EFFECT OF THE SPACE ENVIRONMENT ON MATERIALS FLOWN ON THE EURECA/TICCE-HVI EXPERIMENT

- A PRELIMINARY ASSESSMENT -

6P

Carl R. Maag
T & M Engineering
Glendora, CA 91740 USA
Phone: 818-852-9772, Fax: 818-335-9968

William G. Tanner
Baylor University Space Science Laboratory
Waco, TX 76798 USA
Phone: 817-755-3404, Fax: 817-755-3409

Tim J. Stevenson
Mare Crisium
Old Carisbrooke, Isle of Wight, PO30 1NS UK
Phone/Fax: 44-(0)983-822965

Janet Borg
Institut d'Astrophysique Spatiale
91405 Orsay Cedex, France
Phone: 33-1.69.85.86.32, Fax: 1.69.85.86.75

SUMMARY

The primary benefit of accurately quantifying and characterizing the space environmental effects on materials is longer instrument and spacecraft life. Knowledge of the limits of materials allows the designer to optimize the spacecraft design so that the required life is achieved. Materials such as radiator coatings that have excellent durability result in the design of smaller radiators than a radiator coated with a lower durability coating. This may reduce the weight of the spacecraft due to a more optimum design. Another benefit of characterizing materials is the quantification of outgassing properties. Spacecraft which have ultraviolet or visible sensor payloads are susceptible to contamination by outgassed volatile materials. Materials with known outgassing characteristics can be restricted in these spacecraft. Finally, good data on material characteristics improves the ability of analytical models to predict material performance.

A flight experiment was conducted on the European Space Agency's European Retrievable Carrier (EuReCa) as part of the Timeband Capture Cell Experiment (TICCE). Our main objective was to gather additional data on the dust and debris environments, with the focus on understanding growth as a function of size (mass) for hypervelocity particles 1E-06 cm and larger. In addition to enumerating particle impacts, hypervelocity particles were to be captured and returned intact. Measurements were performed post-flight to determine the flux density, diameters, and subsequent effects on various optical, thermal control and structural materials.

In addition to these principal measurements, the experiment also provided a structure and sample holders for the exposure of passive material samples to the space environment, e.g., the effects of thermal cycling, atomic oxygen, etc. Preliminary results are presented, including the techniques used for intact capture of particles.

INTRODUCTION

The space environment is becoming a major concern for many of the space systems presently considered. This concern is due to a combination of fundamental issues. Ultraviolet radiation (UV), electromagnetic waves that have a frequency just above visible light, is present at all orbits. UV heats surface materials at low levels and can also alter the chemical structure of susceptible materials. Atomic oxygen (AO) is present only in low earth orbit (LEO). AO is ionic oxygen atoms travelling at extremely high velocities relative to the spacecraft. The atoms cause erosion of surfaces and oxidation of susceptible materials. AO presents a serious space environment problem in LEO. Although it only affects exterior surfaces, it is a primary concern for thermal control materials and solar array interconnects. Most structural metals (aluminum, magnesium, and titanium) are resistant to the effects of AO exposure. Polymeric/composite materials, to a certain degree, and silver are susceptible to erosion and oxidation due to AO. The erosion products can act as sources of contamination to sensors by increasing the molecular column density in the field-of-view of the sensors.

PRECEDING PAGE BLANK NOT FILMED

64

The debris environment is a dynamic process in which fragmentation due to collisions creates additional objects of different sizes. Some of the small particles are "washed out" by solar pressure and some of the larger particles de-orbit due to aerodynamic drag, if they are in a low orbit. The size distribution as a function of altitude of the total effect is yet unknown but it has been estimated that a uniform increase of at least 2% per year over the entire monitored size range envelopes all uncertainties. Impacts from space debris may cause damage to manned habitable modules, sensors, reflective or refractive optics, etc.

Micrometeoroid and Debris Impact Studies

A large body of experimental data exists concerning hypervelocity impacts. There are several empirical expressions relating the crater volume to the impacting particle size and mass and many previously flown experiments have examined these relationships. It is also well established that a part of the projectile mass is deposited and detectable on the inner surface of the impact crater. Despite being totally disassociated, elements detected from these sites allow coarse categorization of the impacting particle type, particularly with regard to the all important discrimination of space debris.

