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Gas-Grain Simulation Facility: Fundamental Studies of Particle Formation and Interactions

Volume 1: Executive Summary and Overview

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*Proceedings of a workshop sponsored
by the Exobiology Flight Program
at NASA Ames Research Center
and held in Sunnyvale, California
August 31-September 1, 1987*



Gas-Grain Simulation Facility: Fundamental Studies of Particle Formation and Interactions

Volume 1: Executive Summary and Overview

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PREFACE

This document serves two purposes. First, it provides an overview of the Gas-Grain Simulation Facility (GGSF) project and reports its current status. Second, it records the proceedings of the Gas-Grain Simulation Facility Experiments Workshop. This workshop, held August 31 - September 1, 1987 in Sunnyvale, California, was sponsored by the Exobiology Flight Program at Ames Research Center. The goal of the workshop was to define experiments for the GGSF--a small particle microgravity research facility. This was the second GGSF workshop to date. At the first workshop, held in August 1985 at Ames Research Center, the multidisciplinary scientific rationale for such a microgravity particle research facility was established. The present workshop addressed the opportunity for performing, in Earth orbit, a wide variety of experiments that involve single small particles (grains) or clouds of particles. The first volume of the proceedings includes the executive summary, overview, scientific justification, history, and planned development of the Facility. Twenty experiments from the fields of exobiology, planetary science, astrophysics, atmospheric science, biology, physics, and chemistry were described at the workshop and are outlined in Volume 2 of these proceedings. Each experiment description included specific scientific objectives, an outline of the experimental procedure, and the anticipated GGSF performance requirements. Since these experiments represent the types of studies that will ultimately be proposed for the facility, they will be used to define the general science requirements of the GGSF. Also included in the second volume is a physics feasibility study and abstracts of example Gas-Grain Simulation Facility experiments and related experiments in progress.

The second Gas-Grain Simulation Facility workshop was convened by Glenn Carle, Guy Fogleman, Mark Fonda, and Deborah Schwartz of NASA Ames Research Center. They acknowledge the Exobiology Community at Ames Research Center (ARC) for its generous support during the workshop and in the preparation of these proceedings. They thank Armond Bryce, GE Government Services, and Friedemann Freund, Sarma Lakkaraju, Rocco Mancinelli, John Marshall, Chris McKay, Verne Oberbeck, Steve Squyres, and Carol Stoker, of the Space Science Division at Ames, for their useful editorial comments and thank John Hallett, of the Desert Research Institute in Reno, and Joseph Nuth, of Goddard Space Flight Center, for their assistance in the writing of Chapter 2. The report was generated by the Exobiology Flight Program at ARC under the direction of Guy Fogleman, Mark Fonda, Judith Huntington, and Deborah Schwartz.

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EXECUTIVE SUMMARY

In many astrophysical and geological systems (atmospheric clouds, interstellar clouds, planetary rings, Titan's organic aerosols, Martian dust storms, etc.), processes involving small particles significantly contribute to the overall behavior of the system. Grain nucleation and aggregation, low velocity particle collisions, and charge accumulation are a few of the processes that influence such systems. Particles undergoing these processes include interstellar grains, protoplanetary particles, atmospheric aerosols, combustion products, and pre-biotic organic polymers.

Investigation of such particle systems is essential to the achievement of NASA's scientific goal to attain a deep understanding of the Solar System, Earth, and the origin of life. However, many particle systems are not well understood because parameters relevant to these systems are poorly determined or unknown. Examples of such parameters are the coagulation rate of aerosol particles, the size distribution of particles nucleated from a gas, and the dependence of aggregation efficiency on material properties. Due to rapid particle settling in a 1g environment, these parameters are difficult and in many cases impossible to measure in experimental simulations on Earth. However, one can investigate small particle processes with a general-purpose microgravity particle research facility such as the Gas-Grain Simulation Facility (GGSF).

The need for the GGSF was identified at a workshop held in August 1985 at Ames Research Center. The original concept was to place the GGSF on the Space Station. Many experiments, however, could be performed with the GGSF on the Space Shuttle or another Earth-orbital platform. Because of the very low gravitational acceleration in the Earth-orbital environment, many experiments deemed impractical or impossible to perform on Earth become feasible. In fact, it was the position of the scientists at this workshop that a facility such as the GGSF is the best and perhaps the only way to study many important small particle phenomena.

Having identified the scientific need for the GGSF, the next step was to ensure that the facility will accommodate the requirements of the scientific community. The Exobiology Flight Program at Ames Research Center held a workshop for this purpose in Sunnyvale, California on August 31 - September 1, 1987. The primary workshop objective was to gather an interdisciplinary group of scientists to define a variety of microgravity particle experiments. Twenty experiments were described in detail at the workshop. These experiments will provide the science requirements for the GGSF reference design.

The science community continues to demonstrate a strong interest in and commitment to the GGSF. The workshop was attended by 60 people from six NASA centers, eight universities, and a number of other research institutes and corporations. Workshop participants represented the fields of planetary science, exobiology, astrophysics, atmospheric science, biology, physics, and chemistry. The interdisciplinary nature of the workshop contributed greatly to the workshop's success in obtaining representative science requirements from the potential GGSF user groups.

Based on the information gathered at the workshop, we make the following recommendations:

1. The Gas-Grain Simulation Facility should be installed on a manned or man-tended Earth-orbital platform. It should be a multidisciplinary facility for performing fundamental particle and cloud experiments in the microgravity environment.
2. A specific funding mechanism must be identified for covering costs of research, technology development, and engineering for the facility.

3. Resources should be identified for support of ground-based experimental studies, KC-135 flights, and work that develops potential GGSF experiments or otherwise complements the GGSF development program.
4. A GGSF Science Working Group should be established to advise the project and contractor studies. The Science Working Group should also identify and prioritize candidate GGSF experiments. This group should consist of individuals representing the interests of exobiology, planetary science, astrophysics, and atmospheric science.
5. The goal of the Gas-Grain Simulation Facility development program should be to have the GGSF available for launch and ready for use at the time of Permanent Manned Configuration on the Space Station.

CHAPTER 1

Overview

1.1 Scientific Rationale for the Gas-Grain Simulation Facility

There are many important scientific questions that cannot be addressed without a microgravity particle research facility such as the Gas-Grain Simulation Facility (GGSF). The GGSF provides a new and essential tool for studying small particle phenomena. These phenomena are important to the fields of exobiology, planetary science, astrophysics, and atmospheric science, as well as biology and basic chemistry and physics. The large-scale behavior of many astrophysical and geological systems is often determined by processes involving small particles. Nucleation of particles from a gas, aggregation of small particles into larger ones and low velocity collisions are a few such processes. These processes affect a spectrum of particles from interstellar grains and protoplanetary particles to atmospheric aerosols and combustion products. They are relevant to systems as varied as atmospheric clouds, interstellar clouds, planetary rings, Titan's organic aerosol, and Martian dust storms.

The ability to simulate and investigate these types of systems and processes would present an exciting opportunity to answer long-standing scientific questions concerning the life and death of stars, the formation of the Solar System, and the connection between the Solar System's evolution and the appearance of life. These investigations would also increase our understanding of processes of immediate concern such as acid rain formation, ozone depletion, and climatic change on Earth.

In the study of small particle processes relevant to scientific issues mentioned above, the demands on experiment design are severe. Two common requirements are low relative velocities between particles and long time periods during which the particles must be suspended. Generally, the suspension times required are substantially longer than can be attained in 1g (Note, in this report the symbol "g" will be used as a unit of acceleration where $g = 9.8 \text{ m/s}^2$). Because of this, many processes are not amenable to experimentation in 1g, but could be investigated with a general-purpose particle research facility in Earth orbit. As a result of the very low gravitational acceleration (microgravity) in the Earth-orbital environment, previously impractical or impossible experiments become feasible. One class of such experiments are those in which Earth's gravity interferes directly with the phenomenon under study; another class consists of those in which gravity precludes the establishment of proper experimental conditions.

The Space Station will provide a unique opportunity to perform experiments in Earth orbit. The GGSF, currently under development by the Exobiology Flight Program at Ames Research Center, is a facility-class payload proposed for the Space Station. The GGSF will be used to simulate and investigate fundamental chemical and physical processes such as the formation, collisions, and mutual interactions of droplets, grains, and other particles. By extending the range of conditions in which experiments can be performed, the GGSF will be a powerful tool for studying the physics of small particles and grains. In the GGSF, the effects of gravity will be reduced by a factor of as much as one million. This will allow weak forces to be studied without interference from strong gravitational effects. Important advances in our understanding of the above phenomena should result from this new ability to study subtle small particle effects and interactions.

1.2 The Need For Microgravity

On Earth, experiments that study aerosols or small grain interactions are severely limited by rapid particle settling rates. Aerosol particles and small grains quickly settle out of Earth-based experiment chambers. For instance, in 1g, water drops 1 micron in diameter (in air at STP) will fall 0.8 cm in one minute. Yet, to set up the desired experimental conditions or to collect data on processes of interest, experiments must often run for very long durations. For example, one candidate GGSF experiment aims to study the growth and reproduction of microorganisms suspended in a nutrient aerosol. The microbes are inoculated into drops 10 to 25 microns in radius. These drops must be suspended for days to allow the microbes time to recover from aerosolation, grow, and reproduce. In 1g, a 10 micron drop (in air at STP) will fall nearly one meter in one minute. In microgravity (10^{-5} g), the same drop would settle less than half that distance in one month. Clearly this and other experiments requiring long run times must be performed in microgravity. Many experiments fit into this category, but at least three classes of experiments have specific reasons for requiring long particle suspension times or other features of the microgravity environment.

