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Dr. David H. Scott
Discipline Scientist
Planetary Geology and Geophysics Program
CODE EL
NASA Headquarters
600 Independence Avenue S. W.

Subject: Semiannual report (Contract NASW-3291)

Dear David,

I am enclosing a copy of the Program Abstract forwarded under separate cover for use in the NASA Technical Memorandum. This summarizes our current progress and results under contract NASW-3291.

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Thank You.

Sincerely,

R.M. Schmidt

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Experimental Investigation of Crater Growth Dynamics

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This work is a continuation of an ongoing program whose objective is to perform experiments and to develop scaling relationships for large-body impacts onto planetary surfaces. The centrifuge technique is used to provide experimental data for actual target materials of interest. With both powder and gas guns mounted on the rotor arm, it is possible to match various dimensionless similarity parameters, which have been shown to govern the behavior of large-scale impacts. The development of the centrifuge technique has been pioneered by the present investigators and is documented by numerous publications, the most recent of which are listed below.

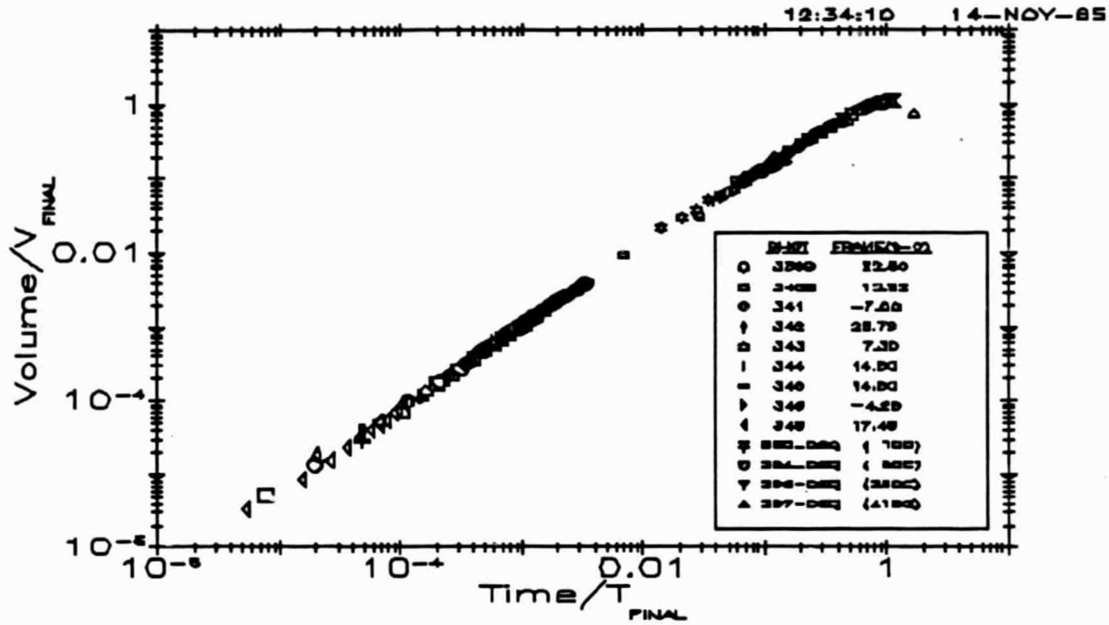
Understanding the dependence of crater size upon gravity has been shown to be key to the complete determination of the dynamic and kinematic behavior of crater formation as well as ejecta phenomena. (See Table 1 in ref. 7). We have identified three unique time regimes in the formation of an impact crater.[2,5] The "early" time regime represents the initial contact during which the target material is overdriven by the impactor. The particle velocity in the target, initially one dimensional, is determined by the high pressure material properties of the impactor and the target.

As the process continues into the "intermediate" time regime, the flow becomes two dimensional and a length scale based upon impactor size evolves. The specific characteristics of the impactor such as size, velocity, and density can no longer be identified in the flow field. In their place an overall size scale evolves which then holds out to much later times. The properties of the flow field depend only upon a particular product of powers of the impactor size a, and impactor velocity U. This quantity aU^{μ} is referred to as a coupling parameter.[5] In particular cases the flow field in the intermediate regime has very special motions. For example, if subsequent to the early-time regime, crater growth is independent of gravity, material strength and wave speed, then crater dimensions should grow as a simple power-law in time with exponent equal to $\mu/1+\mu$.

"Late" time refers to the final stage when retarding forces due to gravity or material strength arrest the decaying flow field to form the final crater or maximum transient crater. For this stage, we have shown that the final crater should depend only upon the coupling parameter product aU^{μ}, gravity and/or strength.[6,10]

The existence of a coupling parameter for water was previously demonstrated by showing that the time of formation could be simply related to the maximum transient crater volume and gravity.[9,11,15] Data for rate of crater growth spanning over two orders of magnitude, were also presented. Those data are now supplemented with microsecond resolution results which show that the power-law growth regime extends over a range of 5 orders of magnitude from a size scale on the order of source dimensions to approximatly 70% of the maximum transient crater volume.[18] This was true for all the different test conditions, which covered a range of gravities from 1 to 500G and produced final formation times on the order of 100 msec for the largest of the 1G tests and less than 4msec for the 500G tests.

