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FEASIBILITY STUDY OF A ZERO-GRAVITY (ORBITAL) ATMOSPHERIC CLOUD PHYSICS EXPERIMENTS LABORATORY

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16. ABSTRACT

This report covers the first nine months (September 1971-June 1972) of a feasibility and concepts study for a zero-gravity (orbital) atmospheric cloud physics experiment laboratory. The primary objective was to define a set of cloud physics experiments which will benefit from the near zero-gravity environment of an orbiting spacecraft, identify merits of this environment relative to those of ground-based laboratory facilities, and identify conceptual approaches for the accomplishment of the experiments in an orbiting spacecraft. The report concentrates on the solicitation, classification and review of cloud physics experiments for which the advantages of a near zero-gravity environment are evident. Identification of experiments for potential early flight opportunities is provided. Several significant accomplishments were achieved during the course of this study. These include: (1) successful completion of the experiment solicitation, (2) development of scientific community support, (3) selection of high priority experiments, (4) determination of program feasibility, and (5) identification of a concept for the multi-experiment cloud physics laboratory.

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FOREWORD

The work reported herein encompasses study efforts during the period September 1971 through June 1972. Without the cooperation provided by members of the atmospheric cloud physics scientific community it could not have been accomplished. The main goal of this effort is to provide an experiment capability in low gravity whereby members of the cloud physics scientific community may further the basic understanding of cloud microphysical processes.

The scope of work, for which the Space Sciences Department at McDonnell Douglas Astronautics Company was supported by NASA, involved the following tasks:

Task I - Organize a scientific advisory group of authorities in the area of cloud physics to propose, review, and evaluate experiments to be flown on the manned zero-g cloud physics research facility. This group will include scientific consultants from universities, other government agencies, and industry. Requirements and opinions of cloud physicists on the proposed experiment will be conducted with the understanding that the experiment would complement and not compete with their research.

Task II - Define the scientific cloud physics experiments which require a manned observer and zero-g cloud physics facility in accordance with the following criteria:

a. Relevance to large-scale cloud behavior and weather control.

b. Scientific merit.

c. Need for zero-gravity.

Task III - Recommend approaches to the design of the zero-g cloud physics experiment facility and the basic equipment hardware necessary to conduct the experiments selected, including support requirements (nominal, peak, and minimal) and power, data requirements, weight, environmental restrictions, onboard computer requirements, calibration, size, maintenance, etc.

Task IV - Evaluate and study the relationship of the zero-gravity cloud physics laboratory to existing and planned space transportation systems as follows:

a. Conduct a preliminary study of facility-carrier integration stressing adaptability and flexibility to short-notice package utilization.

b. Develop preliminary mission requirements and a project development plan.

c. Study the requirements for and the feasibility or preliminary zero-gravity testing.

The extension of this study effort will concentrate on the indepth definition and analysis of the selected experiments, development of specific design requirements for the eventual multi-experiment cloud physics laboratory, conduct indepth definition studies on selected early flight opportunity experiments, and study in more detail the long lead-time components of the laboratory.

This program is being conducted on behalf of NASA's Office of Application and Office of Manned Space Flight. Copies of this report are available from the undersigned.

William W. Vaughan
Aerospace Environment Division
Aero-Astrodynamics Laboratory
NASA-Marshall Space Flight Center

I. INTRODUCTION

The science of meteorology has advanced rapidly toward the development of an understanding of large-scale atmospheric processes. Predictions of large-scale flow patterns in the atmosphere can be made with reasonable success because of the progress in defining and refining the equations of motion and conservation of mass and momentum. These large-scale flow patterns enable us to define and predict patterns of cloudiness. This cloudiness itself, the processes in the clouds, and the redistribution and release of energy in the clouds is what the average citizen thinks of as "weather". Most violent weather phenomena result indirectly from large-scale redistribution of energy and are caused by triggering the release of the latent heat of condensation and heat of fusion within very limited volumes. The vast quantities of energy involved in hurricanes, thunderstorms and tornadoes result from cloud processes and this energy is released through condensation. Atmospheric microphysics determines the changes of large-scale cloud patterns that produce imbedded showers, thunderstorms, squall lines, or lines of precipitation although these changes can be initiated by the underlying terrain.

Man is inadvertently modifying the weather, through the daily addition of millions of tons of foreign substances into the atmosphere. Satellite pictures show anomalous conditions in clouds which are apparently due to additions of materials into the atmosphere by man. In order for man to modify the weather and manipulate the atmosphere in a deliberate fashion, it is necessary to understand the microphysical processes, because these processes constitute the trigger which can release the energy that is available in nature. It is impossible to redistribute energy over the surface of the earth on a scale that will affect large storm systems, but man can bring about the modulation of the release of energy within such a large-scale system. This modulation happens now, either due to man's own inadvertent action or due to what might be called "random acts of nature." Natural cirrus clouds and aircraft condensation trails have been observed to produce ice crystals which then drop into a lower lying cloud layer. These ice crystals triggered the freezing of a limited portion of this lower lying super cooled cloud deck. Such freezing releases heat, initiates convection activity and intensifies the precipitation reaching the ground.

Currently, man controls great river systems and water sheds by the use of dams. By looking in from the outside and remotely sensing and measuring cloud and atmospheric parameters, man in the future will be able to assess a time when the atmosphere is susceptible to releasing precipitation into a watershed. The precipitation release can then be controlled so that it will not cause flooding or rapid run-off. Thus, instead of having random releases of rainfall, there will be programmed releases of rainfall of mans own design. Today we are not able to do this, because of the lack of understanding of microphysics of clouds and the atmospheric system. We need to better understand these microphysical properties so that we know when nature is ready and susceptible for man to modify its pattern to his advantage.

Meteorologists have long understood the requirement for a much better understanding of cloud microphysics. For the last thirty years there have been concentrated efforts to understand some of the following atmospheric processes: why does one cloud develop a spectrum of broad droplet sizes while others develop narrow spectra of sizes; why does one cloud precipitate and others not precipitate; why does one cloud develop rapid electrical charging, charge separation, lightning and thunder, while other outwardly appearing similar clouds do not; why does one thunderstorm produce hail and another not; or why does a field of thousands of clouds produce hundreds of moderate thunderstorms, but only one develops into a tornado. Microphysicists, physical chemists and applied physicists, as well as meteorologists are heavily involved in the study of the phenomena associated with these atmospheric processes.

Numerous microphysical processes are currently under study. Nucleation, growth and scavenging are all heavily involved in clouds and weather. Examples include studies of the rapidity with which precipitable cloud particles grow and the role this growth rate plays in cloud dynamics. Falling particles exert a drive and accumulate mass which destroys positive cloud buoyancy by providing a counteracting force. Other particles blow out the top of the cloud to evaporate into the dry air and are not available for precipitation at the ground. As can be seen by the equations and the cumulus development models there are many points where parameters feed back in an important way into the dynamics of the cloud. This growth of a cloud, including its life span and eventual size, is related to the original spectrum of condensation nuclei, the speed of updraft, the volume of the cloud, and the ratio of the entrained dry air in the total mass of ascending air. The dynamics of the cloud system determines whether a line or a band of precipitation forms, whether isolated severe cells will develop, or whether many smaller cells will result.