One class of experiments involves the study of fragile aggregates. These materials are held together by relatively weak inter-grain forces (e.g., van der Waals, dipole-dipole, and electrostatic). This class of experiments must be performed in microgravity as the grains involved are too delicate to be manipulated in 1g and, in 1g, the larger aggregates are structurally unstable, and collapse under their own weight. Also, in experiments involving the collision of fragile aggregates, gravity-induced stresses affect the collision outcome and therefore must be effectively eliminated.

A second class of experiments involves particle and crystal growth. These experiments are often limited on Earth because particles settle out before they grow to a size of interest. Or, if one can grow crystals to the desired size, the conditions under which the crystals grow may bear little relation to the physical system one is striving to simulate and study. For example, large NH_3 , CH_4 , and CO_2 ice crystals can be grown in 1g under a variety of temperature and pressure conditions, yet to realistically simulate the growth of crystals in the atmosphere of a jovian planet, crystals should be grown slowly under low levels of supersaturation. In 1g, crystals grown in this manner will settle before reaching the desired size. In general, maximum potential growth of particles and crystals, and more realistic simulations utilizing these particles can be obtained in microgravity. Also, gravity induced convection and turbulence disrupts crystal growth (as well as evaporation processes) and inhibits the study of purely diffusional effects on growth. A well controlled, homogeneous, convection-free environment can be achieved much more readily in space than on Earth.

Finally, studies of low velocity (10^{-4} cm/s to 10 cm/s) collisions also require a microgravity environment. Some of these experiments, in contrast to most others, should be performed in as low a vacuum as possible so as to avoid the effects of the gas drag force on the particle. To monitor particles before and during a collision, particles colliding with such low relative velocities must remain suspended for times longer than possible in 1g. Further, any exploration of post-collisional, low energy processes and effects also requires that particles be monitored for periods longer than possible in 1g and without disturbances and stresses induced by gravitational and levitational forces.

Each of the above mentioned types of experiments must be performed in microgravity. Low gravitational accelerations can be achieved for approximately 20 seconds on NASA's KC-135 aircraft, but most experiments require substantially longer periods of low gravity. Levitation techniques are well developed and can be employed in 1g to greatly increase single particle suspension times. However, these techniques cannot be applied successfully in 1g to the above

experiments. The force required to suspend particles in 1g can be much stronger than the force being studied and, in cloud experiments, will coerce coagulation or otherwise disrupt the phenomena of interest. For many important scientific studies, the ability to perform experiments in a convection-free environment, achieve long run times, or study weak forces can only be achieved in a microgravity environment such as that obtained in Earth orbit.

1.3 The Interdisciplinary Nature of the GGSF

The high cost of experimentation on the Space Station provides strong motivation for developing orbital laboratory facilities capable of addressing as wide a range of problems as possible, rather than designing highly specialized facilities capable of addressing only one narrow problem. Also, given the constraints involved in the development of flight experiments for the Space Station, it is desirable that Space Station experimental facilities address scientific problems of fundamental importance. Therefore, an objective for the GGSF project will be to design a facility that is flexible enough to accommodate many scientifically important investigations without compromising the requirements of any particular investigation. There are many small particle experiments that address fundamental scientific issues and have in common the need for microgravity. Although the range of these experiments spans many disciplines and involves a variety of approaches and measurement techniques, it is reasonable to suppose that a modular facility containing a particle suspension chamber with adaptable configuration and measurement capabilities could provide a flexible Earth-orbital laboratory.

It is not surprising that a single facility could address the fundamental issues of several different disciplines. For example, in the field of space sciences, researchers are interested in many of the same processes as the exobiologist; the focus is only slightly different. Both disciplines have a need to understand processes that influence the distribution of elements during planet formation. The exobiologist tends to focus on the biogenic elements while the planetary geologist may focus on rock forming elements or on the noble gases. In astronomy, there is interest in the molecular structure of the interstellar medium. The exobiologist shares this interest, but again tends to focus on the life related molecules and carbon. It is therefore assured that a facility such as the GGSF will have significant impact on each of these disciplines.

CHAPTER 2

Scientific Significance

This chapter summarizes scientific issues that could be addressed on the Gas-Grain Simulation Facility. These issues are relevant to the disciplines of exobiology, planetary science, astrophysics, and atmospheric science. The GGSF will also provide an opportunity to perform a number of experiments important to our understanding of basic phenomena in the field of biology as well as in the fields of physics and chemistry; in fact, many experiments suggested at this workshop would address fundamental physical problems during the course of investigations specific to a particular discipline.

2.1 Exobiology

Exobiology is the study of life in the universe. Exobiologists strive to understand the origin and distribution of the biogenic elements (C, H, N, O, P, S) and the relationship between the Solar System's physical and chemical evolution and the appearance of life. Exobiology research includes tracing the history of organic matter in the primitive Solar System and evaluating the significance of abiologically produced organic matter in the evolution of the terrestrial planets. It is an interdisciplinary field and as such incorporates many aspects of the other disciplines interested in the GGSF. However, exobiology brings a different perspective to the astrophysical, biological, and geological phenomena discussed herein. Often, this perspective involves the study of trace constituents such as the organic components of meteorites or the study of minor chemical processes such as the abiotic production of organics by lightning. These investigations and related experiments were discussed at length in the Exobiology in Earth Orbit Workshops held at Ames in August 1984 and April 1985 (Workshop report to be published as a NASA SP, "Exobiology in Earth Orbit", edited by D. DeFrees, D. Brownlee, J. Tarter, D. Usher, W. Irvine, and H. Klein).

Interactions among gases and grains are fundamental to theories on the origins of the constituents of interstellar clouds, comets, meteorites, interplanetary dust, and Solar System bodies. Interactions between a gas phase and a solid phase include sorption phenomena, heterogeneous catalysis, and many other familiar terrestrial physical, and chemical processes. Such interactions in space may play important roles in the cosmic history of the biogenic elements and compounds. Elucidation of this history involves tracing the physical and chemical pathways taken by the biogenic elements and compounds from their origins in stars to their incorporation into planetesimals.

The observed circumstellar dust and molecules indicate that nucleation and growth of carbonaceous particles occurs in the envelopes of carbon stars. Similar processes are thought to occur under diverse conditions ranging from those in interstellar clouds to those in the atmospheres of the outer planets and their satellites. In both types of environments, observational evidence suggests the presence of fine-grained dust 0.1 to 1 μm in diameter, presumably containing varying proportions of hydrogen, carbon, nitrogen, and oxygen. Based on remote spectrophotometric observations, some properties of cosmic dust have been postulated, yet the physical and chemical characteristics of the material and the nature of the processes that produce it remain poorly understood and almost entirely in the realm of theory.

Although theories of grain nucleation and dust growth are being developed, the complexity of these processes make them difficult to model. The few experimental studies that have been conducted were performed under conditions that do not permit scaling to relevant astrophysical

environments. In such environments, one feature common to the processes mentioned above is the formation and evolution of grains over substantial lengths of time while being suspended in a thin gas phase largely, if not entirely, independent of other grains. This condition should influence the rate of formation, chemistry, structure, morphology, and other characteristics of the dust. While this condition is difficult, if not impossible, to model in a terrestrial laboratory, it may be effectively simulated in microgravity. Experiments in Earth orbit would provide "space truth" for analogous experiments carried out in terrestrial laboratories and on computers. Furthermore, they would yield, under well-defined conditions, samples whose properties could readily be determined and compared with those of natural material either remotely sensed or obtained from meteorites, interplanetary dust, or comets.

A dust grain can grow by the passive accretion of gaseous species to its surface; it can also provide an active surface to catalyze reactions of species sorbed to it or can be changed by chemical reactions with sorbed gases. Chemical reactions between gas and dust hypothesized to occur in interstellar clouds and in the solar nebula may account for organic matter observed by radio astronomers in interstellar clouds and by chemists in meteorites, comets, and interplanetary dust. Grains are of further interest as grain accretion is responsible for the formation of planetesimal-sized objects from small grains in the solar nebula. Other hypothetical gas-grain processes of nebular or interstellar relevance that merit study include the hydration of silicate grains to phyllosilicates by gaseous water, the photoirradiation of icy mantles of grains by starlight, and the thermal evolution of interstellar condensates in the solar nebula. The microgravity environment of the GGSF would provide excellent opportunities for model studies of these processes.

2.2 Planetary Science

Planetary science is concerned with both the cosmological processes that led to the formation of the Solar System (and planetary systems in general) and with the behavior of geological and atmospheric materials on evolved planetary bodies. More specifically, the research interest centers around the behavior and the interaction of particulate materials that have paths distant and free from the influence of a solid or liquid surface. The particles of interest range from centimeter size particles of ice and dust to submicron comminution products and condensates. Some of the most fundamental processes involved in the origin and evolution of the Solar System concern the condensation of solid matter from a gas, the aggregation of small particles to form large particles, and the collisional interaction of particles.

Understanding particle condensation is critical to understanding the earliest stages of Solar System formation. Classical nucleation theory cannot adequately predict the condensation of protoplanetary particles from the early solar nebula. Experiments have been performed in terrestrial laboratories to simulate this process, but such experiments often suffer from convective instabilities induced in the gas from which the condensation takes place. In a microgravity environment, it will be possible to conduct condensation experiments with more refractory materials. Experiments extended to low temperature condensation will also be able to investigate the formation of the icy grains that accreted into the outer planets, their satellites, and comets.

Once grains formed by condensation in the early solar nebula, they underwent aggregation into planetesimals. The Solar System, in its nebular state, began as particulate material that interacted at low relative velocities to form larger aggregates of material and, ultimately, the planetary bodies. Immediately after the first stages of particle aggregation in the solar nebula, planetesimal formation probably involved collisions of particles at relative velocities of a few meters per second or less. The detailed dynamics of such collisions, in particular the nature of the conditions necessary for particles to adhere together after a collision, are poorly understood. The effects of factors such as particle composition, relative sizes, spin, and ambient gas pressure on collision dynamics are not well known.

