INITIAL RESULTS OF HYPERVELOCITY IMPACT TESTS ON TOUGHENED LAMINATED SPACE-QUALIFIED THIN SOLAR CELL COVERGLASS

P.H. Stokes, R. Crowther, and R.J. Walker

Space Debris Group, Space Department, Defence Research Agency, Farnborough, Hampshire, GU14 0LX, UK

C. Goodbody, and R. Kimber

Space Power Group, Space Department, Defence Research Agency, Farnborough, Hampshire, GU14 0LX, UK

M. Price

Pilkington Space Technology, Unit 2, Kinmel Park, Bodelwyddan, Rhyl, LL18 5TY, UK

R. Roybal, and C. Stein

USAF Phillips Laboratory / VTSI, 3550 Aberdeen Ave., SE, Kirtland AFB, NM, 87117-6008, USA

ABSTRACT

The introduction of satellite constellation systems into low Earth orbit (LEO) during the next decade will require innovative engineering solutions to enable cost-effective mass-production of satellite components. In particular, attention is now being paid to reducing the cost and complexity of solar arrays through the application of large area coverglass. As part of the qualification process, the new coverglasses must be tested for a range of environmental conditions, including their ability to withstand impact from micro-size debris. This is important since most constellation satellites will be located in high debris density regions of LEO. A programme of impact testing is planned to simulate the likely impacts experienced by the coverglasses.

1. INTRODUCTION

The placement of a number of distributed space system architectures into low Earth orbit (LEO) is envisaged over the next decade. These will be predominantly constellations of communications satellites, injected into near polar orbits, within a narrow altitude band between 700 and 800 km. Operation at this spatial region will expose the satellites to an enhanced collision hazard from the background orbital debris environment (Ref. 1). Observations have shown that there is a peak population density of orbital debris between 800 and 1000 km. This increased collision risk from the environment, coupled with the large number of satellites proposed for a constellation, requires designers to evolve innovative technologies for cost-effective mass-production components whilst retaining a high level of impact survivability. Large exposed components such as solar arrays are particularly vulnerable to impact. Therefore it is essential that technical advances in array manufacture are the subject of an impact test program. Only then can the integrity of array operations in the proposed environment be validated. In this paper we explore the process of investigating the suitability of a new large area cover glass technique as applied to the solar arrays of a typical constellation satellite.

2. DESCRIPTION OF PST COVERGLASS

The recent growth in the number of proposed LEO constellation systems has meant that there is an increasing demand for quick, cost-effective methods of producing large volumes of spacecraft components. Traditionally, the manufacture of solar arrays for spacecraft has been labour intensive primarily due to the skill needed to interconnect and lay down vast numbers of small area solar cells onto delicate lightweight substrate. However, if the area of the active cell or module (made from either thin film material or crystalline silicon) can be increased substantially, then the number of components and complexity can be reduced and rapid mass production of arrays becomes possible. This results in impressive volumes of manufacture and large cost savings.

Large area coverglass (~ 250 x 400 mm) is currently being developed by Pilkington Space Technology (PST) for the environmental protection of large area photovoltaic modules. The single glass has to meet all of the usual high quality criteria that PST sets for the manufacture of space qualified products. The glass has to be thin (100 to 400 microns) for economics of launch. This necessitates a degree of strengthening to

Proceedings of the Second European Conference on Space Debris, ESOC, Darmstadt, Germany, 17-19 March 1997, (ESA SP-393, May 1997)

ensure that the large area glass can withstand assembly, testing, launch loads, and use in the space environment.

The strengthening is achieved by first toughening both sides of single large area glass using a proprietary PST process. Then, if thin-film modules such as cadmium telluride are desired, the glass acts as the superstrate upon which the active material is deposited. A second similarly toughened glass sheet is then laminated onto the first sheet to produce a suitably toughened assembly. If the module is to be made from crystalline silicon cells instead of thin film, then the two sheets are laminated together first and then adhered to a matrix of several large area cells.

