DETERMINATION OF DIRECTIONALITY AND SOURCES OF IMPACTORS ON THE DOUBLE LAYER FOIL CAPTURE CELLS OF THE LDEF

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ABSTRACT

One section of the double layer microparticle capture cell experiment on the trailing face of LDEF was studied using SEM/EDX. An impact cluster was discovered at the edge of the segment which was caused by molten silicates. Elliptical perforations and "pancakes", due to low velocity impacts, indicated that the event was from the south-Earth direction. The bumper shield effect of the double layer structure was also studied.

1. INTRODUCTION

In 1990, NASA's Long Duration Exposure Facility (LDEF) was retrieved from Low Earth Orbit at an inclination of 28.5°, and a mean altitude of 458 km, after a 5.78-year exposure (1.82×10^8 s) in space. It was stabilised geo-centrally with an 8° offset of the velocity vector at 7.64 km/s toward the north. It had 14 exposed pointing directions, 12 of which were peripheral in 30° steps including space and Earth faces (Ref. 1). For cosmic dust and space debris research, the exposed time x area product is essential for statistically valid arguments of flux and, thus, LDEF provided the largest product so far in this regard.

The Micro-abrasion Package (MAP) experiment (A0023) was provided to LDEF by the University of Kent at Canterbury (UKC). It consisted of double foil layers of metals (aluminium (Al) or brass) with thickness between 1.5 to 31.1 µm and a stop plate at the bottom. MAP foils were situated on 5 pointing faces: north, south, space, leading (east) and trailing (west) (Ref. 2).

The top foil was used as a "bumper shield" to dissociate hypervelocity impacting microparticles. The second layer was situated close to the top as a "catcher" of impactor residues so that chemical analysis of the materials enabled determination of the origin of the parent bodies.

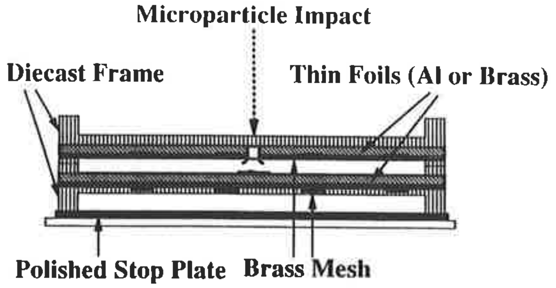

Figure 1. MAP capture cell structure.

2. ANALYTICAL PROCEDURE

2.1. Importance of west face data

Despite the lowest flux of impacts among all the faces except the Earth side, the west face has several advantages in its study.

(1) In accordance with the United States Space Command (USSCOM) catalogue, the trailing edge was not expected to receive space debris unless they had highly eccentric and low inclination and elliptical orbits. Yet despite this, the Chemistry of Micrometeoroid Experiment (CME) reported 15 % of their detection favoured man-made particles (Ref. 3).

(2) Impacting particles on this face require a higher velocity than the orbital velocity of LDEF and the overall lower impact velocities compared with the leading edge give a greater chance for particulates to survive so that successful chemical analysis can be expected (Ref. 4, 5).

(3) In this study, the "w3" was chosen for detailed analysis among 8 triangle sections of the west face. The a and d segments of the top Al foil had 1.5 µm thickness (the thinnest option) and 2.6627×10^{-3} m^2 active area each while both b and c segments were 4.83-µm-thick and 1.01748×10^{-2} m^2. All the segments of the bottom foil consisted of a 12.0 µm thickness of brass. The separation of foils was 2.7 mm which could concentrate deposits from the top in a small area. Therefore when "slow" catch-up projectiles penetrated the top foil, some residues would be deposited on the bottom layer.

2.2. Analytical technique

All foils of the w3 section were scanned with an automated stereo image CCD camera system, called the Large Optical Scanning System (LOSS), for perforations by back illuminating the foils in a class 100 clean room (Ref. 6). Each penetration diameter size was derived from the CCD pixel count by fitting a photometric calibration curve. Potential impact sites were re-visited at x40 magnification, with the resolution limit of > 3 µm, in order to distinguish actual impacts from tears or contamination (Fig. 2).

