# MICROMETEOROID MULTIPLE FOIL PENETRATION AND PARTICLE RECOVERY EXPERIMENTS ON BOARD SPACE SHUTTLE'S LONG DURATION EXPOSURE FACILITY (LDEF).

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## ABSTRACT

Experiments designed for the investigation of the near-Earth micrometeoroid flux on the Space Shuttle Long Duration Exposure Facility (LDEF) are described. The paper examines, in particular, how two of the experiments deploy a series of multiple layer foil arrays to investigate the physical properties of incident meteoroids and lead to partial recovery of the micrometeoroids for laboratory analysis. Several thousand penetrations are expected to be returned after 12 months' exposure in Space.

Since the beginning of space exploration considerable data pertinent to micrometeoroids has been gathered: flux-mass relationships, velocities and orbits of the particles have been established by use of detectors on board satellites and space probes. The study of impact craters on lunar samples has provided a more comprehensive sample of the past impact erosion scene, and by the limited retrieval of material exposed on space craft we have obtained some impact craters formed in 'real time' during space flights such as the Apollo window and Skylab data (Cour-Palais 1974, Hemenway et al. 1975). The study of undisturbed extraterrestrial particles must, however, remain a goal of space research; to this end dust collectors have been flown on balloons and rockets and recently high altitude U2 aircraft. From Brownlee's U2 collection (Brownlee et al. 1977) we should possibly anticipate the best future hopes for the retrieval of truly pristine extraterrestrial material by virtue of the gentle atmospheric deceleration, but the discrimination between true cosmic dust particles and terrestrial contamination will always remain a concern in this area, if not an impediment. Real time space recovery remains a challenge.

Four meteoroid experiments were selected for early Shuttle flights to develop a better understanding of the near-earth meteoroid environment. Detectors will be exposed to space for some 12 months on LDEF facility to be launched by the Space Shuttle in 1982. The

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Shuttle era will undoubtedly revolutionize space research; in the first few flights, the potential of this transportation system is being used to enter two new dimensions for microparticle studies, namely:

(1) Laboratory recovery of controlled exposure surfaces, with subsequent access to full microanalytical techniques.

(2) Vastly increased area-time exposure products in space, leading to increased sample numbers and the extension of sampling to higher masses.

## 1. THICK TARGET EXPERIMENTS

These comprise selected metallic (Al, Au, Cu, Stainless Steel, W) and glass surfaces usually of several millimetres thickness.

(i) F. Horz as a principal investigator (PI) is deploying two sealed canisters which are opened in orbit to expose very high purity gold surfaces. Other unprotected surfaces will complement the Chemistry of Micrometeoroids (CME) experiment, which is aimed at the larger mass meteoroid crater residue analysis.

(ii) D. Humes (PI) initially proposed the deployment of aluminium foil of some 25 microns thickness over some 50% of the LDEF area: this experiment is now likely to be degraded in favour of unprotected solid impact surfaces. The enormous sample area available on LDEF nevertheless elevates a simple experiment such as this to one of high scientific value.

Crater size distributions from these two thick target experiments will enable, with the aid of laboratory calibration by solid particle accelerators, the evaluation of the incident microparticle flux in the near Earth environment. Information of the velocity, particle density and incidence direction will generally be difficult to decode because of the late stage equivalence of the impact process in the velocity range anticipated, but for low velocity impacts this could be partially determined.

A more critical issue is the determination of the chemical composition of the impacting particles. In general they are physically destroyed, and mixed with target material in the process of crater formation. Although little or no pristine material is likely to be left for chemical analysis, particularly in metals such as tungsten or gold, it is possible to collect quite sufficient projectile residue material for analysis. Based on laboratory experiments, such residues may be reduced to a probable initial composition (Horz et al.1975). For craters showing evidence of remnants of projectile, chemical analysis will be made with X-Ray microprobe and Ion or Auger microprobe. If possible Atomic Absorption Spectrophotometry or Neutron Activation Analysis will be used.