This assembly is strong enough to withstand the rigours of ground handling and launch. However, uncertainty as to how this new glass substrate would respond to hypervelocity impacts from the LEO space debris environment has precipitated the need for an impact test programme using a ground-based hypervelocity impact test facility. Four different types of glass substrate have been manufactured for the test programme. The characteristics of these samples are summarised in Table 1.

Sample #	Glass type	Laminate composition	Adhesive	Size (mm)
1	PST CMG	200/100 μm	CV2500	40 x 40
2	PST CMG	300/300 μm	CV2500	40 x 40
3	PST CMG	200/100 μm	Teflon	40 x 40
4	PST CMG	300/300 μm	Teflon	40 x 40

Table 1. Characteristics of glass substrate samples

3. DEBRIS ENVIRONMENT RISK ASSESSMENT

As the amount of debris in LEO continues to increase, there is a growing recognition of the collision hazard that this population poses to satellite operations (Ref. 2). This hazard is due to the high energy associated with a hypervelocity collision between debris and a satellite, and has serious implications for satellite survivability. A collision with a sub-millimetre particle can cause significant damage or degradation to a satellite surface, whereas an encounter with a sub-decimetre object can be potentially lethal.

The risk to a LEO constellation satellite is further enhanced, as it will be operating at an altitude and inclination close to the peak density of the debris environment. In order to predict the flux levels of the population of smaller-size debris, that a constellation satellite can expect to encounter, we have used the NASA ORDEM96 engineering model (Ref. 3). We assume data for a typical constellation satellite operating at 700 km, with a 98.2 degree inclination. The predicted flux levels for the debris environment, as at 1 January 2000, are shown in Fig. 1.