Very fine differences in drop size spectra and the temperature at which ice forms can have a major impact upon weather development. Atmospheric observations show clearly that whether the ice forms in a cloud at minus 10°, 15° or 20°C, can determine whether the cloud goes to 40,000 feet and becomes a thunderstorm, whether it tops off at 14,000 feet or 15,000 feet, or whether the whole cloud top blows out causing the cloud to quickly dissipate. The determining factor is the temperature at which the majority of water within the cloud turns to ice. This temperature determines the ice crystal shape (e.g., plates, dendrites or columns) which in turn determines the rate of the aggregation of ice crystals and eventually controls the size of raindrops. Man may eventually be able to choose between big raindrops or little raindrops. This would be especially important in areas with soil erosion problems.

The range of laboratory research extends from the millimeter rain drops and ice crystals down to submicrometer condensation nuclei. Nature requires at least a million 10 μm diameter cloud drops to combine in order to produce a one millimeter diameter precipitation drop. These droplets possess certain surface, electrical, and aerodynamic properties which establish whether or not these million small drops can combine to form the one big drop. Individual ice crystals must also be studied to determine how they grow and whether these ice crystals will somehow splinter and multiply to form more ice crystals. Other problems include electrical charging of ice crystals during the growth and collision processes and the effect of this charging on thunderstorm electrification. Many microphysical processes have been studied in some detail in the laboratory, but under conditions which are not very representative of those in a cloud. In any cloud, the average element or group of elements within that cloud has a lifetime of something on the order of twenty minutes. Within this time these cloud particles will grow and perhaps evaporate again.

In nature there are many cubic miles of clouds. Most cloud elements are internal to the cloud and are not effected by the edges of the cloud. A terrestrial laboratory has the problem of trying to duplicate a system where there are no edge effects and where a cloud can survive to have a number of things happen to it in twenty minutes. The smallest of these cloud elements fall at several centimeters per second and as they grow they reach fall velocities above one meter per second. This means, in a cloud chamber that is a meter in vertical dimension, there is less than one second of observational time for the larger of these particles. Attempts to overcome this limitation include the capture of individual particles and placing them on wax paper, teflon, copper, or stainless steel surfaces, hanging them on a thermocouple, suspending them on a spider web or on a thread, or by placing them between two immiscible liquids. These approaches have not been very successful because the suspension medium generally causes effects greater than the forces or actions that are being measured.

There have been many significant accomplishments in terrestrial laboratories. However, comparison between the results achieved in the laboratory and what is observed in nature often gives no correlation whatsoever. In studying the whole regime of meteorology from the large scale motions which produce cloud systems down to what is called "weather" (i. e., rain, snow, lightning) there are gaps in understanding microphysical processes which occur between the inception of the cloud system formation and the events eventually occurring at the ground. Much of these data lie in the area called "cloud physics".

Cloud physics research under zero or low gravity conditions offers solutions to many of man's problems. Under zero-gravity the experimenter can suspend a drop in a chamber and observe it through a microscope for long periods of time. The droplet can be frozen, thawed out and another drop propelled into it. Observations can be made of the migration and collection of particulates that may be near or around the drop. There are numerous experiments (i.e., does a freezing drop splinter and/or acquire a charge) that can be done in this unique environment that cannot be done on earth. Other important experiment areas include the diffusional growth of drops and ice crystals and studies of the effect of temperature on ice crystals's type and form.

Cloud physics researchers can take advantage of zero-gravity to define many of the processes in clouds which are not fully understood today. This knowledge would enable man to influence weather by changing, for example, drop distributions, and nuclei concentrations, or by adding pollutant compositions. It is plausible that early in the next century man will be preventing thunderstorms, tornadoes or squall lines. Within the present century it is reasonable to expect snow pack and consequent water enhancement and the possibility of alleviating damage caused by hail and hurricanes.

The goal of this NASA sponsored study effort is to provide an experiment capability in low gravity whereby the cloud physics scientific community may further their basic understanding of cloud microphysical processes. The basic concept for satisfying this goal is a general purpose laboratory available to the entire scientific community wherein a wide variety of important experiments can be accomplished.

II. PRELIMINARY INVESTIGATIONS

During the course of the NASA-sponsored research and engineering requirements study "Oceanography and Meteorology - A Systems Analysis to Identify Orbital Research Requirements", (O&M Report), April 1968, Contract No. NAS 8-21064, described in Executive Summary Report, Vol. I, Douglas Report DAC-58120 and Technical Report, Vol. II, Douglas Report DAC-58121, the analysis of meteorological requirements indicated significant knowledge gaps in the area of weather and climate modification. This analysis emphasizes that modification of the colloidal state of a cloud to dissipate fog, cause rain or snow, alleviate natural weather disasters, etc., is a major national concern. The O&M report indicated the requirement for better experimental data on phase transition, particle capture, and coalescence. These requirements are critical to a better theoretical understanding of the colloidal modification processes. It was pointed out that terrestrial experiments in all of these areas are encumbered by many difficulties.

The O&M report contained a discussion of how problems arise because of the need to constrain a drop or a crystal in order to make observations. Several suspension techniques, such as wind tunnels, thread or web suspensions and special coated surfaces have been used to study and observe gravity independent processes such as electrical forces and diffusion effects. However, the errors introduced by the various suspension techniques are of a magnitude equal to or greater than some of the forces or phenomena under study. If these investigations were carried out within a zero-gravity environment, cloud elements could be suspended for long periods without the problem of movement and the need for solid support.

One of the major conclusions of the O&M report was that a cloud chamber in a space laboratory, in which cloud physics experiments could be conducted, should be considered. It appeared that the required apparatus would not be excessive in weight and volume and that the impact upon engineering design requirements of the spacecraft should be minimal.

The identification of zero-gravity platforms as an important means of overcoming many of the troublesome problems of terrestrial cloud physics laboratories provided the impetus for the Space Sciences Department, McDonnell Douglas Astronautics Company-West (MDAC-W) preliminary in-house effort from 1968 to 1971. This work included discussions with leading cloud physicists throughout the scientific community located at universities, government laboratories and private meteorological organizations. It was determined that definite interest existed and a feasibility study was warranted. This feasibility study was developed under experiment definition funds provided by NASA's Office of Manned Space Flight through the sponsorship of NASA's Office of Applications. The Marshall Space Flight Center (MSFC) was designated as the contract center and the Aerospace Environment Division of MSFC's Aero-Astrodynamics Laboratory was designated as the contract monitor. An extension of this contract was approved and initiated on 16 July 1972. This included in-depth definition of candidate experiments, further definition of the requirements for eventual Shuttle Sortie laboratory, multi-experiment zero-g atmospheric cloud physics laboratory and pre-Shuttle flight opportunities, and the accomplishment of preliminary definition work on the zero-g chambers.

III. FEASIBILITY AND CONCEPTS STUDY

The primary objective of this study was to encourage the submission of experiment suggestions from every institution where cloud physics laboratory work is underway. An additional and parallel objective was to inform the entire discipline about the objectives of this program. Therefore, agencies that are involved in weather modification, field experimentation and cloud-seeding commercial firms were included in the solicitation.

