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A STUDY OF METEOROID AND DEBRIS IMPACTS ON THE LDEF ULTRA HEAVY COSMIC RAY EXPERIMENT THERMAL BLANKETS

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ABSTRACT

The Ultra Heavy Cosmic Ray Experiment (UHCRE) occupied the largest area on LDEF of all the experiments flown and was situated on all the faces on the LDEF's periphery except rows 3, 9 and 12. Under contract from ESA (Contract No. 110745) nine sections of the thermal blankets, kept at ESTEC, were delivered to the Unit for Space Sciences for analysis. The blankets were scanned using an automatic scanning system which searched for and logged all perforations in them, the total number being 591. Cumulative fluxes are derived for each of the thermal blankets and the angular distribution of the perforations around the periphery of LDEF is examined. A technique is used for transforming from the laminated teflon structure of the thermal blankets to equivalent thicknesses of aluminium making it possible to compare the large amount of thermal blanket data with that of more conventional meteoroid and debris experiments on LDEF.

1. INTRODUCTION

The Ultra Heavy Cosmic Ray Experiment (UHCRE) was situated on nine of LDEF's twelve peripheral faces and exposed an area of approximately nineteen square metres to the LEO environment. The thermal blankets were of a second surface mirror variety and were originally intended only for the thermal control of the Ultra Heavy Cosmic Ray Experiment (AO178, ref. 1) in the tray below. On the return of LDEF, the thermal blankets were found to be peppered with a large number of impacts and provided opportunity for carefull analysis. This paper describes the results of a comprehensive study performed at the University of Kent under contract from ESA and goes on to discuss some of the conclusions which may be drawn from the results of this study. The thermal blankets were each scanned using a scanning system developed at the Unit which searched for all perforations in them using a photometric method of detection (ref. 2). This scanning system recorded the positions of all the perforations it detected allowing the user to return later and revisit the impacts sites for imaging and analysis.

The Impacts on the thermal blankets were of a very characteristic morphology due mainly to the laminated structure of the thermal blankets (FEP teflon coated with black conductive paint) and its behaviour during the hypervelocity impact process. This morphology may be interpreted to give some indication as to the nature of the impacting particle and this aspect of the analysis is discussed later. Fig 1 shows a schematic of a typical impact feature and Fig 2 an actual impact from the thermal blankets.

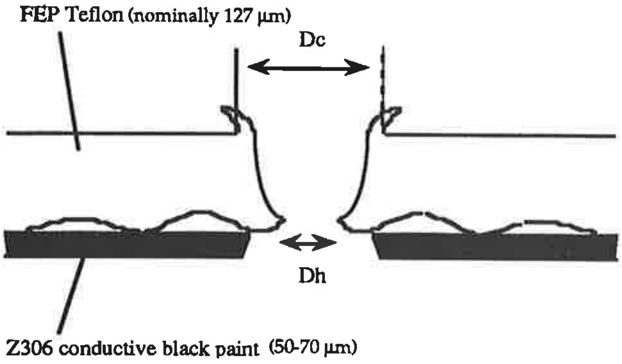

Figure 1. Schematic of a cross section through a thermal blanket impact, showing parameters measured; the upper hole diameter refered to as the crater diameter, Dc and the exit hole diameter, Dh. The paint is bonded to the teflon using a Ag/Inconel primer ~600Å thick.

The main features measured were the dimensions of the entrance hole, Dc and the exit hole, Dh, although in the case of two of the thermal blankets (C08c and A04c) far more information was retrieved pertaining to the dark erosion rings as well as the hypervelocity impact. Full results will not be dealt with here though. but will be made available in the ESA contractor full report. With information on the perforation dimensions it is then possible to go on and make some predictions on the meteoroid and debris environment.

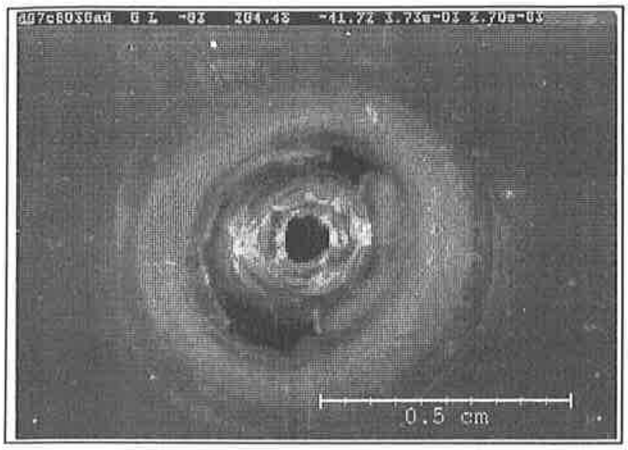

Figure 2. A typical impact feature from thermal blanket d07c showing the characteristic rings and spall features. The field of view at this magnification is 1.9 x 1.4 mm.

