Proceedings of the First European Conference on Space Debris, Darmstadt, Germany, 5-7 April 1993 (ESA SD-01)

AN INVESTIGATION INTO THE RELEVANCE OF IMPACTS ON LDEF FROM MAN-MADE DEBRIS IN ELLIPTICAL ORBITS.

M. J. Neish

Unit for Space Sciences,
University of Kent,
Canterbury, Kent CT2 7NR, U.K.

ABSTRACT

It has recently transpired that the original assumption that man-made debris cannot strike the West or Space faces of LDEF is fallacious. Experiments such as the Chemistry of Micrometeoroids (CME, A0187-1) suggest that a significant portion of impacts on the trailing face have been from debris. For this to hold true, the debris particles must have occupied elliptical orbits with perigees at or below LDEF's altitude and apogees considerably higher. Examples of this are debris in Geocentric Transfer Orbit (GTO particles), with inclinations of 28.5° (Kennedy Space Center launches) and 7° (Kourou lanches). Such particles possess the required orbital elements.

Accepting that elliptically orbiting debris is now an issue to be examined, orbital dynamics shall be combined with impact probability theory in this paper to arrive at possible incident flux directions for particles in elliptical orbits. An application of this technique with regard to the anomalous number of elliptical impacts detected on a South-facing clamp of LDEF is demonstrated.

1. INTRODUCTION

Debris models have until very recently assumed that all debris in Low-Earth Orbit (LEO) occupy circular orbits, mainly due to the effects of air-drag [ref. 4]. These models have been based upon data from the American satellite tracking system (USSPACECOM) two-line elements.

Figure 1 shows a typical debris flux incident on LDEF from debris in circular orbits.

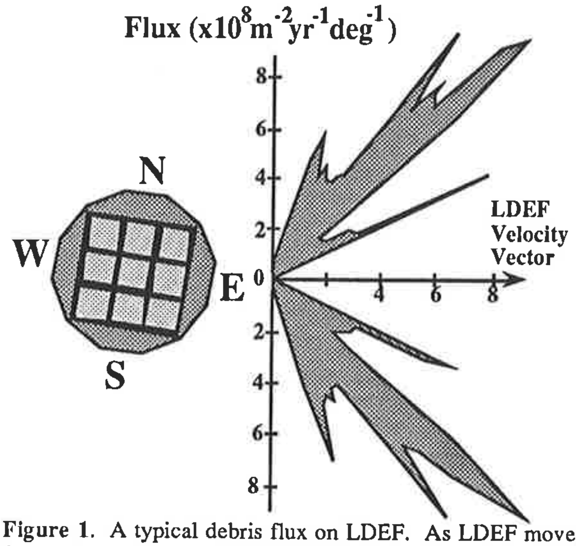


Figure 1. A typical debris flux on LDEF. As LDEF moves from left to right, most of the debris will strike in the form of two "butterfly wings" as shown here. Furthermore, all impacts will occur within the plane of the paper because of the circularity of the debris orbits. Reproduced from ref. 6.

It is obvious that all impacts will occur on the forward-facing peripheral faces and none on either the Space or Earth faces, as all particles will be orbiting in the plane of the paper, with no component of velocity either in or out of it.

Consequently, prior models have assumed that debris was unable to strike the LDEF trailing faces, as in order to do so they would have to be catching LDEF up from behind and would therefore be constrained to elliptical orbits.

To confound matters, the Chemistry of Micrometeoroids Experiment flown aboard LDEF (ref. 13), detected a significant fraction of debris impacts on the LDEF trailing face, shown in Figure 2. The resulting craters displayed the typical hypervelocity tell-tale lips, indicating a substantial normal impact velocity.

The only plausible sources for these craters are particles in elliptical orbits and with low inclinations [ref. 2]. Of these, the most likely causes of the trailing face impacts are particles occupying 28.5° inclination orbits, as they result in a higher normal impact velocity (2.2km/s as opposed to ≈1.5km for a 7° inclination particle) and also have a higher probability of striking the spacecraft.

