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

METEOROID/DEBRIS SIMULATION AT ERNST-MACH-INSTITUT (EMI)
- Experimental Methods and Recent Results -

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ABSTRACT

The EMI-light gas gun acceleration facilities available for the simulation of micrometeoroid/orbital debris impact, as well as high-speed diagnostic installations and special instrumentation to visualize hypervelocity impact phenomena, are described.

Using this equipment, various bumper shield arrangements have been tested in a wide range of particle masses and impact velocities, within the frame of the COLUMBUS Meteoroid/Debris Protection Study (MDPS), presently performed by ESA-ESTEC. Some recent essential results are presented. They demonstrate the effectiveness, but also the limitations and constraints of bumper shield protection systems.

1. INTRODUCTION

Within LEO- and GEO-regions, space vehicles operate in an environment characterized by a growing population of orbital debris.

Collision probabilities with dangerous hypervelocity particles have already reached non-negligible levels, especially for long-term manned missions.

Therefore, appropriate protective measures have to be undertaken in an effort to avoid critical hypervelocity impact damage to space vehicles. For this purpose, essentially "Whipple-type" bumper arrangements are commonly applied (Whipple, 1958). They are designed and evaluated with the help of experimental and numerical simulation methods. In the case of the ESA-module COLUMBUS the experimental simulation work is presently performed at the EMI acceleration facilities.

2. SIMULATION INSTALLATIONS

For the acceleration of particles to simulate micrometeoroid/ debris impacts, two-stage light gas gun facilities are available. The operation principle of light gas guns was already described in 1957 by Crozier and Hume. A detailed description of the EMI acceleration facilities has been given by Stilp (1987). Table 1 summarizes the principal features of those three accelerators and their main pieces of equipment, which are involved in micrometeoroid/debris simulation work. Fig. 1 presents the respective mass/velocity performance diagram for these accelerators.

Depending on their mass, particles in the range between µg and g can be accelerated up to maximum velocities of about 10 km/s by means of these accelerator devices. Their velocity can be measured with high accuracy (error <1%) using appropriate light barrier and microwave Doppler radar systems.

In order to achieve even higher impact velocities, an interesting version of accelerator arrangement is presently under development at the EMI. It takes advantage of the so-called "counterfire method". Two light gas guns, one accelerating the target, and the other accelerating the projectile, are placed in counterfire position. Fig. 2 shows this arrangement schematically. For the acceleration of

	Gun	Tube Caliber [mm]		Basic Instrumentation
		Pump	Launch	
Closed Indoor Range No. 1	single-stage gas (air, He) powder two-stage light gas (He, H_2)	- - 65	30 - 40 10 - 40 25 - 30	semi-automatic honing machine; blast tank (2.5 m^3); impact tank; flash X-ray channels; three 150 kV, four 180 kV, one 600 kV; two shadowgraph stations; TRW image converter camera; Dynafax and high speed cameras; special ballistic pendulum.
Closed Indoor Range No. 2	two-stage light gas (He, H_2)	40	8,5 - 15	semi-automatic honing machine; blast tank (1.5 m^3), impact tank with gas and dust filters; three 150 kV flash X-ray channels; two shadowgraph stations with image converter cameras (< 5 nsec); microwave radar.
Closed Indoor Range No. 3	two-stage light gas (H_2)	15	5	blast and stainless steel impact tank with high vacuum pump system (10^{-6} torr); two nanolite shadowgraph stations; equipment for impact flash measurement (time-resolved spectroscopy).

Table 1: Description of acceleration facilities.

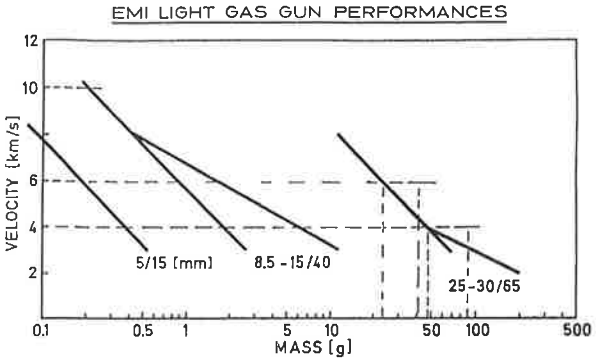

Figure 1: Mass-velocity performance diagram.

sufficiently large target samples a fourth 50 mm caliber light gas gun facility is available at one of the EMI proving grounds. The fact, that in this method mass, shape, physical state, and encounter velocity of the projectile are strictly defined quantities, is highly advantageous. In special shaped charge methods, which also yield jet tip particle velocities beyond 10 km/s (e.g. Bol, 1992), these quantities are generally not sufficiently defined.