2. RESULTS

2.1 The Cumulative Flux Distributions

Crater diameter, Dc and exit hole diameter, Dh, measurements were taken, for all impacts which perforated the black coating. The first, most obvious piece of information which may be derived from these measurements is the cumulative flux distribution which is given as the number of perforations occuring per metre squared per second. The complete set of flux curves for all of the thermal blankets is shown in figure 3.

The flux distributions in figure 3 are largely as one would expect, being aware of the orientation of LDEF. The thermal blankets in the forward facing directions, A10c, C08c, D07c and C11c display a much higher flux than the thermal blankets which were situated away from the ram direction those being A04c, E02c and the South facing covers C06c and B05c. The thermal blanket C06c is a significant one since it is the only cover from the UHCRE to be found on one of the primary faces of LDEF. This is important because it allows direct comparison to be made between thermal blanket data and other important meteoroid and debris experiments, which were situated mainly on the primary faces of LDEF. These included the units own MicroAbrasion Package experiment (ref 3) which was situated on rows 3, 6, 9, 12 and on the space face of LDEF.

Other important features to note on the graph are; in the region of smaller hole diameters and therefore of relatively small particle sizes, the south facing fluxes "cross" the West pointing ones. This also occurs at larger sizes but this is in a region of poor statistics and therefore of little significance. The fact that the fluxes "cross" at small sizes may be significant indicating a difference in particle population. Assuming that the properties of the thermal blankets are all similar i.e. all of similar thicknesses (which is acceptable until the last few months of LDEF's time in orbit, when Atomic Oxygen erosion became a significant factor affecting the thermal blankets), the crossing over of the fluxes can be due only to differing impactor parameters, within the realms of the statistical errors. These varying parameters may be because C06c and B05c