Particles in these orbits would be hard for USSPACECOM to detect as they spend only a very short time in the vicinity of low-Earth orbit.

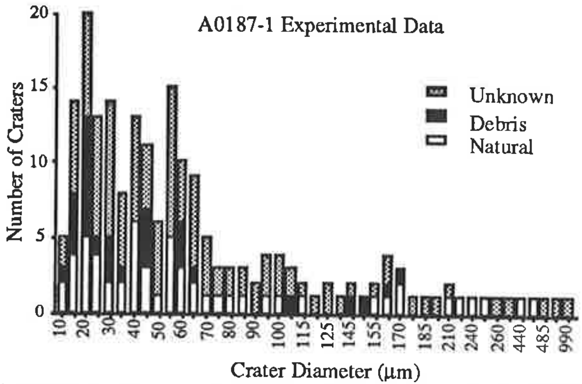


Figure 2. Bar chart showing the results of the CME experiment. The overall percentage of observed debris is ≈15%. Taken from ref. 5.

Low inclination orbits would present an additional tracking problem in that USSPACECOM suffers a "blind spot" in equatorial regions due to a lack of detectors. It is therefore reasonable to presuppose that there may be considerable numbers of objects in these orbits of which we are not aware.

2. DIRECTIONAL SIGNATURES OF PARTICLES IN ELLIPTICAL ORBITS

As a result of the discovery of debris impacts on the LDEF trailing surfaces, models have now been adjusted to take into account the presence of elliptically orbiting debris [refs. 2, 8 and 11].

As a complement to these models and to the ongoing work being carried out at the University of Kent with regard to elliptical craters [refs. 9 and 11], individual debris orbits can be examined for resultant impact angles on various LDEF faces. This may enable observed elliptical craters to be traced back to a possible source, or at least a reasonably confident assertion to be made about their origin. In order to carry out the necessary calculations, one needs to employ collision probability [ref. 1], which implicitly assumes a random distribution of longitudes of nodes and arguments of the perigee. At each position within LDEF's orbit, there are four possible impact configurations, each equally probable, which must be accounted for (shown schematically in figure. 3).

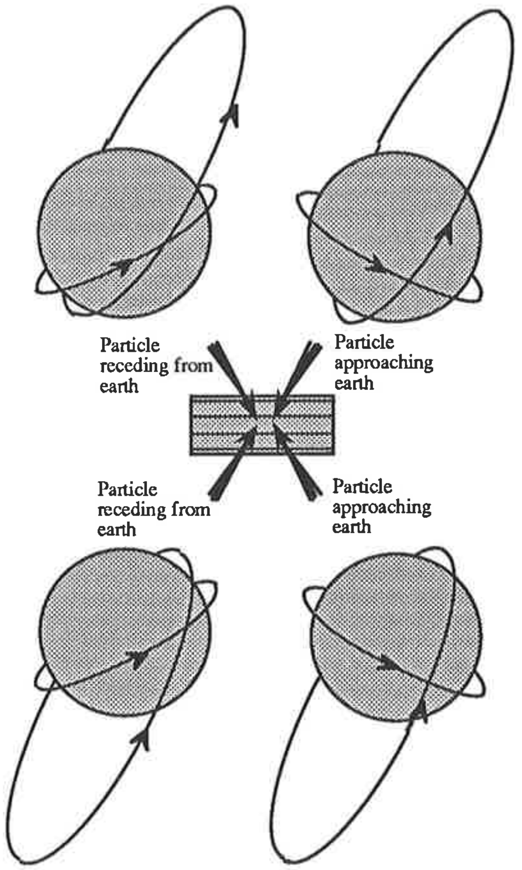
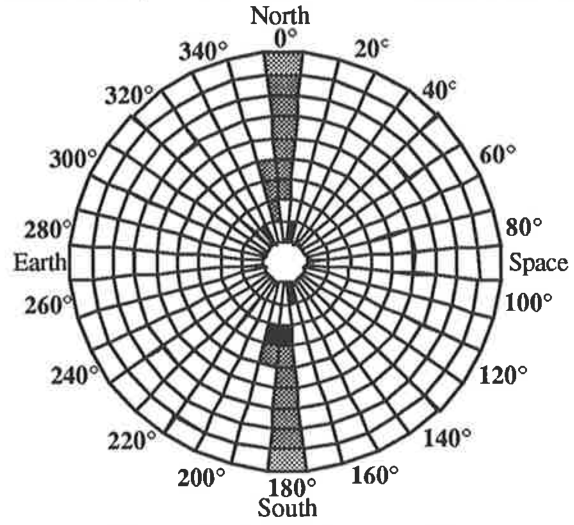
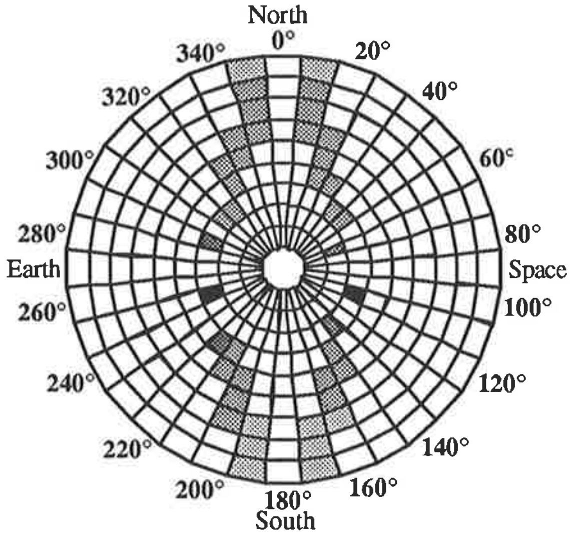


