EPSC Abstracts
Vol. 8, EPSC2013-989, 2013
European Planetary Science Congress 2013


# The effect of planetary curvature on impact crater ellipticity

**G.S. Collins** (1), K. Miljković (1,2) and T.M. Davison (1)
(1) Impacts and Astromaterials Research Centre, Dept. of Earth Sciences and Engineering, Imperial College London, South Kensington Campus, SW7 2AZ, London, United Kindgom (g.collins@imperial.ac.uk); (2) Univ Paris Diderot, Sorbonne Paris Cité, Institut de Physique du Globe de Paris, UMR 7154, F-75013, Paris, France.

## Abstract

Mapping of the largest impact basins on the terrestrial planets reveals that many have elliptical planforms. In contrast, less than 5% of small impact craters are elliptical. Elliptical craters are formed if the impact angle is shallower than a threshold angle. A possible explanation for the high number of large elliptical basins is that high relative surface curvature—the ratio of impactor-to-planet diameter—may increase the elliptical crater threshold angle and encourage elliptical crater formation. Numerical simulations of strength-dominated cratering on curved bodies show that relative curvature has the opposite effect, requiring an alternative mechanisms for elliptical impact basin formation.

## 1. Introduction

Recent measurements of the largest impact basins in the Solar System suggests a propensity for elliptical crater formation in basin-forming impacts. Four of the six largest impact basins in the Solar System, and six of the eleven basins with diameters larger than 500 km, have an ellipticity ($e$ = length/width) greater than 1.2 [1]. At smaller crater sizes, elliptical craters account for only $\sim 5\%$ of the total population.

Elliptical craters are formed by oblique impact if the trajectory angle to the target plane is less than a threshold angle $\theta_e$. As this threshold angle increases with decreasing cratering efficiency—the ratio of crater diameter to impactor diameter—the propensity for large impacts to produce elliptical craters can be partially explained by the decrease in cratering efficiency with increasing crater size [2]. However, unless large basins have a cratering efficiency less than two, an additional mechanism is required to promote elongation of the crater in large impacts.

As the large elliptical basins on Mars and the Moon have diameters comparable to the planetary radius, a potential cause of crater elongation is the curvature of the planet [1]. However, SPH simulations of giant impact crater formation on Mars suggest that the ellipticity of large impact basins is not affected by planetary curvature until the ratio of impactor to planet diameter exceeds ~0.3 and may even decrease with impact angle in very grazing collisions [3]. To address this controversy we quantify the effect of relative curvature on impact crater formation in strength-dominated impacts using iSALE-3D.

## 2. Methods

iSALE-3D is a three-dimensional, multi-material and multi-rheology finite difference shock physics code used for simulating impact processes [4, 5, 6, 7, and references therein]. iSALE-3D has been used previously to explore the effect of impact angle on crater size and shape in frictional (geological) targets [5] and strong, ductile metal targets [8].

Here we used iSALE-3D to simulate the oblique collision of two spheres of different sizes (Fig. 1) for comparison with the results of oblique impacts on a planar surface [8]. Three different size ratios between the impacting sphere (diameter $D_i$) and the target sphere ($D_t$) were considered ($\chi = D_i/D_t = 0.04$, $0.08$ and $0.2$). Impact angle $\alpha$ measured relative to the tangent of the target at the point of impact was varied between $10°$ and $90°$ (vertical).

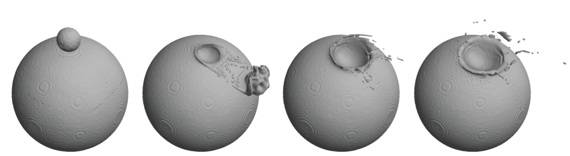

Figure 1: Oblique collision between two spheres with a size ratio of 0.2 at 20° from the tangent surface.

For simplicity and to allow the simulation results to be tested by laboratory experiment we used a simple material model appropriate for a strong, ductile metal for both the impactor and target; this comprised the

Table 1: Results from impact simulations. $L/D_i$ and $W/D_i$ are crater length and width measured across the sphere and normalized to projectile diameter, respectively; $e$ is the crater ellipticity, calculated as $e = L/W$. $Y$=20 MPa.