Letters were sent to scientists in the field of cloud physics and weather modification that had articles published in meteorological journals during the period 1968-1971. Letters were also sent to those who had presented papers at the American Meteorological Society cloud physics meetings. This letter solicitation included individuals associated with universities, government laboratories and private research organizations. A limited solicitation was made to scientists outside the United States. Attached to each of the solicitation letters was an explanation of the zero-gravity cloud physics program which emphasized several major points. These included the role of gravity in limiting terrestrial research, the purpose of the solicitation effort, and the requirements associated with suggestions, i.e., scientific merit, relevance and the need for zero-gravity.

The letter emphasized that the intent of the zero-g cloud physics research program was to complement and extend earth based cloud physics research. The selected experiments would compete with other scientific experiment candidates for manned and unmanned space flights on the basis of scientific and technological merit. The letter also pointed out that the study would extensively involve consultant cloud physicists in the form of an advisory board, and as members of a team which will suggest and evaluate approaches to specific problems envisioned in the various experiments. Selection of the set of experiments from the list of suggestions was to be made by a panel consisting of consultant cloud physicists, and NASA and McDonnell Douglas Astronautics Company scientific personnel.

In addition to the mail solicitation, visits were made to the universities and government laboratories where major cloud physics laboratory research programs were underway and individual and group conferences were held with many of the leading researchers in the cloud physics field. An announcement of the study and solicitation effort was also published in the Bulletin of the American Meteorological Society, Vol. 52, December 1971.

The responses to this solicitation served as the basis for further analysis by MDAC scientists. This preliminary analysis was designed primarily to prepare and clarify the experiment suggestions for detailed study by the NASA-MDAC Senior Scientific Board. The requirement for this independent scientific board was recognized and agreed upon by both NASA and MDAC-W prior to the initiation of this feasibility study. This board's task was to independently evaluate the experiment suggestions in terms of scientific merit and relevance and the requirement for zero-gravity. Four internationally known scientists in the field of cloud physics and weather modification agreed to serve on this board: Drs. C. L. Hosler, L. J. Battan, P. Squires, and H. Weickman. Brief biographies of each member are included in Appendix A.

The Scientific Board held its first meeting on 3 and 4 February 1972. Drs. Hosler, Battan and Squires participated. The meeting resulted in the selection and classification of a set of experiments that met the major program requirements of relevance and scientific merit as well as having a requirement for zero or low gravity. The Board agreed that the concept of accomplishing significant cloud microphysics research in low or zero-gravity was clearly feasible.

Selection and classification of the experiments enabled MDAC scientists to study the engineering problems and requirements associated with the development of a zero-gravity cloud physics laboratory. This preliminary engineering analysis delineated the various subsystem requirements for the laboratory and indicated potential systems and techniques to meet these subsystem requirements. An additional objective of this phase of the research was the delineation of the long lead-time requirements of the various laboratory subsystems which allowed necessary program planning to be initiated.

Two major briefings were prepared and delivered during the course of the feasibility study. The first briefing was prepared and delivered to personnel of the Marshall Space Flight Center on 23 February 1972 and to staff personnel in the Office of Applications and the Office of Manned Space Flight at Headquarters NASA on 24 February 1972. Participants in the briefing and their subject matter were:

Mr. William Vaughan (Contract Technical Monitor)	MSFC	Program background and organization.
Dr. C. L. Hosler Chairman, NASA/MDAC Senior Scientific Board	Pennsylvania	The role of cloud physics weather modification and benefits to man.
Mr. A. D. Goedeke Chief Scientist, Space Sciences	MDAC-W	Cloud physics program interface with McDonnell Douglas programs.
Dr. L. R. Eaton, Program Scientist and Mr. A. B. Hollinden Program Manager	MDAC-W	Progress report and study results for first five months of study.

As a result of the 24 February 1972 briefing, NASA Headquarters requested that a briefing be prepared for the Applications Committee of NASA's Space Program Advisory Council. This briefing was presented on 5 April 1972 at Goddard Space Flight Center, Greenbelt, Maryland.

The briefings were well received. The concensus was that feasibility had been established and the very important scientific community support was present. There was general agreement also, that the program should try to take advantage of flight opportunities prior to Space Shuttle in order to test and develop engineering requirements and concepts and to gather some scientific data. Emphasis was placed on the need for early in-depth definition studies of the candidate experiments.

Several papers and reports have been prepared and distributed. "Zero-Gravity Cloud Physics" presented at the International Conference on Aerospace and Aeronautical Meteorology, May 22 to 26, 1972 in Washington, D. C; "Zero-Gravity Research in Cloud Physics and Weather Modification" presented to the International Committee on Space Research (COSPAR), Working Group 6, Applications of Space Techniques to Meteorology and Earth Surveys, in Madrid, Spain in May 1972; and a summary report "Summary Description of the Zero-Gravity Cloud Physics Experiment" that described the progress and results of the first five months of the study was completed and distributed. The substance of the material covered in the summary report and the two paper papers is included herein.

Several significant accomplishments were achieved during the course of this study. These include: 1) successful completion of the experiment solicitation, 2) development of scientific community support, 3) selection of high priority experiments, 4) determination of program feasibility, and 5) identification of a concept for the multi-experiment cloud physics laboratory including subsystems and components of the laboratory with particular emphasis on those items requiring long-lead time research and development.

IV. EXPERIMENTS—ZERO-G CLOUD PHYSICS

The previous sections have set the background of the program and have indicated the potential of a zero-gravity laboratory for cloud physics experiments. This section will discuss in approximate chronological order the various actions completed during the NASA-sponsored feasibility study.

Solicitation

As previously stated, the primary feasibility study objective was to encourage the submission of experiment suggestions from every institution where cloud physics laboratory work is underway. A second objective was to inform cloud physicists about the objectives of the program. Therefore, agencies involved in weather modification field experimentation and commercial cloud-seeding firms were included. Letters were submitted to over 200 individuals in universities, government laboratories, and private research organizations.

In addition to the mail solicitation, over twenty visits were made to the organizations where major cloud physics laboratory research programs were underway and individual and group conferences were held with many of the leading researchers in the cloud physics field. For example, discussions were held with scientists at the National Center for Atmospheric Research (NCAR), NOAA Environmental Research Laboratories (ERL) at Boulder, Desert Research Institute of the University of Nevada, University of Wisconsin, New Mexico Institute of Mining and Technology, University of Missouri at Rolla, Illinois State Water Survey, State University of New York at Albany, Colorado State University, Rand Corp., Battelle Pacific Northwest Laboratories, Headquarters Air Weather Service USAF, University of Denver, Naval Research Laboratories, Pennsylvania State University, Meteorology Research Inc., Cornell Aeronautical Laboratory, Buffalo, New York, and the University of California at Los Angeles.

Table 1 summarizes the solicitation effort. Replies were received from 39 of the 54 organizations that had been solicited and there were experiment suggestions from 31, including most of the universities where major cloud physics laboratory research is underway (see Figure 1).