Figure 3. The four possible impact configurations for an elliptically orbiting particle intercepting a circularly orbiting spacecraft.

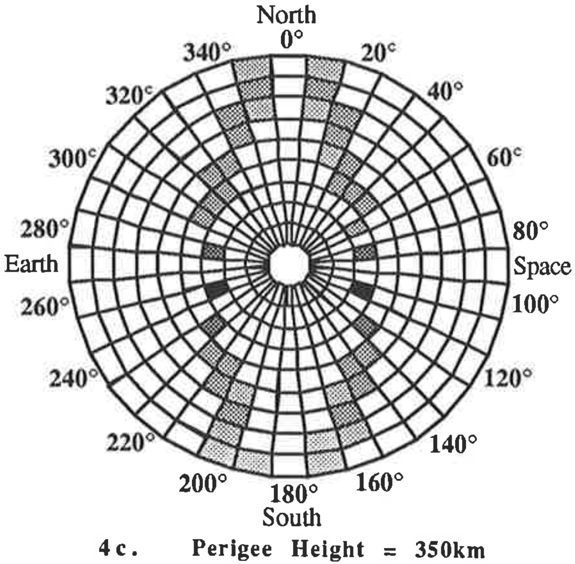
To illustrate the technique at work, figures 4a-d illustrate the directional signatures of a highly elliptical orbit (apogee height = 36000km) at an inclination of 28.5°, intersecting the LDEF trailing face. Such orbital characteristics correspond to that of a man-made particle left in a GTO orbit. The opening out of "lobes" is readily appreciable as one moves from diagrams 4a through d: as the perigee height is gradually decreased from LDEF's altitude to 300km, an increasing radial velocity component results (see figure. 3). Therefore perigee height is an important consideration as it can alter the incident particle direction substantially (as much as 40° in this example). An overall higher flux is observed if the perigee corresponds to LDEF's altitude, on account of the particles spending much more time there.. In figures 4, 5 and 6, radial distance from the centre of the plots indicate impact angle from the normal (in steps of 10°), while the azimuth angle represents direction with respect to other LDEF faces as labelled. Flux is coded in shades of grey, with lighter shades and darker greys signifying low and high fluxes respectively. The flux values themselves are