For the CME experiment sensitivity is from $10^{-12}$g to $10^{-7}$g and a total of some 200 craters of > 5 microns diameter should provide invaluable data on particle composition. By virtue of the area-time exposure product, an almost direct determination of the faintest radio-meteoroid influxes will be attempted for the first time since the Pegasus satellites. As yet the mass sensitivities of such radar methods are unknown to a factor of 10.

## 2. MULTIPLE FOIL PENETRATION AND COLLECTION EXPERIMENTS

### 2.1 Frecopa Experiment

The experiment developed for use by the DERTS group at Toulouse is shown in Figure 1, in its space exposed configuration. The aim of the experiment (P.I.: J.C. Mandeville) is primarily to investigate the feasibility for future missions of multilayer thin film detectors acting as energy sorters in order to collect micrometeoroids, if not in their original shape, at least as "break-up" fragments suitable for chemical analysis.

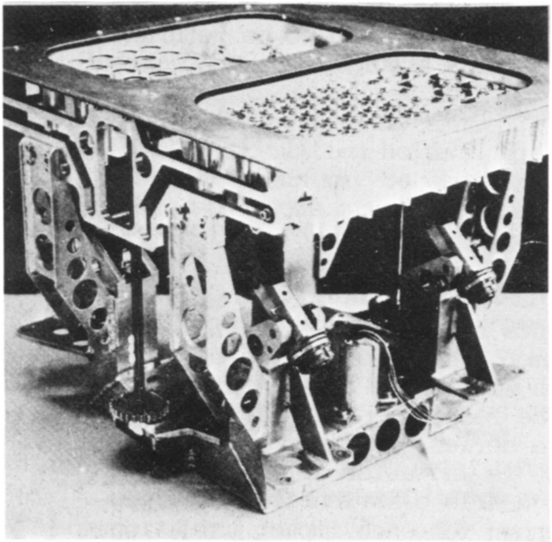

Figure 1. Frecopa remote operated vacuum canister deployment (Changeart & Chadras, 1979)

One or more thin metallic foils are set in front of the main target in order to get selective detectors. The experiment will include 31 samples with a sampling surface of 240 $cm^2$. The samples will be mounted on one mount plate inside a "Frecopa" box (for maximum protection of fragile thin metal films, before and after exposure to space). Foil thickness ranges from 0.75μm to 5μm of aluminium; such arrays are expected to slow down particles with diameters between 1 and 10μm without complete destruction.

### 2.2 Microabrasion Package (MAP)

Aimed at providing a very large collection area at high sensitivity, the MAP experiment (P.I: J.A.M. McDonnell) shown in Figure 2 exposes a double layer of foil (mylar and/or aluminium) varying from 1.5μm to 25μm thickness positioned above a polished aluminium plate. The significant feature of the experiment is the combination of metre dimensioned surfaces with micrometer dimensioned sensitivity. Normally an impossible task for analysis, this will be achieved by the use of high quality foils combined with hole location, by optical scanning followed by electron microscopy. First and second foil penetrations are position-correlated to determine incidence directions. Although unprotected during flight, foil ruggedness is sufficient to obviate tear-damage. Any confusion between possible tears and hypervelocity penetrations would in any case be simply ruled out under microscopic inspection. Five such deployment areas are used on LDEF to determine geocentrically referenced flux anisotropies. A total of some 1,000 penetrations is expected to be returned to Canterbury, based on conservative flux estimates (McDonnell, 1978).

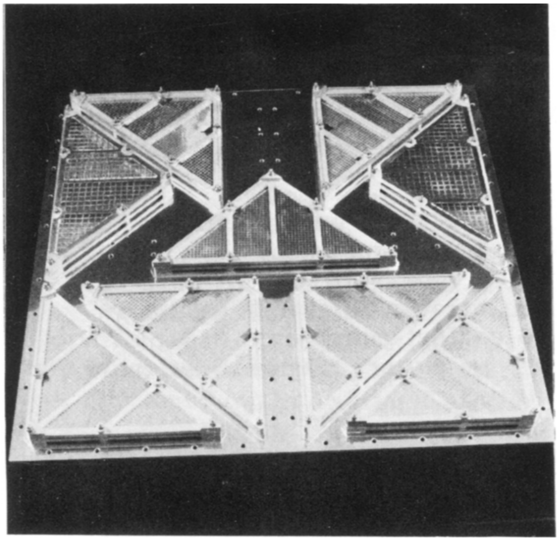

Figure 2. Microabrasion multiple foil package (MAP) array of the University of Kent.