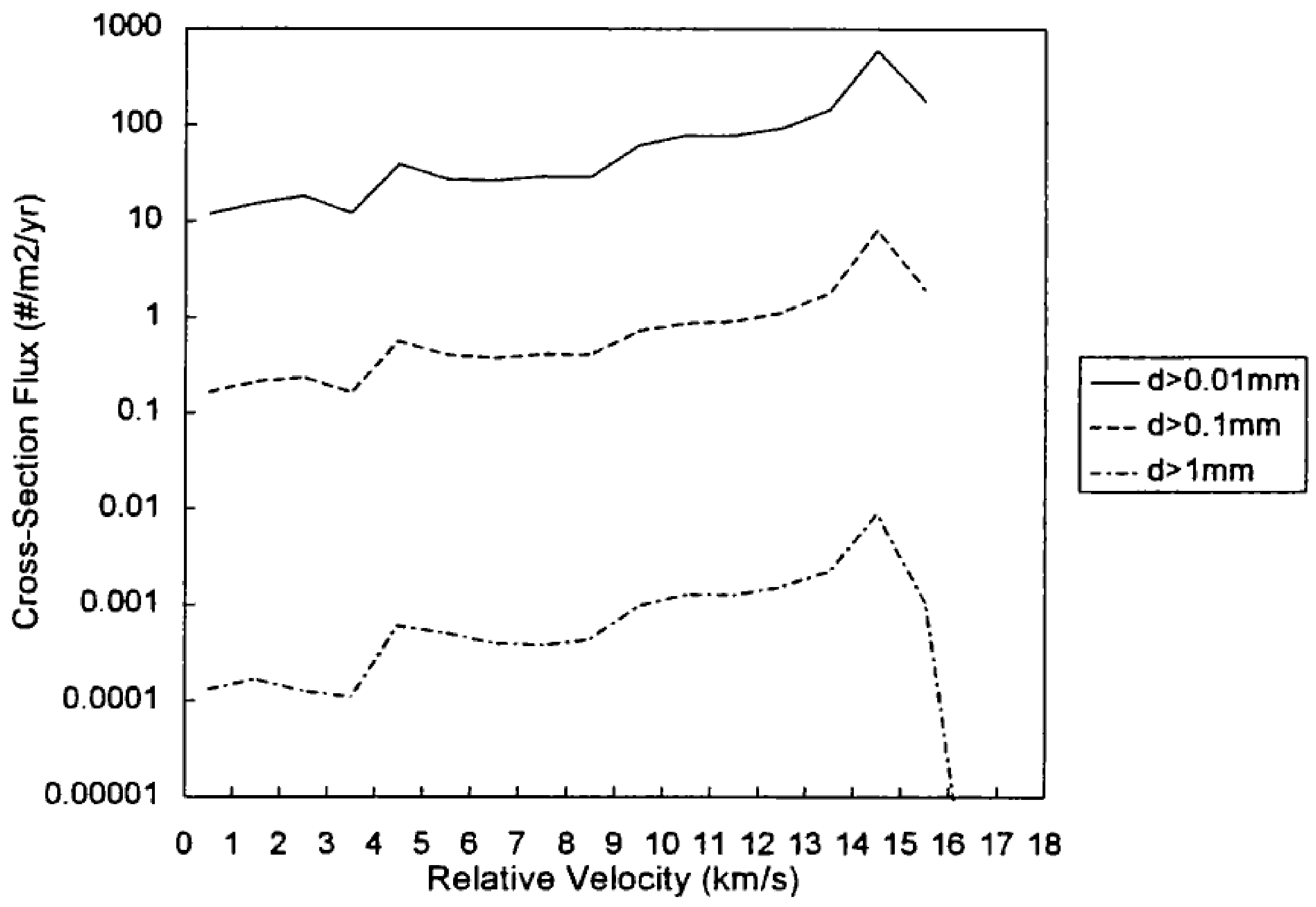

Figure 1. ORDEM96 Flux vs. Velocity Distribution for a 700km, 98.2deg Orbit (1.1.2000)

The flux was examined for three different debris size ranges, i.e. greater than 0.01 mm, 0.1 mm, and 1 mm. We see that the flux level of the population of 0.01 mm+ particles is approximately five orders of magnitude greater than that from the 1 mm+ environment. Therefore for a typical constellation satellite with a ten year life we might expect to see in the region of 100,000 impacts greater than 0.01 mm on the solar arrays, whereas the number of impacts from 1 mm+ particles should be in single figures. At these size regimes, we would not expect to lose the satellite following a hypervelocity impact, but we might anticipate some degradation in the performance of the solar arrays, and the possibility of operational anomalies. Further we must ensure that an impact on a solar array should not introduce a large amount of additional debris into the environment.

In Fig. 1 we also see that the speed of encounter between a target constellation satellite and the impacting debris can vary between 0 and 16 km/s. The most probable impact speed occurs at a value of approximately 14.5 km/s, for all debris objects greater than 0.01 mm.

4. IMPACT TEST PROGRAM

The preceding analysis enabled us to prescribe boundaries on the projectile size and velocity for the impact test programme. 1 mm particles may have the potential to cause significant degradation or operational anomalies in solar array performance, but the small number of expected impacts over the mission life means the overall hazard may be relatively low. By contrast, the damage from an individual 0.01 mm size particle is unlikely to adversely affect a solar array. However the accumulation of many such impacts during the mission life may degrade performance. Therefore we restricted the impact tests to projectiles in the range 0.01 mm to 1 mm.

With regard to the velocities of the impact test projectiles, clearly it would be advantageous to investigate the damage at 14.5 km/s. Unfortunately, for the particle size range of interest, such a speed exceeds the limitations of most hypervelocity impact guns. Currently the typical upper limit is approximately 10 km/s. The desire to try to exceed this velocity, rather than extrapolate data from lower velocity encounters, was one of the reasons for choosing the laser driven flyer method at the Phillips Laboratory Hypervelocity Impact Test Facility.

Given the above boundaries, and the capabilities of the test facility, we were able to construct a prioritised impact test matrix (Table 2). The matrix was arranged so that the four sample types would each be subjected to impacts from representative projectiles with sizes ranging from 0.05 mm to 1 mm, and velocities of 5 km/s and 10 km/s. The objective is to prioritise the test programme on the basis of impact response of the specimen targets.