Within the evolved planetary system, particles of ice and dust form an unconsolidated component of some planetary bodies in the form of ring structures such as those of Jupiter, Saturn, and Uranus. Again, interest lies in understanding low energy collisions of such particles since this process determines the structure and behavior of ring systems. The particles of interest here are more coherent solids than the ice/dust aggregations mentioned above. Collisions result in an effective viscosity for the rings and in development of diffusional instabilities that are manifested as intricate small-scale structures. In this case the most important parameter to understand is the coefficient of restitution which describes the inelasticity of collisions. Attempts have been made to study low velocity particle collisions by suspending particles from pendula, but such experiments suffer severely from the restriction of particle motions. However, full three-dimensional interactions, including spinning particles and the interaction of more than two particles, can be conducted in a microgravity environment. The evolution of the planetary ring systems may also have been dependent on the interaction of electrostatically charged micron to sub-micron size dust particles that interact electrically with an ambient plasma. The behavior of such particles also has direct relevance to understanding comets that emit dust at large heliocentric distances.

Interacting particles are also found within the atmospheres of the terrestrial planets. Such materials range from grains less than a micron to several tens of microns in size and owe their presence in suspension to the action of aeolian, volcanic, and impact processes. Particle aggregation caused by the electrostatic interaction of these atmospheric particulates may strongly influence the life-span of dust storms, the behavior of volcanic eruption plumes, and the potentially global effects (such as species extinction) of impact dust falls. For example, it has been hypothesized that a large meteorite or comet impact could have caused substantial atmospheric dust loading on Earth and subsequent faunal (e.g., dinosaur) extinctions. Such hypotheses are dependent on the rate of dust aggregation and the rate at which particle aggregates settle from the atmosphere. Aggregation rates also play a crucial role in calculations of "nuclear winter" scenarios.

All aggregation experiments are severely restricted in duration by rapid settling in a 1g gravitational field. The microgravity environment on the Space Station will allow the process of particle aggregation to be studied in great detail under a wide range of conditions. A sample of specific parameters that need investigation includes aggregation rates, the size distribution of aggregates, and the dependence of aggregation efficiency on material properties.

2.3 Astrophysics

Astrophysics is the study of matter and energy in the universe. As such, it is concerned with the formation, life cycle, and death of stars, as well as with processes that occur in the interstellar medium. Small grains play an important role in several stages of stellar evolution. In protostars, the infrared opacity of the accretion disk is controlled by the properties of grains; size distribution, composition, degree of aggregation, volatile content, and other parameters all play important roles in determining the properties of the protostar. The efficiency with which grains coagulate into larger aggregates will determine the size of the objects that remain in orbit after the T-Tauri phase has swept away the excess gas of the accretion disk and will therefore determine the probability of planet formation. As stars near the end of the hydrogen-burning phase, atmospheric pulsations might eject matter high into the stellar atmosphere. If such matter contains a sufficient concentration of refractory vapor, it will nucleate into small grains that can be pushed away from the star by radiation pressure. These grains tend to drag the surrounding gas away with them and can set up conditions in which a steady rate of mass loss is established. Such mass loss eventually leads to extensive shells (planetary nebulae) surrounding old stars: here too grains play a significant role in scattering light from the central star throughout the nebula.

When the material produced in circumstellar outflows mixes with that in the general interstellar medium, a variety of gas/grain interactions might occur. Such interactions include chemical sputtering, hydration, oxidation, reduction, adsorption, surface catalysis, and the formation of grain mantles. Each of these processes will affect both the surface properties of the grains as well as the chemical composition of the interstellar gas. Other processes such as annealing, cosmic-ray bombardment, grain coagulation or grain-grain collisions will only affect properties of the grains. Even though many aspects of the above processes can be studied in terrestrial laboratories, several crucial measurements can be made only in a microgravity environment. Examples of such measurements include the coagulation efficiency and final morphology of a variety of refractory grains, the strength of the aggregates, both with and without ice mantles, and the optical properties of "fractal" aggregates of dielectric particles, of metal grains, and of mixtures of the two.

Astrophysicists will use the microgravity environment of the Space Station to measure the formation rate, optical properties, and intrinsic strength of particle aggregates that would collapse under their own weight in a terrestrial laboratory. Such aggregates may also play key roles in the transport of condensible species and specific isotopic anomalies from circumstellar environments into primitive stars (in particular, the protostellar nebula). However, before models of such transport mechanisms are constructed, measurements of the formation and destruction rates of the aggregates must be performed. Similarly, if we are to test theories that predict the abundance patterns of such aggregates throughout the galaxy, then some means of detecting them must be found. Experimental studies in the Gas-Grain Simulation Facility aboard the Space Station will play a central role in our quest for understanding these phenomena.

2.4 Atmospheric Science

Particle nucleation, growth, and evaporation, interactions, and low-rate surface chemical reactions are processes that are currently of major interest in atmospheric science. Investigation of these topics is important for our overall understanding of phenomena such as acid rain formation, ozone depletion, precipitation mechanisms, and radiation transfer in the atmosphere.

A low gravity environment offers opportunities to investigate specific processes under controlled conditions over long time periods and in the absence of convective fluid motion. Particle interactions can be simulated over a range of velocities that are inaccessible at 1g; aerosol scavenging, water cloud, and ice formation can occur uninfluenced by convection and particle settling. Presently the study of nucleation kinetics on realistic atmospheric nuclei is limited to the relatively short time periods imposed by gravitational settling. In a microgravity environment, slow surface chemical reactions on ice crystals can be studied over extended periods of time. In addition, drop oscillation and interaction can be investigated in the absence of external and internal circulation.

The advantage gained in carrying out such experiments in microgravity is not that it permits better simulation of atmospheric processes -- it does not do this -- but that it permits elimination of physical variables in situations that are already complex and gives vital scientific insight into atmospheric phenomena that could not be obtained in any other way.

CHAPTER 3

Candidate GGSF Experiments

3.1 Classes of Experiments

In the upcoming two-year GGSF reference design study, the twenty experiments described at this workshop will be used to ensure that the facility meets the needs of all potential user communities. Study of the candidate experiments can also guide development of future GGSF experiments. However, before the information contained in the descriptions of these experiments can be fully utilized, the experiments must be categorized. Several classification schemes were suggested at the workshop. The experiments could be classified by the physical processes studied, scientific priority, complexity of experiment, chamber size and type, initial particle concentration, particle composition, subsystems needed, experiment environment, cleanliness, required crew time, or disciplinary field. Experiment classification will be an important near term step in obtaining the science requirements of the GGSF.

Five working groups, representing the fields of exobiology and life science, planetary science, astrophysics, atmospheric science, and physics and chemistry, were convened during the 1987 workshop. Division of the workshop participants into these smaller groups gave scientists with common interests the opportunity to work together to define GGSF experiments. This section discusses the GGSF science objectives of each working group and, as an example classification, associates each experiment with the group from which it was generated. Many of these experiments, however, could fit readily into one of the other discipline categories. Furthermore, some of the other schemes mentioned above would be more appropriate classifications since they would better organize the information contained in the experiment descriptions. Brief descriptions of the experiments follow in section 3.2.

Exobiology and Life Science Working Group

Participants: R. Mancinelli (Co-Chair), C. McKay (Co-Chair), L. Allamandola, D. Andersen, G. Carle, B. Clark, B. Khare, V. Oberbeck, E. Peterson, J. Raymond, C. F. Rogers, T. Scattergood, D. Schwartz, P. Stabekis, C. Stoker, S. Welch, R. Williams, L. White

Objectives: Simulate and study organic material in or on small grains in various astrophysical or geological settings such as Titan's upper atmosphere, interstellar space, and comets upon entry into a planetary atmosphere. Such studies are important for understanding the development of prebiotic materials in the Solar System and on Earth. Study the survival and reproduction of microorganisms in aerosols to investigate the possibilities of an aerosol-based biological system in, for instance, a jovian atmosphere. Investigate the growth inhibition mechanisms of crystals due to protein inhibitors; these mechanisms are important to processes such as bone growth.

Experiments: 9, 11, 12, 14, 17, 19, and 20

Planetary Science Working Group

Participants: J. Marshall (Co-Chair), S. Squyres (Co-Chair), B. Clark, R. Greeley, R. Leach, W. K. Rhim, R. Williams

Objectives: Study low-velocity collisions of ice particles in order to understand orbital dynamics of planetary ring systems. Study low-velocity collisions of particle aggregates; this is relevant to models of the accretion of stellar nebula material into larger pre-planetary bodies. Simulate and study aggregation of finely comminuted geological material in planetary atmospheres in order to understand processes related to volcanic eruptions, meteorite impact, and aeolian activity.

Experiments: 1, 4, 5, and 14

Astrophysics Working Group

Participants: J. Nuth (Co-Chair), F. Rietmeijer (Co-Chair), L. Allamandola, F. Freund

Objectives: Study agglomeration in dust clouds composed of grains carrying electric dipole moments. This study will help determine whether filamentary agglomeration of dipolar grains is the mechanism by which light passing through interstellar dust clouds is polarized. Simulate and study the putative gas-dust reaction textures in extraterrestrial materials such as carbonaceous chondrite meteorites and interplanetary or cosmic dust. Study the coagulation and properties of fractal particles. Simulate and study the radiative emission properties of particles and aggregates in environments such as circumstellar shells, planetary nebulae, and protostellar disks in order to understand how radiative energy is converted from UV to IR.

