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Research Opportunities on the Space Station

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1. Introduction

This paper reviews two interdisciplinary facilities that have been proposed for the Space Station: the Gas-Grain Simulation Facility and the Cosmic Dust Collector Facility. Both of these facilities provide opportunities for scientists interested in carbon related research to perform experiments in earth orbit. Most of this paper is devoted to the Gas-Grain Simulation Facility[1] (GGSF). The Cosmic Dust Collector[2] (CDC) will be discussed briefly at the end of the paper.

2. The Gas-Grain Simulation Facility

Numerous experiments involving clouds and small particles cannot be performed on Earth due to the Earth's gravitational field. In 1g, the large sedimentation rate of micron sized particles and the effects of gravity induced convection prohibit many interesting studies of particle phenomena. Although such studies cover a wide range of disciplines, they all have in common the study of processes involving small particles and weak interactions and would benefit greatly from the microgravity environment of the Space Station. Because of the very low gravitational acceleration experienced by particles in the Space Station, many experiments that are impractical or impossible on Earth become feasible in the Space Station environment. The advantages of the Space Station's microgravity environment are discussed in more detail in Section 3.

The GGSF (see the figure for a functional diagram) is a facility-class payload being developed for the Space Station by the Exobiology Flight Program at Ames Research Center. The purpose of the GGSF is to perform basic research; the GGSF will be used to investigate and simulate fundamental chemical and physical processes such as condensation, growth, formation, nucleation, evaporation, accretion, coagulation, scavenging, collisions and mutual interactions of droplets, crystals, grains and other particles in a microgravity environment. Examples of experiments that have been suggested for the GGSF will be discussed in Section 4. The GGSF is a "lab in space" that will extend ground based experimental programs to new domains as well as allow completely new types of experiments to be performed. Although the facility is simple in concept, it will be able to perform a variety of experiments in a wide range of disciplines: Exobiology, Planetary Science, Astrophysics, Atmospheric Science, as well as basic Physics and Chemistry.

The GGSF, which would occupy a Space Station double rack, consists of a number of subsystems supporting an experimental chamber. The experimental chamber will have a working internal volume of four to ten liters and may be connected to subsystems that provide environmental (e.g., temperature, pressure, gas mixture and humidity) controls, mechanisms for injecting and removing particles and clouds of particles, levitation systems (e.g., electrostatic, acoustic, laser trapping and aerodynamic) to keep particles in fixed positions away from the chamber walls, energy sources (e.g., UV light), and a number of experiment monitoring and measuring devices (e.g., video cameras, optical particle counters, spectrometers). See reference 3 for a recent determination of the functional requirements of the GGSF.

Because of limitations on crew time, the facility will be designed to operate in a nearly autonomous mode. One possible scenario is as follows: A chamber designed for a sequence of experiments is "plugged in" to the GGSF and subsystems attached in the configuration necessary for the first experiment. A command is then given to begin the execution of preprogrammed instructions to perform the experiment. After the first experiment is completed, the system may be reconfigured for the second experiment. The experiments would be performed in a logical order, perhaps from "clean" to "dirty." When the sequence of experiments associated with the first chamber is completed, the chamber is removed and stored for return to earth and a second chamber is attached for the next sequence of experiments (alternatively, a chamber cleaning subsystem could be activated before a second sequence of experiments is performed in the same chamber). New experiment chambers will be brought to the Space Station periodically, so the GGSF would have a very long useful lifetime.

The GGSF will be designed to have an adaptable configuration; the subsystems may be connected to the experiment chamber in a number of ways. Also, the GGSF will be implemented in an evolutionary fashion. The earliest experiments performed on the GGSF will be those that are the simplest (i.e., require the smallest number of subsystems); the more complicated experiments will be performed later in the facility's development. The above can be achieved by requiring the facility to be modular in design. Modularity will also allow subsystems that become outdated to be replaced by those using more modern technology.