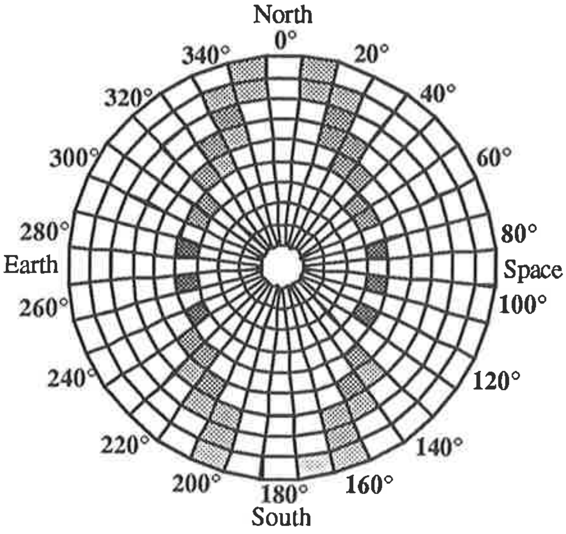
4a. Perigee height = 458km
Apogee height = 36000km



4b. Perigee Height = 400km
Apogee height = 36000km



4c. Perigee Height = 350km
Apogee height = 36000km



4d. Perigee height = 300km
Apogee height = 36000km

arbitrary, for the technique as employed here is merely of a qualitative nature. Information on mean normal impact velocities for each segment can also easily be inferred. The "gaps" observed in the plots, especially in fig. 4d, are not real, but the results of computer binning. General symmetry can be appreciated, although slight *asymmetry* is caused by the 8.4° offset and 1.1° tilt of the spacecraft.

Perhaps a more practical application of this technique is provided by data from one of the South-facing experimental clamps, analysed at Kent (figure 5), which was found to contain an inordinate number of elliptical craters caused by particles apparently originating from the ram direction but with a bias towards Earth [refs. 9 and 11].

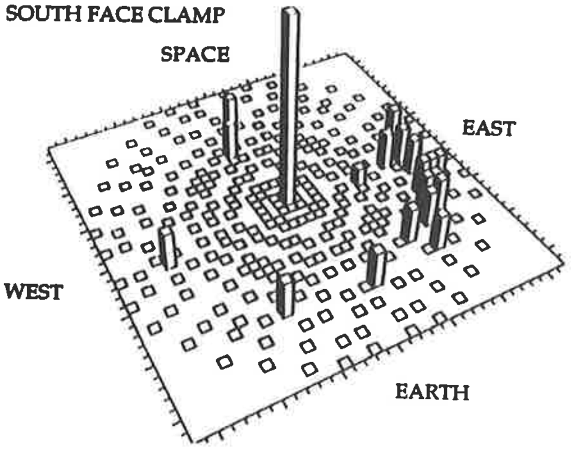


Figure 5. Plot of elliptical craters on a South facing clamp of LDEF, clearly showing the impacts from the Earth direction. The tall bar in the centre represents the unresolved impacts observed. Diagram taken from ref. 11. Experimental data gathered by P. J. Newman at the University of Kent.

Due to the effects of earth shielding it is unlikely that these impacts are of a natural origin A possible explanation for this is provided by small 10μm particles in high inclination orbits, striking LDEF as they recede from the earth. Certain features of Molniya-type orbits appear to favour it as a possible cause:

- At 63.4° inclination, Molniya orbits are at the "critical inclination" where no advancement of the line of apsides is observed. This effect can give rise to an asymmetric flux on LDEF as, for example, particles will be able to strike a South-facing surface as they recede from the earth but not as they approach (see figure 3 and employ some mental acrobatics!). Likewise they would strike a North-facing surface as they approach Earth. It should be interesting to find out if subsequent thorough analysis of a North-facing clamp reveals such a bias towards the Space direction on that surface.

- Small particles with a low perigee would re-enter into the atmosphere in a very short time-scale, thus constraining any small particles detected to a region close to the parent body. Larger particles, which would take longer to decay, would therefore have more time in which to distribute themselves randomly about the Earth. It follows that a stream of particles is more likely to consist of small particles.

