the MPAC silica aerogel.

1. Introduction

It is important to investigate μm - mm sized micrometeoroids and space debris in the nearby space environment. This range of debris size includes the majority of primary impactors on spacecraft, and also of secondary debris formed by collisions. The distribution and composition of small-sized debris are not well known, as these particles are too small to be observed with ground-based telescopes or radar. *In-situ* sampling of dust particles is useful to obtain information regarding the composition and source of the debris.

MPAC is a passive experiment designed to evaluate the micrometeoroid and space debris environment, and to capture particle residues for later chemical analysis. MPAC experiments are not only useful for evaluation of the dust (meteoroids & debris) environment in the orbit of the International Space Station (ISS), but also useful in estimating the effects of dust collisions on the ISS and of its own emission of debris.

2. Description of MPAC&SEED Experiment

The Micro-Particles Capturer (MPAC) is a particle-capture experiment consisting of three identical units (numbered #1 to #3), each containing silica aerogel [hereafter aerogel], polyimide foam and an aluminum witness plate, and deployed on the exterior of the Russian Service Module (SM) of the ISS. A more detailed description of this experiment, together with impact flux and chemical data for impactor residues is given by Neish *et al.*, [1] and Kitazawa *et al.*, [2]. MPAC is mounted on a frame about 1 m long, which it shares with the Space Environment Exposure Device (SEED), a materials exposure experiment (Figure 1).

Three SM/MPAC&SEED units were launched aboard Progress M-45 on 21 August 2001, and attached side-by-side on a fixture mechanism attached to a handrail outside the SM via extravehicular activity (EVA) on 15 October (Figure 2). The first unit (hereafter SM1/MPAC&SEED, or SM1/MPAC if referring only to the particle capture segment) was retrieved via EVA after 315 days' exposure, and brought back to Earth on board Soyuz TM-34. Then SM/2MPAC&SEED was retrieved after 865 days' exposure and SM3/MPAC&SEED was retrieved after 1403 days' exposure.). All SM/MPAC&SEED units were retrieved safely. Details of the SM/MPAC&SEED experiment plan are reviewed in Neish *et al.*, [3] and Kitazawa *et al.*, [4].

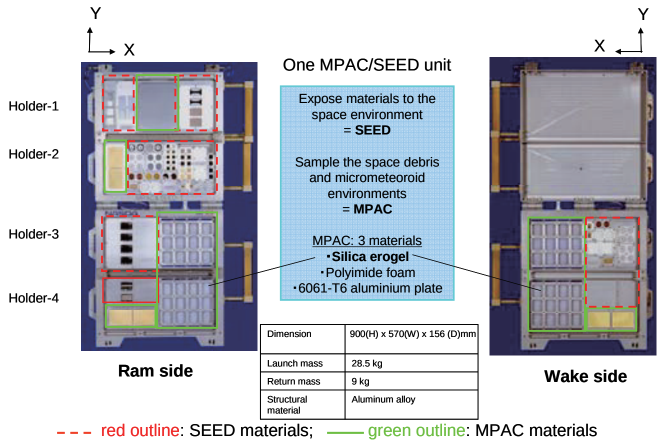

Fig. 1 Configuration of SM/MPAC & SEED.

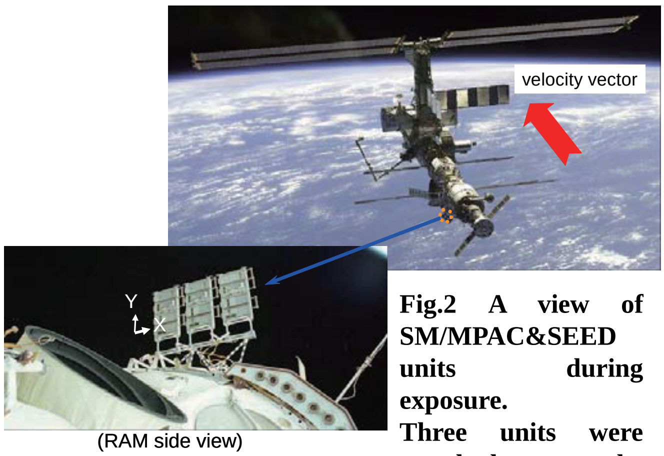

Fig.2 A view of SM/MPAC&SEED units during exposure. Three units were attached on the