The perforations were then examined for morphology and size by using a 525M Philips Scanning Electron Microscope (SEM). Elliptical holes and streams of craters can be recognised as direction indicators of impacts. To measure relative impact angles with respect to the MAP frame, whose direction on LDEF is known, the SEM with 10 kV accelerating voltage for electron beam had 0° tilt from the surface of the specimen. Chemical compositions of residues were also analysed using an Energy Dispersive X-ray spectroscopy (EDX) attached to the SEM. The X-ray spectra of any interesting sites such as residues and lips of penetration holes were measured with 20 kV accelerating voltage in 100 seconds. The tilt between the beam and specimens was 20°.

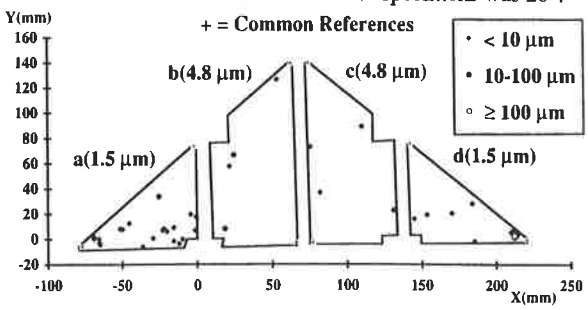

Figure 2. Penetrations on MAP w3t Al foil segments scanned by LOSS.

3. BUMPER SHIELD EFFECTS

A total of 61 perforations were found on the top foil (w3t), 23 of which were concentrated within a small area of 2.33×10^{-5}

m^2 on the segment d. No perforations were found on the bottom layer. The combined area of segment a and d received the penetration flux of 1.04×10^{-6} m^{-2} s^{-1} and b and c received the flux of 5.40×10^{-7} m^{-2} s^{-1}, both of which fairly agreed with the smoothed flux data (Ref. 7). For the cluster on w3td, the flux was the order of 2-3 higher than the model. This cluster appeared to be secondary cratering from a near but higher position on the LDEF surface.

The double layers were converted to a single Al shield to compare it with the effectiveness of the bumper shield (Fig. 3). The Al plates of thickness of 39.1 and 42.4 µm, equivalent to the MAP double foils in contact with one another, would shield against a flux of 1.70×10^{-6} m^{-2} s^{-1}. Yet the upper limits of the separated double layers in a & d and b & c were proven as equivalent to 70 µm and 110 µm respectively. This is an example of the bumper shield with the real flight data. This also implies that, within the 69-month exposure in middle to late 1980's, even such a simple and micron-thick double-layer structure had some advantage for the trailing edge which expects the lowest flux of impacts on an Earth-orbiting satellite.

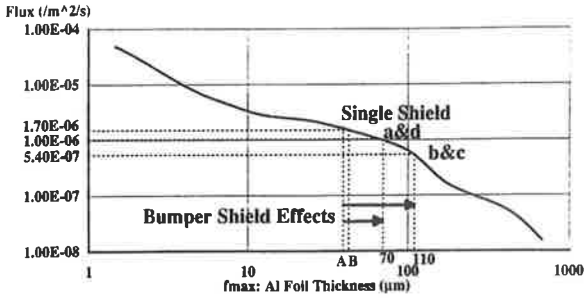

Figure 3. MAP w3 bumper shield effects.
A: 1.5 µm Al + 12 µm Brass = 39.1 µm Al
B: 4.8 µm Al + 12 µm Brass = 42.4 µm Al

4. TRACING DIRECTION AND ORIGIN

4.1. Crater cluster

The crater cluster on w3td was examined with SEM/EDX. The flux was 2.36×10^{-5} m^{-2} s^{-1} (Fig. 4) and most craters indicated low velocity impacts with irregular or elliptical morphology. Only a few 10 µm size circular holes were found. The top foils recorded an evidence of fluid splash which included streaks of sub-micron craters, i.e. "pancake" shaped droplets beside elliptical perforations as seen on the surface of lunar rocks (Fig. 5). The trend of the ejecta flow coincided with the semi-major axis of the craters and "pancakes" indicating direction of origin. Most of their lips were not developed much unlike hypervelocity impacts but the foil appeared to be torn by impactors. Fluctuated grains were scattered around large penetrations.