High speed diagnostic equipment, like flash X-ray tubes and image converter cameras, are also available to record the dynamics of impact penetration and perforation processes. Flash X-ray exposure times are in the order of 30 ns. Individual tubes triggered in sequence thus allow records of very fast processes. Minimum framing intervals of image converter cameras available at the EMI are in the order of 1 μs, at exposure times of about 200 ns. For example, these techniques are used to study the development and the propagation of behind bumper fragment clouds. Qualitative evaluations of the kinematic fragment cloud parameters can also be obtained from size frequency and spatial distributions of craters produced by behind bumper fragments within back-up plates. For this purpose a versatile automatic image processing system is available.

A planar impact facility equipped with a so-called VISAR (Velocity Interferometer System for Any Reflector) has been used to simulate fragment cloud impact into back-up plates by means of flat low density disc impactors. Stresses within the plates have been determined using the VISAR system in combination with corresponding pressure measurements by means of carbon gauges. This facility consists essentially of a normal large caliber combined powder and single stage gas gun and the interferometer system with a high performance laser. All types of target rear side movements including shock spallation effects can be recorded.

3. EXPERIMENTS AND RESULTS

3.1 Normal Impact on Bumper Systems

"Whipple"-type bumper systems have been investigated within a wide range of target and projectile parameters. Different configurations of single bumper as well as dual bumper systems (1.bumper plate - 2.bumper plate - back-up plate) of Al have been tested. Comparative experiments with Kevlar bumpers and Kevlar/Al-laminate bumpers have been performed. The results obtained have been reported in detail by Schneider et al. (1991). The main conclusions from these results are the following:

a) For equal areal density, dual bumper systems are more effective than single bumper systems. This means that application of the so-called "multi-shock concept" (Cour-Palais and Crews, 1990) can reduce the shielding mass.

b) There is evidence, that combinations with the second bumper consisting of Kevlar are more effective than pure Al- configurations. Favourable shielding results have also been obtained with Al/Kevlar-laminates for both bumpers.

c) For particles in the mass range ≥ 1g existing shielding concepts are insufficient, at least as long as tolerable shielding masses are considered.

d) Particles with velocities around 3 km/s are most dangerous due to ineffective fragmentation during bumper penetration.

3.2 Oblique Impact Experiments

The experiments have been completed by an oblique impact series on dual bumper systems.
Generally, the fragment cloud behind the first bumper is split into two components with different expansion directions (Fig. 3). One cloud component, consisting mainly of projectile material, continues to move in impact direction; the other, containing a higher amount of target material, expands below the impact site tending towards the direction of the plate normal (see also Schonberg and Taylor, 1989). This enhanced degree of fragment dispersion is favourable because it leads to decreased loadings of second bumper and back-up plates.

Impact damage effects have been evaluated from crater characteristics on second bumper and back-up plates and from image converter camera records of fragment clouds.

With impact angles increasing, more and more ricochet fragments are ejected at very small angles with respect to the bumper front surface. As can be seen from witness plates, they can cause considerable damage (Fig.4).

All oblique impact experiments and respective results have been reported in detail by Schneider et al. (1992). Compared to normal impact, the degree of back-up plate damage is generally smaller in oblique impacts.

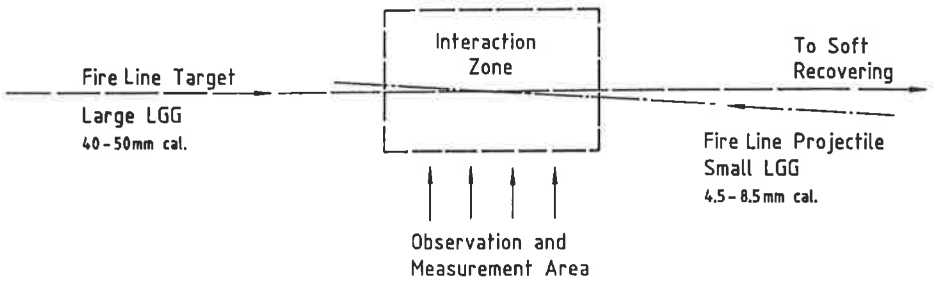

Figure 2: Scheme of "Counter-Fire" principle.