## 3. THE PENETRATION OF THIN FOILS

Since the Frecopa and MAP experiments referred to in Section 2 feature similar target configurations, common discussion of the broad principles of thin foil penetration will serve to identify the science return expected from them both. The response of a multi-layer foil can obviously be broken down into a series of single impact situations provided (1) that the foil response is known for all types of 'projectile' and (2) that the full debris distribution (i.e. projectiles for the second foil) is known for each impact situation. In general solutions are known for much less than the desired range of parameters. We identify here several situations where theory and experiment provide reasonable accord, and where results will be better understood.

### 3.1 Low Velocity Penetration

If the impact pressure of the interface between target and projectile is less than the projectile crushing strength, the projectile will be decelerated without damage. Such a situation can lead to particle retention in the first foil target for very small particles, or for larger ones retention after multiple passage through several foils. Experiments by Grün and Rauser (1968) and McDonnell (1970 and 1979) and Pailer and Grün (1979) show that a deceleration based on momentum conservation via the intercepted target mass is appropriate. The projectile velocity-density window for undamaged retention may extend up to 5 km $s^{-1}$ for iron projectiles on mylar, but be as low as 0.1 km $s^{-1}$ for fluffy projectiles on a metallic target (e.g. Mandeville and Vedder, 1971). The rupture of such agglomerates by a very thin first foil may lead to a shower of impacts on the second foil; their angular distribution related to the first foil shock might then be used to determine the initial agglomerate binding strength.

It is seen that this "window" for particle disruption thus offers a powerful incident velocity and density discriminant; the multiple foils yield the incidence direction too, and hence the type of orbit may be reconstructed. The double foil penetration on the Frecopa and MAP experiments generally yield more information than thick targets because of the evidence of the successive degradation of the particle. For very small particles (<10μ) the foil quality for a series of 1μm foils required to stop such particles imposes a practical limit on the detection sensitivity in this situation.

### 3.2 High Velocity Penetration

Here impact pressure greatly exceeds target strength, and the compressible-fluid situation holds. The equation of state and momentum-energy considerations may be used to construct either quasi-analytical hydrodynamic solutions or a multi-cell type computer simulation (see Fechtig et al. 1978 for review). A particular situation of relevance to particle distributions incident on the Earth is that of marginal hypervelocity penetration, where relief of the stress wave at the rear of the foil leads to incipient rupture. Such regions have been defined for micron foils as a function of velocity (McDonnell (1970)) and measurement of the penetrations versus thickness leads to the marginal penetration flux spectrum analogous to the lunar impact crater size distribution (e.g. Mandeville (1976), Morrison & Zinner (1977)). Particle disruption is complete in this situation, but particulate target debris may be generated by the spallation process at the rear of the foil.

For hypervelocity impacts of increasing size relative to marginal penetration, rupture of the rear foil at an effectively earlier phase of the crater expansion leads to adiabatic expansion from a higher point on the Hugoniot curve, and the final specific energy may well be sufficient for penetrating particle-target material to be liquid or even vapour (Fechtig et al. 1978). The meteoroid bumper, proposed by Whipple (1952) is an example of this situation, where although the target is thin compared to the particle, the impact shock melting permits complete dispersal of the solid particle prior to its incidence on the second foil.

## 4. CONCLUSION

Particle collection experiments in space must remain generally difficult, perhaps even impossible at the highest meteoritic velocities. The lower velocity window for multiple layer foil deceleration does, however (when considering the orbital velocity of space shuttle) prove sufficient to expect the retention of considerable material at least partially intact. With the vastly increased area of Shuttle, such experiments may now expect to provide quite realistic numbers of extraterrestrial micrometeoroids which rightly deserve the best of laboratory analyses. Investigation of the near-Earth region of space and the use of Shuttle launches to get access to an orbiting "hypervelocity impact laboratory" will offer considerable promise in the near future.

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