Figure 6 shows the signature of precisely such a Molniya type orbit intersecting a South-facing surface. All components with a bias towards Space have been "chopped off" the diagram, as they would only occur if the line of apsides has advanced sufficiently, something not likely to happen if the particles are small, as they would decay long before progressing that far (see second bullet point above).

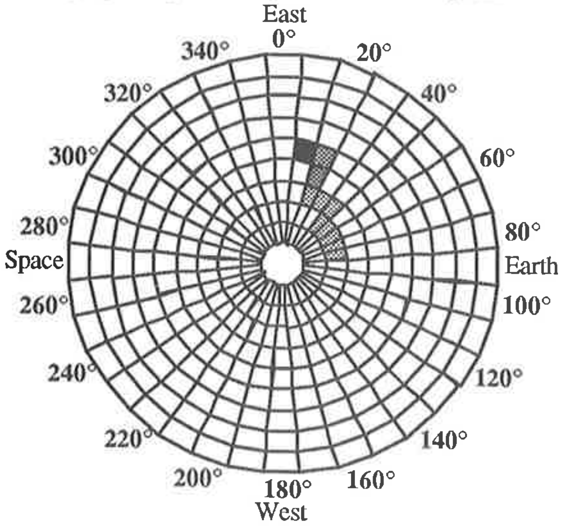


Figure 6. The directional signature of a 63.4° orbit intersecting a South-facing surface of LDEF, perigee height=300km, apogee height=36000km. Mean normal impact velocity=7.7km/s.

Although certainly a plausible explanation for the observed craters, it is by no means conclusive. For one, the highest flux according to the diagram is incident from between 40° and 50° from the normal, and with present knowledge it is hard to predict if such an angle would result in sufficient crater ellipticity to allow an accurate ascertainment of incident direction. The critical incident angle from the normal above which a crater assumes a significantly elliptical morphology is not precisely known, and is dependent on velocity. However, it is shown to be around 60°-65° by hydrocode models [ref. 12].

Another, perhaps more reasonable cause, could be a sporadic event such as the passage of the Space Shuttle plume, or even an aerofragmenting natural particle.

Lastly, figure 7 shows the directional signature of a 98.5° orbit on the South face for comparison with Figure 6. These also provide an Earth bias with incident angles even further from the normal.

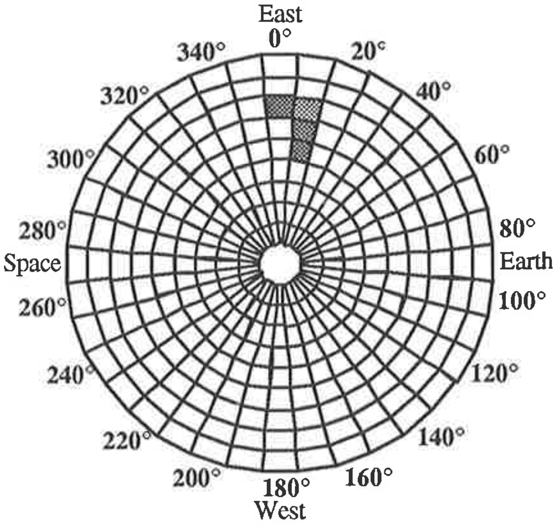


Figure 7. Directional signature of a 98.5° orbit intersecting a South-facing surface on LDEF. Perigee height = 300km, apogee height = 36000km. Only particles receding from the earth are shown, in order to illustrate the Earth bias.

3. CONCLUSIONS

The technique outlined in this paper can serve as a useful complement to debris models, particularly the one being developed at the University of Kent which also provides directional information of a similar nature to that in this paper. The approach here is essentially the reverse of that taken by models. Individual components of the debris environment are looked at in turn, in contrast to the models which calculate fluxes for the entire debris population.

Experimental data, such as the South-facing clamp discussed here, are vital for revealing directional biases which one can then attempt to explain by this method if the models prove insufficient. Models, by virtue of their inherent time-averaging, may be subject to masking the directional effects of elliptically orbiting components behind the more considerable circularly orbiting component. They may, likewise, be prone to overlooking sporadic streams of particles.