3. Inspection Procedure

3.1 Visual Inspection of the entire surface of SM/MPAC&SEED

Visual inspection of the entire surface of SM/MPAC&SEED and creation of basic data sets for curation were carried out according to the following procedures: 1) Each surface of the SM/MPAC&SEED

structure (includes MPAC's samples and SEED's environment monitor samples) was scanned with the aid of an 8x optical scope. 2) When an impact-like feature was detected, the ID of the impacted part and the X and Y coordinates of the impact were recorded. 3) Dimensions of the feature were measured, and photographs and/or sketches were made of the feature with the aid of a 50-175x CCD optical scope. 4) A morphological assessment of the feature was made (impact-induced or not).

3.2 Silica Aerogel Inspection

After removal of all aerogel tiles from the frame, silica aerogel tiles (exposed area: 37mm x 37mm per tile) were inspected as follows: 1) Each tile was scanned individually with the aid of a 150x CCD optical scope. 2) When an impact feature (T/D_{ent}>1 and D_{ent}>100µm, T: Track length, D_{ent}: Diameter of the track on the aerogel surface) was located, its X and Y coordinates were recorded and photographs and/or sketches of the feature were made. 3) Track length, inclination angle to the surface and other morphological parameters of the track were measured, and particle remnants were searched for. When typical tracks were found, aerogels were sliced with a microtome into thin, small pieces of between 1 and 3 mm thickness and the following procedures were performed. 4) Optical microscope images and SEM images of selected typical tracks were obtained. 5) EDS, X-ray diffraction and Raman spectroscopic analyses were carried out to determine the chemical composition of residues left in the tracks.

4. Inspection results

4.1 Entire Surface of SM/MPAC&SEED

Visual inspection of SM/MPAC&SEED was conducted on all sample holders. Data sets of impact features were compiled for curation. Morphological judgment placed the feature in one of three categories. Class I (the first quality level): hypervelocity impact-induced features which meet all of three criteria (<1> the feature has a crater-like rim and/or central peak, <2> the feature has radial cracks and/or ejecta, <3> the feature has a shape similar to those induced by hypervelocity impact experiments.). Class II (the second quality level): probably hypervelocity impact-induced features which meet one or two of the criteria. Class III: not hypervelocity impact-induced features.

The number of impact-induced features was almost directly related to the exposure period (Figure 3). The impact rate was almost constant, with the sum of Class I and Class II events about 15 impacts per year. Detailed analyses of impact features and residues will be performed.

4.2 Silica Aerogel Inspection

The inspection of silica aerogels from SM1/MPAC and SM2/MPAC has been completed, but the inspection of SM3/MPAC is still underway. Here we present the findings on SM1/MPAC and SM2/MPAC aerogels. Inspection data and discussion of dust impacts on the 6061-T6 Al plate and polyimide foams are reviewed in Neish, *et al*.[1] and Neish, *et al*.[3].

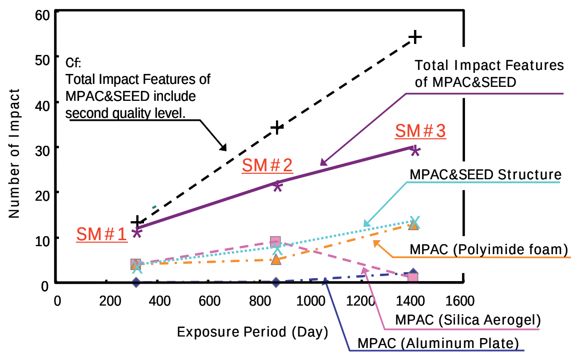

Fig.3 Number of impact features of the first quality level (Class I) on SM/MPAC&SEED versus exposure period.

4.2.1 Surface alterations of silica aerogel

Figure 4 shows surfaces of retrieved aerogels.