An ultra high speed framing camera has now been used to obtain very early time explosion crater growth in water. Framing rates up to 1.4 million pictures/sec provided interframe times on the order of source relaxation times. However, no definitive observation of early-time growth has been observed for the types of sources tested to date. Higher-velocity impacts should extend the duration of the early time regime and will be pursued next. The complete growth curve for crater volume is shown below. Comparable curves for crater depth and radius also show power-law growth. Both are in good agreement with the expected value of the exponent equal to $\mu/3(1+\mu)$.



Other ongoing data analysis of high-G experiments in saturated sand also are in good agreement with the appropriate power-law growth behavior as was seen for the water experiments above.[12,14] Detailed examination[16,17] of previous data for explosions in dry sand obtained by Piekutowski[8] and more recent impact data in both dry and wet sand obtained at Ames by Schmidt and Piekutowski[13] indicates that these data have many of the same growth features also. While there are still individual details that are not completly understood, it appears that the radius follows the expected growth rule in most of the shots. However, especially for the dry Flintshot sand, the depth has already "flattened out" by the earliest times observed (200-600μsec). We suspect that the effects of gravity occur earlier in time for depth than for radius, since the latter is at zero depth. The volume, which depends more strongly on the radius tends to be in resonable agreement with the expected power-law behavior. Another explanation now being examined is that the effective origin of the flow field does not coincide with the center of the explosive charge, but seems to be at the bottom of the charge as observed by Piekutowski.[8] For the impact experiments, it very clearly depends upon the impact conditions and for the lower velocities into water the effective origin was on the order of 10 diameters below the surface.

These experiments to record dynamic data for crater growth provide a very detailed and critical test of a complete and unified scaling theory for impact cratering. They provide very important information that is required to apply and extend the scaling to planetary problems currently under investigation by the technical community.

1) Bjorkman, M. D. (1984) Feasibility of determing impact conditions from total melt volume (abstract). In *Lunar Planteary Science XV*, 64-65.

2) Holsapple, K. A. (1984) On crater dynamics: Comparisons of results for different target and impactor conditions (abstract). In *Lunar Planetary Science XV*, 367-368.

3) Holsapple, K. A. and K. R. Housen (1985) Cratering estimates for rock and ice (abstract). *Lunar Plant. Sci. XVI*, Houston.

4) Holsapple, K. A. and K. R. Housen (1985) Scaling of catastrophic impacts. *Memoirs of Italian Astronomical Society* (in press).

5) Holsapple, K. A. and R. M. Schmidt (1985) Point-source solutions and coupling parameters in cratering mechanics. Submitted for publication to *J. Geophys. Res.*

6) Housen, K. R. (1984) Cratering flow fields: A general form and the Z-model (abstract). In *Lunar Plantary Science XV*, 377-378.

7) Housen, K. R., R. M. Schmidt, and K. A. Holsapple (1983) Crater ejecta scaling laws: Fundamental forms based upon dimensional analysis. *J. Geophys. Res.* **88**(B3), 2485-2499.

8) Piekutowski,A. J.(1980) Formation of bowl-shaped craters. *Proc. Lunar Sci. Conf. 11th*, 2129-2144.

9) Schmidt, R. M. (1981) Scaling crater time of formation (abstract). *EOS (Trans. Amer. Geophys. Union)*, **62**, 944.

10) Schmidt, R. M. (1983) Strength-gravity transition for impact craters in wet sand(abstract). In *Lunar Planetary Science XIV*, 666-667.

11) Schmidt, R. M. (1983) Centrifuge quarter-space cratering results: A gravity criterion for kinematic similarity (abstract). *EOS (Trans. Amer. Geophys. Union)*, **64**,747.

12) Schmidt, R. M. (1984) Transient crater motions: Saturated sand centrifuge experiments (abstract). In *Lunar Planetary Science XV*, 722-723.

13) Schmidt, R. M. and A. J. Piekutowski (1982) Quarter-space impact experiments: Particle-motion and crater-growth measurements (abstract). *EOS (Trans. Amer. Geophys. Union)*, **63**, 1020.

14) Schmidt, R. M. and A. J. Piekutowski (1983) Development of the quarter-space technique for cratering experiments on a centrifuge (abstract). In *Lunar Plantary Science XIV*, 668-669.

15) Schmidt, R. M. and K. A. Holsapple (1984) Explosively generated water waves (abstract). *EOS (Trans. Amer. Geophys. Union)* **65**, 221.

16) Schmidt, R. M., K. R. Housen, M. Luke, and A. J. Piekutowski (1984) Scaling consistency tests for cratering experiments (abstract). *EOS (Trans. Amer. Geophys. Union)* **65**, 983.

17) Schmidt, R. M., K. R. Housen, and A. J. Piekutowski (1985) Experimental observations on crater growth regimes (abstract). *EOS (Trans. Amer. Geophys. Union)* **66**, 296.

18) Schmidt, R. M., K. R. Housen, and V. T. Webbeking (1985) Growth of water cavities over a range of 10^6 in time (abstract). *EOS (Trans. Amer. Geophys. U.)* **66**.

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A Centrifuge has been used to investigate large-body impacts onto planetary surfaces. At elevated gravity, it is possible to match various dimensionless similarity parameters which have been shown to govern large-scale impacts. Observations of crater growth and target flow fields have provided detailed and critical tests of a complete and unified scaling theory for impact cratering.

The scaling theory has also been applied to the problem of collisional fragmentation. This exercise has shown that current methods of scaling laboratory experiments up to asteroidal size scales may be incorrect. In particular, asteroids may be considerably easier to shatter than predicted by current models of fragmention.