N91-22164

EXPLORATION OF PLANETESIMALS BY A TRIPARTITE TETHERED SPACECRAFT

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ABSTRACT

Asteroids and comets exert such a small gravitational force that it is not practical to survey them from orbit. One must instead continuously accelerate using maneuvering rockets to move around the surface. A space exploration craft in three parts connected by lightweight cables can survey asteroids and comets, and deploy landers, without requiring the large thrusters and the continuous depletion of fuel required by a single craft.

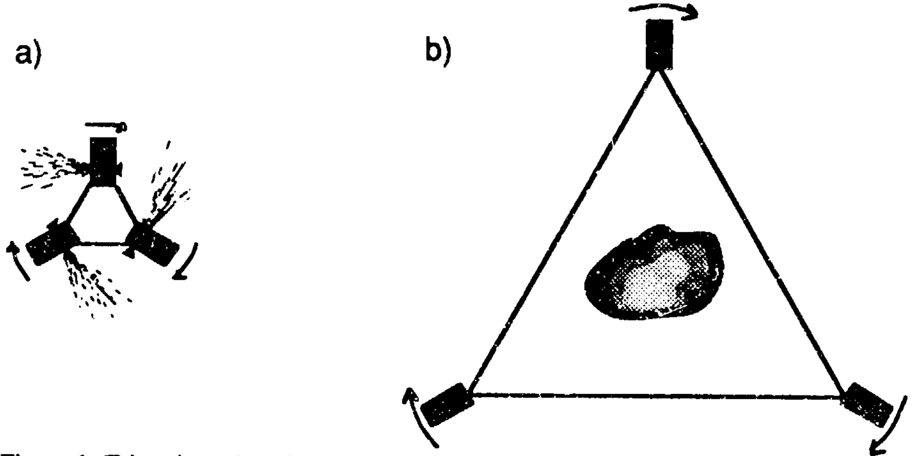

Figure 1: Tripartite tethered spacecraft a) using thrusters and paying out line to spin-up from single unit to b) spinning configuration up to 100 km across able to indefinitely survey the surface of a planetesimal.

The spacecraft is deployed by spinning up from a compact configuration using low thrust jets, and then maintains surveying orbit without any major expenditure of energy.

The triangular tether arrangement is stable, but care must be taken in changing orbits and with deploying and recovering samplers, as can be demonstrated with a simple simulation. Even 100 km long tethers occupy a low payload fraction.

BACKGROUND

An important goal of our space program is to understand the origins and evolution of our solar system. The planetesimals — the comets and asteroids, which litter the system are some of its oldest, least modified pieces, and so it is important to study them and retrieve samples.

Though they are tiny relative to the planets there are still some sizeable pieces (ref. 1); more than 500 main belt asteroids are known with diameters from 40 up to 600 km. Near

Earth, most are small objects with diameters up to 10 km. The largest by far is 433 Eros with dimensions 18x36 km. There are believed to be thousands of earth approaching asteroids with diameters nearer 1 km, and [illegible] times that number in the Main Belt. The size of comets are less well known; their solid nucleus is obscured by evaporating gases and glowing plasma. The recent interception and investigation of comet Halley, one of the biggest, showed its core to be potato shaped 16 km X 9 km but its density is only 100 to 300 kg/m^3 (ref. 2).

The gravitational attraction of even the largest asteroids is miniscule, and that of the comets, with their low density, is completely insignificant. A 10 km diameter spherical asteroid (they are actually very irregular), with density $7x10^3$ kg/m^3 and mass $3.7x10^{15}$ kg has a gravitational attraction 10^{-3} that of Earth's at its surface. Orbital velocity at the surface of such a rock is only 7 m/sec, and that of a 2 km diameter comet with density 10^2 kg/m^3 is about 0.1 m/sec.

These numbers are so low that it is impractical to use gravity to orbit around such a body while studying it. Surveying planetesimals requires the continuous use of thrusters. That energy requirement is a severe problem in spacecraft design, especially for comets which should be studied for a large fraction of an orbit to observe their structural and dynamical evolution as they approach the Sun.

PRESENT SURVEY PLANS

Configuration

The Comet Nucleus Sample Return Mission (ref. 3) is not yet well defined, but envisions a space craft of around 1000 kg (600 kG body, two 150 kg sampler/landers, and a return capsule). The samplers will return cores from the comet, while their lander will monitor the surface activity for an extended period. The objective is to return the data and some unmodified comet matrix to Earth for study.