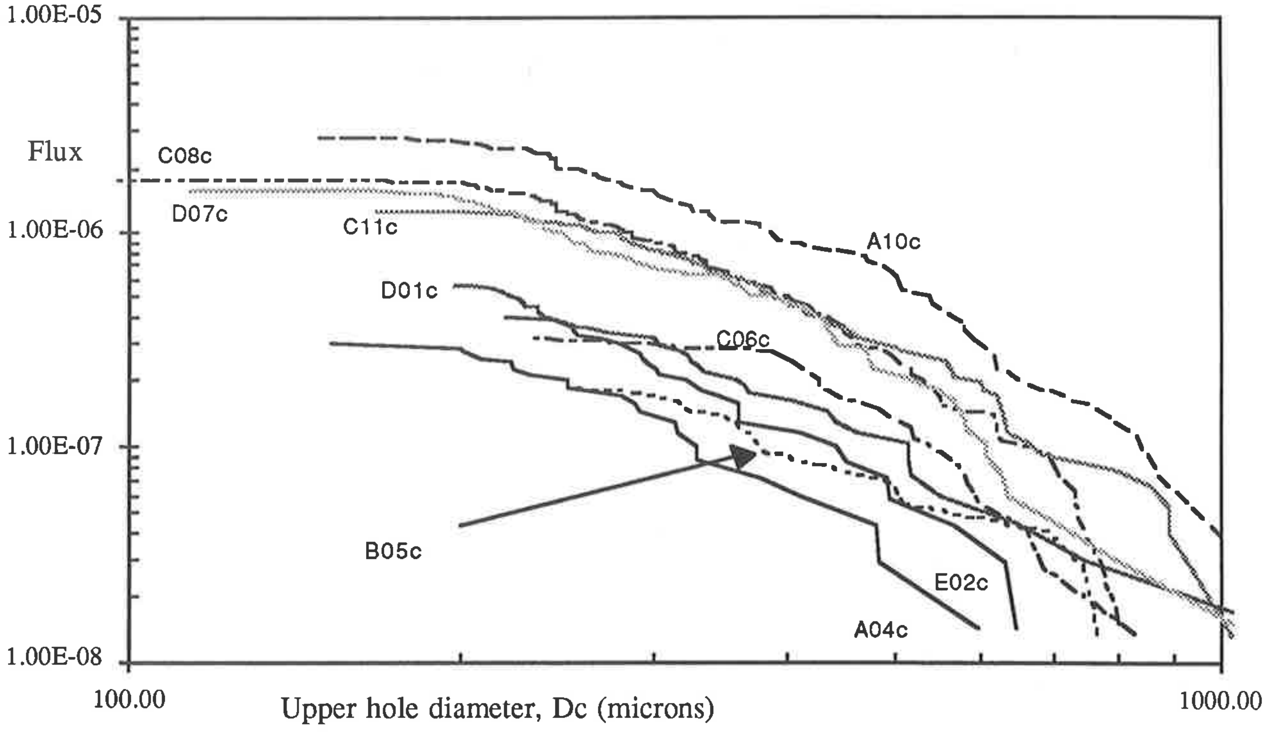

Figure 3. The complete set of flux distributions for all of the thermal blankets scanned.

faced outof the ecliptic plane for the most part of their exposure to the microparticle environment and did not encounter as numerous a population as the rear facing thermal blankets which were in the ecliptic all of the time and exposed to many more faster, smaller particles. The most significant and promising feature of the combined cumulative fluxes though is the fact that they all have lower limit cut-off values at different perforation diameters . This effect appears to be due to differing depth to diameter ratios of the craters at the marginal perforation limit, a feature dependant on the particle properties. Since the thermal blankets were all of similar thicknesses, even before exposure to the LEO environment (see table 1) the differing marginal perforation limits may represent a varying depth to diameter ratio (Tc/Dc) which in turn could imply differences in impactor densities and velocities from face to face around LDEF (ref. 4).

Thermal blanket No.	avge. thickness of thermal blanket (μm)
exposed	
D01c	182.76
E02c	188.59
A04c	167.49
B05c	180.77
C06c	189.76
D07c	163.35
C08c	176.71
A10c	146.47
C11c	169.40
unexposed	
D01c	183.55
E02c	188.62
A04c	169.97
B05c	195.65
C06c	204.11
D07c	194.72
C08c	176.81
A10c	186.74
C11c	210.66

Table 1. The thicknesses of the thermal blankets exposed and unexposed to atomic oxygen erosion.

2.2 The Marginal Perforation Limit.

The diameters of the impact craters were determined at the marginal perforation limit for each of the thermal blankets using the information in figure 3. These are plotted on a polar plot below in figure 4 to illustrate the variation of the marginal perforation limit around the periphery of LDEF. To allow comparison the flux values at the marginal perforation limits are included in figure 5. As would be expected the fluxes are higher for the leading side of LDEF due to its motion and perhaps unexpectedly the marginal perforation limits do not correlate with the fluxes once again illustrating the behaviour observed in figure 3.

In order to determine the crater depth at the marginal perforation limit, we need to know the thickness of the thermal blankets since at the marginal perforation limit this is the crater depth, Tc. The thickness of each thermal blanket was measured by wieghing small sections of the thermal blankets which were exposed to atomic oxygen and shielded from it.

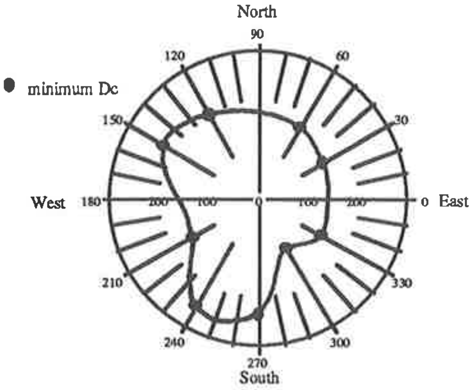

Figure 4. The variation of the crater diameter at the marginal perforation limit for each thermal blanket.

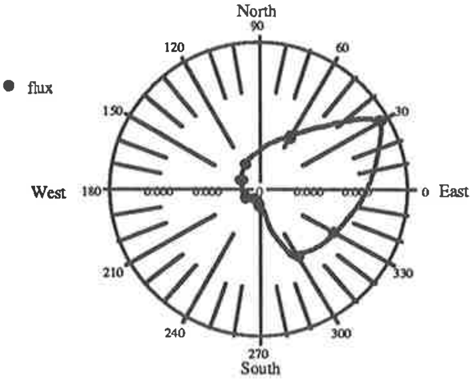

Figure 5. The flux at the marginal perforation limit for each of the thermal blankets examined.