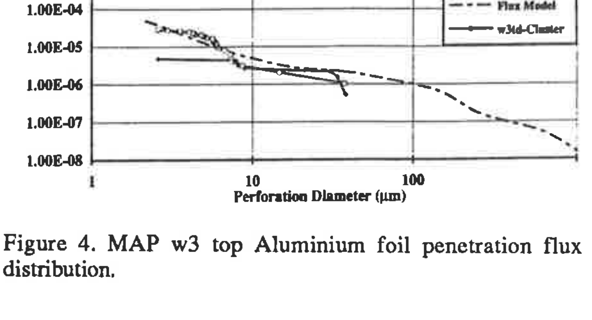

Figure 4. MAP w3 top Aluminium foil penetration flux distribution.

Figure 5. Crater cluster of top Al 1.5 µm foil with molten Silicon "pancake" splash.

4.2. Chemical analysis

The EDX results indicated that all the residues around the cluster on the top foil consisted of silicates (Fig. 6. a-c). On the bottom foil there was a concentration of residues with Al and Si peaks underneath of a 50 µm top penetration. As the bottom foils were made of brass, the Al detected was contributed from the fragments of the top foil (Fig. 7) and this proved the efficiency of capture cell for the chemical analysis.

Apart from the background, no other elements were detected but Al and Si. Possible sources of Al other than the top foils were fragments of space debris such as aluminium oxide spherules and space borne instruments or those of the LDEF payload trays and the MAP diecast frames driven from the primary hypervelocity impacts. However neither were associated with silicate materials.

The area of spread residue was not clearly identified but the Si and Al were traceable around the order of 100 µm diameter from the projected centre of the top penetration. Yet smaller separation of the double layer would improve higher concentration in smaller area such as the UKC's Timeband Capture Cell (TiCCE) experiment on the European retrievable Carrier (EuReCa) currently in LEO, which has 0.5-1.0 mm separation between top foils and gold stop plate.

Figure 6-a. A top penetration at the cluster seen from the entry side.

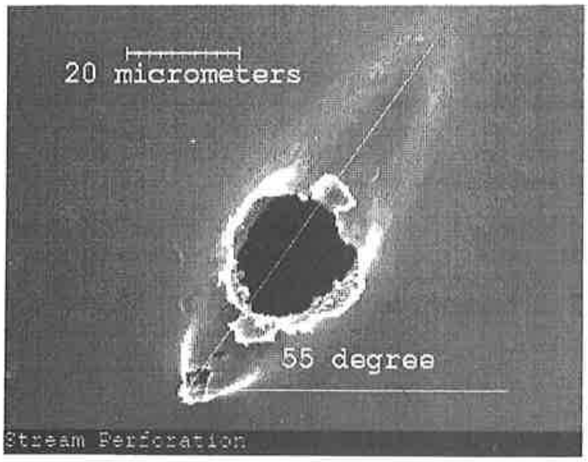

Figure 6-b. The same pentration as Fig. 6-a seen from the exit side.

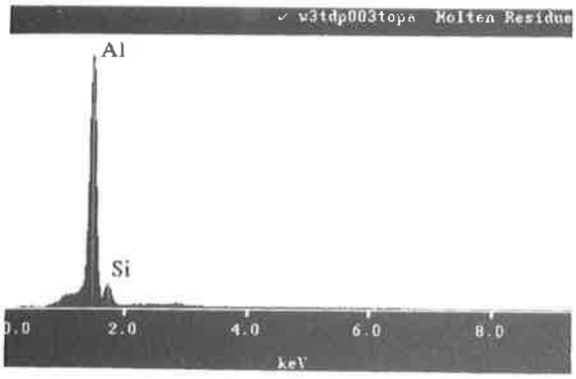

Figure 6-c. EDX spectra of residues on the lip of the same penetration which consisted of silicon.