Table 1

CONTACTS WITH SCIENTIFIC COMMUNITY

	Solicitations Submitted	Replys Received	Suggested Experiments
Universities and Institutes	27	22	18
Government Laboratories	12	8	6
Private Research Organizations	8	3	2
Foreign Meteorology Services	7	6	5
TOTALS	54	39	31

Most organizations had several suggestors and suggestions

SOLICITATION
RESPONSE

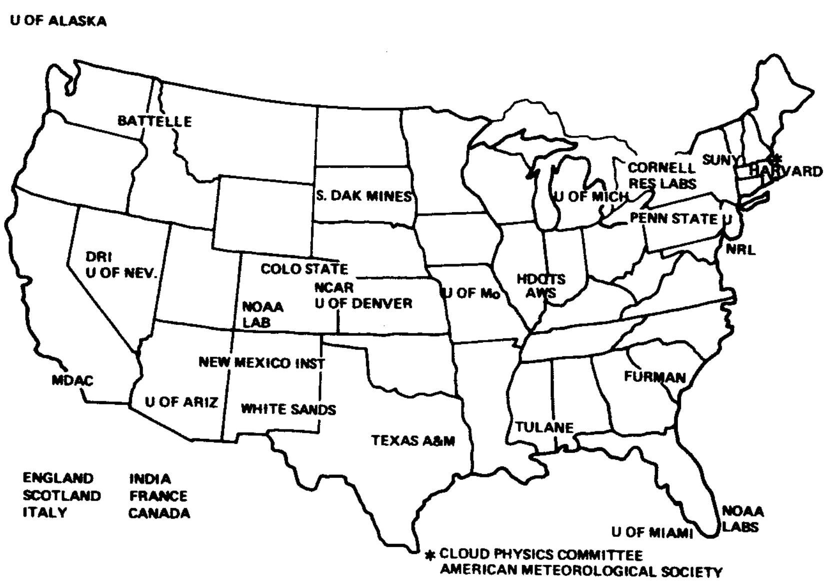


Figure 1

Table 2 is a listing of the contributors grouped according to their organizational affiliation. The experiment suggestions that resulted from MDAC pre-contract activity are listed on Table 3. There were 80 specific experiments proposed which required very low gravity conditions.

Table 2 (Page 1 of 5)

FEASIBILITY STUDY EXPERIMENT SUGGESTERS AND SUGGESTIONS

Battelle Memorial Institute, Pacific Northwest Labs	
Alkezweeny, A. J.	Scavenging processes: Brownian, diffusiophoresis, thermophoresis
Fuquay, J. J.	Scavenging processes: Brownian, diffusiophoresis, thermophoresis
Slinn, W. G. N.	Scavenging processes: Brownian, diffusiophoresis, thermophoresis
Colorado State University, Fort Collins, Colorado	
Corrin, M. L.	Gas adsorption and desorption onto aerosols
Cornell Aeronautical Labs, Buffalo, N. Y.	
Kocmond, W. C.	Nucleation of soluble, insoluble and hydrophobic nuclei; scavenging and resulting contact nucleation
Denver Research Institute, Denver, Colorado	
Fukuta, N.	Memory effect of ice and cloud condensation nuclei, diffusion accommodation coefficients of liquid and ice, diffusiophoretic scavenging, ice crystal growth habits, nucleation time lag phenomena, droplet coalescence under electric fields
Furman University, Dept. of Physics/Chemistry, Greenville, S. C.	
Soldano, B. A.	Electrification processes related to electrical double layer of cloud droplets

Table 2 (Page 2 of 5)

FEASIBILITY STUDY EXPERIMENT SUGGESTERS AND SUGGESTIONS

Harvard University, Kresge Center for Environmental Health	
Spengler, J. D.	Droplet dynamics, interactions and breakup
Headquarters, Air Weather Service, Scott AFB, Ill.	
Appleman, Herbert	Nucleation efficiencies of submicron silver iodide particles, droplet shattering upon freezing, charged droplet coalescence
Institute of Occupational Medicine, Edinburgh, Scotland	
Ogden, T. G.	Nucleation and charge separation processes.
National Center for Atmospheric Research, Boulder, Colorado	
Langer, G.	Nucleation and propagation of ice phase in supercooled clouds, scavenging by droplets and ice crystals.
Lodge, J.	"Blow-out" from evaporating saturated solutions, splintering during droplet freezing.
Kyle, T. G.	Droplet freezing process, shattering and electrical separation.
National Oceanic & Atmospheric Administration, Environmental Research Labs, Boulder, Colorado	
Ruhnke, L. H.	Ionization level of a spacecraft environment, charge separation related to ice crystal growth, coalescence and electric fields, flow dynamics of air as affected by charge and electric fields.
National Oceanic & Atmospheric Administration, Experimental Research Labs, Miami, Florida	
Cotton, W. R.	Diffusional growth characteristics of ice crystals, ice crystal collisions with electrical effects, nucleation characteristics, giant nuclei, electrical effects on collision and coalescence.

Table 2 (Page 3 of 5)

FEASIBILITY STUDY EXPERIMENT SUGGESTERS AND SUGGESTIONS

NOAA, National Hurricane Lab, Miami, Florida	
Scott, W. D.	Droplet nucleation, splintering, optical properties of ice, scavenging and droplet coalescence.
Ossevuatorio SSMA Monte Cimone-Laboratorie, Bologna, Italy	
Prodi, F.	Scavenging processes.
Naval Research Laboratories, Washington, D. C.	
Ruskin, R. E.	Droplet growth rates and calibration of terrestrial equipment.
Saskatchewan Research Council, Saskatoon, Canada	
Maybank, J.	Nucleation processes (contact, bulk, condensation).
South Dakota School of Mines & Technology, Rapid City, S. D.	
Davis, B. L.	Giant nuclei growth characteristics.
State University of New York, Albany, New York	
Blanchard, D. C.	Droplet breakup distribution during collision as a function of oscillation and surface tension.
Gokhale, N. R.	Contact nucleation versus bulk nucleation characteristics of giant nuclei.
Jiusto, J. E.	Freezing droplet splintering, crystal types as a result of droplet freezing, snowflake aggregation, tensile strength of dendritic crystals.
Texas A&M, Dept. of Meteorology, College Station, Texas	
Byers, H. R.	Electrical effects on collision-coalescence processes and aggregation, splintering.

FEASIBILITY STUDY EXPERIMENT SUGGESTERS AND SUGGESTIONS

Tulane University, New Orleans, Louisiana	
Watts, R. G.	Thermal and mass transfer mechanisms of diffusional growth of droplets.
Sogin, H. H.	Heat transfer at low Reynolds numbers.
University of Alaska, Geophysical Institute	
Jayawerra, K. O. L. F. Ohtake, T.	Supercooling of cloud droplets, ice crystal growth habits, optical properties of droplets and ice, splintering, and break-up of melting snow flakes.
University of Clermont, Clermont, France	
Soulage, R. G.	Diffusion and coalescence growth of droplets and ice crystals.
University of Manchester, P. O. Box 88, Sackville St., Manchester, England	
Latham, J.	Splintering of freezing droplets, multiplication of sea-salt condensation nuclei by electrical disintegration, corona emissions from ice crystals.
University of Michigan, Dept. of Meteorology & Oceanography	
Dingle, A. N.	Diffusion growth of ice and liquid in electric fields, scavenging, nucleation-contact versus bulk, electrical effects on growth processes.
University of Missouri at Rolla	
Kassner, J. L., Jr.	Scavenging forces.