Shot #	**Sample type**	**Projectile size (mm)**	**Projectile velocity (km/s)**
1 - 4	1 - 4	1.00	10
5 - 8	1 - 4	0.10	10
9 - 12	1 - 4	1.00	5
13 - 16	1 - 4	0.10	5
17 - 20	1 - 4	0.50	10
21 - 24	1 - 4	0.05	10
25 - 28	1 - 4	0.50	5
29 - 32	1 - 4	0.05	5
33	Best 1 of 4	0.01	10
34	Best 1 of 4	0.01	5
35	Best 1 of 4	1.00	> 10
36	Best 1 of 4	0.10	> 10
37	Best 1 of 4	0.50	> 10
38	Best 1 of 4	0.05	> 10
39	Best 1 of 4	0.01	> 10

Table 2. Priority matrix for impact test program

The sample type that is found to be least susceptible to damage from the first set of impacts (shots 1 to 32) is then subjected to a further series of shots. This is to try to establish the effects of impact velocities beyond 10 km/s, and particle sizes down to 0.01 mm.

5. IMPACT TEST FACILITY

The Phillips Laboratory Hypervelocity Impact Test Facility uses a relatively new technique - the laser driven flyer method (Ref. 4) - to accelerate particles for debris impact simulations. The technique has two configurations. In the first configuration a thin metal foil is accelerated by focusing a laser on the interface of a metal foil bonded to a glass substrate, as in Fig. 2. The laser produces a confined plasma at the interface which further absorbs laser energy, generating high pressure to accelerate the flyer toward the target.