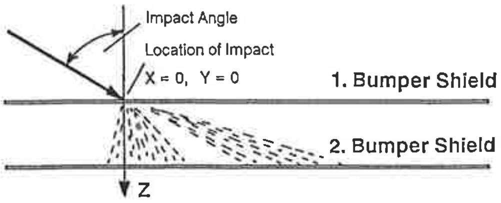

Figure 3: Oblique impact fragment distribution.

Figure 4: Damage in witness plate caused by ricochet fragments
(Impact of a 5 mm diameter Al-sphere on a 0.8 mm Al-bumper at an impact angle of 75° and a velocity of 7 km/s).

3.3 Impacts into cooled targets

Comparative experiments, applying dry-ice-cooled targets, have been performed in order to detect eventual temperature dependencies (e.g. influence of increased brittleness) of the impact behaviour. The temperature range applied was between room temperature and -76°C. Up to now, no significant influence of the bumper temperature has been observed, neither in the bumper plate nor in the back-up plate damage characteristics. The number of experiments at lowered temperatures, however, is still poor.

3.4 Impacts into pressurized targets

In orbit the COLUMBUS wall will be stressed due to internal pressurization. In order to find out the impact behaviour and damage effects of a back-up wall under a realistic stress distribution, several impact experiments with the back-up plate connected to a special pressure reservoir have been performed. The targets were configurated in a way, that COLUMBUS orbit conditions were simulated as closely as possible (representative size, cylindrical plate shape, pressure difference adjusted to yield realistic wall stresses). The experiments have been performed with and without bumpers. Thus, fragment cloud impact as well as direct particle hit have been simulated. By means of slits of different lengths, which were sawed into the back-up plates and tightly re-closed by a rubber platelet, the effect of artificial pre-damages of different degrees has been investigated. The results have also been reported by Schneider et al. (1992). Fig. 5 shows the case of a back-up plate burst damage which was initiated by a behind bumper fragment cloud originating from a 10 mm diameter particle impact.

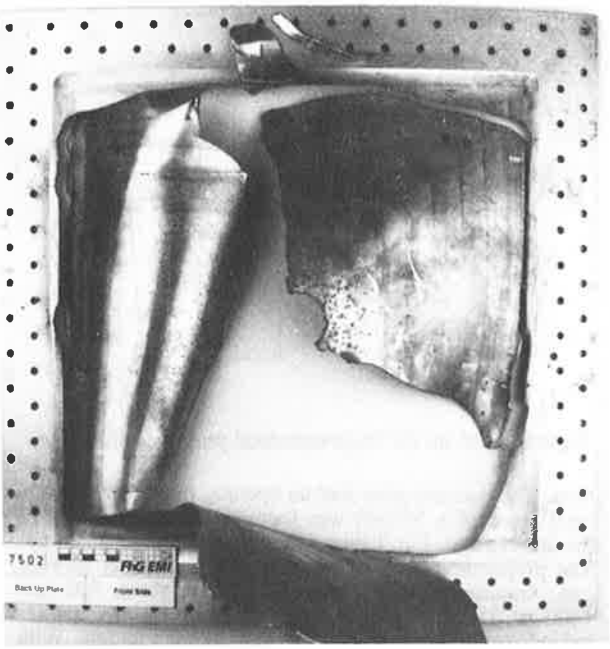

Figure 5: Disrupted back-up plate due to pressurization (Impact of a 10 mm Al-sphere at 5.2 km/s on a 0.8 mm Al-bumper at a spacing of 90 mm).

3.5 Planar impact of low density projectiles

By means of Manganin gauges attempts have been undertaken to measure pressure levels within back-up plates undergoing fragment cloud impact. However, due to the random nature of individual fragment impacts, the pressure signals obtained were not sufficiently reproducible and in favourable cases gave only the order of magnitude of the respective pressure levels.