FEASIBILITY STUDY EXPERIMENT SUGGESTERS AND SUGGESTIONS

University of Nevada, Desert Research Institute	
Hallet, J.	Diffusional growth of ice, and shattering, droplet interactions (coalescence), nucleation characteristics and electrical characteristics of ice crystals.
Hoffer, T. E.	Saturation vapor pressure over supercooled water, nonventilated evaporation rates of droplets and diffusional growth habits of ice scavenging.
Squires, Patrick	Accommodation coefficients during initial diffusional growth.
Telford, J. W.	Collision and coalescence under "slow motion."
University of Roorkee, Roorkee, India	
Kamra, A. K.	Electric field and charge effects of droplet coalescence, charge separation due to droplet collisions.
White Sands Missile Range, Atmospheric Sciences Lab., New Mexico	
Low, R. D.	Soluble particle nucleation condensation coefficients and contact nucleation.

As a result of the emphasis in the solicitation efforts the experiments submitted did not include all problems in cloud physics. Experiment suggestion were biased specifically toward a requirement for zero-gravity in addition to relevance to cloud behavior and weather modification and scientific merit of the experiment.

Classification Basis

To facilitate analysis of the submitted experiments, they were classified according to characteristics of primary interest. The classification compared cloud constituents (liquid, liquid-ice, nuclei, and gas) with the various cloud physics phenomena such as nucleation, growth, scavenging, charge

Table 3

PRECONTRACT EXPERIMENT SUGGESTERS AND SUGGESTIONS

New Mexico State, Institute of Mining and Technology, Socorro, New Mexico	
Brook, N. M	Electric effects in coalescence, droplet interactions.
Moore, C.	Droplet interactions, evaporation.
NOAA, Environmental Research Labs, Boulder, Colorado	
Phillips, B. B.	Droplet evaporations, vapor flow from water to ice.
Weickmann, H. K.	Ice crystal growth.
Pennsylvania State U., University Park, Pa.	
Hosler, C. L.	Growth habits of ice crystals, sound wave effects, charge generation processes.
State University of New York, Albany, N. Y.	
Cheng, R. J.	Aggregation of ice crystals, small drop emissions from larger drops.
Vonnegut, B.	Rayleigh - charge breaking.
University of Manchester, England	
Brazier-Smith, P. R.	Rayleigh - charge breaking.
University of Missouri at Rolla, Missouri	
Carstens, J. C.	Thermo and diffusiophoresis, coalescence.
Kassner, J. L.	Homogeneous nucleation, drop interactions, evaporation.
Podzimek, J.	Thermo and diffusiophoresis.
Zung, J. T.	Droplet evaporations.

separation, and absorption. The basis for this classification is described in the following paragraphs.

Precipitation mainly involves growth by ice and liquid particle collision and adherence through riming, clustering, and coalescence.. Collision processes require relative velocities between particles which in turn requires differences in sizes or geometric shapes. These differences are generally due to varying parameters such as condensation nuclei characteristics and humidity distribution.

Most practical weather modification techniques are concerned with the production of a few large ice or water particles in a cloud of many smaller particles which thus initiates the collision process. These large particles are produced by their enhanced diffusion growth resulting from the lowering of their saturation vapor pressure below that of the ambient vapor pressure. This supersaturation condition is produced in warm clouds by the addition of giant salt particles which results in a low vapor pressure salt solution. Dry ice (solid CO_2) and various ice nucleating agents (e.g., AgI) are used in supercooled droplet clouds to produce a few frozen droplets with a corresponding lower saturation vapor pressure. In both of these cases, the modified particles grow at an accelerated rate, depending on temperature, humidity and relative numbers of modified to unmodified droplets.

There are four important processes in clouds which must be better understood before deliberate weather modification can occur. These are nucleation, growth, scavenging, and electrical charge separation.

Nucleation: Nucleation in cloud physics refers to the process of initiating the liquid or ice phase of water. Water vapor (free of ions and particulates) will not form a liquid phase unless a high supersaturation exists and the liquid will not freeze until it is cooled to below -35°C. These two conditions for homogeneous nucleation do not exist under normal atmospheric conditions, but they are of theoretical interest as a foundation for the understanding of the general heteorogeneous nucleation processes.

The normal atmosphere contains particles below 1.0 μm diameter that remain suspended due to their negligible fall velocities. The number of these particles between 0.01 and 1.0 μm available to serve as condensation nuclei is sufficient to limit the normal atmospheric supersaturation to well below one percent (relative humidity of 101.0 percent). Particles greater than one micrometer are generally referred to as "giant nuclei" and are limited in number due to gravitational fallout and because they are the first nuclei to become active in water droplet formation. Giant nuclei are provided artificially for warm cloud modification.

Ice nuclei are much more limited in numbers than condensation nuclei because of their special physical requirements. Cloud seeding often uses the supercooled condition that results from this shortage of ice nuclei.

Laboratory investigations have shown that once certain particles have acted as nucleating sites for water or ice, their activation characteristics are changed. This phenomenon is known as an ice and condensation nuclei memory effect.

Nucleation processes are involved in all forms of weather. At the present time, most weather modification involves the manipulation of nuclei (cloud seeding) within a given weather system. Current research is aimed at determining the role of the various atmospheric nuclei parameters (number, composition, effectiveness, and sources, including pollutants). Further understanding of the role of nuclei will aid in modification efforts such as: the increase of snow and rain for city and agricultural use; the decrease of destruction by hurricanes and hail; and the dissipation of airport and highway fog and smog. Basic to such modifications is knowledge of the nuclei to use, the appropriate number to introduce, the proper injection region in the weather system, and the optimum injection time during the development cycle.

Growth: Once nucleation has been initated, liquid or ice grows by condensation (vapor diffusion) until the particle reaches a few tens of micrometers in size. The quantitative values of the various thermal and vapor accommodation coefficients are very important to this initial diffusional growth phase. Above twenty micrometers diameter, field observations and theoretical computations indicate that other growth processes in addition to diffusion must be involved in order to explain the growth of particles to millimeter size in reasonable times, where they are able to fall from clouds as precipitation.

Included here are processes such as collision, coalescence (merging of two droplets), aggregation and riming. These processes require a coexistence of particles (liquid or ice) with a range of sizes. Studies of the growth rates during various phases of growth are an important area of laboratory research and include: Diffusional growth under normal atmospheric supersaturations (relative humidities below 101.0 percent), and freezing with possible break-up (splintering) as related to growth processes.

The study of growth processes is important in the "when and where" questions of weather modification while splintering affects the quantities of nucleating materials required.

Scavenging: Droplets and ice crystals greater than a few micrometers in diameter collect (scavenge) gases, radioactive particles and other atmospheric constituents. There is a continuing process of "washing-out" or cleansing of the atmosphere.

Particles below a few micrometers in diameter are collected by several processes, including those associated with Brownian motion, temperature gradients during evaporation (thermophoresis), vapor transport during condensation (diffusiophoresis), gravity induced collisions (inertial) and electrical forces on charged particles. Normal fallout removes particles greater than 20 μm in diameter. Scavenging is important in connection with ice nucleation efficiencies relative to weather modifications techniques and wash-out efficiencies as related to air pollution problems.

Electrical Charge Separation: Cloud physicists are concerned with the processes of obtaining charge separation within natural clouds. Laboratory investigations are concerned with charge transfer processes that occur during collision of ice with liquid or ice. Better understanding of electrical processes has potential in such areas as the reduction of forest fires and property damage due to lightning, and the assessment of the role of electrical phenomena in growth and scavening processes.