The status of the GGSF program as of November 1987 is as follows: Two workshops have been held - one in 1985 to establish the scientific feasibility of the facility[4] and one in 1987 to create a database of strawman experiments[5]. Recently, Martin Marietta completed a physics feasibility study of the facility[6], and a preliminary Level 1 Requirements Document was sent to NASA headquarters. Presently, the twenty strawman experiments proposed at the 1987 workshop are being studied in order to determine the science requirements of the facility. A two year GGSF reference design study is scheduled to begin in the middle of 1988. On the completion of the reference design study the Announcement of Opportunity for experiments for the GGSF will be released. The Exobiology Flight Program's goal is to have the GGSF available for launch and ready for use at the time of the Permanent Manned Presence of the Space Station (mid 1990's).

3. The Microgravity Environment

A Space Station laboratory has the advantage of a microgravity environment. Microgravity reduces the effect of many environmental forces. On Earth, one micron particles used in an experiment would fall to the floor of a chamber relatively quickly (a micron-sized particle in one atmosphere would fall a meter in one hour at 1g). On the Space Station, however, the terminal velocity of such a particle falling through a gas would be reduced by as much as five or six orders of magnitude (since the terminal velocity of a particle is proportional to the acceleration due to gravity). This effect allows long duration particle experiments to be performed.

Although the sedimentation rate is reduced, it is not eliminated. Tidal effects and the mass of the Space Station itself create gravitational accelerations of 10^{-4} to 10^{-6} g inside the GGSF. Levitation is required in long duration experiments to counteract the resulting sedimentation. The levitation force required, however, is four to five orders of magnitude weaker than that required to keep particles suspended at 1g. This is a major advantage for experiments that study phenomena involving weak interaction forces. A number of possible techniques to levitate particles, in gas as well as in vacuum, were studied in detail in reference 6. This study found that all levitation methods either induce coagulation or otherwise render unrealistic the simulation of multiparticle interactions. This issue is not important in single particle experiments, but is critical in cloud or multiparticle experiments. Cloud experiments can be done without levitation, however, as long as wall effects are not important to the experiment.

The large sedimentation rate problem is not the only problem associated with particle experiments in 1g that is resolved by use of microgravity. The reduction of the gravitational convection due to buoyant forces is another major advantage of the microgravity environment. Also, in some experiments, such as the study of fractal particles, the forces studied are so weak that they would be overwhelmed by gravitational forces in 1g.

See references 1 and 4 - 6 for a more detailed discussion of the advantages and problems associated with the microgravity environment of the Space Station.

4. Example GGSF Experiments

Twenty experiments were suggested for the GGSF at the 1987 workshop[5]. Four example experiments from the 1987 workshop are described in this section. These four were chosen on the basis that they were related to studies of carbon in the galaxy and/or provided instructive examples of types of experiments that could be performed on the GGSF.

(a.) Emission Properties of Particles and Clusters[7]. The objective of this experiment is to measure the radiative properties of clusters of molecules and microparticles in order to understand how radiative energy is converted from UV to infrared. This process, which is not well understood, is important in environments such as circumstellar shells, planetary nebulae, protostellar disks, reflection nebulae and HI/HII interfaces. Clusters of polycyclic aromatic hydrocarbons, carbon grains, or silicates are generated and positioned in the chamber. The baseline emission is measured. The particles are then warmed up or excited by UV radiation and the emission spectrum is measured with spectrometers/monochrometers at different excitation levels. Microgravity is necessary in this experiment because suspension times in 1g are not long enough to accumulate enough signal to measure the emission spectra of free species.