The unexposed sections came from around the edges of the thermal blankets where they were clamped down under the experiment tray lips and therefore shielded from the atomic oxygen environment. The thiicknesses measured are reproduced in table 1 and schematically in figure 6. over the page.

Using these values for the thicknesses of the thermal blankets a ratio for Tc/Dc can be derived for each one. This information is presented also as a polar plot and shown in figure 7 below.

The varying ratio of Tc/Dc proves to be of great interest when viewed as a function of angle around LDEF. It becomes possible by inference to observe the various populations of microparticles in the LEO environment. It can be seen from figure 6 that the ratio Tc/Dc on the leading side of LDEF is much higher than that on the trailing. This effect could be

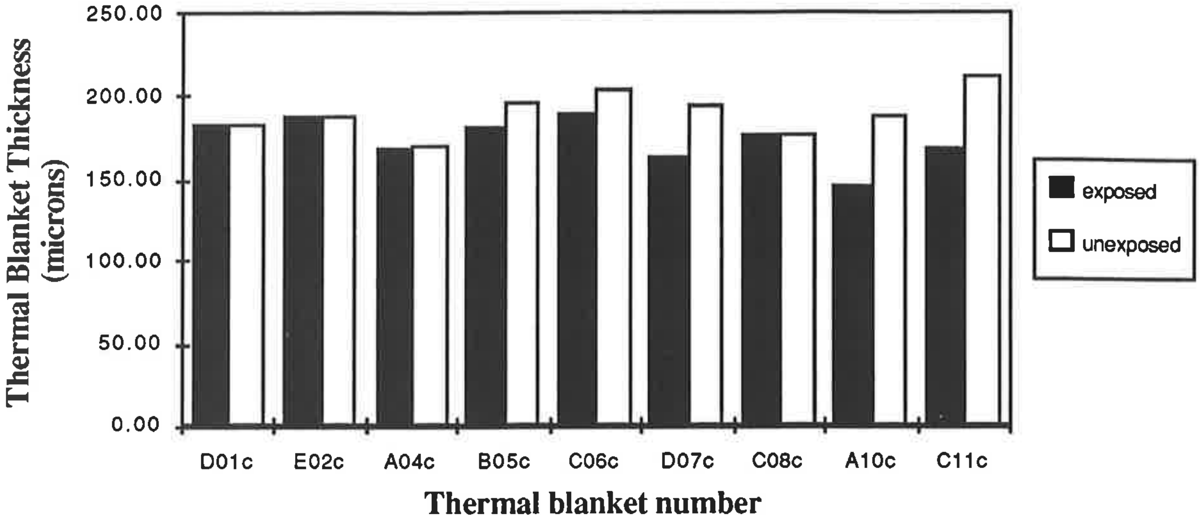

Figure 6. The relative thicknesses of the complete thermal blankets (paint and teflon) before and after exposure to the LEO environment

attributed to relatively high density particles, possibly space debris, which range from 2.8 $g.cm^{-3}$ for large aluminium particles to 4.0 $g.cm^{-3}$ for the more significant aluminium oxide particles from solid rocket boosters (ref. 5). This is unlikely to be a velocity effect because it is on the leading edge of LDEF where all of the impact velocities are of the order of 18 kms^{-1} for unbound particles and about 11 kms^{-1} or less for bound particles, depending on their orientation in orbit. In this region it has been demonstrated experimentally (ref. 6) and and by hydrocode modelling (ref. 7) that Tc/Dc remains constant for particles of similar density. Therefore although the dynamics for such a material are not defined completely it is possible to see from the varying Tc/Dc ratios in figure 6 that there can be found, even at this size regime, differing particle populations.

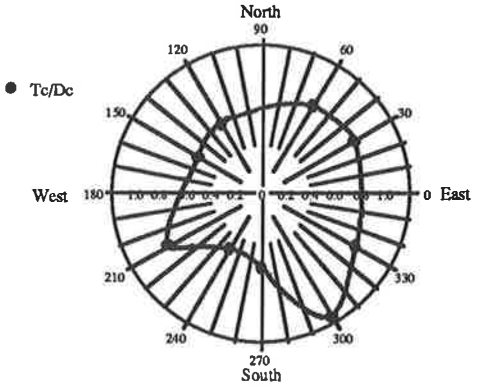

Figure 7. The angular variation of the Tc/Dc ratios for the thermal blankets.