Classification Summary

Table 4 presents the number of suggested experiments in each classification. It should be recognized that within each element of the matrix there exists the possibility of a number of experiments and that within each experiment there are a range of sub-experiments involving parameter changes such as temperature, electrical field, and humidity. Two items should be noted. First, no experiments were initially submitted in the area of photochemical processes due to the source of the solicitation lists. This area was suggested later in connection with its effect on fogs and smog, and is important enough that further solicitation along this area is being pursued. The second item is the lack of suggestions in such areas as scavenging by ice particles. Further analysis showed that although important, gravity associated difficulties were such a deterrant in these areas that little or no research was currently underway and that very little had been completed in the past. These areas will be included as the scientific community becomes better acquainted with the potential of a zero-gravity facility.

Figure 2 categorizes the various phenomena in areas of applications. These areas include modification of rain, snow, fog, hail, thunderstorms, hurricanes and smog. Progress has been made in the area of dissipation of cold fogs with dry-ice and silver iodide and dissipation of warm fogs by using giant salt (NaCl) nuclei. Recent tests have shown that these methods are not effective with the warm fog-smog combination that exists in such locations as the Los Angeles International Airport. A low gravity environment would be especially beneficial in this area of research.

Senior Scientific Board Evaluation

A summation (Appendix B) of the pertinent facts concerning the submitted experiments was compiled and sent to the Scientific Board for analysis prior to a meeting of NASA, MDAC-W and Board members on 3 and 4 February 1972. This summation included summary sheets describing the

Table 4

EXPERIMENT CLASSIFICATION REPLY STATISTICS

Phenomena	Substance Examined			
	Liquid	Liquid-Ice	Ice	Nuclei
Nucleation		9		8
Growth	16	10	10	6
Scavenging	4	6		
Charge Separation		3	1	
Optical		1	2	
Photo Chemical				
Ab- and Adsorption				1
Other Processes		3		

EXPERIMENT CLASSIFICATION REPLY STATISTICS
APPLICATIONS

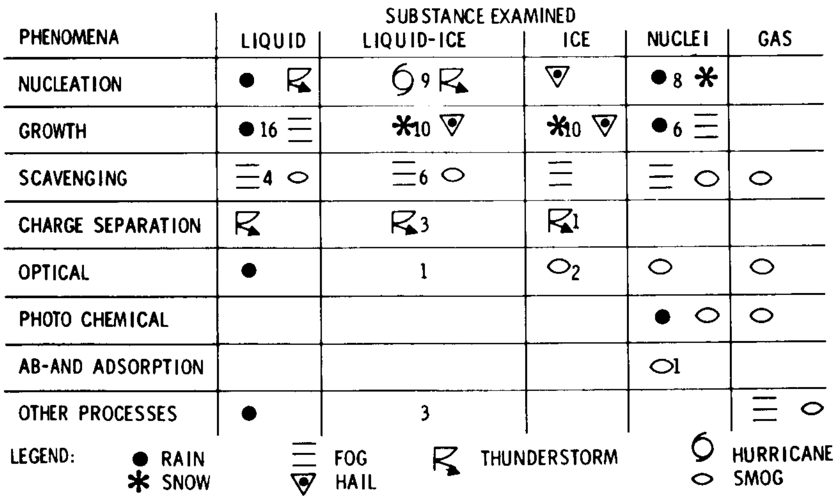


Figure 2

suggested experiments and an experiment classification matrix. In addition to defining zero-g advantages, this summation also included a listing of present terrestrial laboratory problems. This summation did not involve specific ideas on how to perform the experiments as experiment design was scheduled later in the program.

The analysis of the Scientific Board included a discussion of the scientific merit, relevance, zero-g requirements of each experiment suggestion, and an estimate of the relative priority of each of the suggested experiments. Three categories were chosen and the highest priority was given to those experiments which would produce currently needed data. These are categorized in Table 5 as category 1 experiments. Other important experiments were category 2 experiments. Those suggestions that needed further clarification as to purpose, method, relevance or the requirement for zero-gravity were labeled as category 3 experiments.

The Scientific Board then analyzed each of the priority experiment suggestions with a view toward the operational ease or difficulty of performing such an experiment. Two major factors were considered: hardware requirements and man-involvement requirements.

Hardware considerations included the requirements of chamber type, environmental ranges, motion control and supporting equipment. Man-involvement considerations dealt with educational background requirements relative to decision making processes and the manipulative and observing requirements during the conduct of the experiment. The results of the analysis are also shown in Table 5 and indicate that there is a wide range of hardware and man-environment requirements. Some very important and significant research can be accomplished with off-the-shelf hardware and by an astronaut following a check list. Other experiments are very involved requiring special motion and environmental controls as well as very refined observation systems. The more sophisticated experiments may require an astronaut with several years of graduate training in cloud physics. As is shown on Table 5, there are important high priority experiments (Category 1) that are in the least complex operational classification (Category 4).

Table 5

SCIENTIFIC BOARD ANALYSIS

Experiment	Scientific Importance	Operational Classification
Diffusion) (Qualitative	1	4
Diffusion (Quantitative)	1	5, 6, 7
Breakup (Qualitative)	1	4
Breakup (Quantitative)	1	5, 6, 7
Ice Nuclei Memory	1	5
Homogenous Nucleation	1	5
Contact/Bulk Nucleation	1	5, 6
Aggregation	1	5, 6, 7
Phoretic Processes	1	5, 6
Coalescence	2	6, 7
Giant Nuclei	2	5, 6
Photochemical Nuclei Sources	2	5, 6
Oscillation	3	
Collision	3	

Legend

SCIENTIFIC IMPORTANCE AND RELEVANCE

1. Important research needed as soon as possible (Very High Priority)
2. Important research but less priority than category 1 (High Priority)
3. Experiments require further clarification from suggestor

OPERATIONAL CLASSIFICATION

(Different experiment goals, may involve different levels of operational complexity)

4. Simple equipment no special astronaut requirements adaptable to early flight opportunities
5. May involve one complex subsystem and brief intense training period for astronaut. May be adaptable to early flight opportunities
6. More than one complex subsystem. Special training for astronaut
7. Complex experiment. Graduate training required in cloud physics

Each of the experiment suggestors were asked to discuss the terrestrial research difficulties associated with their experiments and also to discuss the advantages of a zero-gravity environment. The Scientific Board used these comments as a basis and interjected their own ideas and suggestions. A condensation of these follows.

Terrestrial Research Difficulties

Although many advances have been made in the field of cloud microphysics, researchers have always been hampered and limited by certain problems. Current researchers are faced with many of the same difficulties. A brief description of some of these research difficulties as related to nucleation, growth, scavenging and electrical charge separation are identified and examples of problems associated with chambers are described below.

Nucleation: Nucleation investigations of particles between 0.1 and 10 μm diameters involve the determination of the nucleating properties of natural atmospheric nuclei and potential cloud seeding materials. The important parameters in these determinations are temperature, humidity and size distributions.

Expansion chambers, mixing chambers, flat plates covered with hydrophobic materials (e.g., teflon) and specially prepared filter papers have all been used to study the characteristics of ice and condensation nuclei. All nucleation activity is a function of humidity, and in addition, temperature and rate of cooling must also be considered for ice nucleation. The greatest limitation is the inability to provide in laboratory chambers the low supersaturations and low cooling rates that are characteristic of normal atmospheric processes. These limitations are related to problems of gravity induced settling and convection. The plate or filter support techniques introduce unnatural effects because of the physical contact between the nuclei and support surface.

