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Stardust cometary and interstellar dust collector calibration: modelling impacts on Al-1100 foil at velocities up to 20 km s^{-1} and comparison with experimental data.

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Abstract

We demonstrate cometary and interstellar dust size calibration using computer simulations of impacts on the foil sections of the collector on NASA's *Stardust* [1] mission. We have used the *Ansys Autodyn* [2] software package to model impacts into Stardust foil (100 µm thick Al-1100) at velocities from 1 – 20 km s^{-1} with silica and soda-lime glass projectiles with diameters between 500 nm – 22 µm. Experimental data from light gas gun (LGG) shots of projectiles with tightly constrained size are compared with modelling results to create multiple validation tie-points for impacts by small particles at the Wild 2 cometary dust encounter velocity of 6.1 km s^{-1}. Following experimental validation for a range of velocities from 1 to 7.5 km s^{-1}, the numerical model is then used to extrapolate to crater dimensions expected from higher velocity impacts by interstellar dust grains with diameters of 2 and 20 µm.

Modelling details

A Cowper-Symonds [3] strength model and a Mie-Gruneisen equation-of-state were used as material parameters for the Al-1100 target. This strength model enables the modelling of the effects of the very high strain rates (>>10^{8} s^{-1}) present during the impact. A 2-D 300 (y) x 200 (x) cell half-space Lagrangian mesh was used to model the target. The mesh was graded so as to give a high resolution (cell size = 0.05 x projectile radius) at the impact region. Shock transmission boundaries were placed on the edges of the target to emulate a semi-infinite target.

Experimental methodology

Shots were performed using the Kent two-stage LGG [4]. The projectiles were monodisperse silica (for projectiles with diameter < 10 µm) and soda-lime glass spheres (diameters > 10 µm) commercially available from Micromod (Germany) and Whitehouse Scientific (UK) respectively. SEM/EDX imaging of projectiles and impacted foil targets was carried out at the Natural History Museum using a carefully calibrated JEOL 5900 LV SEM. Craters were measured following the method of [5]; crater diameters, D_C, were defined as the distance from top of the crater lip to the top of the diametrically opposed crater lip.

Comparison with experimental data (6 km s^{-1})

Numerous experimental data from earlier work [6] are available for comparison to modelling of larger craters (> 40 µm diameter). However, most Stardust cometary craters are much smaller [7], prompting us to perform a new suite of calibration experiments [8]. Our projectiles now also overlap the size range appropriate for calibration of interstellar dust impacts on Stardust, although we cannot achieve the high velocity range [9] by LGG.

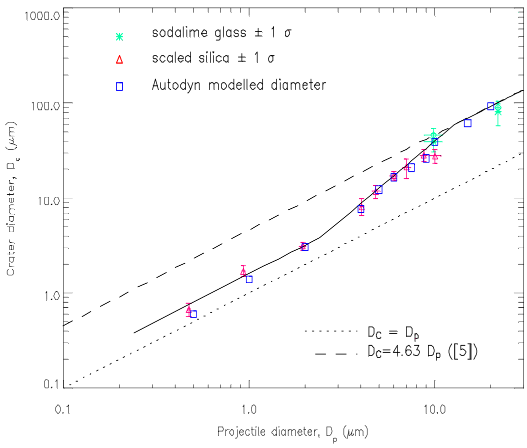

Figure 1: *Autodyn* modelled data vs. experimental data for impacts at a velocity of 6.1 km sec^{-1}, note good agreement between experiment and model.

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To take into account the density difference between the two projectile materials (ρ_{silica} = 2.2 g cm^{-3}, $\rho_{sodalime}$ = 2.4 g cm^{-3}), silica crater diameters were increased by 4%, according to the formula of [6]. *Autodyn* model output is in very good agreement with the experimental data. In particular the change of the projectile and crater size relationship seen to occur in shots of grains between 2 and 10 µm is well reproduced, we attribute this to a function of the higher strain rates produced by impact of smaller projectiles.

Impact speeds above 6.1 km sec^{-1}

Sawle [9] detailed experiments with Pyrex spheres accelerated using a plasma rail-gun to a velocity of approximately 15 km s^{-1} and then impacted onto Al-1100 and Al-2014 T6 foils and semi-infinite targets. The results for impacts on semi-infinite Al-1100 are summarised in Table 1. Also given are the results from our *Autodyn* simulations (using the same parameters as above) for glass spheres within the diameter range as [9]. The last column in Table 1 gives the crater depth.

Table 1: Experimental and modelled crater dimensions for a 125 µm diameter Pyrex projectile impacting an Al-1100 target at 15 km s^{-1}.

	V (km sec^{-1})	D_p (µm)	D_C (µm)	Depth (µm)
Sawle [9]	15 ± 0.75	127 ± 25	965 ± 48	474 ± 28
Autodyn	15.00	125.00	1023.00	491.00

Autodyn output for a modelled 125 µm diameter glass projectile falls close to experimental data of [9], within 5% (although just outside stated errors), giving us confidence in the accuracy of the Al-1100 strength model at high speeds.

We next modelled the crater diameter expected for 2 µm and 20 µm glass projectiles as a function of impact velocity (Fig. 2). The larger projectiles show that crater size is controlled by velocity over the whole range, albeit with different behaviour above and below 6 km s^{-1}. Smaller projectiles, however, do not show a substantial change in crater diameter. More modelling is needed to establish if the difference in behaviour is again due to strain rate effects.

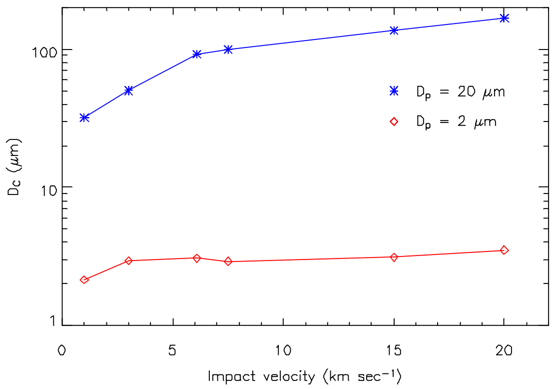

Figure 2: Modelled crater diameter versus impact velocity for 2 µm and 20 µm diameter projectiles

Conclusions

We can now present a model for craters on the interstellar collection foils of *Stardust.* The model has been optimised to work for micron scale projectiles and over a wide speed range (up to 20 km s^{-1}). We find that the model accurately predicts the crater diameter for projectile diameters of 500 nm – 30 µm at 6.1 km s^{-1}. For particles smaller than 2 µm, the crater diameter is virtually constant for impact velocities between 3 - 20 km s^{-1}. Large projectiles show a dependence of crater size on impact speed, which differs above and below 6 km s^{-1}. We hope soon to be able to compare our models with results obtained experimentally from high speed shots at the Heidelberg dust accelerator.

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