Experiments: 13, 15, 16, and 17

Atmospheric Science Working Group

Participants: J. Hallett (Co-Chair), M. Tomasko (Co-Chair), J. Hudson, P. McMurry, S. Pope, J. Raymond, W. K. Rhim, J. Richard, C. F. Rogers, C. Stoker, W. Thompson, E. Trinh

Objectives: Determine the crystal habits of ices grown at low temperatures and measure their optical scattering properties; this is important for understanding microphysical processes of the outer planets. Investigate aggregation of ice crystals and the ice scavenging of aerosols to better understand atmospheric cleansing. Study water condensation on a characterized aerosol to investigate the process of cloud formation. Study the incorporation of water into smoke aerosols and investigate other basic cloud physics problems.

Experiments: 2, 3, 6, 7, 8, 14, and 18

Physics and Chemistry Working Group

Participants: W. R. Thompson (Co-Chair), E. Trinh (Co-Chair), F. Freund, G. Fogleman, J. Hallett, J. Haggard, B. Khare, J. Miller, S. Sandford, D. Traver

Objectives: In bimetallic molecular aggregates, study the transition from atomic/molecular behavior to bulk material behavior to better understand the role of geometry and composition in the properties of alloys. Investigate the interaction of colliding crystals as they approach and contact in order to understand the growth of grains in planetary atmospheres and the collisional disruption or coalescence of particles in the interstellar medium. Study the effect of convection on coagulation and wall deposition of aerosols of micron and larger size particles. Study the formation and optical scattering properties of organic aerosols.

Experiments: 2, 9, 10, and 18; Note, most of these experiments could be assigned to one of the other topical working groups.

3.2 Experiment Summaries

This section briefly describes each of the candidate experiments defined at this workshop. The experiments have been numbered arbitrarily. Appendix E contains the complete experiment descriptions. As noted below, some of the experiments were also discussed in the report on the 1985 GGSF Workshop (NASA CP 2496, Dec. 1987).

Experiment 1 Low-Velocity Collisions Between Fragile Aggregates (Also in '85 Workshop Report under same title, pg. 11)

Contact(s): S. J. Weidenschilling (Planetary Science Institute)

Objective: Investigate the aggregation, disruption, and momentum transfer processes induced by low velocity (<100 cm/s) collisions between particles and aggregates.

Approach: Aggregates of silicate grains or mixtures of silicate and ice grains will be manufactured on Earth and transported to the GGSF or produced by *in situ* condensation from a gas phase. After the aggregates' properties are measured, two aggregates will be positioned in the chamber and given a low relative velocity toward each other. The resulting impact will be documented by high-speed stereo photography or video.

Justification: Low velocity collisions of aggregates comprised of sub-micron grains probably indirectly controlled large-scale processes such as the earliest stage of aggregation of solid bodies in the solar nebula. Microgravity conditions are necessary because the aggregates are very fragile and cannot be manipulated in 1g. Also, at 1g, the collisional outcomes would be affected by gravity induced stresses.

Experiment 2 Low-Energy Grain Interaction/Solid Surface Tension

Contact(s): W. R. Thompson (Cornell)

Objective: For solid, angular particles (crystals), study the physics of coalescence (surface contact readjustment, luminescence resulting from contact, etc.) that is caused by low velocity collisions between particles.

Approach: Similar to Experiment 1 except that particles used are crystals of various composition. The ice may be grown *in situ*.

Justification: Coagulation efficiencies of solid particles have not been measured directly. The coagulation process takes place between atmospheric particles and determines, in part, the residence time of hazes in planetary atmospheres and therefore determines a number of global physical effects. Microgravity conditions are necessary because collisions must occur at low relative velocities. Also, the reconfiguration processes are low energy phenomena that would be difficult to study in the presence of 1g gravitational forces.

Experiment 3 Cloud Forming Experiment

Contact(s): J. Hudson (Desert Research Institute)

Objective: Determine the condensation coefficient (i.e., the rate at which droplets grow) for small size (.01 to 20 microns) nuclei and droplets in various aerosols. Investigate the polydispersity of the droplet size spectrum. Study the incorporation of insoluble aerosols into the droplets.

Approach: An aerosol is produced, characterized, and injected into a chamber of known humidity. The chamber is expanded, and the concentration and size distribution of the resulting droplets are measured. Compressions and expansions are repeated with more nuclei, more gas, etc. Properties such as droplet concentration and size spectra will be measured. Observed and predicted properties will be compared.

Justification: Sampling problems in experiments performed in the atmosphere are severe, and thus measurements of droplet concentrations in such experiments cannot be used to validate current cloud formation theories in any detail. With this experiment, a careful check could be made of existing theoretical treatments of cloud formation. A better understanding of how nuclei and early growth processes react to actual adiabatic expansions will also give a better insight into precipitation processes. Microgravity conditions are necessary because the experiment must be done with low supersaturations and in the absence of gravity-induced convection and fallout.

Experiment 4 Planetary Ring Particle Dynamics (Also in '85 Workshop Report as "Low Velocity Collisions of Ice Particles", pg. 12)

Contact(s): S. Squyres (Cornell)

Objective: Conduct low velocity (10^{-4} to 10 cm/s) collisions of simulated planetary ring particles in a variety of configurations and environments in order to study the dynamics of planetary ring structures. For example, the coefficient of restitution will be measured over a range of relative velocities, collision geometries, and particle textures, sizes, and temperatures.

Approach: Similar to Experiment 1, except that "ice balls" (predominantly H₂O) are used.

Justification: Energy losses and momentum transfer in low velocity collisions are one of the important factors that determine the dynamics of planetary ring structures. Microgravity conditions are necessary because the relevant impact velocities are so low that particles would fall out of any reasonably sized chamber in 1g.

Experiment 5 Aggregation of Fine Geological Particulates in Planetary Atmospheres (Also in '85 Workshop Report as "Aggregation of Finely-Comminuted Geological Materials", pg. 13)

Contact(s): J. Marshall (Arizona State University/ARC)

Objective: Understand the way in which finely comminuted materials aggregate within and ultimately precipitate from planetary atmospheres. In particular, determine the growth rate, size, composition, and other parameters of aggregates as a function of time, initial particle size, particle charge, atmospheric composition, and mode of comminution.

Approach: The chamber is filled with finely comminuted lithological material (dust-sized basalt, quartz, pyroclastic material, etc.). Time sequenced high magnification photography, spectrophotometry, nephelometry, and light scattering techniques will provide records of aggregation events.

Justification: The rate and extent of aggregation determines particle settling rates and thus the time of atmospheric residence and the geographic distribution of the material. Residence times of fine particles injected into planetary atmospheres are relevant to hypotheses concerning nuclear winter, climatic change, species extinction due to climatic change, the potential hazards of volcanic eruptions, and the distribution of volcanic products, the duration of (e.g., Martian) dust storms, and the distribution of loess. Microgravity conditions are necessary because particle settling in 1g acts too rapidly to allow growth potential of aggregates.

Experiment 6 Condensation of Water on Carbonaceous Particles

Contact(s): C. F. Rogers (Desert Research Institute)

Objective: Examine the hypothesis that H₂O condensation on insoluble, carbonaceous particles is initiated by an adsorption process that requires times on the order of 100 to 1000 seconds.

Approach: Smoke particles in the 0.1 to 1 micron size range are generated by combustion of fuels (including acetylene and liquid petroleum), size classified by an electrostatic classifier, and injected into a continuous flow diffusion chamber. By varying the flow rate, the particles can be given different exposure times in an H₂O supersaturated environment. The particles are then passed through an optical particle counter. Forward scattering of white light by each particle is measured in order to determine the amount of water that has condensed on the nucleus.

Justification: Studies of bulk samples of carbonaceous materials indicate that H₂O adsorption equilibrium requires long periods of time (hours). Present data with respect to submicron particles is limited to particle exposure times of about 100 seconds in supersaturated environments. A longer exposure time is required in order to test current understanding of this process. Microgravity conditions are necessary because experiments in 1g are short-duration due to convection and settling. The microgravity environment would allow longer duration experiments in a more quiescent background.

Experiment 7 Optical Properties of Low-Temperature Cloud Crystals (Also in '85 Workshop Report as "Growth of Particles in Other Planetary Atmospheres", pg. 22)

Contact(s): M. Tomasko (University of Arizona)

Objective: Determine the crystal habits of ices grown at low temperatures. Measure single-scattering optical properties of the ices as a function of size and shape.

Approach: Different gas mixtures are admitted into the chamber and the temperature is lowered. The scattering properties of the crystals that form are measured with a detector array. The crystals are then collected electrostatically and photographed. This procedure is repeated under varying conditions.

Justification: Clouds are formed in the atmospheres of the outer planets when gases with a range of partial pressures precipitate out and form ice crystals. Spacecraft observations have led to the derivation of optical single scattering properties for these particles, but their physical properties remain undetermined. This experiment would simulate the Jovian atmosphere and catalog the properties of ice crystals grown under a variety of temperature and pressure conditions. This is an important step in making the connection between the optical and physical properties of crystals in the size range of interest. This information will permit advances in the understanding of

microphysical properties and chemistry in atmospheres of outer planets. Microgravity conditions are necessary because the time required to grow ice crystals at a low level of supersaturation exceeds 1g fall times in reasonably sized chambers. Also, scattering measurements must be made on many crystals, so levitation at 1g would not work.

Experiment 8 Ice Scavenging and Aggregation

Contact(s): J. Hallett (Desert Research Institute)

Objective: Under controlled conditions, and in the absence of convection and ventilation, investigate (1) the aggregation of ice crystals and (2) the ice scavenging of aerosols.