Procedure

The exploration strategy after rendezvous is: global characterization from a distance of 200 km for six days, one day to transfer to a 50 km distance above a specific surface for high resolution pictures, then transfer to 100 km distance to wait for landing instructions. On a landing command, move in to 10 km, wait until the proper surface is underneath, and use thrusters to maintain the spacecraft in a forced synchronous orbit with that patch of ground. From this position, the spacecraft launches the sampler/lander and takes high resolution pictures. After recovery of the sampler, the spacecraft retreats to 100 km to await decision on a second landing site.

Limitations

The constant maneuvering described above is made necessary by the dust and gas hazards near an active comet nucleus. "To provide the additional thrust required for the 'forced-synchronous' orbit, it will almost certainly be necessary to provide an auxiliary chemical propulsion system on the spacecraft." This propulsion system does not yet exist, and is one of the critical technologies required to enable CNSR (ref. 4).

TETHERED ORBIT SURVEY

Configuration

A radical approach to this maneuvering problem is to divide the spacecraft into three parts, tie them together with thin fibers, and spin them. Once this tripartite spacecraft is spinning fast enough for stability, no further energy is required to maintain their orbit. It can be maneuvered over the target comet and monitor it from all sides for extended periods with no further expenditure of maneuvering energy.

These three parts need not be the same mass or have the same instruments; a configuration consisting of two module types is

- A — overall control, Earth communications, return pod, maneuvering thruster, attitude jets, spin-up thruster
- B — local control, sampler/lander, photographic equipment, local communications equipment, attitude jets, spin-up thruster
- B' — local control, sampler/lander, photographic equipment, local communications equipment, attitude jets, spin-up thruster

While the spacecraft is together, the attitude jets would combine to give 6 orthogonal pairs of orienting jets. When separate, the pair of jets on each unit would orient the spin-up thruster on each unit as required for spin-up, spin-down, or transverse maneuvering.

The units would be connected with high strength fibers. Studies of tethered probes for low earth orbit or space shuttle experiments have suggested a variety of materials. Kevlar 29 have been suggested by a number of researchers both bare (ref. 5), and metal coated for protection and communication purposes (ref. 6). A polyethylene (Spectra 1000) was preferred by one for its temperature stability(ref. 7). 100 kg of Spectra 1000 would be sufficient to provide three 100 km tethers with 850 N breaking strength. That is orders of magnitude greater than needed for this system. Orbiting 1/hr with a tether length of 100 km (an altitude of 57.7 km) requires an acceleration < 0.02 N, or .002 of Earth's gravity. If each part of the spacecraft weighs 500 kg that only requires a tension of 0.5 N in the 100 km fibers. The fibers have a strength of $3\text{x}10^9$ N/m^2 = 30 N/(0.1mm)^2. This 0.1 mm dia fiber has a safety margin of 100 X! Three 100 km lengths weigh only 3 kg (polyethylene). A thicker fiber may be desirable to limit stretchiness. These fibers have a tensile modulus of $1.7\text{x}10^{11}$ N/m^2 = $1.7\text{x}10^3$ N/(0.1mm)^2, so a 0.5 N force stretches the fiber by .03%, or 30 m in 100 km.

Procedure

This tripartite spacecraft would be launched and proceed to the rendezvous as a single unit. On rendezvous with the comet, the parts would spin up to a low speed and then undock so that the centrifugal force would help control the attitude of each unit. The attitude jets on each unit would align the thrusters in the plane of rotation and they would then spin-up the system further while the reeling mechanisms paid out line until they reached the desired configuration — 100 km separation rotating once per hour, for instance. To limit bouncing, the thrusters and reels would combine to maintain a constant tension on the lengthening tether. The reels don't need any significant power for this maneuver. Once the desired condition is reached, the attitude jets reorient the thrusters so they can maneuver the spinning system around the comet. They can then study the comet indefinitely without using thruster power.

If a closer look is desired, the thrusters are aligned in the plane of rotation again, but opposite to the rotation direction, and the thrusters are fired to spin-down while the reels take in tether; again, the two actions combined to maintain a constant tension on the tether. In this case, the reels need power.

If a sample is required, one of the sampler/landers is launched from as close to the surface as possible. It is not necessary to remain in forced synchronous orbit because one of the three nodes will always be visible to and in communication with the lander. The system will orbit asymmetrically because of the weight loss (about 150 kg out of 500 kg); the lighter module farther from the center of rotation. On recovery of the sampler, the weights and hence the orbiting configuration will change again.

When the mission is over, the thrusters are aligned to spin-down and the tether is reeled in. Collected samples are transferred to the return pod, and then the A module separates from the other two modules and returns home.