Growth: Extensive studies have been made of growth processes such as collision of large water droplets and diffusion growth of large water and ice particles by the use of vertical fall columns and wind tunnels. These approaches permit a realistic dynamic study of certain growth processes that include properties induced by gravity.

Another area that is receiving a great deal of attention is the diffusional growth from the initial nucleation of submicrometer diameter particles. These studies usually involve the growth of these initially small particles to a few micrometers where they can be observed with an optical microscope and photographed. Diffusion, expansion and mixing chambers are being used to study these growth processes. Great effort is being expended to obtain the low supersaturations and cooling rates that are characteristic of the normal atmosphere. These latter conditions have received more emphasis as a result of the large discrepancies between laboratory measurements, theoretical computations and field observations. Laboratory conditions produce a monodispersed cloud of droplets fairly independent of the initial nuclei source. Theory, using laboratory results, indicates that the necessary collision processes will not be initiated. Field measurements have shown a range of cloud droplet sizes in contrast to the uniform droplet sizes found in the laboratory.

A partial answer to these differences is believed to lie in the unrealistic laboratory growth conditions. Gravity induced air convection and particle settling prevent the achievement of desired lower cooling rates and lower supersaturations.

Scavenging: Scavenging of submicrometer particulates onto supercooled droplets is one of the most important processes in inducing droplet freezing (and resulting weather modification) through artifical seeding (e.g., AgI). Scavenging by ice and liquid also plays an important role in cleansing the atmosphere of gases and particulate matter. Scavenging involves Brownian and gravity induced motion, and forces due to temperature and vapor gradients.

Brownian motion, temperature and vapor gradients are not a function of gravity. Thus these forces are often studied by the suspension of droplets on fibers or by the use of various chambers. Experiments using fiber suspensions have indicated that the vapor gradient does play a role in the transport of submicrometer particles to ice and water surfaces. The thermal conduction of the support fiber does not permit the evaluation of the thermal gradient forces.

Gravity settling and observation restrictions limit the use of various chambers for the qualitative and quantitative studies of the various scavenging forces.

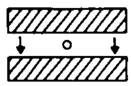
Electrical Charge Separation: Most laboratory studies of the atmospheric related electrical charge production and separation mechanisms involve the mechanical support of the liquid or ice. These supports are necessary to eliminate motion and thus permit the necessary delicate electrical measurements. A number of measurements have been made but there is no real agreement as to which mechanism is the most important. This uncertainty is a result of the extreme difficulty of preventing electrical and thermal conduction through the supports.

Chambers: In nature initial diffusional droplet growth occurs over a period of tens of seconds to minutes under supersaturations often much less than 1.0 percent (101 percent relative humidity). In an earth-based laboratory, the study of such particle growth processes involves the use of diffusion chambers as shown on Figure 3. Considering the physics of diffusional processes, a diffusion chamber must be limited to about one centimeter in height if a given fixed relative humidity is to be obtained in a few seconds.

Because of gravity induced motions, terrestrial laboratory diffusion chambers must produce accelerated growth rates by the use of high supersaturations (greater than 0.3 percent) in order to prevent the growing droplets of water from falling onto the lower chamber wall. This relatively high supersaturation produces droplets of nearly equal diameter in contrast to field observations.

Cloud physicists express a strong need for the use of lower supersaturation (<0.3 percent) as found in the atmosphere and the associated longer

DIFFUSION CHAMBERS



TERRESTRIAL DIFFUSION CHAMBER

- CHAMBER DEPTH –DIFFUSION PHYSICS (1 CM MAX)
- DROPLET DIAMETER–OBSERVATION (2 MICRONS MIN)
- GROWTH TIME–GRAVITY FALL-OUT * (2 SEC MAX)
- REQUIRED SUPERSATURATION–TIME AND DIAMETER (0.3% MIN)
- SIZE DISTRIBUTION–NARROW DUE TO HIGH SUPERSATURATION

NATURAL

- SUPERSATURATION–OFTEN BELOW 0.1 PERCENT
- ASSOCIATED GROWTH TIMES–GREATER THAN TENS OF SECONDS

* TERRESTRIAL LIMITATIONS

Figure 3

growth times. These conditions are necessary before a realistic understanding of the initial droplet growth by diffusion can be understood and utilized in weather modification processes.

An analysis similar to the above can be made for an expansion chamber. A condensed version of this analysis follows:

In an expansion chamber, the desired supersaturation is obtained by an expansion of the air. The air is cooled upon expansion while walls remain at the initial warmer temperature. Heat conduction from the wall to adjacent air causes air density variation and results in gravity driven convection. This convection limits most expansion chambers to considerably less than one second useful time.

Advantages of a Zero-Gravity Environment

A consideration of the laboratory problems indicates that gravity is one of the major limiting factors. There is a range of particulate sizes between

0.01 μm to 10μm that are involved in physical processes which are independent of gravity. A zero or low gravity environment would enhance the observation and study of these processes. The advent of space platforms provides the potential for cloud microphysics research in zero-gravity. The elimination of gravity would provide three basic advantages in conducting cloud physics experiments. The first advantage is the removal of mechanical support of drops and crystals. Without such mechanical support, the following experiment problems can be eliminated: (1) thermal conduction through supports; (2) mechanical obstruction to heat and mass transport; (3) surface modification by fluid-interface contamination; (4) electrical conduction through supports; (5) optical interference of support; and (6) mechanical damping of supports.

The second advantage is the separation of gravity from other forces of interest. This is accomplished because in zero-g the problems of convection, drop settling or fallout, and relative motion between particles are not serious. Since these problems are essentially eliminated, better observation can be made of electrical forces, particle motion due to vapor flow (diffusiophoreses) and temperature differences (thermophoreses), and Brownian motion.

The third advantage is the long duration of observing time available because drops and particles can be suspended for indefinite periods. This is especially applicable to atmospheric physics research chambers.

A space platform would permit the reduction of droplet settling by at least 10^3 with a potential reduction of 10^5. With the settling restriction removed, the physical design requirements for diffusion chambers can be relaxed.

A space platform would reduce air convection in expansion chambers by a factor between 10^3 and 10^5. This convection reduction along with appropriately cooled chamber walls places the expansion chamber as a prime choice for cloud physics experiments in a low gravity environment.

Experiment Approaches and Concepts

The basic assumptions that guided MDAC's initial approach to the zero-g feasibility study as well as the Scientific Board analysis were as follows:

The ultimate zero-gravity cloud physics experiments facility should be a laboratory available to the entire cloud physics community in which a wide range of experiments could be performed. The laboratory should be an independent, complete, pallet-type facility which could be integrated into any of a number of space flight opportunities. Man's involvement is important and will become progressively more so, starting with elementary manipulations and data gathering, and moving toward decision making capabilities requiring a substantial educational background in cloud physics. The possibility of early carry-on experiments should be considered in order to more fully define the requirements for a sophisticated advance experiment facility. In addition, the early experiments should be directed toward providing some fundamental scientific answers.