High purity metallic surfaces have been used for the collection of grains down to submicron sizes [1]. During the impact, a characteristic crater is formed, with rounded habits and a depth to diameter ratio equivalent to the velocity and size of the impacting particle and the encountered metal. During the impact, the particle is destroyed and the remnants are mixed with the target material, concentrating in the bottom of the crater and on the surrounding rims. A major strength of the metallic collectors lies in the fact that analytical techniques can be applied without modification to the craters. Identification of carbon and organic material is quite possible; this is essential for the study of extraterrestrial material (C, H, O, N).

The impact of a hypervelocity projectile (> 3km/s) is a process which subjects both the impactor and the impacted material to a large transient pressure distribution. The resultant stresses cause a large degree of fragmentation, melting, vaporization and ionization (for normal densities). The resulting pressure, however, is directly related to the density relationship between the projectile and target materials. As a consequence, a high density impactor on a low density target will experience the lowest level of damage.

Historically, there have been three different approaches toward achieving the lowest possible target density. The first employs a projectile impinging on a foil or film of moderate density but whose thickness is much less than the particle diameter. This results in the particle experiencing a pressure transient with both a short duration and a greatly reduced destructive effect. A succession of these films, spaced to allow nondestructive energy dissipation between impacts, will reduce the impactor's kinetic energy without allowing its internal energy to rise to the point where complete destruction of the projectile mass will occur. An added advantage to this method is that it yields the possibility of regions within the captured particle where a minimum of thermal modification has taken place [2].

Polymer foams were employed as the primary method of capturing particles with minimum degradation [3]. The manufacture of extremely low bulk density materials is usually achieved by the introduction of voids into the material base. When these low density micropore foams are used, the shock pressures that occur during impact are minimized, which in turn maximizes the probability of survival for the impacting particle.

EURECA EXPERIMENTATION

As a consequence of the experimental data developed during both recent and earlier STS missions and the data expected from this mission, the authors have produced and delivered an experiment for the European Space Agency, European Retrievable Carrier (EuReCa). The Hypervelocity Impact (HVI) experiment was flown as part of the TICCE experiment. The EuReCa payload was launched on the Space Shuttle Atlantis (OV-104) on 31 July 1992, providing a total mission exposure of nearly eleven (11) months in low earth orbit. The TICCE/HVI experiment is shown in Figure 1.