Note that the values of Tc/Dc for rows 5 and 6 compared to row 4 also differ by a relatively large amount suggesting a difference between the impactor properties between these faces.

2.3 Separating Micrometeoroids and Debris

Based on a single premise it is possible to make some tentative predictions about the relative populations of dust and debris in the Low Earth Orbit environment. If, as was stated in the previous section, it is assumed that the impacts with a high Tc/Dc ratio are due to high density, slow travelling particles, typical of orbital debris and consequently the low Tc/Dc ratio impacts are assumed to be created by low density, fast microparticles. It is not possible to determine a Tc/Dc ratio for each impact in a thermal blanket since they are not all marginal perforations but an equivalent parameter in this case is the ratio of exit hole to entrance hole diameter Dh/Dc (see fig. 1). For the debris particles we assume that Dh/Dc ~ 1 and in the case of the fast low density natural particles Dh/Dc < 1. Assumptions have to be made since when analysing the images it is not always easy to see the exit hole spall features particularly when Dh/Dc ~ 1.

With this basic premise it is possible to sort the impacts on each thermal blanket into two categories of natural micrometeoroids and man made debris. In figures 8 and 9 these predictions are presented in the form of percentage populations of the total number of impacts on the face and compared to the predictions of G. Drohlshagen, (ref. 8) determined using ESABASE (ref 9).

As can be seen from the graphs the predictions are not completely accurate when compared to the predictions of theoretical models such as ESABASE but the model is not without its shortcomings, for instance for the debris predictions on the rear face there can be no impacts since ESABASE does not include any elliptical orbits in its debris model, when it has been demonstrated they exist (ref. 10). It is notable that the lack of agreement is in the wake direction of LDEF only and consistent predictions exist between experiment and theory in the ram direction. This behaviourr indicates that there may an additional effect due to the hypervelocity impact process that has not been taken into acount, producing this discrepancy.

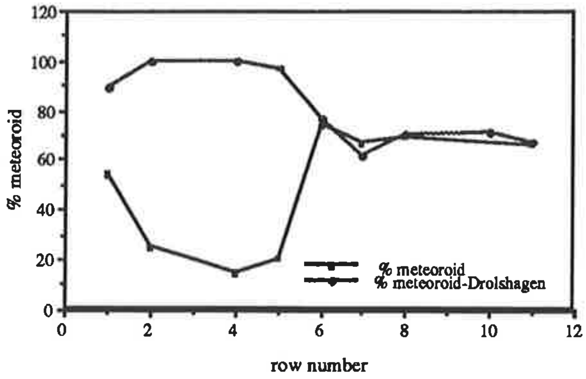

Figure 8. Meteoroid population predictions for the various rows around LDEF's periphery

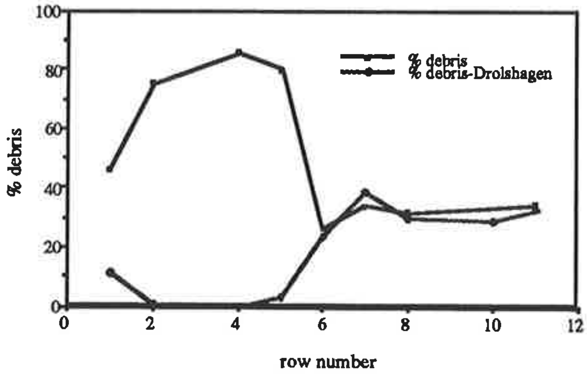

Figure 9. The predictions produced for the debris component of the microparticle environment.

CONCLUSIONS

The UHCRE thermal blankets although unique in their structure, as an impact experiment, hold a great deal of information on the micrometeoroid environment in LEO. Although less than one third of the total area was examined in this study the return was significant. The cumulative fluxes produced are important in their own right as a guide to risk assesment models but with appropriate calibrations in the laboratory may return far more information. Such calibrations are currently underway.

The thickness measurements of the teflon thermal blankets performed for this study are also imporrtant from a materials point of view. When compared with measurements of the Atomic Oxygen environment they provide valuable information about the behaviour of such materials under these conditions.

By examining the marginal perforation limits on each of the thermal blankets it was possible to predict the existence of other sources of microparticles and possibly space debris. This is important when considerintg the size regime encompased by the thermal blankets which is the >100µm size range a region where debris is believed to dominate over the natural micrometeoroid background. The predictions made in section 2.3 although not entirely in agreement with theory demonstrate what is possible and highlight the need for callibration of the thermal blankets.

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