The aerogel surfaces on the WAKE side are yellowish and have countless fine cracks. SM2/MPAC displays more pronounced yellow discoloration and more fine cracks than SM1/MPAC. The appearance of the surface of the aerogel near the cracks is similar to that produced by the deposition of metal vapor with a thickness on the order of one µm. In contrast, the RAM sides became whitened and a maximum of about seventy very minute tracks (D_{ent} <20µm, and T<300µm) per aerogel were detected in SM1/MPAC. Moreover, in SM2, about a thousand foreign bodies were found in each aerogel (milk-white ellipses, average diameter about 100 µm) instead of minute tracks. Similar shapes are produced when atomized organic solvent hits the aerogel. EDS detected carbon in addition to the Si and O that are the main ingredients of the aerogel.

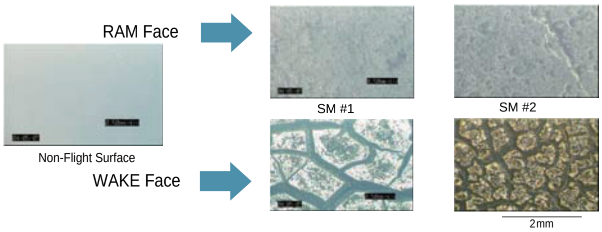

Fig. 4 Surface alterations of exposed aerogel.

4.2.2 Typical tracks in silica aerogels

Figure 5 shows comparisons of two impacts with hypervelocity impact experiment results (Kitazawa, *et al*.,[5]). Regardless of surface alterations of the aerogel, tracks from experimental hypervelocity impacts are quite similar to those seen in flight tests.

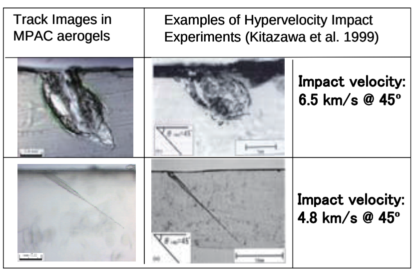

Fig.5 Comparison of tracks in MPAC aerogels with experimental hypervelocity impact tracks.

4.2.3 Chemical composition of captured particles

Metals (aluminum and others), TiO_2, ZnO, $CaCO_3$ etc. were found in captured dust particles and/or inner wall surfaces of tracks. Figures 6-8 show examples of chemical analyses. Figure 6 shows an analysis of the inner surface of a track. An Al component was detected by EDS and the Raman spectrum indicates the Al is metallic rather than a component of Al_2O_3. Figure 7 shows one of the smallest particles for which Raman analysis was possible. Analysis shows the particle to be TiO_2, a typical space debris component.

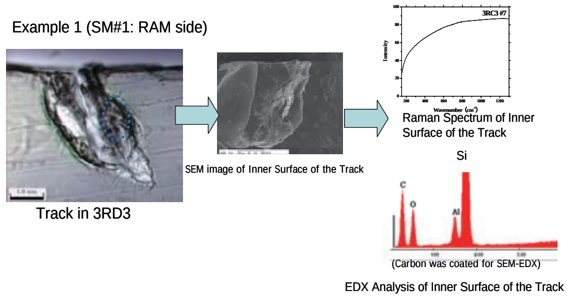

Fig. 6 Analysis of the inner surface of a track. Metallic aluminum was detected.

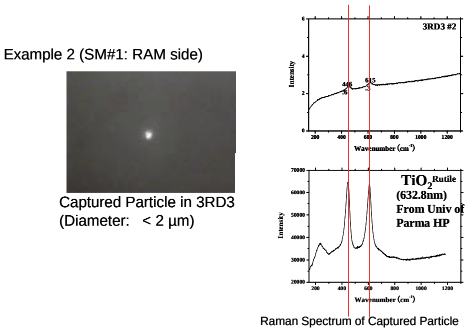

Fig. 7 Analysis of a minimum-size particle of TiO_2.