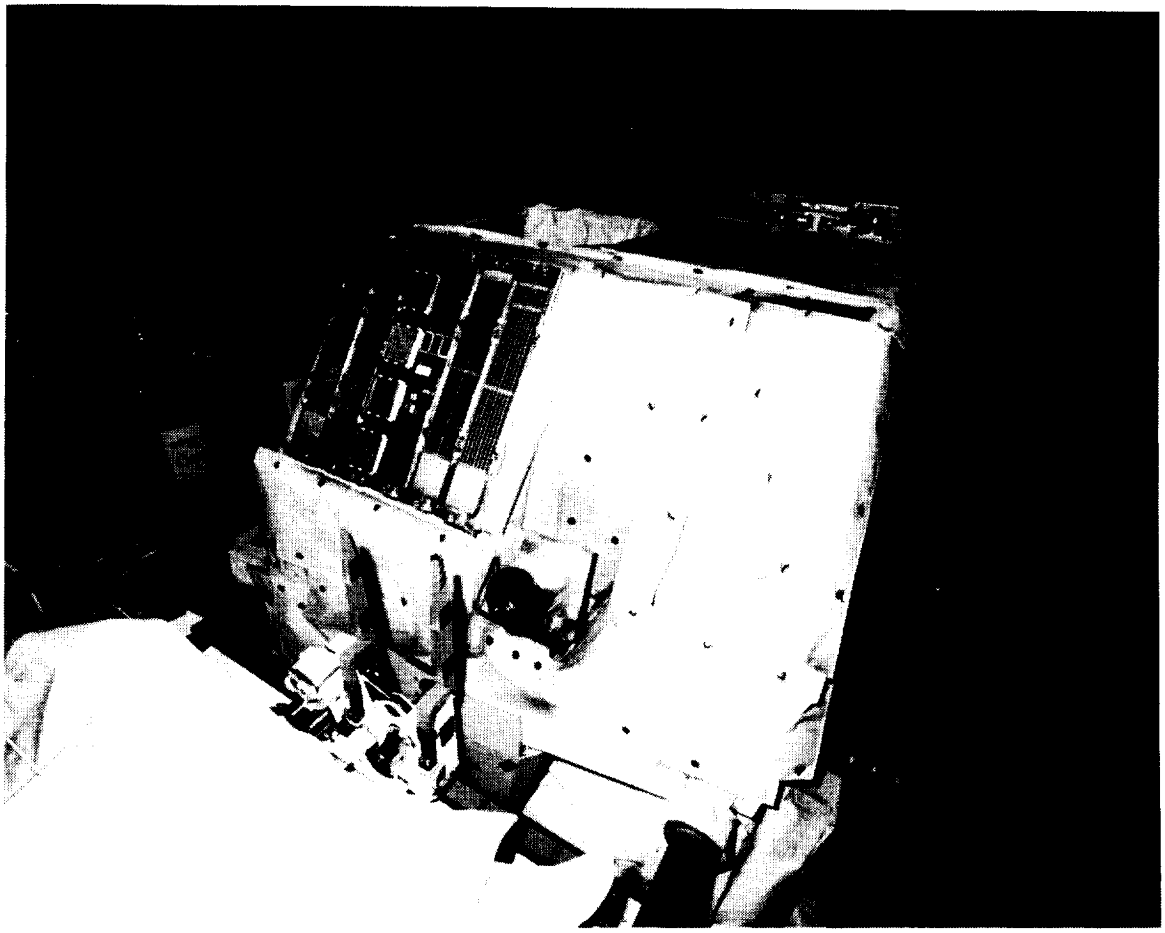

Figure 1. The TICCE/HVI experiment shown mounted to the EuReCa spacecraft.

Objectives of the TICCE/HVI Experiment

The primary objectives of the experiment were to (1) Examine the morphology of primary and secondary hypervelocity impact craters. Primary attention will be paid to craters caused by ejecta during hypervelocity impacts on different substrates; (2) Determine the size distribution of ejecta by means of witness plates and collect fragments of ejecta from craters by means of momentum sensitive micro-pore foam; (3) Assess the directionality of the flux by means of penetration hole alignment of thin films placed above the cells. (4) Capture, intact, the particles which perforated the thin film and entered the cells. Capture medium consisted of both previously flight tested micro-pore foams and Aerogel.

EuReCa 1 Experimental Design

The experiment is comprised of a variety of materials bonded to a large substrate. The design allowed for data to be acquired for both engineering and scientific interests. As previously discussed, the investigators used the numerous techniques to both quantify and understand the effect of the micrometeoroid and debris complex. One of the principal techniques used was the thin film capture cell. The topmost cell (one of two on the experiment) possessed a thin Aluminum film (nominal $t_f < 500$ Å) stacked above a coated substrate. The plane of the film contains 100 cm^2 of impact surface over a Buckbee Mears (90% transmissive) grid which supports the thin film. Each mesh has been covered with an aluminum-coated epoxy layer nominally 5 μm thick to inhibit production of

X-rays by 20kV electrons during laboratory analyses. An estimate of the trajectory of grains within the experiment can be derived from analysis of penetrations made in the thin film and impact sights. Beneath the thin film and above the substrate a network of collimating plates were installed. Each highly polished 0.625 mm thick 3300 aluminum plate was 100 mm long with a height of 8 mm, and possessed slots so that they could interlock with perpendicular plates. These divisions assured that grains whose velocity vectors make a large angle with respect to the surface normal of the 500 Å film would not impinge on another cell, but will impact the witness plates of a specific cell or be stopped by a thin film. The 3300 aluminum witness plates would also record the demise of "barely" penetrating grains. The underside of each thin film will be investigated to assess the constituents of debris clouds deposited on each thin film. The primary function of the 3300 aluminum witness plates near the substrate will be to record the ejecta produced when a hypervelocity grain encounters a semi-infinite stopping plate, viz., the substrate, which has been coated with 2000 Å of Gold. It was not necessary that each portion of the substrate surface be normal to the particle's incident direction. In fact, since the grains which penetrate the film will be directional, the effects of oblique hypervelocity impacts can be examined using the orbital debris and micrometeoroid complex. Angles up to 45° with respect to the substrate surface normal have been accommodated in the design of several of the cells.