Approach: (1) Water ice crystals are nucleated, allowed to grow and positioned if necessary. Two crystals are given a low relative velocity (by an acoustic or electric impulse) toward each other and the resulting impact is observed with a high speed camera. (2) Crystals are grown (or evaporated) in a surrounding aerosol. The aerosol flux is observed with an aerosol spectrometer.

Justification: These studies are important in understanding the mechanism by which the atmosphere cleanses itself. In order to separate molecular and bulk motion of aerosols, experiments must be performed in the absence of convection. Microgravity conditions are necessary in order to enable low impact velocities to be achieved and because a convection-free environment is not achievable in 1g.

Experiment 9 Synthesis of Tholin in Microgravity and Measurement of its Optical Properties

Contact(s): B. Khare (Cornell)

Objective: Measure the optical and scattering properties of suspended organic aerosols.

Approach: A gas mixture of roughly 10% CH₄ and 90% N₂ will be exposed to UV light to simulate the production of haze particles (tholins) in Titan's upper atmosphere. Substrates and microscopic slides placed in the experiment chamber will be used to measure the optical constants n and k . A spectrometer ($\lambda = 0.2\text{-}2.5 \mu\text{m}$) will measure the suspended tholins' scattering properties at all phase angles.

Justification: This experiment will yield data important to the resolution of well posed scientific questions about the nature of Titan's organic haze and will provide information valuable to the preparation of future planetary probe experiments such as the proposed Cassini mission to Titan. Microgravity conditions are necessary because this experiment must be performed without the particles interacting with the chamber walls. Suspension times of the particles in 1g would not be sufficiently long to achieve this.

Experiment 10 Metallic Behavior of Aggregates

Contact(s): D. Podolski Traver (TRW)

Objective: Study the onset of metallic behavior of molecular aggregates (1) as a function of cluster size and composition (particle ensemble measurement) and (2) as a function of fractal dimension (single particle measurement).

Approach: Bimetallic aggregates are condensed from a vapor or by expansion through a nozzle. The size distribution and optical spectrum are simultaneously measured. The size distribution is measured by laser light scattering techniques. The UV-visible spectrum is monitored for signatures of transition to metallic behavior.

Justification: The transition from atomic/molecular behavior to bulk material behavior is not well understood. This study would increase our understanding of the role of geometry and composition in the properties of alloys; also, it could lead to discoveries of new classes of compounds with new electrical properties. Microgravity conditions are necessary because the produced aggregates will be fragile and gravitationally unstable. Also, containerless processing is needed in order to avoid contamination.

Experiment 11 Investigations of Organic Compound Synthesis on Surfaces of Growing Particles

Contact(s): V. Oberbeck (ARC)

Objective: Study the UV photolysis of amino acids and other complex organic compounds on the surfaces of growing particles and simulate this process as it occurred in Earth's primitive atmosphere.

Approach: A multicomponent aerosol cloud is generated and exposed to a UV light source. The aerosol size spectrum is monitored with an aerosol spectrometer. Periodically, samples of the aerosol are taken from the chamber for chemical analysis (on the Space Station, if possible, or on Earth).

Justification: This experiment is relevant to the hypothesis that molecules important to the evolution of life on Earth were produced in the atmosphere on the surfaces of growing particles of cometary origin. The molecules were then protected from ultraviolet degradation through further growth of the particles by coagulation. Microgravity conditions are necessary in this experiment because the particle suspension time in 1g is not long enough for photolysis to have a significant effect or for particles (~0.1 μm -sized) to coagulate and form larger (~1 μm) particles.

Experiment 12 Crystallization of Protein Crystal-Growth Inhibitors

Contact(s): J. Raymond (Alaska Department of Fish and Game)

Objective: Determine the mechanism of crystal growth inhibition due to protein inhibitors. Produce macroscopic crystals (~1 mm in radius) of antifreeze glycoprotein (AFGP) that are suitable for X-ray diffraction analysis in order to determine conformation of these molecules and clarify binding mechanisms of protein crystal growth inhibitors to their crystal substrates.

Approach: A drop (~0.5 cm in radius) of saturated protein solution is suspended in the chamber. The chamber environment is 1 atm. of air at 50% relative humidity and 4°C. By occasional use of acoustic levitation, the droplet is held away from the chamber walls for 12 to 24 hours until the drop has dried. The resulting material, which is either a glass or a crystal, is removed from the chamber and stored for return to Earth. Sample analysis will include microscopic inspection and/or X-ray diffraction (on the Space Station, if possible, or on Earth).

Justification: Crystal growth inhibition is an important biological process that occurs in phenomena such as bone growth and is important to the prevention of kidney stone growth. Although it is known that this process is controlled by proteins, the manner in which the proteins

act is not well understood. Microgravity conditions are needed as large crystals must be grown in the absence of convection in order for the X-ray diffraction analysis technique to be used. Also, containerless processing is necessary to avoid edge effects interfering with crystal growth.

Experiment 13 Dipolar Grain Coagulation and Orientation (Also in '85 Workshop Report as "Orientation of Weakly Ferroelectric Dust Grains", pg 31)

Contact(s): F. Freund (SETI Institute/ARC)

Objective: Investigate the process of grain agglomeration in clouds of dust grains that carry electric dipole moments. Determine the grains' fractal dimensions. Study the polarization of light passing through filamentary agglomerations oriented in an external electric field.

Approach: 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. This process is repeated using different values of the external electric field.

Justification: Filamentary agglomeration of dipolar grains is a possible mechanism by which non-spinning interstellar grains can be oriented in the galactic magnetic field. Oriented filamentary structures provide a possible mechanism by which light passing through interstellar clouds could be polarized. Microgravity conditions are necessary because the dipole-dipole interaction between grains is weak and overwhelmed by 1g gravitational forces. Also, suspension time at 1g would not be long enough for large aggregates to form.

Experiment 14 Titan Atmospheric Aerosol Simulation (Also in '85 Workshop Report as "Pre-biotic Atmospheric Chemistry", pg. 27)

Contact(s): C. McKay (ARC) and T. Scattergood (SUNY/ARC)

Objective: Simulate the formation of organic haze particles in Titan's atmosphere. Study the growth of these organic particles and measure their optical properties. Determine the chemical composition of the particles.

Approach: A pre-mixed gas of CH₄, N₂ and H₂ is put into the chamber and allowed to equilibrate. The baseline scattering is measured. The gas mixture is irradiated with UV to form particle(s). Levitation may be needed at this time to fix the position of the particle(s). Optical properties, particle shape, and size distribution are measured by laser scattering techniques throughout the 1 to 4 week period during which the particles grow by coagulation. Samples of the particles are then returned to Earth for chemical analysis.

Justification: This experiment will yield data important to the resolution of well posed scientific questions about the nature of Titan's organic haze and will provide information valuable to the preparation of future planetary probe experiments such as the proposed Cassini mission to Titan. Microgravity conditions are necessary because this experiment must be performed without particle-wall interaction. Suspension times of the particles in 1g would not be sufficiently long to achieve this.

Experiment 15 Surface Condensation and Annealing of Chondritic Dust (Also discussed in '85 Workshop Report: see section 2.2, pg. 4)

Contact(s): I. MacKinnon and F. Rietmeijer (University of New Mexico)

Objective: Simulate the putative gas-dust reaction textures in extraterrestrial materials, especially carbonaceous chondrite meteorites and interplanetary or cosmic dust. Study surface energy related effects (e.g., adsorption effects) that occur. Obtain information on chemical composition and complexity of interstellar dust and Solar System condensates.

Approach: Oxide cores are injected into the chamber. Metal-bearing gases are then injected sequentially as a function of decreasing condensation temperature. The time between introduction of subsequent gaseous species increases as the temperature is decreased. The experimental products are then collected and analyzed on the Space Station or returned to Earth for analysis.

Justification: Discrepancies exist between condensation models and observed textures in chondritic materials. Microgravity conditions are necessary because this experiment must be performed without allowing the particles to interact with the chamber walls. Suspension times of the particles would not be sufficiently long in 1g to achieve this. Also, the absence of turbulence is required in the first stages of the experiment.

Experiment 16 Studies of Fractal Particles (Also in '85 Workshop Report as "Properties of Tenuous Fractal Aggregates", pg. 31)

Contact(s): J. Nuth (NASA Goddard) and J. Stephens (Los Alamos National Laboratory)

Objective: Measure the coagulation coefficients of a variety of bare silicates, ice-coated silicates, organic-refractory coated silicates, and organic-refractory grains. Grow fractal aggregates of these materials and measure their light scattering and extinction properties as a function of wavelength. Measure the particle's cohesive strength. Look for observable signatures to distinguish fractal aggregates from a distribution of particles.

Approach: Refractory silicates are nucleated from vapor and allowed to coagulate. The optical properties are monitored using light scattering techniques. Once grains have aggregated to a desirable size, they are broken apart with acoustic shock waves to measure their cohesive strength. Particles are allowed to re-coagulate and further measurements are made. Particles are coated with ice or irradiated to obtain organic-refractory coatings on silicates and measurements are repeated.

Justification: Fractal growth of particles may play important roles in circumstellar and interstellar environments as well as in the early solar nebula. This experiment also represents the study of a new class of materials with many potentially important properties that cannot be studied in the gravitational environment found on Earth. Microgravity conditions are necessary because of the long suspension times required and because macroscopic fractal particles would be gravitationally unstable at 1g and collapse under their own weight.

Experiment 17 Emission Properties of Particles and Clusters (Also discussed in '85 Workshop Report: see Section 2.2, pg. 3)

Contact(s): J. Goebel and L. Allamandola (ARC)

Objective: Measure the radiative properties of clusters of molecules and microparticles in order to understand how radiative energy is converted from UV to IR.

