Numerical Simulation of *N*-Body Asteroid Aggregation

Fabio Ferrari*, **Alessandro Tasora#**, **Pierangelo Masarati***, **Michéle Lavagna***

* Dipartimento di Scienze e Tecnologie Aerospaziali
Politecnico di Milano
via La Masa 34, 20156 Milano, Italy
[fabio1.ferrari, pierangelo.masarati, michelle.lavagna]@polimi.it
Dipartimento di Ingegneria Industriale
Università degli Studi di Parma
viale delle Scienze 181/A, 43100 Parma, ItalyA
alessandro.tasora@unipr.it

Abstract
Nowadays, small celestial bodies such as asteroids and comets represent the new frontier of the exploration of the solar system. The exploration of these small bodies is motivated by great scientific interests, and represent a great challenge for modern space engineering.
Among the many engineering challenges, the effective design of trajectories to fly a spacecraft in the proximity of an asteroid requires the study and understanding of the physical and inertial properties of the asteroid, and in particular its mass distribution.
Recent studies and observations support the idea that asteroids between 100 m and 100 km in size may be gravitational aggregates [1]. Such aggregates have very low tensile strength, possessing no cohesive force other than gravity.
This evidence motivates the work presented here, whose purpose is to study the gravitational aggregation process of a cluster of particles and to investigate favorable conditions for the formation of an asteroid.
The objective of the study is to obtain a highly accurate model of the asteroid mass distribution by studying it as gravitational aggregate. The problem to be investigated is twofold: (a) the study of gravitational aggregation dynamics, and (b) the study of the physical and dynamical properties of the final aggregate.
The first aspect includes the analysis and numerical simulation of typical scenarios, for small and medium-size (hundreds of meters) asteroid aggregation, to identify the conditions that lead to the formation of the aggregate or to the dispersion of the particle cloud. The properties of the final aggregate, as a result of the dynamical simulation, are then studied and classified depending on the initial conditions and simulation scenario.
The physical problem is modeled as a classical *N*-body problem, with mutual gravitational interaction between all particles. Collision detection is also implemented and contact forces are included to describe the dynamics of the colliding bodies. The *N*-body problem is a well known mathematical problem, with a well known mathematical formulation, but still the full comprehension of its solutions and dynamical behavior is very far to be reached.
It has been proved that no analytical solution exists: the problem is characterized by a highly non-linear (chaotic) behavior, which is reflected in a strong dependence of the solution on the initial conditions. At the time being, typical capabilities of *N*-body integration software include the handling of few hundreds of bodies of simple (spherical) shape of bodies. Collisions and contact interaction between particles are often resolved by interfacing with hydrodynamics codes. In this paper, the problem is implemented using Chrono::Engine[1] (C::E) [2], which is able to handle the contact and collision of large numbers of complex-shaped objects.
From a computational standpoint, the problem is characterized by the need to consider long simulations of a large number of interacting particles, simultaneously subjected to gravity and contact forces.
Gravity implies a many-to-many interaction, which depends on the inverse of the square of the distance. The cost of evaluating gravity is N^2, although it can be reduced by clustering the interactional effect between far clusters of particles. Contact forces require collision detection and the handling of problem non-smoothness.

[1] `http://www.chronoengine.info/`, last accessed December 2014.

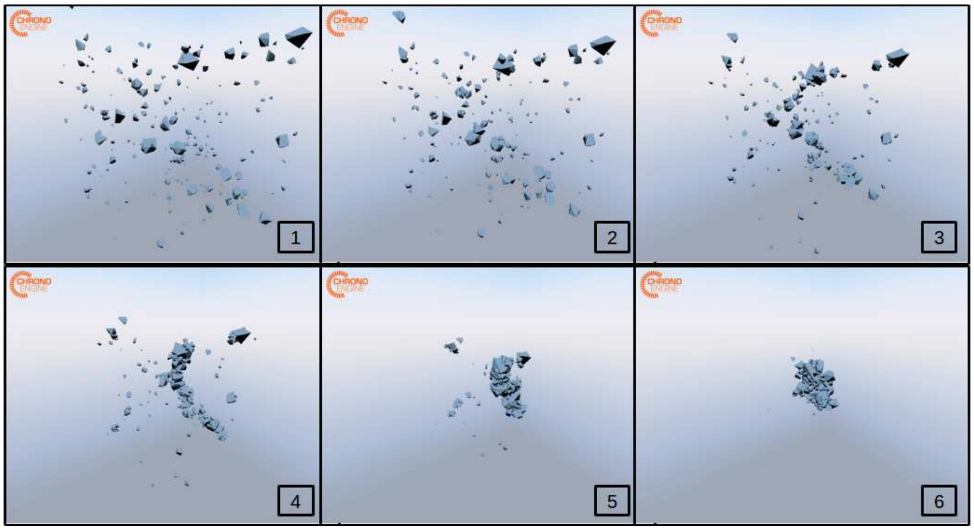

Figure 1: Example of asteroid aggregation.

C::E has been designed to simulate the collision of large numbers of irregularly-shaped bodies. Gravity has been added in the form of the gradient of potential energy U defined as

$$U(\mathbf{r}) = G \int_V \frac{\rho(\mathbf{r})}{|\mathbf{r}|} \, \mathrm{d}V$$

The current phase of the project entails the setup of the procedure. For this reason, no optimization has been performed yet. The partitioning of the domain using octrees, and the GPU-based parallelization of gravitational forces computation will be pursued in a subsequent phase.

Preliminary Results

Significant scenarios have been analyzed in the framework of possible and realistic asteroid formation processes. Different initial condition sets have been investigated: the initial dynamical state of the N bodies plays a fundamental role in the dynamical evolution of the cloud of particles and determines the outcome of the simulation.

More in detail, the state of the N bodies have been initiated by imposing either zero initial relative motion between them, random initial relative motion, or an orbital angular momentum with respect to the center of mass of the system. The effects of the rotation state of the single rigid body particle has also been investigated.

Preliminary results show good agreement between theory and observation, and indicate that the numerical code is capable of predicting natural aggregation phenomena.

References

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