Passage of a Particle Through a Thin Film

The pressure an impacting dust grain experiences during a hypervelocity impact can be sufficient to alter the state of matter of the particle. However, very short duration high-pressure pulses can be sustained in large dust grains without fragmentation or complete phase change occurring. In this class of events the cross-sectional area of the impinging dust grain and the thickness of the target are important components of the interaction. The surface area over which a force is administered and the length of time in which the impulse is delivered define the magnitude and the duration of the pressure pulse which gives rise to a sustained shock front in the material. The duration of the shock front will also be determined by the depth of penetration and therefore the thickness of the target, T_f. If one considers the dynamics of an impact event from the perspective of a penetrating particle, the ratio which defines the aspect ratio of the dust grain, i.e., L/D_p, may be investigated to determine the residual length of the particle upon encounter with a thin target. In the case of a thin film penetration event, the ratio of interest is that between the diameter of the dust grain, Dp, and the thickness of the film, T_f. It has been well documented [3] that a projectile with a high aspect ratio will penetrate to a depth defined by the following relationship:

$$p = L \left(\frac{\rho_P}{\rho_T}\right)^{0.5} \qquad (1)$$

The penetration depth, p, of a rod into a thin film can be equated with the film thickness, T_f, and the residual length L_R of the penetrating rod can be equated with the residual diameter of the dust grain. The change in the diameter of the dust grain can be roughly estimated to be

$$\frac{L_R}{D_p} \sim 1 - \frac{T_f}{D_p}\left(\frac{\rho_P}{\rho_T}\right)^{0.5} \qquad (2)$$

In the case of a ratio of $D_p/T_f = 30$ the residual diameter of the dust grain would be greater than 90% by this estimation. Even though the uneroded nature of the material composing the incident dust grain can only be assessed by other measurement means, the foregoing analogy may serve as a metric for further analysis.

Of particular interest in these investigations is a specific empirical form which relates penetration hole size with the diameter of the penetration hole. This experimentally derived equation for the description of the penetration relationship for iron projectiles impacting aluminum films of various thicknesses was developed by Carey, McDonnell, and Dixon (CMD) [4]. The Carey, McDonnell & Dixon (CMD) empirical equation is being compared with the results of computer simulations of hypervelocity impacts for various velocities of interest for surfaces flown in LEO.

$$\frac{D_h}{D_p} = 1 + 1.5\left(\frac{T_f}{D_p}\right) v^{0.3} \left(\frac{1}{1 + \left(\frac{T_f}{D_p}\right)^2 v^{-n}}\right);$$

$$n = 1.02 - 4\exp\left(-0.9\, v^{0.9}\right) - 0.003\,(20 - v) \qquad (3)$$

DATA ANALYSIS AND EXPECTED RESULTS

Primary analyses will be performed using a Scanning Electron Microscope (SEM) outfitted with a Princeton Gamma Tech (PGT) elemental analysis system (Beryllium window). Since each unit cell is ~10 mm square, samples will be easily prepared for viewing in the SEM. The SEM is sufficiently large to support the viewing of 5 cm substrate material.

Count of hypervelocity impact craters on the witness plates with diameters larger than 4 μm will be accomplished by the use of SEM photographs. Once digitized by means of a high-resolution optical scanner, these data will be analyzed using a hypervelocity impact morphology system.

Analysis of the substrate will be of particular importance. The same procedure outlined above to analyze the witness plates will be applied to the substrate. Of primary interest will be the recovery of data concerning the affects on the substrate's optical properties, which have been subjected to primary and secondary hypervelocity impacts. Also recoverable from the substrate (and perhaps the witness plates) will be data pertaining to the fragmentation of grains by the thin films.

Principal theoretical analyses will be conducted using hydrocodes to establish the limiting mass which will penetrate all, two, or only one of the thin films. Comparisons of the computational results with experimentally derived parameters will be carried out. Results of both two-dimensional (2D) and three-dimensional (3D) computer simulations of the hypervelocity impact events which penetrate the EuReCa 1 thin films will be reported at a later date. A relationship between the particle diameter, D_p, and the diameter, D_h, of the hole created in a 500 Å aluminum thin film (T_f) and micropore foam (T_m) for relevant particle and target parameters will be derived and will be compared with empirical equations. That relationship will be used to analyze *in situ* data of the thin film experiments flown in LEO, and to determine the size distribution of grains which penetrate the thin films and are captured intact in the micropore foam [2].