Therefore, pressure signals produced by behind bumper fragment clouds have been simulated by means of flat polycarbonate discs (density 1.2 g/cm^3), substituting fragment clouds. They have been fired onto a sandwich-type Al-target shown in the section sketch of Fig.6. Two Carbon gauges were mounted between a target plate of 1.6 mm thickness and a backing plate of 10 mm thick-

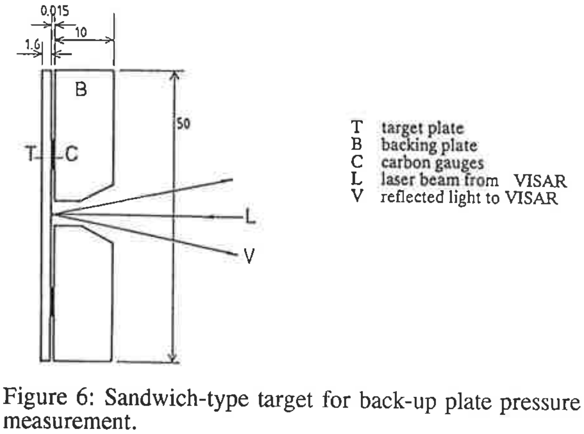

Figure 6: Sandwich-type target for back-up plate pressure measurement.

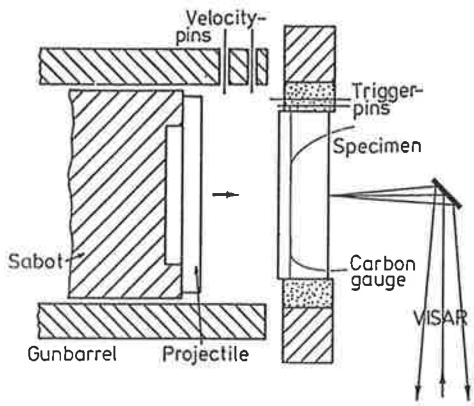

Figure 7: Set-up for fragment cloud pressure simulation.

ness. The backing plate had an opening through which the laser beam of a VISAR was focussed on the rear side of the target plate. Fig.7 shows the total experimental set-up. The projectile was accelerated in a large caliber powder gun. Impact velocities ranged between about 500 and 1400 m/s, according to expected fragment cloud velocities behind second bumper plates of dual bumper targets. With the VISAR the free surface velocity of the target rear side was measured. From this velocity and the shock wave velocity the pressure in the target plate was calculated (Nahme et al., 1992). In parallel the pressure profile was measured by means of the Carbon gauges. Both results are in good agreement. As examples, Figs. 8 and 9 show a Carbon gauge record and a VISAR velocity record of the target plate rear side, respectively.

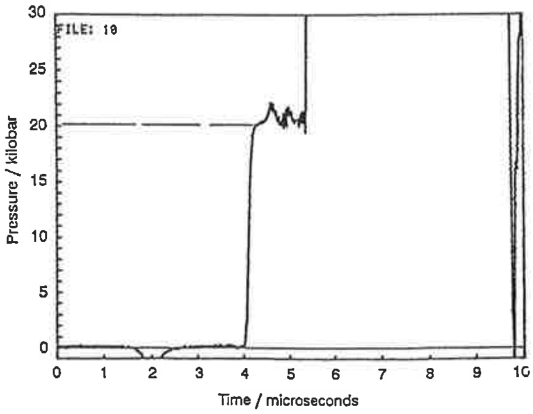

Figure 8: Example of a carbon gauge pressure record.

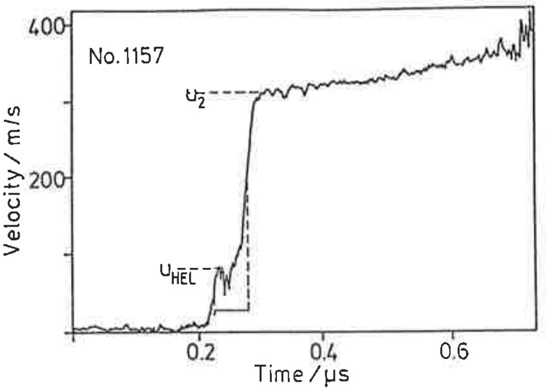

Figure 9: VISAR-velocity-time record corresponding to the pressure signal of fig.8.

4. SUMMARY

The described facilities and experimental results demonstrate, that by means of simulation experiments, many aspects of debris impact processes can be investigated within a realistic range of impact velocities.

Efforts are undertaken with the objective to still increase this experimentally accessible range of impact velocities.

The results obtained up to now demonstrate, that for the COLUMBUS Meteoroid/Debris Shield System further optimization experiments, especially involving fibre-reinforced materials, are necessary.

The phenomenon of catastrophic impact bursting of the pressurized module hull should be investigated in a parametric study.

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