Approach: Clusters of polycyclic aromatic hydrocarbons, carbon grains, or silicates are generated and positioned in the chamber. The baseline emission is measured. The particles are warmed up or excited by UV radiation and the emission spectrum is measured with spectrometers/monochrometers at different excitation levels.

Justification: Radiative emission properties of particles in environments such as circumstellar shells, planetary nebulae, protostellar disks, reflection nebulae, and HI/HII interfaces are not well understood. Microgravity conditions are necessary because suspension times in 1g are not long enough to accumulate enough data to measure the emission spectra of free species.

Experiment 18 Effect of Convection on Particle Deposition and Coagulation

Contact(s): P. McMurry (University of Minnesota), W. K. Rhim (Jet Propulsion Laboratory), J. Miller (Martin Marietta), and G. Fogleman (GE Government Services/ARC)

Objective: Study the effect of convection on the coagulation and wall deposition of micron and larger size particles.

Approach: A monodisperse aerosol of microspheres is produced using a vibrating-orifice aerosol generator. The size spectrum is monitored during the following three phases: approach to steady state; while in steady state for a period of time long enough to obtain sufficient statistics; and during the transient decay after the aerosol generator is turned off. The chamber is evacuated and the experiment is repeated for different aerosol concentrations, different levels of controlled convection, or different size microspheres.

Justification: The effect of convection on wall deposition and coagulation is not well understood in general and has not been measured for micron and larger size particles. Microgravity conditions are necessary because the experiment needs well characterized, non-gravity-induced convection, and must be performed without gravity-induced deposition.

Experiment 19 Growth and Reproduction of Microorganisms in a Nutrient Aerosol

Contact(s): S. Welch (Bio Systems Research)

Objective: Determine if it is possible for microorganisms to reproduce in an aerosol. Develop microbiological techniques for use in microgravity.

Approach: A culture of selected microorganisms is inoculated into a dilute water-based nutrient solution that has been demonstrated to support growth of the selected organism. The solution is introduced into the chamber in an aerosol form. The aerosol size distribution and microorganism concentration are monitored for several days while the chamber is maintained at an Earth-normal environment. The entire remaining aerosol is then collected and analyzed for the metabolism of nutrient components and total growth yield.

Justification: Microorganisms are known to act as condensation nuclei in clouds on Earth. However, little is known about the life cycles of such organisms. In addition, a Jovian biota has been postulated that consists of microorganisms living entirely in the atmosphere. This experiment investigates the possibility of an aerosol-based biological system. Microgravity conditions are necessary because the large aerosols needed for this experiment will not stay suspended long enough in 1g.

Experiment 20 Long Term Survival of Human Microbiota in and on Aerosols

Contact(s): S. Welch (Bio Systems Research)

Objective: Determine if it is possible for human microbiota to survive for long periods of time in an aerosol in microgravity. Develop microbiological techniques performable in microgravity.

Approach: Same as Experiment 19, except that human microorganisms (nonpathological) are used and that the aerosol is analyzed periodically to determine microorganism survival.

Justification: Aerosols may remain suspended for long periods of time in microgravity (for instance, in the habitation module of the Space Station). It is important to understand the impact of this long suspension time on crew health. Microgravity conditions are necessary for the same reasons as in Experiment 19.

CHAPTER 4

The Gas-Grain Simulation Facility

4.1 Initial Concept and History

In the 1970's, a group of atmospheric scientists began development of an Atmospheric Cloud Physics Laboratory (ACPL), a facility designed to study, in microgravity, processes relevant to atmospheric science such as condensation, ice nucleation, ice crystal growth habits, scavenging, and cloud formation. The ACPL was designed to fly on the Space Shuttle, but development was canceled in 1980. (Note, although the ACPL was canceled for funding reasons, it was scientifically and technically feasible. In fact, the results of ACPL feasibility and design studies will be useful in GGSF development.) A group at Ames Research Center independently proposed the idea of studying basic particle formation and interactions in a generic microgravity particle research facility. These scientists saw a need to extend the range and capability of current laboratory conditions in order to better simulate small particle and cloud processes. Astrophysicists and planetary scientists from Ames Research Center wanted a microgravity facility for studying the fundamental processes involved in the origin and evolution of the Solar System. Also, geologists and atmospheric scientists envisioned using such a facility to study dust coagulation processes in the atmospheres of Earth and other planets. These ideas were first presented in late 1984 in an Ames Space Science Division report on the scientific uses of the Space Station and later at the Space Station Planetology Experiments Workshop held June 1985 in Flagstaff, Arizona. It became clear at this workshop that interest in and need for such a facility spans a wide range of scientific disciplines. As a result, the need for a multidisciplinary facility such as the Gas-Grain Simulation Facility was realized.

Ames Research Center's strong and varied interest in performing experiments on this type of facility led Ames to take the lead role in the development of the GGSF. Consequently, a GGSF workshop was held at NASA/Ames in August 1985 (the facility was called the "Microgravity Particle Research Facility" at that time). The workshop was attended by scientists who had identified a need in their fields for a microgravity particle research facility. The goal and result of the workshop was the establishment of the scientific feasibility of the GGSF and the initial identification of technical and scientific requirements of the facility. In a continuing effort to develop the GGSF, Ames Research Center conducted the present (1987) workshop. This workshop produced a database of twenty candidate experiments. An in-depth study (currently underway) of the candidate experiments will help further determine the science, subsystem engineering, and environmental requirements of the facility. In addition, the experiments will be used as a basis for a GGSF engineering reference design. These GGSF workshops not only resulted in this database of possible GGSF experiments, but brought together scientists from many disciplines and led to the establishment of a scientific community interested in performing particle research in microgravity with the GGSF.

During the last few years, several steps were taken toward the development of the GGSF. At Ames Research Center working groups were convened and a preliminary study was initiated to develop engineering concepts and address basic scientific and engineering issues. During these efforts, issues requiring detailed study were identified. Recently, to address these and other issues, Martin Marietta conducted a physics feasibility study of the facility and presented the results at the 1987 workshop. The Martin Marietta study found both single particle and cloud GGSF experiments feasible (see Appendix A).

As of this publication (Summer 1988), the status of the GGSF project is as follows: A preliminary Level One Requirements Document was submitted to NASA headquarters in late 1987, and a two year GGSF reference design study is scheduled to begin in mid 1988. On completion of the reference design study, the Announcement of Opportunity for GGSF experiments 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 Permanent Manned Configuration of the Space Station (mid 1990's).

4.2 Facility Hardware and Subsystems

The GGSF (see figure 4.1) will occupy a Space Station double rack of approximately 3.5 m³. It will consist of several subsystems supporting an adaptable 4 to 10 liter experiment chamber. Subsystems will provide environmental control (e.g., temperature, pressure, gas mixture, and humidity), measurement equipment (e.g., video cameras, optical particle counters, spectrometers, and photometers), and energy sources. Subsystems will also furnish: command and control capability; mechanisms for producing, injecting, and removing particles and clouds of particles; and levitation devices for positioning particles and keeping them in fixed positions away from the chamber walls. Based on Atmospheric Cloud Physics Laboratory reference design studies, GGSF mass and power requirements are estimated to be 400 to 500 Kg and 400 to 1500 W peak (750 W average) respectively.

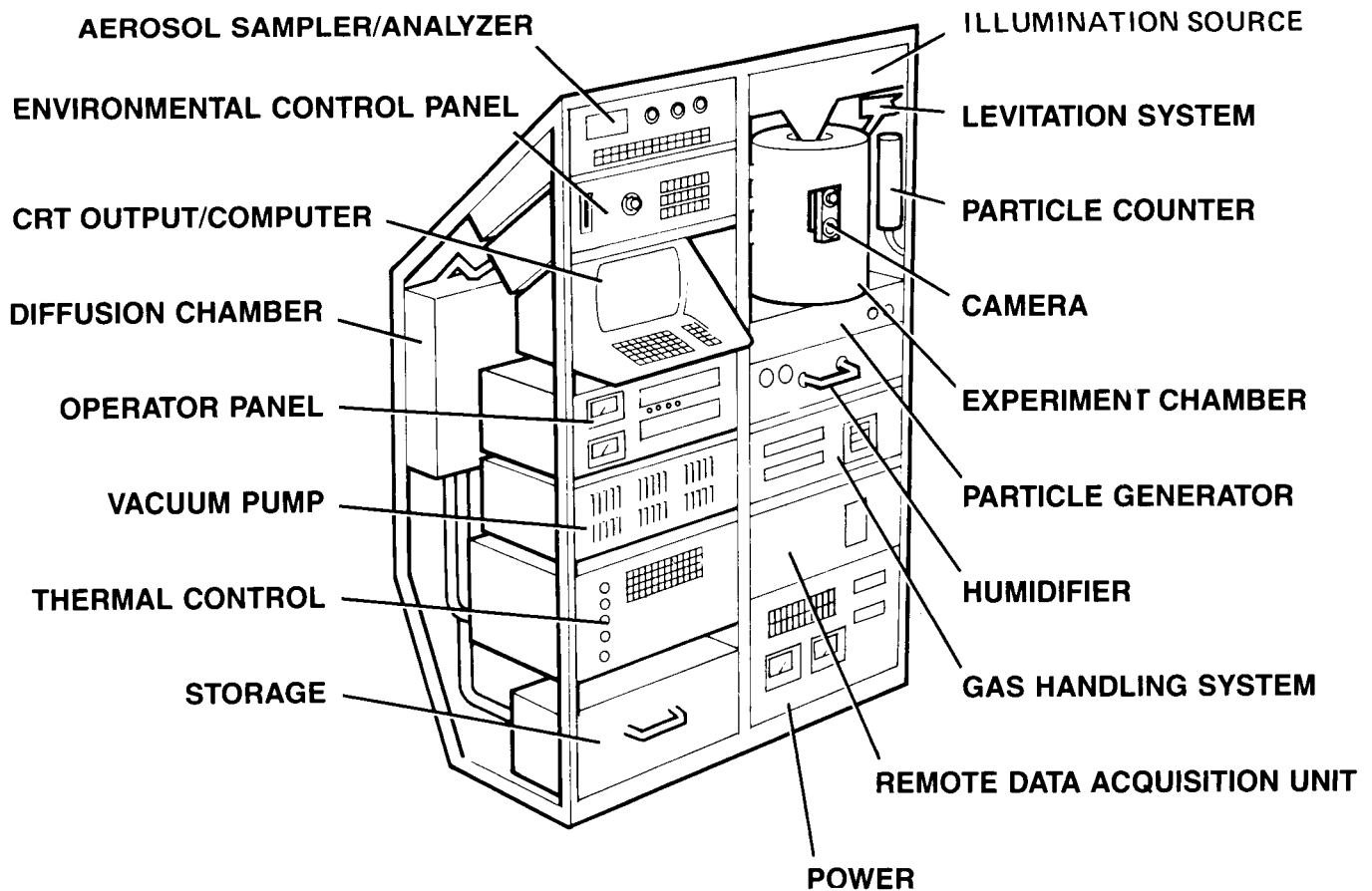


Figure 1.— Gas-Grain Simulation Facility.