| $\chi$ | 0.2 | | | 0.08 | | | 0.04 | | | Flat | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha$ | $L/D_i$ | $W/D_i$ | $e$ | $L/D_i$ | $W/D_i$ | $e$ | $L/D_i$ | $W/D_i$ | $e$ | $L/D_i$ | $W/D_i$ | $e$ |
| 10 | 1.01 | 0.92 | 1.10 | 1.51 | 1.31 | 1.15 | 1.87 | 1.25 | 1.50 | 3.26 | 1.91 | 1.71 |
| 15 | 1.56 | 1.56 | 1.00 | 2.30 | 1.98 | 1.16 | 2.48 | 2.01 | 1.23 | 3.40 | 2.72 | 1.25 |
| 20 | 2.35 | 2.36 | 0.96 | 2.82 | 2.80 | 1.01 | 3.16 | 2.78 | 1.14 | 3.78 | 3.45 | 1.10 |
| 30 | 4.42 | 4.36 | 1.01 | 4.34 | 4.32 | 1.00 | 4.44 | 4.27 | 1.04 | 4.62 | 4.57 | 1.01 |
| 40 | 5.43 | 6.11 | 0.89 | 5.64 | 5.61 | 1.01 | 5.37 | 5.29 | 1.04 | 5.33 | 5.30 | 1.00 |
| 90 | Destructive | | | 7.97 | 7.90 | 1.01 | 7.05 | 7.03 | 1.00 | 6.35 | 6.35 | 1.00 |

Tillotson equation of state with parameters for aluminium and a simple von Mises shear strength model (constant shear strength of 20-200 MPa). Impact velocity was kept constant at 5 km/s and gravity was neglected. The smaller sphere was resolved by at least 8 cells in every scenario.

## 3. Results and Discussion

The results of our parameter study are summarised in Table 1. Several interesting trends are observed. Defining $\theta_e$ as the impact angle below which crater ellipticity first exceeds 1.1, we observe that $\theta_e$ decreases with increasing impactor-to-target size ratio $\chi$. Hence, contrary to the geometric "footprint" model of [1] elliptical crater formation is suppressed rather than enhanced by increased target curvature. Although the data are limited, we observe no increase in crater ellipticity at angles below the threshold angle for $\chi \geq 0.08$. For steep impact angles $\alpha > 45°$, cratering efficiency increases with increasing impactor-to-target size ratio (at fixed impact angle) because as the surface becomes more curved the crater diameter is greater for the same excavated mass. However, at low impact angles $\alpha < 30°$ cratering efficiency decreases with increasing $\chi$ owing to the dramatically reduced coupling between impactor and target in grazing impacts on a curved surface.

Our results suggest that planetary curvature cannot explain the high number of large elliptical craters. Alternative mechanisms for elliptical impact basin formation include binary asteroid impact, elongated asteroid impact and the offset between the crater centre and the centre of the thermal anomaly.


## Acknowledgements

This work was funded by STFC grants ST/G002452/1 and ST/J001260/1.


## References


[1] J. C Andrews-Hanna and M. T Zuber. Elliptical craters and basins on the terrestrial planets. In *Large Meteorite Impacts and Planetary Evolution IV*, volume in press of *GSA Special Paper*. GSA, Boulder, CO, 2010.

[2] G. S. Collins, D. Elbeshausen, T. M. Davison, S. J. Robbins, and B. M. Hynek. The size-frequency distribution of elliptical impact craters. *Earth and Planet. Sci. Lett.*, 310:1–8, 2011.

[3] Margarita M. Marinova, Oded Aharonson, and Erik Asphaug. Geophysical consequences of planetary-scale impacts into a mars-like planet. *Icarus*, 211 (2):960–985, February 2011. ISSN 0019-1035. doi: 10.1016/j.icarus.2010.10.032.

[4] A. A. Amsden and H. M. Ruppel. A simplified ALE computer program for calculating three-dimensional fluid flow. *Los Alamos National Laboratories report*, LA-8905:151, 1981.

[5] D. Elbeshausen, K. Wünneman, and G. S. Collins. Scaling of oblique impacts in frictional targets: Implications for crater size and formation mechanisms. *Icarus*, 204: 716–731, 2009.

[6] G. S. Collins, H. J. Melosh, and B. A. Ivanov. Damage and deformation in numerical impact simulations. *Meteoritics and Planetary Science*, 39(2):217–231, 2004.

[7] K. Wünnemann, G. S. Collins, and H. J. Melosh. A strain-based porosity model for use in hydrocode simulations of impacts and implications for transient crater growth in porous targets. *Icarus*, 180:514–527, 2006.

[8] T. M. Davison, G. S. Collins, D. Elbeshausen, K. Wünnemann, and A. Kearley. Numerical modeling of oblique hypervelocity impacts on strong ductile targets. *Meteorit. Planet. Sci.*, 46(10):1510–1524, 2011.