(b.) Dipolar Grain Coagulation and Orientation[8]. The objective of this experiment is to investigate the process of grain agglomeration in dust clouds of grains with an electric dipole moment and to study the polarization of light passing through filamentary agglomerations that are oriented in an external electric field. This experiment investigates this phenomena as a possible mechanism for the formation of elongated grain agglomerates and grain alignment in interstellar clouds resulting in the polarization of light. Dust is produced *in situ* or brought from earth and injected into the chamber. Grain agglomeration and alignment are followed in time using light scattering techniques and polarization measurements. The process is repeated using different values of an external electric field. Microgravity is necessary in this experiment because the dipole-dipole interaction between grains is weak and would be overwhelmed by gravitational forces at 1g. Also, suspension time at 1g would not be long enough for large aggregates to form.

(c.) Surface Condensation and Annealing of Chondritic Dust[9]. The objective of this experiment is to simulate the putative gas-dust reaction textures in extraterrestrial materials, especially carbonaceous chondrite meteorites and interplanetary or cosmic dust, to study surface energy related effects that occur, and to obtain information on chemical composition and complexity of solar system condensates. Oxide cores are injected into the chamber. Metal-bearing gases are then injected sequentially as a function of decreasing condensation temperature. The experimental products are then collected and analyzed on the Space Station or returned to Earth for analysis. Microgravity is necessary because this experiment must be performed without allowing the particles to interact with the chamber walls and because suspension times of the particles would not be sufficiently long in 1g. Also, the absence of turbulence is required during the first stages of the experiment.

(d) Studies of Fractal Particles[10]. The objective of this experiment is to measure the coagulation coefficients of a variety of bare silicates, ice-coated silicates, organic-refractory coated silicates and organic-refractory grains, to grow fractal aggregates of these materials, measure their cohesive strength, and measure their light scattering and extinction properties as a function of wavelength. Refractory silicate nucleation sites are nucleated from vapor and allowed to coagulate. The particles' optical properties are monitored using light scattering techniques. Once grains have grown to a desirable size, they are broken apart with acoustic shock waves to measure their cohesive strength. Particles are allowed to recoagulate and more measurements are made. Finally, particles are coated with ice or irradiated to obtain organic-refractory coatings on silicates and the measurements are repeated. Microgravity is necessary because of the long suspension times required and because macroscopic fractal particles would be gravitationally unstable at 1g and would collapse under their own weight.

The above examples are representative of the variety of experiments that have been suggested for the GGSF. Other experiments that have been suggested for the GGSF involve low-velocity collisions (important for the understanding of the formation of planetary rings), properties of aerosols, particulate aggregation (important in atmospheric processes such as dust storms), other atmospheric processes, ice growth, and a simulation of the organic haze in Titan's atmosphere.

5. The Cosmic Dust Collector Facility

The Space Station also affords an opportunity to collect cosmic dust. The Cosmic Dust Collector (CDC)[2,11] will be discussed only briefly here. The CDC is a facility class payload being developed for the Space Station by Johnson Space Center. The CDC is an externally attached payload proposed for the Initial Operating Configuration of the Space Station. The facility will be designed to capture individual particles and to measure their trajectories with enough precision to determine their astrophysical source.

Two capture techniques have been suggested: atomized capture and intact capture. Atomized capture in "capture cells" preserve (at most) elemental and isotopic composition. Intact capture, however, would also preserve molecular composition and structural information. Intact capture (in underdense media) would probably be the preferred method for most carbon studies. The Exobiology Flight Program at Ames Research Center is sponsoring a study at the Jet Propulsion Laboratory on intact capture techniques and technology for potential CDC experiment development.

6. Conclusion

A wide range of fundamental scientific problems associated with studies of carbon in the galaxy can be addressed by conducting microgravity particle experiments or by collecting cosmic dust on the Space Station. The Gas-Grain Simulation Facility and the Cosmic Dust Collector are experimental facilities proposed for the Space Station that could open new frontiers in carbon research. Persons wishing to suggest or discuss experiments for either of these facilities should contact the author at the above address.

Acknowledgement

The functional diagram of the GGSF is from a sketch by D. Schwartz.

References

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GAS-GRAIN SIMULATION FACILITY