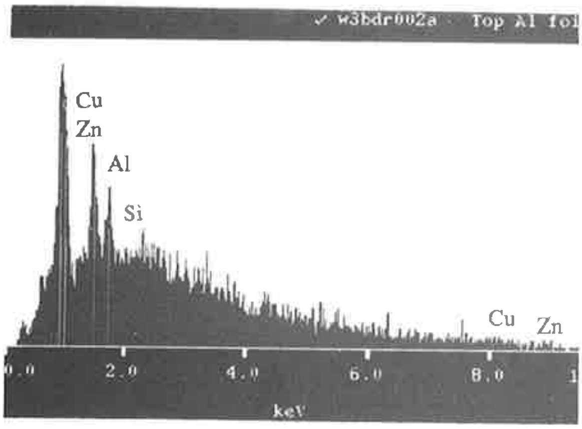

Figure 7. EDX spectra of the bottom brass foil with Al and Si peaks.

4.3. <u>Tracking impact directions</u>

Two dimensional angles of 5 elliptical penetrations with respect to the MAP frame were identified (Fig. 8) and their vectors converged to a small region around the brass mesh and the diecast frame of MAP (Fig. 9). They seemed to come from the south-Earth direction at low velocity (< 3 km/s). As for the inclination, although no sufficient parameters were available, the converged "hypocentre" was close to the edge of the payload tray of LDEF which at least shielded the segment from low angle impacts from the Earth direction (Fig. 10). The distance between the "hypocentre" and the Al payload tray edge was too long to concentrate the secondary impacts in such a small area. Thus the most probable impact site is on the edge of the diecast frame.

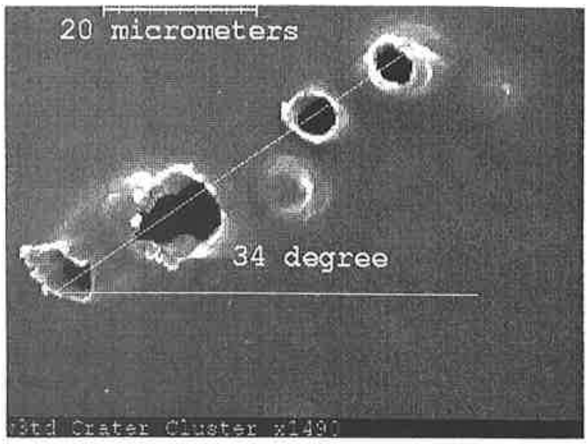

Figure 8. A group of low velocity impacts on the top foil with the directionality seen from the exit side.

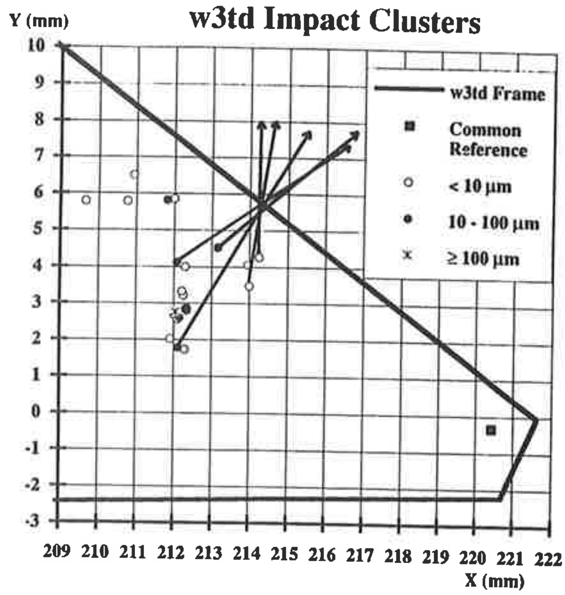

Figure 9. Trace of impact angles of five penetrations in the crater cluster.

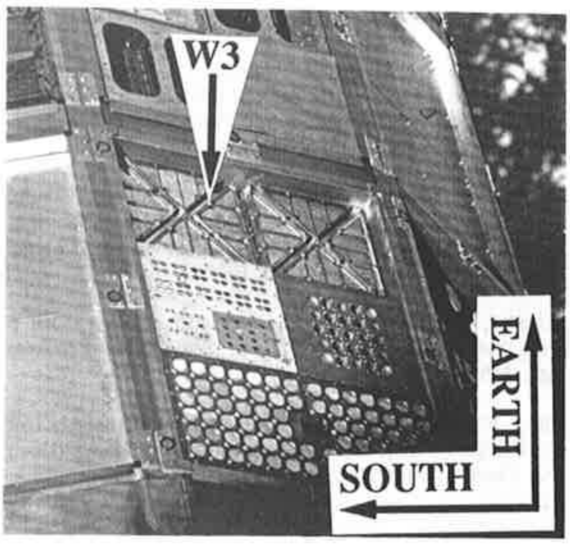

Figure 10. Location of MAP w3 segment on the west face of LDEF (Courtesy of NASA).