The GGSF will be modular in design; that is, it will have an adaptable configuration allowing subsystems to be connected in a number of ways. Modularity will also allow the GGSF to evolve. At an early stage, the GGSF would be capable of supporting those experiments which promise high scientific yield and require only a few simple subsystems. The facility, then, could be scientifically useful while it evolves to meet the demands of more technologically difficult experiments. Further, modularity will allow outdated subsystems to be replaced.

An important GGSF subsystem, the facility's computer, will control all operations of the facility during an experiment and have an autonomous decision making capability. It will monitor system status, select relevant information packets, and send them to the Space Station data bus for forwarding to ground operations. The operations team on the ground could then review the downlink data and transmit commands to execute preprogrammed sequences or to enter a new program sequence. During an experiment, data summaries could also be sent down to ground control. Data exchange requirements, estimated at 20 to 40 kilobytes per day, are modest. Data/command uplinks will occur about twice per week. In addition to telemetry data, all the raw data and engineering system information will be recorded for later retrieval. By using Artificial Intelligence and allowing for a system that can be controlled by commands from the ground, crew time requirements for the operation of the facility can be greatly reduced. Aside from time needed for the initial set-up and calibration of experiments, crew time requirements will be minimal.

One possible GGSF operational sequence is as follows: A chamber designed for a series of experiments is "plugged in" to the GGSF and subsystems are attached in the configuration necessary for the first experiment. A command is then given to begin the execution of preprogrammed instructions required 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 could have a very long, useful lifetime.

4.3 Integration with the Space Station

The microgravity facility will be located within one of the pressurized modules of the Space Station. Since many of the suggested GGSF experiments require gravitational accelerations of 10^{-4} to 10^{-5} g, it will be necessary to consider the background gravitational gradient when deciding where in the Space Station to place the GGSF. The GGSF would take advantage of some of the user support systems supplied by the Space Station such as the 10^{-3} torr "house" vacuum and data from the accelerometer system. Also, given the delicate physical and chemical properties of some particles generated in the GGSF, some preliminary sample analysis on the Space Station may be desirable. Such analysis would require special sample handling equipment and analytical tools. For example, a preliminary survey indicates that some GGSF experiments would use a Scanning Electron Microscope, a Gas Chromatograph, a Mass Spectrometer, a (micro) mass measurement system, and/or a High Pressure Liquid Chromatograph if they were available. These analytical tools have been requested by the Life Sciences and Materials Science communities. The possibility for joint use of such equipment is being explored.

CHAPTER 5

Development of the Facility

5.1 Project Development Milestones

The development of this Space Station facility will require an integrated and extensive program. The project schedule (see figure 5.1) will provide a framework for the planning and integration of multidisciplinary ground-based scientific research programs and technological studies into a common facility development approach. The following points are proposed as necessary near-term steps toward development of the GGSF:

1. A multidisciplinary GGSF Science Working Group (Executive Summary Recommendation no. 4) should be formed immediately and begin meeting on a regular basis.
2. A detailed facility development study must be initiated. This study should identify experiment requirements, define facility mission requirements, and establish a preliminary reference design for a GGSF prototype chamber to be used in ground-based scientific and engineering studies.
3. An interdisciplinary NASA Research Announcement (NRA) for funding GGSF ground-based research and technology development programs should be initiated. The NRA should also provide a source for funding GGSF-related KC-135 studies to test and develop microgravity experimental apparatus and techniques.
4. The GGSF should be made an integral part of Space Station planning. In particular, a Mission Science Objectives and Requirements Document for the facility should be developed by the GGSF Project Team and reviewed by the GGSF Science Working Group (SWG) for inclusion in the Space Station mission requirements data base.

Continued development of the GGSF could be enhanced greatly if NASA Headquarters quickly establishes a mechanism for the funding of the development steps proposed above. The success of the project schedule published in this report requires that such a mechanism be established no later than fiscal year 1989.

5.2 Ground-Based Research Required for Success

In this section, both experimental and theoretical areas of ground-based supporting research are discussed. Areas that are well-defined or are currently under development are summarized, and further studies required for successful GGSF development are suggested.

5.2.1 Particle Handling Techniques

As noted in previous chapters, one benefit of the Space Station microgravity environment is the reduction of particle settling rates and the consequent increase in particle suspension times. Decreased settling rates will allow many GGSF experiments to be performed with little or no need for levitation of particles during the actual experiment. Many experiments, nonetheless, will require levitation for handling and positioning particles. A variety of levitation techniques needs to be considered since no single technique will work for all types and sizes of particles. In addition, the extent to which each levitation technique will disrupt fragile particles and aggregates should be

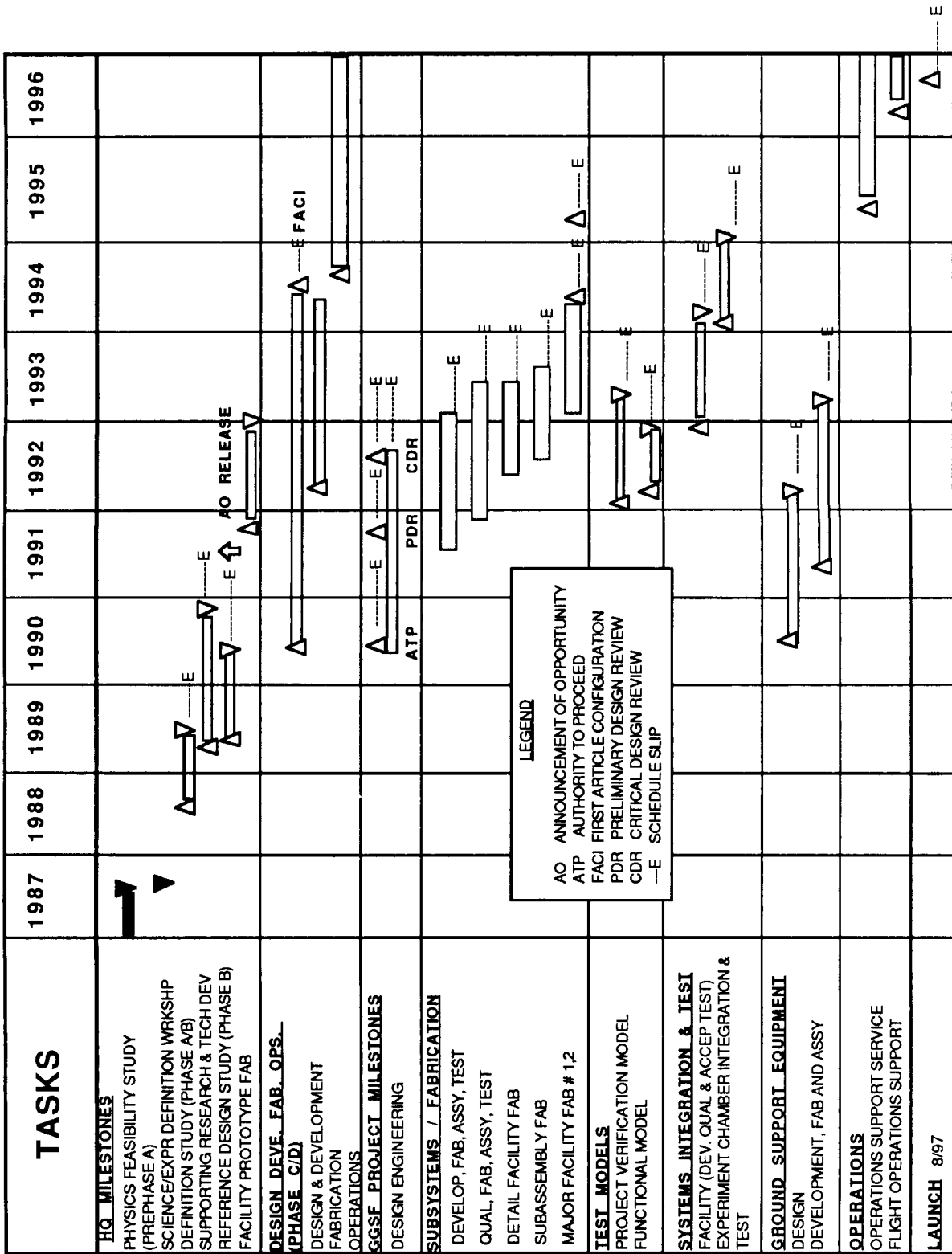


Figure 5.1 Schedule for Gas-Grain Simulation Facility Project

investigated. Existing levitation techniques are summarized below and discussed further in Appendix A.