Dynamics

Algorithms for stably paying out tether have been investigated for leashed experiments in Earth orbit (ref. 8), though only up to lengths of about 20 km. That dynamics problem is difficult because leashed experiments have to come to the end of their tether with zero velocity and acceleration simultaneously, or the experiment slowly bounces all the way back to the experimenter. It is not so hard for a rotation triangular system. We have set up a simple simulation program to model its kinematic behavior. We found it very stable if, during spin-up, one lets the fiber pay out at a rate so that the tension in the tethers remains about constant. Errors only cause some jello-like wobbling around the equilibrium triangle. One prevents that by turning on and off the thrusters slowly relative to the time required for a wave to travel the length of the tether. That time seems to be a few minutes for 100 km tethers(ref. 9).

Release and recapture of the sampler/lander modules causes an abrupt change in the mass of the modules, and could cause instability problems. Our simulation shows the need to use thrusters in a radial direction to compensate for mass loss and to smooth out the transition.

Energetics

For stated conditions, need to accelerate 1000 kg to about 300 km/hr. That is $1/2 \times 10^7$ N-sec per spin-up. If spin-up and spin-down are done maintaining a constant tension in the tether, the reels would require no net power; they would be electric generators during spin-up and use their stored energy to reel in the tether during spin-down. Motor, generator, and battery inefficiencies would cause some net power drain. That power could be provided by solar cells.

Limitations

Tether malfunction would abort the mission. Impact by a micrometeoroid, breaking a tether is the most likely cause, but the probability may be hard to estimate; there is only sparse data on the micrometeoroid density outside the Earth's moon orbit. Making the tether of a braided tow reduces that problem (ref. 10). There is also substantial ionized gas — presumably corrosive, in the vicinity of comet which could weaken the tethers.

Mechanical problem in the reels would also be fatal. Designs have been studied for and will be tested in low Earth orbit (ref. 11).

SUMMARY

We have suggested a tripartite spacecraft connected by long lightweight tethers as an alternate approach to surveying microgravity planetesimals — comets and asteroids. The mass of the tethers is an small fraction of the total spacecraft mass. A configuration and exploration plan have been sketched out. This configuration is stable during spin up and spin down operations, but there may be problems stabilizing it during release and recapture of sampler/lander modules. In addition, there may be a problem insuring that the tethers are not broken by micrometeoroids.

REFERENCES

1. *Planetary Exploration through Year 2000, Part I: A core program*, (Govt. Printing Office, Washington, 1986) p.106.
2. H. Balsiger, H. Fechtig, and J. Geiss, "A close look at Halley's Comet," *Scientific American*, **259** #3, 96 (Sept. 1988).
3. *Planetary Exploration through Year 2000, Part II: An augmented program*, (Govt. Printing Office, Washington, 1986) p.113.
4. *ibid.*, p. 208.
5. W. Seyboldt, J. Puls, W. Hallman, W. Ley, W. Wienss, "Tether Interests and Activities within Germany," *Tethers in Space: Toward Flight*, proceedings from the 3rd Int. Conf. on Tethers in Space — Toward Flight, San Francisco, CA, 17-19 May 1989 (Am. Inst. of Aeron. & Astron., Washington, 1989), p. 9.
6. R.F. Orban, "Advances in space tether materials," *ibid.* , p. 333.
7. J.K. Harrison and C.C. Rupp, J.A. Carroll, C.M. Alexander, E.R. Pulliam, "Small Expendable-Tether Deployer System (SEDS) Development Status," *ibid.*, p. 19.
8. J.R. Glaese, "A length rate control law applicable to space station tether deployment/retrieval," *ibid.*, p. 162; P.K. Lakshmanan, V.J. Modi, A.K. Misra, "Space Station based tethered payload control strategies and their relative merits," *ibid.*, p. 166.
9. D.D. Tomlin, D.K. Mowery, "Tethered satellite system control system design," *ibid.*, p. 143; M. Pasca, M. Pignataro, A. Luongo, "Three dimensional vibrations of tethered satellite system," *ibid.*, p. 153.
10. E. Scala, "Tethers in space, and micrometeoroids," *ibid.*, p. 372
11. J.A. Hoffman, "Operational complexities of real tether systems in space," *ibid.*, p. 381.M. Greene, D. Gwaltney, G. Stover, D. Kromann, J. Walls, "GetAway Tether Experiment (GATE) for the Tether Dynamics Explorer (TDE) Series," *ibid.*, p. 33.