Based on the present knowledge of the space debris and micrometeoroid fluxes, all cells should be penetrated by grains with the properties: $m_p = 3.4 \times 10^{-13}$ g; $r_p = 3.8$ g/cm^3; $v_p = 7.00$ km/s; thus, $r_p = 0.3$ μm.

PRELIMINARY RESULTS

Data from the two-dimensional (2D) computer simulations of hypervelocity impact events for the TICCE/HVI thin films conform to a high degree with the Carey, McDonnell, and Dixon (CMD) equation for all densities tested.

Early examination of the aerogel samples flown on the EuReCa TICCE exhibit signs of shrinkage (~ 6 percent in both length and width). Recovery as a function of time will be monitored.

Visual impacts were observed in the deceleration films covering the polymeric foam capture cell experiments. Perforations are visible in all cells. A flux of 10^{-4} impacts/m^{2-}s (5μm particles) has been calculated for one of the capture cells. Three grains have been removed intact. Work is proceeding to analyze the perforations and remove other grains. The largest impact crater observed on the HVI plate was elliptical (1.85 x 1.34 mm), with a spall zone of 6.2 mm. Figure 2 shows the impact.

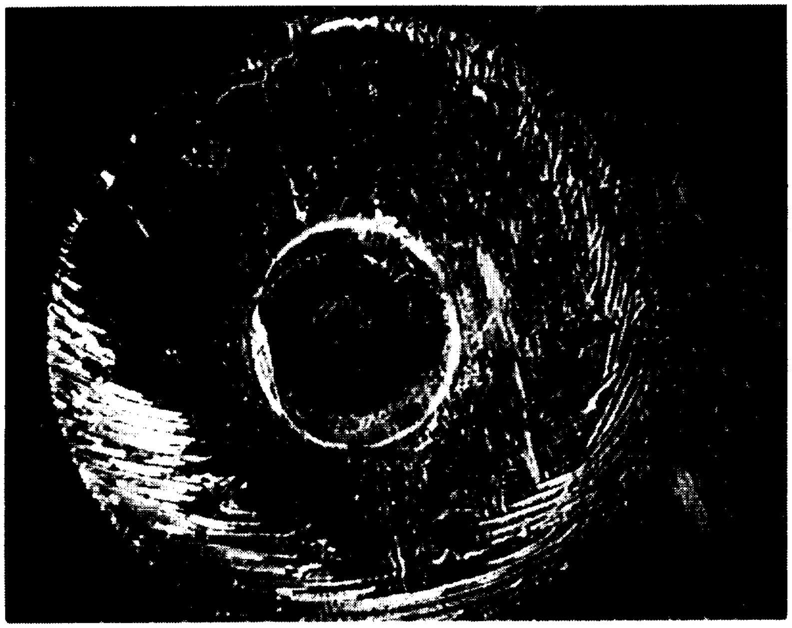

Figure 2. Largest impact observed on the TICCE/HVI experiment.

ACKNOWLEDGEMENT

The authors are indebted to Professor J.A.M. McDonnell for providing space on the TICCE payload to accommodate our experiment.

REFERENCES

1. Bibring, J-P., Borg, J., Langevin, Y., Rosenbaum, B., Salvetat, P. and Surkhov, Y.A., *Lunar and Planetary Sci.* XVI, 55-57, 1985.

2. Tanner, W. G, McDonald, R. A., Alexander, W. M, Maag, C. R., An examination of hypervelocity particle penetration parameters for thin films flown in space, *Intl. Journal of Impact Engineering*.

3. Maag, C. R., Tanner, W. G., Stevenson, T. J., Borg, J., Bibring, J-P, and Alexander, W. M. (1993) Intact capture of hypervelocity impact particles and ejecta, 1st European Conference on Space Debris, esa SD-01.

4. Carey, W. C., McDonnell, J. A. M. and Dixon D. G., An empirical penetration equation for thin metallic films used in capture cell techniques, 85th Proceedings of IAU.