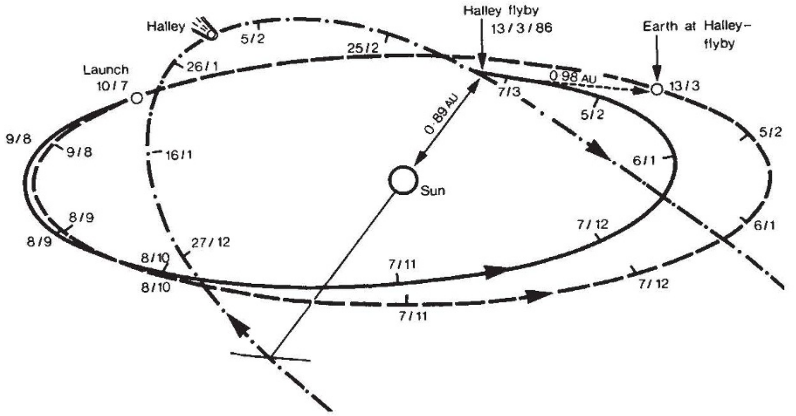
Astronomy

Giotto spacecraft in danger

from Max K. Wallis



Reference trajectory of Giotto spacecraft

ESA's interplanetary spacecraft Giotto will fly by comet Halley in March 1986 on a trajectory that will bring the spacecraft within a few hundred kilometres of the comet nucleus. It is intended that it should pass through the scientifically interesting, relatively dense part of the dust cloud surrounding the nucleus. This will inevitably disturb the spacecraft's attitude, and could lead to a loss of information. An important consideration in the design of Giotto has therefore been to identify the exact cause of the disturbance so that appropriate countermeasures can be taken.

Giotto will be spinning nominally at 15 r.p.m. and is equipped with a two-element shield to protect its vital equipment from damage by dust particles impacting at a relative velocity of 69 km s^{-1}. The outer 1-mm aluminium 'bumper' shield causes small particles to fragment and vaporize, while the inner Kevlar sheets, some 25 cm behind it, protect against the expanding debris.

It was first thought that impacts of 10–100-mg grains would present the greatest danger, for at 69 km s^{-1} these might only partially fragment, smash through several millimetres of shielding and perhaps disrupt crucial components. But it is now realized that the mission is endangered by still smaller grains causing tilts of the axis by more than 1 degree, the width of the transmitted radio-beam. There is no rapid re-orientation mechanism, so once contact with Earth is lost the spacecraft would pass far through the comet and lose much of the scientific data before the transmission link could be restored.

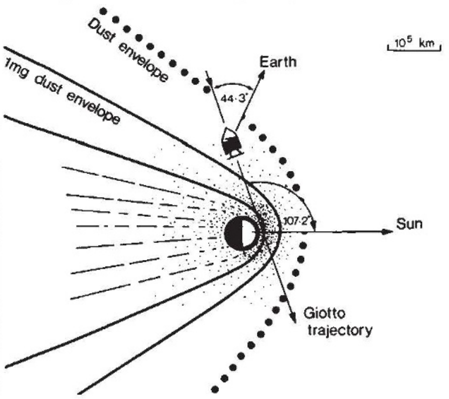
The present strategy is to fly as close to the comet as feasible without substantial risk of exceeding the 1-degree perturbation. So it is important to calculate that risk carefully. One aspect of the calculation is inevitably uncertain, since the actual dust particle fluxes and sizes will only be known from studies carried out once comet Halley has brightened in the months before the encounter, and indeed will only be accurately determined by the Giotto mission itself.

A second difficulty is that impulses due to the 69 km s^{-1} impacts cannot be simulated in practice. When ESA scientists Coupe and Dean first studied the problem (*ESA J.* **7**, 15; 1973), they assumed that impacting particles simply give up their momentum to the spacecraft. Totalling the impulses over a theoretical distribution in size, they found that the rare largest particles cause the greatest perturbation. They therefore devised a Monte-Carlo calculation to simulate stochastic impacts ranging over size and position and found tilts of the axis of around 1–2 degrees and infrequently of several degrees.

But impacts at 69 km s^{-1} do not simply deliver momentum. As shown by experiments with dust particles moving a factor of 10 more slowly, they cause vaporization of a much greater mass of material which, if it escapes anisotropically, can exert many times greater an impulse than the initiating momentum. Tony McDonnell of the University of Kent conducts such experiments and, extrapolating from his group's and others' results, has pointed out that a multiplication factor of around 40 is in order. This perhaps applies only to particles of less than a microgramme in mass, for larger ones penetrate to the inner shield or even further, where the vapour they release does not penetrate primarily forwards.

As technical factors limit experimental particle speeds to about 10 km s^{-1} or exceptionally 20 km s^{-}, laser impacts are being studied as a way to simulate the 69 km impacts. Recent laser experiments at SERC's Rutherford-Appleton Laboratory (W.M. Burton *Adv. Space Res.* **2**, from the COSPAR Symposium on 'Impact processes on solid bodies', 1982) and France's Ecole Polytechnique (J-P. Bibring *et al. J. Phys.* **44**, L189; 1983) have demonstrated crater formation analogous to that from dust impacts. The impulse in some cases is sufficient to penetrate 0.5-mm aluminium sheets. If the scaling factors relating them to solid particles can be established, the high-power laser bursts will be the best way of simulating hypervelocity impacts.

Another feature of Giotto is that its shield and exposed instruments present asymmetric surfaces to the oncoming dust. The ESA scientists decided that because the spacecraft rotates, the net effect of unbalanced impacts would be zero. I have challenged this as conceptually flawed. The situation is analogous to an unbalanced spinning top, or more accurately, to an unbalanced gyroscope in a head wind: the asymmetric torque induces a precession of the rotation axis, the precession angle growing with time. For the spacecraft spinning in free space, the mathematical problem is a classical demonstration of the use of Euler's equations: the angular momentum vector wanders in inertial space at the same time as the spacecraft axis precesses. While Giotto rotates once every 4 seconds, the precession which depends on anisotropy in inertial moments has a 35-s period. I calculate that on the planned spacecraft trajectory through comet Halley, the angular momentum vector tilts by up to 1.5 degrees and combines with a precession of ±0.5 degrees, depending on the actual momentum factor. Thus the mission appears at risk not only from possible milligramme-sized impacts, but also from



Geometry of the Giotto encounter with Halley.

the 'rain' of non-penetrating microgramme dust.

The scientific controversy needs to be resolved quickly. As the spacecraft design is well advanced, it will be necessary to decide whether to meet the problem, for example, by attaching counterbalancing sections to the shield to improve symmetry. The higher-mass grains that penetrate the outer bumper and generate puffs of vapour between the shield sections have not yet been taken into account, as their modelling and calculation present difficulties — it may be that laser impacts on a scale model can help quantify and test practical solutions. □

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