Figure 8 shows one of the most interesting of the captured particles, a 20 µm particle that is a mixture of Ag_2O and Ag_2S, an aggregation of smaller particles with sizes of tens to hundreds of nm. A natural pyroxene grain of about 1 µm in diameter is included whose EDS and X-ray diffraction and Raman analyses indicate it to be a fragment of H-Chondrite. X-ray diffraction identifies the particle as orthopyroxene, and EDS shows the composition of the particle to be $Wo_1En_{85}Fs_{14}$ ($Ca_{0.02}Mg_{1.70}Fe_{0.28}Si_2O_6$)

4.2.4 Estimated impact flux on silica aerogel

Table 1 shows a comparison of the impact flux estimated from inspection of the aerogel and calculated results from MASTER-2001. Particle diameter *d* was estimated using a linear relationship between d and D_{ent}, as reported in the experimental results of Kitazawa *et al*., [5] and MASTER-2001 results refer to Neish, *et al.*[3]. Flux results from the aerogel investigation indicate five to 100 times greater flux than MASTER-2001.

Table 1. Impact flux estimated from detailed inspection compared with calculated results from MASTER-2001.

RAM Side

Particle Diameter [µm]	Impection Results SM #1	Impection Results SM #2	Model Forecasts [/m²/yr]
5	5.1×10^3	—	1×10^3
10	1.6×10^3	—	4×10^2
20	6.3×10^2	3.9×10^2	2×10^2

WAKE Side

Particle Diameter [µm]	Impection Results SM #1	Impection Results SM #2	Model Forecasts [/m²/yr]
5	4.2×10^4	—	2×10^2
10	2.2×10^3	—	7×10^1
20	1.4×10^2	2.6×10^2	2×10^1

5. Discussion

5.1 Entire Surface of MPAC&SEED

A database of impact-like features and part IDs of all MPAC&SEEDs are available for curation. The database also includes detailed inspection results for MPAC samples. The sample curation system and sample distribution plan will be discussed in the next step.

In Figure 3, the number of impact-induced features was almost directly related to exposure period and the impact rate was almost constant. These data show that during the exposure period of MPAC&SEED (October 15, 2001 - August 19, 2005), there was no noteworthy change in the dust flux environment.

5.2 Silica Aerogel Inspection

5.2.1 Surface alterations of silica aerogel

In a previous aerogel experiment in space (Kitazawa, *et al.*, [6]), no noteworthy surface alterations were reported. In contrast, the surface alterations of MPAC's aerogels are quite remarkable, and seem to be the result of the deposition of carbon-containing particles (whether gas, liquid or solid) over the entire aerogel surface.

Problems in the operation of space stations such as MIR and ISS are strongly related to the gas-particle environment that forms around the station, which can contaminate external surfaces. The attitude control thrusters widely used on space stations contribute significantly to the formation of a gas-particle environment (Rebrov and Gerasimov [5]).

Figure 9 shows location of Soyuz, Progress, Service Module of ISS, and MPAC&SEED. The effects of contaminants emitted from the thrusters of the ISS, Soyuz and Progress are under discussion.

5.2.2 Typical tracks in silica aerogels

Regardless of any surface alterations of the aerogels, the shape of penetration tracks, which are presumed to have been formed by hypervelocity collisions with dust particles, are in good agreement with track shapes observed in hypervelocity impact experiments (Kitazawa, *et al*., [5]). Therefore, it is possible to estimate the impact parameters of the dust particles, such as their diameter, impact velocity, impact direction, etc., from the results of the hypervelocity impact experiment.

5.2.3 Chemical composition of captured particles

The captured particles were mainly metals (aluminum and others), TiO_2 and other artificial space debris. The space debris particle shown in Figure 8 is a mixture of Ag_2O and Ag_2S, but it includes a small natural grain about 1 nm in diameter. Therefore, the particle is secondary debris formed by natural meteoroid impact on the surface of the spacecraft. In addition, as the particle features indicate, it is an H-Chondrite, and the presumed size of the original meteoroid in earth orbit is greater than the observed hundred µm.

5.2.4 Estimated impact flux on silica aerogel

Flux values estimated from inspection of the aerogels shown in Table 1 are five to 100 times higher than predicted by MASTER-2001. The causes of elevated flux levels may be; 1) model uncertainties, 2) elevated flux values from dust swarms (dust clouds), 3) contaminants emitted from the ISS, Soyuz, Progress or the Shuttle, 4) secondary debris. It is thought that at least the flux of the smallest particles (less than 10 µm) is affected by contaminants.