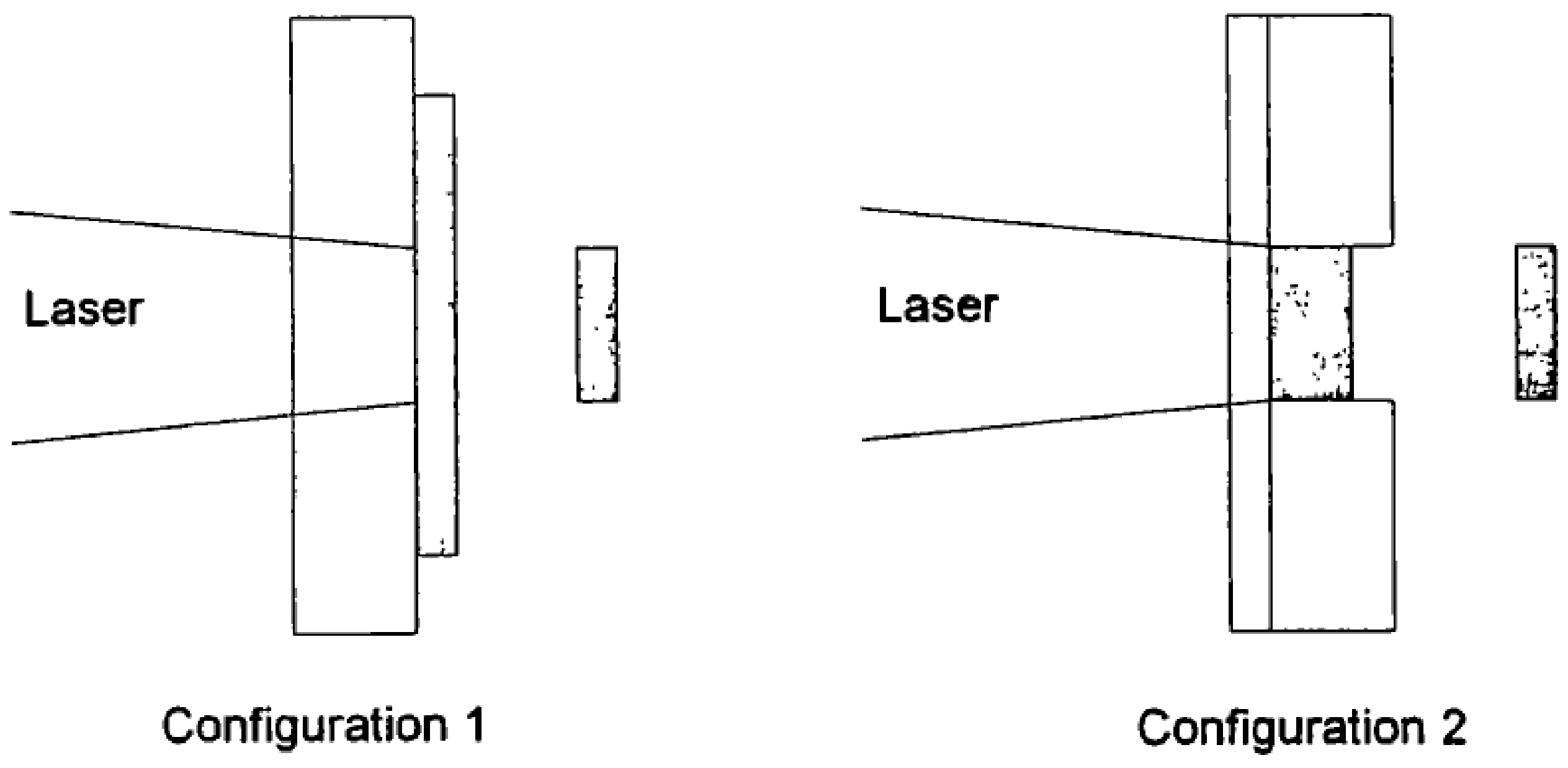

Figure 2. Laser driven flyer technique showing both configurations

In the second flyer configuration, also shown in Fig. 2, the laser focuses on a polymer disc in contact with a metal disc placed in a barrel. The polymer is vaporised and the expanding gas drives the metal disc toward the target.

A high power pulsed laser, capable of up to 20 joules in 20 nanoseconds, is used. Simple optics are used to direct the laser beam onto the flyer. The velocity of the flyer is measured with a VISAR - a laser interferometer which measures velocity from a reflecting surface. A time of flight mass spectrometer (TOFMS) is used to characterise the chemistry produced by flyer impact with a target.

A more complete description of the experimental set-up, and the advantages of the laser driven flyer method over other particle accelerators, is given in Ref. 4.

6. RESULTS

A comprehensive set of damage equations will be constructed to quantify ballistic limit, crater/hole size, and secondary debris cloud characteristics for the chosen candidate material. The resulting equations will be reported in a future paper, and should reveal which of the four laminated glass options is best suited to respond to the broadest range of impact conditions.

7. CONCLUSION

The impact responses of four different types of coverglass, manufactured by Pilkington Space Technology, are being tested using the laser driven flyer technique at USAF Phillips Laboratory. A full test programme has been initiated and targeting strategy outlined. Further investigations are ongoing and will include the development of a comprehensive set of damage equations. The coverglass option which is most ideally suited to withstand the anticipated LEO debris environment will be identified in a future paper.

8. ACKNOWLEDGEMENTS

DRA gratefully acknowledge the contribution that Pilkington Space Technology and USAF Phillips Laboratory have made in the production of this paper.

9. REFERENCES

1. Crowther, R., Stokes, P.H., Walker, R.J., Barrows, S.P., and Swinerd, G.G., Characterisation of the Potential Impact of Space Systems on the Orbital Debris Environment: Satellite Constellations, *Aerosense Conference*, Florida, April 1995.

2. Crowther, R., Marsh, V., Stokes, H., and Walker, R., Interactions Between Space Systems And The Orbital Environment, *SPIE Conference*, Denver, August 1996.

3. Kessler, D.J., Zhang, J., Matney, M.J., Eichler, P., Reynolds, R.C., Anz-Meador, P.D., and Stansbery, E.G., A Computer-Based Orbital Debris Environment Model for Spacecraft Design and Observation in Low Earth Orbit, *NASA TM 104825*, November 1996.

4. Roybal, R., Shively, J., Stein, C., and Tolmak, P., Laboratory Simulation of Hypervelocity Debris, NASA Conference Publication 3341, *19th Space Simulation Conference*, Baltimore, Maryland, October 1996.

Chapter 6

Shield Design, Protection and Validation