Plans for the future entail some predictions of fluxes on other faces of LDEF. For example, if one makes a sweeping assumption that all debris striking the trailing face of LDEF is in a highly elliptical 28.5° inclination orbit, then it is possible to estimate fluxes on all other faces of the spacecraft, including incident angles. It should be interesting to see if elliptical craters are observed on these faces with the predicted orientations, *and* in the predicted numbers with respect to the total number of craters.

By constraining the argument of the perigees and longitudes of the nodes (as with Molniya-type orbits), the effects on effective particle fluxes on LDEF can be further investigated.

ACKNOWLEDGEMENTS

Special thanks to Tony McDonnell, Neil Mackay, Steve Mullen and Simon Green, who bailed me out at a difficult moment. Of course, thank you, as ever, to Miki.

REFERENCES

1. Kessler, D.J., "Derivation of the Collision Probability Between Orbiting Objects: The Lifetimes of Jupiter's Outer Moons", Icarus, Vol. 48, pp39-48, 1981.

2. Kessler, D.J., "Origin of Orbital Debris Impacts on LDEF'S Trailing Surfaces", NASA Johnson Space Center, 1992.

3. Kessler, D. J., Reynolds, R. C., Anz-Meador, P. D., "Orbital Debris Environment for Spacecraft Designed to Operate in Low Earth Orbit", NASA Technical Memorandum 100 471, 1989.

4. Flury, W., Janin, G., Jehn, R., Klinkrad, H., "Space Debris in Elliptical Orbits", Mission Operations Department, Mission Analysis Section, ESA/ESOC, Darmstadt, Germany, 1992.

5. Hörz, F., Bernhard, R. P., "Compositional Analysis and Classification of Projectile Residues in LDEF Impact Craters", NASA Technical Memorandum 104750, 1992.

6. Eichler, P., Rex, D., "The Risk of Collision Between Manned Space Vehicles and Orbital Debris - Analysis and Basic Conclusions", Flugwissenschaften und Weltraumforschung, 1990.

7. Chobotov, V. A., "Dynamics of Orbiting Debris Clouds and the Resulting Collision Hazard to Spacecraft", Journal of the British Interplanetary Society, Vol. 43, pp187-195, 1990.

8. Green, S. F., McDonnell, J. A. M., "A Numerical Model for Characterisation of the Orbital Debris Environment", Proc. of Hypervelocity Impacts in Space Symposium, pp251-256, 1992.

9. McDonnell, J. A. M., "The LEO Microparticulate Environment: LDEF's 5.75 Year Perspective on Orbital Space and Meteoroids", Proc. 1st European Space Debris Conference, this volume.

10. Hörz, F., Bernhard, R. P., Warren, J., See, T. H., Brownlee, D. E., Laurance, M. R., Messenger, S., Peterson, R. P., "Preliminary Analysis of LDEF Instrument AO187-1 "Chemistry of Micrometeoroids Experiment"", Proc. of 1st LDEF Post-Retrieval Symposium, 1991.

11. MacKay, N. G., Green, S. F., Deshpande, S. P., Newman, P. J., "Interpretaion of Impact Crater Morphoogy and Residues on LDEF Using 3-D Space Debris ad Micrometeoroid Models", Proc. 1st European Space Debris Conference, this volume.

12. McDonnell, J. A. M., Gardner, D. J., Newman, P. J., "Hydrocode Modelling in the Study of Space Debris Impact Crater Morphology", Proc. 1st European Space Debris Conference, this volume.

13. Clark, L. R., Kinard, W. H., Carter, Jr, D. J., Jones, Jr, J. L., (ed), "The Long Duration Exposure Facility (LDEF) - Mission 1 Experiments", NASA SP-473, pp127-130, 1984.

14. ibid., pp124-126.

15. Mandeville, J. C., Borg, J., "Study of Cosmic Dust Particles on Board LDEF - the Frecopa Experiments AO138-1 and AO138-2", Proc. 1st LDEF Post-Retrieval Symposium, pp419-434, 1991.