6. Near Future Plans

Detailed inspection of SM3/MPAC and analysis of contamination will be carried out. An MPAC&SEED experiment is also scheduled for the Japanese Experimental Module (Kibou).

Acknowledgments

Prof. T. Nakamura and Prof. T. Hanada, Kyushu University, Prof. E. Sato, Dr. T. Goka, Dr. S. Kibe and Dr. H.Yano, JAXA, have kindly contributed innumerable useful suggestions concerning the experiments and the analysis of the resulting data. Dr. J.-C. Liou, NASA/JSC, also kindly gave us helpful comments about space debris and aerogel dust collectors. Grateful acknowledgment is hereby expressed to all those cited above.

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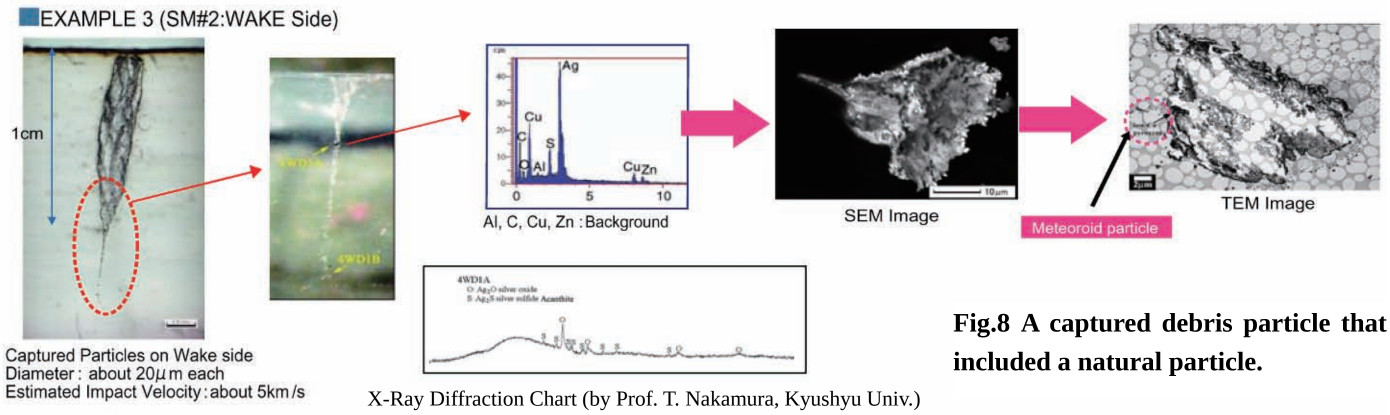

Fig.8 A captured debris particle that included a natural particle.

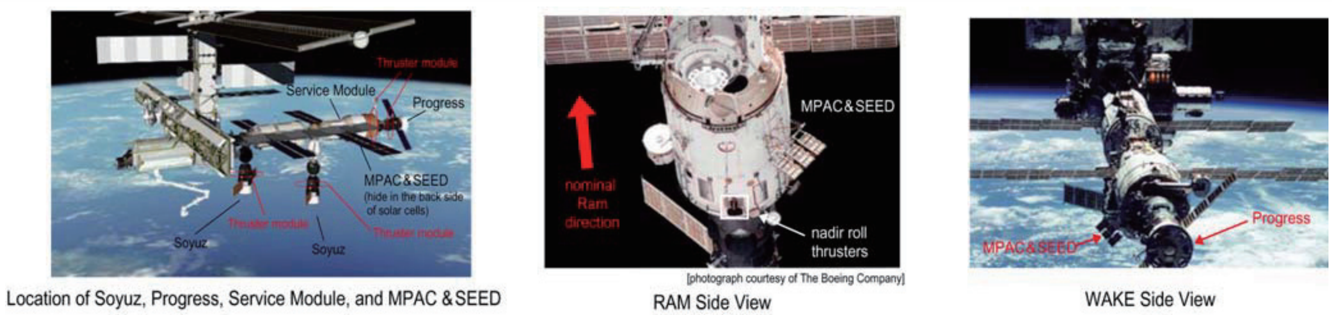

Fig.9 Location of Soyuz, Progress, SM, and MPAC&SEED.