Levitation by light pressure (e.g., two opposing laser beams) can be used to isolate and suspend highly transparent and highly reflective particles. Several existing light-pressure levitation techniques are well developed. These techniques could be used to position or suspend many particles in a gas of sufficient pressure, but may only be able to suspend single particles in a vacuum. To use light levitation in GGSF experiments, existing techniques should be developed further for application in a microgravity environment.

Light-pressure levitation can also be used on particles that absorb light. Such particles, if highly absorptive, may experience an additional strong radiometric (photophoretic) force. This force is caused by the heating of gas molecules on the illuminated side of the particle. Sometimes the radiometric force greatly exceeds the light pressure force on the particle. In such cases, use of radiometric levitation would be more appropriate than light pressure levitation. Radiometric levitation techniques are well developed for the confinement of both single and multiple highly absorptive particles, but not for partially absorptive particles. In response to radiometric forces, partially absorptive particles, depending on composition, can either undergo positive photophoresis (the particle is forced away from incident light) or negative photophoresis. Before this levitation technique could be used in GGSF experiments, more study should be conducted on the response of partially absorptive particles to radiometric forces. In particular, response as a function of particle composition and shape, as well as the frequency, polarization, and intensity of the light used must be better understood. Also, many GGSF experiments will require that the experiment chamber be illuminated during acquisition of data. The radiometric effects of chamber illumination on experiment processes should be studied to determine non-invasive illumination sources.

The acoustic approach to particle levitation is one of the more highly developed methods used in microgravity and Earth-based research. Acoustic levitation techniques that can be used in microgravity include single axis interference, triple-axis methods, hemispherical focusing radiator, siren, tetrahedral arrangements, ring type radiator and single mode methods (see Appendix A). While acoustic levitation is understood well for large particles, it is not well understood for particles smaller than roughly one tenth of the acoustic wavelength. The lower limit on the size of a particle that can be levitated by a given wavelength should be determined for the above mentioned techniques. Also, each technique places many restrictions on size and shape of container, composition of chamber walls, and composition of ambient gas. These restrictions should be investigated to determine the feasibility of using acoustic levitation in the GGSF.

Another levitation technique that could be used on charged particles is electrostatic levitation. Electrostatic levitation works on liquid and solid particles in a gas or vacuum. Two methods are possible: electrostatic levitation with feedback and levitation by a combined alternating and static electric field. The former works for any particle size and has been shown to work in low gravitational fields. A tetrahedral positioner works well for large particles, but application to small particles may require more analysis. The second method has been successful in levitating an aerosol particle on Earth, but the technique may require testing in microgravity before it could be applied in Space Station experiments.

Other possible methods for manipulating particles are electromagnetic levitation (applicable to conducting particles), aerodynamic levitation, and mechanical manipulation techniques. More study should be done on these techniques as well as on methods for injecting particles into and extracting particles from the chamber.

5.2.2 Multiple Particle Techniques

The levitation techniques discussed in 5.2.1 do not lend themselves to particle-growth or cloud experiments as they coerce coagulation and can overwhelm weak inter-grain interactions. Yet, owing to low settling rates in microgravity, many GGSF particle-growth and cloud experiments could be performed without levitation. First, however, research is needed to identify the effects of chamber walls on the processes of interest. Experimental studies and computer modeling of wall deposition should be performed. The characteristics (e.g., inertness or stickiness) required of chamber walls should be determined and existing materials identified or new ones developed to satisfy these requirements. Effective chamber cleaning agents and techniques must also be developed.

5.2.3 Particle Measurement Devices

Particle measurement and experiment monitoring devices will constitute important GGSF subsystems. Some experiments may require the development of experiment-specific measurement techniques. However, many generic devices such as condensation nuclei counters and microscope imaging systems will be common to a number of GGSF experiments. The development work necessary for adapting these measurement devices (and those mentioned in section 4.2) to GGSF requirements are discussed in section 5.3.

5.2.4 Ground-based Theoretical and Experimental Work

Facility development research should be complemented with a ground-based research program aimed at investigating issues specific to particular candidate GGSF experiments. For example, the development of some experiments may require study of the pros and cons of *in situ* particle production and determination of feasible *in situ* production methods. Also, candidate GGSF experiments as well as other GGSF experiment ideas should be developed over the next few years by the principal investigators. This work will be important preparation for the Announcement of Opportunity (scheduled for 1990). During this period of development, testing of experimental concepts aboard the NASA KC-135 aircraft would be advisable in many instances. In addition to the above, theoretical work and computer modeling of GGSF experiments are necessary in order to understand and better plan microgravity particle experiments.

5.3 Technological Developments Required for Success

Most technology (e.g., acoustic levitators, residual gas analyzers, optical and data handling equipment) needed for conducting GGSF experiments currently exists and is used in laboratories on Earth. However, adaptation and further development of available technologies will be required to satisfy the general needs of the GGSF and specific needs of each experiment. Such development is also needed to address microgravity constraints and Space Station mass, volume, safety and crew-time restrictions.

Handling and processing small particles in microgravity introduces new problems not encountered in 1g and therefore not addressed by current particle handling devices and techniques. Volume and mass constraints may require the miniaturization of existing measurement instruments. Limited crew-time will require specific developments in artificial intelligence, telescience, and robotics to render the GGSF as autonomous as possible. Vibration isolation in microgravity, system testing and debugging, *in situ* calibrations, and data storage and retrieval are other common issues that must be addressed. A standardized procedure for transporting and handling samples should be established and corresponding equipment developed. Also, systems engineering is necessary for creating adaptable interfaces and ensuring proper cooperation between the various subsystems.

Development of new technologies is not necessary for the success of the GGSF, but adapting existing technologies to the needs of the system may require extensive development work. Some spin-offs from these development activities are likely to occur. For example, techniques and systems designed to handle particles in microgravity may have application in areas such as air quality management for the Space Station life support system.

5.4 Early Flight Opportunities

A two-year development study scheduled to begin in mid-1988 could produce a reference GGSF chamber design by mid-1990. At this time, a prototype chamber could be fabricated and tested on a series of KC-135 flights. Not only would testing of the prototype chamber be integral to facility development, it would be very useful in developing proposed GGSF experiments. The GGSF is targeted for installation on board the Space Station in the fall of 1996. While the facility is being developed, a prototype chamber could be readied for possible integration as an early experiment on the proposed Commercially Designed Space Facility (to be launched in 1992) or manifested on a Space Shuttle mission.

5.5 Long-term Evolution of the Facility

The GGSF experiment program is expected to be a long term evolutionary activity on the Space Station. GGSF instrumentation will develop as new experiments are proposed for the facility and as the facility evolves. As new types of experiments are proposed, improvements of existing subsystems may be required. Also, Space Station capabilities may sufficiently advance to allow for some on-board preliminary particle analysis activities. For these reasons, it is important that the GGSF be designed with evolutionary development in mind. The subsystem configuration of the GGSF should be flexible enough to allow for future needs. Subsystem modularity and phased development of the facility will help ensure an adaptable GGSF. Outdated subsystems could then be replaced by modules using current technology.

5.6 Administrative Organization and Requirements

The project advocated in this report is achievable with adequate funding and is well within the established time frame for Space Station development. Currently, the GGSF project is sponsored by NASA Headquarters Life Sciences Division through a joint Memorandum of Agreement (MOA) with the NASA Headquarters Solar System Exploration Division. The MOA establishes the Life Sciences Division in the lead management role for initiating the development of this facility with additional scientific and programmatic guidance to be provided by the Solar System Exploration Division. The GGSF project will be implemented and managed by the Ames Research Center Exobiology Flight Experiments Program.

Since the establishment of this interdisciplinary facility crosses traditional scientific boundaries within the research community and administrative boundaries within NASA Headquarters, communication between the appropriate NASA administrative organizations must be established early in order to facilitate decision making and establish effective funding mechanisms. As a first step in this process, NASA Headquarters has established the Life Sciences Exobiology Flight Program Branch (Code EBF) as the single point of contact for the user community of this program. The Flight Program Branch will have a comprehensive overview of all aspects of the project and will ensure that all interested parties are informed in a timely manner of progress and developments relevant to the GGSF project.

Recently, Ames Research Center established an internal GGSF exobiology research team. A NASA Headquarters Science Working Group (SWG) will be formed shortly and must include representatives from all user disciplines. The SWG chairperson will maintain effective communication with appropriate NASA Headquarters representatives, keep investigators informed about important developments, and provide advocacy and representation when needed. The SWG must also keep in close contact with Space Station Working Groups and Task Forces.

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16. Abstract <p>This document serves two purposes. First, it provides an overview of the Gas-Grain Simulation Facility (GGSF) project and reports its current status. Second, it records the proceedings of the Gas-Grain Simulation Facility Experiments Workshop. This workshop, held August 31-September 1, 1987 in Sunnyvale, California, was sponsored by the Exobiology Flight Program at Ames Research Center. The goal of the workshop was to define experiments for the GGSF—a small particle microgravity research facility. The workshop addressed the opportunity for performing, in Earth orbit, a wide variety of experiments that involve single small particles (grains) or clouds of particles. Twenty experiments from the fields of exobiology, planetary science, astrophysics, atmospheric science, physics and chemistry were described. Each experiment description included specific scientific objectives, an outline of the experimental procedure, and the anticipated GGSF performance requirements. These experiments represent the types of studies that will ultimately be proposed and will be used to define the general science requirements of the GGSF. Volume 1 includes the overview, scientific justification, history, and planned development of the GGSF. Volume 2 contains a physics feasibility study, abstracts of related experiments in progress, and descriptions of proposed experiments.</p>					
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