ORIGIN OF THE MOON: A PRELIMINARY NUMERICAL STUDY OF COLLIDING PLANETS. M.E. Kipp* and H.J. Melosh**, *Sandia National Laboratories, Albuquerque, NM 87185; **Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721.

Recent work suggests that the moon originated from the collision of a Mars-size protoplanet with the proto-earth. This scenerio readily accounts for many geochemical peculiarities of the Moon, such as its depletion in volatiles and iron, and the bulk Moon's similarity to the earth's mantle. The mechanical details of such an impact, however, are too complex to be addressed by simple analytic models.

We have performed preliminary numerical computations of the early stages in the impact of a Mars-size protoplanet with the proto-Earth and evaluated its potential for the creation of a moon-size satellite. We used the code CSQ II on a Cray I computer at Sandia National Labs. The code is two-dimensional, so this computation actually represents the eccentric collision of two cylinders, not spheres. The finer resolution available in a 2-D code makes this a reasonable approximation for a first effort. The mesh we used is 120 x 120 cells, where each cell is 250 km square.

Both planets are assumed to have iron cores with radii equal to one half the planet radius. Since no silicate equation of state is presently available in CSQ II, we approximated the planet's mantles by aluminum. Aluminum is a reasonably good approximation to olivine in both density and Hugoniot relation [compare the data for Twin Sisters and Mooihoek Dunite in (1), Fig. 12, with the aluminum data of (2)]. Since the computation did not include gravity, the orbital evolution of the ejected plume could not be followed further than its initial stages. Our primary interest here is the physics of ejection where gravity is not of great importance.

The results are illustrated in Figure 1(a-d). The first frame, Fig. 1a, shows the two planets just before contact. The projectile planet is exactly half the size of the target proto-Earth. Fig. 1b documents the beginning of a fast forward-moving jet of hot, highly shocked vapor and a slower, cooler backward-moving jet. These jets evolve further in Fig. 1c. The tip of the fast jet is at a temperature of about 10,000°K, has an average density near 60 kg/m^3, and is traveling in excess of 20 km/s. This material escapes the earth entirely and is not of interest for the origin of the Moon. This vapor cloud continues to translate and expand in Fig 1d. It is composed predominantly of projectile mantle material.

The "neck" of the hot plume in Fig. 1d, however, is more likely to become trapped in earth orbit. Its velocity of circa 10 km/s is less than earth escape velocity (11 km/s), but higher than low earth orbital velocity (7.7 km/s). Its density ranges between 300 and 1000 kg/m^3 and its temperature is in the vicinity of 6,000°K. Although it is difficult to extrapolate this to three dimensions, it seems probable that at least one lunar mass is ejected in this "neck". It contains roughly equal amounts of projectile and target mantle material. Neither planet's core is ejected in the jet, although the projectile's core remains at more than 6,000°K after the release wave decompresses it. It will thus eventually vaporize and mix with vaporized mantle material from both the projectile and target. This vapor, however, moves too slowly to attain orbit directly.

These preliminary numerical computations are in substantial agreement with the conclusions of (3). They thus support the possibility that the Moon originated from material ejected in a collision between the Earth and a Mars-size protoplanet early in solar system history.

REFERENCES. (1) R.G. McQueen, S.P. Marsh, and J.N. Fritz (1967), Hugoniot Equation of State of Twelve Rocks, *J. Geophys . Res.* **72**, pp. 4999-5036. (2) L.V. Al'tshuler, S.B.. Kormer, and R.F. Trunin (1960), Equation of State for Aluminum, Copper and Lead in the High Pressure Region, *Soviet Physics JETP* **11**, No. 3, pp. 573-579. (3) H.J. Melosh and C.P. Sonett (1986), When Worlds Collide: Jetted Vapor Plumes and the Moon's Origin, In *Origin of the Moon*, in press.

Fig. 1a-1d. Four stages in the collision of a Mars-size protoplanet with the proto-Earth at 15 km/s. Each frame is separated by about 6 minutes from the previous one. The stipple density is proportional to the material density. The initial velocity of the projectile is horizontal (parallel to the x-axis) from left to right in (a), thus making this an oblique impact with an impact parameter equal to one half of the proto-Earth's radius.