A FRESH LOOK AT CRATER SCALING LAWS FOR NORMAL AND OBLIQUE HYPERVELOCITY IMPACTS;

A.J. Watts, D.R. Atkinson, S.R. Rieco, J.B. Brandvold, S.L.Lapin, C.R. Coombs; POD Associates, Inc., 2309 Renard Place SE, Suite 201, Albuquerque, NM 87106.

INTRODUCTION

With the concomitant increase in the amount of man-made debris and an ever increasing use of space satellites, the issue of accidental collisions with particles becomes more severe. While the natural micrometeoroid population is unavoidable and assumed constant, continued launches increase the debris population at a steady rate.[1,2] Debris currently includes items ranging in size from microns to meters which originated from spent satellites and rocket cases. To understand and model these environments, impact damage in the form of craters and perforations must be analyzed. Returned spacecraft materials such as those from LDEF and Solar Max have provided such a testbed. From these space-aged samples various impact parameters (i.e., particle size, particle and target material, particle shape, relative impact speed, etc.) may be detetermined. These types of analyses require the use of generic analytic scaling laws which can adequately describe the impact effects. Currently, most existing analytic scaling laws are little more than curve-fits to limited data and are not based on physics, and thus are not generically applicable over a wide range of impact parameters. During this study, we have generated a series of physics-based scaling laws for normal and oblique crater and perforation formation into two types of materials: aluminum and Teflon.

BACKGROUND

Due to orbital mechanics and satellite geometries, very few impacts involve "normal" collisions. Christiansen[3] has shown that the angle of approach modifies the resulting penetration, thus, in order to correctly interpret the environment and the consequential impact effects, the effect of obliquity must be properly understood. Similarly, density of both the projectile and target must be known. Presently, it is assumed that most micrometeoroids have a density of ~0.5 g/cm^3 [4] while the debris value is ~4.7 g/cm^3 for particles <1 cm, and decreases with particle size[1] since most large pieces are not chunky pseudo-spheres, but rather odd-shaped items which, on average behave as if partly porous. In addition, target and projectile yield strengths, fracture strength, and melt energy properties must also be understood.

DAMAGE INTERPRETATION AND MODELLING

Impact damage ranges from simple pitting, erosion and cratering for impacts into plastically yielding materials, through conchoidal and star cracking for brittle targets, to complete perforation, large-scale spallation/fragmentation, and material melting and vaporization. LDEF data indicate additional effects, such as delaminations of multilayered material and the generation of rings of ejected material, and/or permanently deformed material. These impact effects may be enhanced by the introduction of thermal cycling, UV and AO embrittlement and erosion. These effects may be synergistic and may alter material properties so as to modify impact cratering, star cracking and perforation effects.

To correctly interpret the space environment, the resulting modes of impact damage and the potential methods which may be employable to mitigate the effects, one MUST properly understand the rules of impact damage. Unfortunately, existing experimental facilities cannot replicate the complet range of conditions. As a result, one must rely on either extrapolation of experimental data obtained at lower speeds or with non-typical materials, or from computer models. Although computer modelling eases the interpretation of material responses, it does not necessarily provide all the required data and is expensive and time consuming: thus the need for analytic scaling laws.

WATTS' SCALING LAWS

Many scaling laws are simple curve-fits to limited data derived by investigators fitting their own data. These laws rarely agree on the proper power index to be applied to impact velocities or densities, nor do they agree on whether to use such terms as hardness numbers or yield strengths. Also, these parameters are often only applied to the target and not the impactor, despite the fact that one must deal with both bodies. These are but a few of the problems evident in the current scaling laws.

Keeping these conditions in mind, using actual spacecraft data, CTH[5] hydrocode computer models and, laboratory data, POD has developed generically applicable scaling laws for predicting crater diameters, penetration depths, and the Ballistic Limit perforation conditions for both aluminum and Teflon for any impact angle of incidence; equations 1, 2, 3 respectively.

$$(d_c/d_p)=1.0857(\rho_t/\rho)^{0.2857}(\rho/Y_t)^{0.2857}(c_t/c_p)^{0.2857}(u_0\cos\theta)^{0.5714}/(1+(\rho_t/\rho)^{1/2})^{0.5714} \quad (1)$$

$$P/d_p=(1/4)(4/3)^{1/3}(\rho_t/\rho)^{1/3}(\rho/Y_t)^{1/3}\{(c_{0t}+s(u_0\cos\theta-u_{t,crit})/(1+(\rho/\rho_t)^{1/2}))(u_0\cos\theta-u_{t,crit})\}^{1/3} \quad (2)$$

$$T/d_p = (1/8)(4/3)^{1/3}(\rho_t/\rho)^{1/3}(\rho/Y_t)^{1/3}\{(c_{0t}+s(u_0\cos\theta-u_{t,crit})/(1+(\rho_t/\rho)^{1/2}))(u_0\cos\theta-u_{t,crit})\}^{1/3}$$
$$+ (1/4)\{\rho_t(u_0\cos\theta)^2/(2\sigma_t(1+(\rho_t/\rho)^{1/2})^2)\}^{1/N} \quad (3)$$

In addition, POD has also developed and validated criteria for predicting partial and complete projectile ricochets; equations 4 and 5, respectively.

$$\sin\theta \geq c_{0t}/u_0 + s\cos\theta(1+(\rho/\rho_t)^{1/2}) \quad (4)$$

$$\tan\theta = r_c/d_p = 1/2\ (d_c/d_p) \quad (5)$$

Equation 3 actually has TWO parts, one relating to the crater depth, and one relating to the reflection of the shock pulse from the target rear surface. The former term depends on tensile strength and has roughly a 2/3 index for impact speed, while the latter term depends on tensile strength and has roughly a unit index for impact speed. Thus, both target yield strength and tensile strength are strong drivers for determining perforations.These equations satisfy dimensional analysis; however, these equations were derived from physics and thus suffer none of the irregularities which hamper the other existing scaling laws. In comparisons to CTH hydrodynamic code calculations, these equations closely matched the predictions for both aluminum and Teflon. In comparison with experimental data[6], these equations also closely matched the data for aluminum and Teflon.

REFERENCES: (1) Kessler D.J. *et. al.* (1987) *NASA TM-100471*. (2) Kessler D.J. (1990) Updates to *NASA TM-100471*. (3) Christiansen E.L. (1992) Design and performance equations for advanced meteor./debris shields, 1992 Hypervelocity Impact Symposium, Austin, TX. (4) Cour-Palais B.G. et al. (1969) *NASA SP-8013*. (5) Bell R.L. et al (1991) The CTH Code, Sandia Nat'l Lab (6) Horz F. et al. (1992) 1992 Hypervelocity Impact Symposium, Austin, TX.