5. CONCLUSIONS AND DISCUSSION

Despite the fragile foils, the possibilities of liquid silicate impacts during pre-launch period under the NASA quality control and post-launch treatment in the class 100 clean room were unlikely. Si based glue was used between the frame and the brass mesh but it did not appear on the entry side of the top foils. Therefore the primary impact would not be able to produce the splash of glue on the surface. Although the mesh was made of Cu and Zn with gold coating, there was no trace of those heavy metals in any of impact residues.

The MAP capture cells were located on the row 3 and the bay C of LDEF, which is next to the central section of the trailing row. On the centre, there was a trunnion for the Space Shuttle orbiter grapple but it could not be the cause of the crater cluster because it was at the north-space direction of the MAP accommodation. Thus the results suggest that a silicate micrometeoroid impacted on an edge of the MAP diecast frame in the south direction and sprayed liquid-state droplets upon the foil forming the secondary impacts. However an optical observation of the MAP frame x 40 magnification did not discover the primary hypervelocity impact. This is an unique event from previous studies of the trailing face of LDEF and a detailed inspection on the frame edge with SEM has to be performed.

No evidence of debris impacts was found in this study but the rest of available MAP segments of the west face with various sensitivities are being explored further at UKC. Especially for chemical analysis, the comparison with the CME results is crucial to verify the natural particles and space debris flux ratio on the trailing face. Also such compositional studies for the four other faces of MAP will help better understanding of impact directionality.

In addition, the MAP double layer structure can demonstrate the efficiency of the bumper shield effects with the actual flight data by comparing penetration flux ratio between the top and bottom layers. It will be useful information for future spacecraft design such as the Space Station Freedom pressurised module walls which have a similar altitude and a direction control but a longer mission duration than LDEF.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. McDonnell, J.A.M. and Stevenson, T.J., Hypervelocity impact microfoil perforations in the LEO space environment (LDEF, MAP AO 023 Experiment), *Proc. First LDEF Post-Retrieval Symp.*, NASA-3134, 443-458, 1991.

2. McDonnell, J.A.M. and the Canterbury LDEF MAP Team, Impact cratering from LDEF's 5.75-year Exposure: Decoding of the interplanetary and Earth orbital population, *Proc. Lunar and Planet. Sci.*, Vol. 22, 185-193, 1992.

3. Kessler, D.J., Origin of orbital debris impacts on LDEF's trailing surfaces, Presentation at *LDEF Second Post-Retrieval Symp.*, NASA/JSC, Houston, USA, 1992.

4. Hörz, F. and Bernhard, R.P., Compositional Analysis and Classification of Projectile Residues in LDEF Impact Craters, *NASA Tech. Memo. 104750*, NASA/JSC, Houston, USA, 1992.

5. Hörz, F., Bernhard, R.P., Warren, J.L., See, T.H., Brownlee, D.E., Laurance, M.R., Messenger, S. and Peterson, R.B., Preliminary analysis of LDEF instrument AO187-1 "Chemistry of Micrometeoroids Experiment", *Proc. LDEF First Post-Retrieval Symp.* NASA CP-3134, 487-501, 1992.

6. Paley, M.T., An automated system for obtaining impact penetration, location, size, and circularity on a foil with special reference to the LDEF, *Proc. Hypervelocity Impacts in Space*, Editor J.A.M. McDonnell, University of Kent at Canterbury, 48-53, 1992.

7. McDonnell, J.A.M., Deshpande, S.P., Niblett, D.H., Neish, M.J. and Newman, P.J., The near Earth space environment - an LDEF overview -, *Advances in Space Research*, Editor W. Flury, Pergamon Press, in press, 1993.