The analysis of the Scientific Board with regard to experiment importance and difficulty agreed with these basic assumptions. The Boards conclusions were: (1) It is feasible and highly desirable that the advantages of zero-gravity be assimilated into the cloud physics research program, (2) There are a large number of important experiment areas and experiments that can be done early in zero-gravity, (3) Some very important cloud physics research could be accomplished with relatively simple equipment by a non-scientist astronaut in a carry-on mode, but the majority of important experiments will require sophisticated apparatus and a trained experimenter.

The Scientific Board analyzed the experiment suggestions first of all with respect to scientific merit and a brief condensation of the analysis is contained in Table 5. The first group of experiments, which can be characterized as very high priority but not requiring special cloud physics training for the experimenter, included four basic classifications. They are (1) accommodation coefficients for nuclei, droplets and ice crystals; (2) vapor pressure over super-cooled droplets; (3) "blow-out" associated with the evaporation of saturated solutions and "freeze-splintering" of supercooled droplets; and (4) ice-nuclei memories. It should be understood that these are not single experiments but generally they involve parameter changes such as temperature, pressure, relative humidity, electric fields, initial charge distribution, acoustical fields and gas composition. The second group of equally high priority experiments are differentiated by the requirement for experimenter decision - making that require a cloud physics background. Included in this group are (1) ice riming; (2) propagation of ice phase during freezing; (3) contact versus bulk nucleation; (4) scavenging including the effects of diffusiophoresis, thermophoresis and Brownian motion; (5) corona emission from ice crystals; and (6) optical parameters of ice crystals including scattering coefficients and polarization. There will be a variety of experiments within each of these areas dependent on parameter variability. The third group of experiments were determined to be very important in terms of scientific merit but of lower priority than the first two groups. Generally they will require an experimenter with a cloud physics background. This group includes (1) giant nuclei; (2) collision or coalescence; (3) liquid cloud condensation nuclei memories; and (4) dipole studies associated with ice growth or melting in an electric field. A small number of experiments were set aside by the scientific board for further reconsideration. These were experiments where the requirements for zero-gravity were not clearly established or further clarification of the experiment suggestion was required.

An example of the group one experiment is the supercooled water saturated-vapor-pressure experiment. Suggested by Dr. Thomas Hoffer of the Desert Research Institute, the requirement for a few large particles to initiate the collision process was previously described. The role of nuclei in the production tion of these large liquid and ice particles was also mentioned. The basic diffusion growth equation for both ice and liquid takes the form

$$\frac{dM}{dt} = \frac{4\pi C}{(A + B)} \frac{p - p_s}{p_s}$$

where

M = the mass of the particle

t = time

C = form factor ($C = r$ for a sphere; $C = 2\,r/\pi$ for a disk shape)

A, B = are functions of temperature and saturated vapor pressure

p_s = saturation vapor pressure of the ice or liquid particle

p = ambient vapor pressure.

This equation indicates the relation of the mass growth rate (dM/dt) to the vapor pressure difference between the ambient (p) and the particle (p_s). In cold cloud seeding, p would be the saturation vapor pressure of the supercooled water droplets while p_s is the lower saturation vapor pressure of the few ice crystals. Laboratory determinations of this pressure difference are hampered by the inability to cool water much below 0 °C. This problem exists because freezing is induced by surface contact between the water under investigation and the support medium.

The presently used values of the saturation vapor pressure over supercooled water are extrapolated from above-freezing measurements. Because of the importance of this vapor pressure difference in weather modification, it is important that these extrapolated values be either verified or corrected.

A zero-gravity environment would permit the suspension of a water drop in the center of a temperature controlled chamber as shown in Figure 4. The chamber temperature would be lowered at appropriate temperature steps, e.g., 0.5 °C, and sufficient time allowed for diffusion and thermal equilibrium within the chamber. The chamber internal temperature and pressure would be recorded and the temperature again lowered. These steps would be repeated over a temperature range from +20 °C to -30 °C. Freezing would not be premature because there will be no support contact with the drop.

The evaluation of particle scavenging forces is an example of a Group 2 experiment suggested by scientists at Battelle Northwest. Scavenging of submicrometer particles b droplets and ice crystals greater than a micrometer is the means by which the atmosphere is cleansed of the particulate matter which possesses negligible fall velocity. This same principle of scavenging is also the process that is utilized for most weather modification efforts.

An important problem in scavenging is the evaluation of the relative importance of the possible scavenging mechanisms (thermal, diffusional and Brownian

SUPERCOOLED-WATER SATURATION
VAPOR PRESSURE EXPERIMENT

WHY
- COLD PRECIPITATION PROCESSES

WEATHER MODIFICATION ELEMENT
- GROWTH

OBJECTIVE
- DETERMINE SATURATION VAPOR PRESSURE OF SUPER COOLED WATER

APPLICATION
- THESE DATA GOVERN WHEN AND WHERE DECISIONS

SPECIFIC KNOWLEDGE REQUIREMENT SATISFIED
- DIFFUSIONAL GROWTH OFICE IN A SUPERCOOLED WATER CLOUD

METHOD

- EVACUATE CHAMBER
- INSERT DROPLET
- COOL (0.5C STEPS, -40C < T < + 20)
- MEASURE TEMPERATURE AND PRESSURE

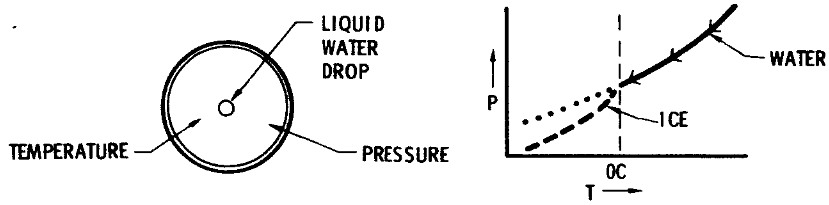


Figure 4

motion) of submicrometer particles onto droplets and ice crystals between one and twenty micrometers. Inertial properties of particle motion plays an increasing role above this size range.

Terrestrial laboratory experiments are hampered by either gravity fallout of the droplets or the results are restricted by the thermal conduction of any mechanical supports.

A zero-gravity environment would permit the suspension of particles and droplets having no fall velocity and no mechanical supports. Figure 5 indicates one method that could be used to evaluate the importance of thermal, diffusional and Brownian motion forces in the scavenging processes.

Freezing nucleation (initiation of freezing) would be used as an indication of when a particle has been captured by a supercooled droplet. A cloud of droplets and nuclei would be injected into a chamber maintained at a known temperature, pressure, and humidity according to the conditions 1, 2 and 3 as indicated in Figure 5. The number of frozen droplets versus time indicates the relative scavenging efficiency under a given set of conditions. The chamber would be cleaned (purged) and another cloud of droplets and particles injected under different conditions.

The three basic conditions are as follows:

Evaporation: The humidity is adjusted so that the droplets are evaporating at a given rate. Under this condition the droplet is cooler than its environment providing a temperature gradient toward the droplet (gradient from higher to lower temperature). The water vapor gradient is outward from an evaporating droplet as indicated by the arrows in the figure. Random Brownian motion would be inward in all cases.

Equilibrium: No vapor difference or temperature difference exists once equilibrium is obtained. The only scavenging force would be Brownian motion.

PARTICLE SCAVENGING FORCES EXPERIMENT

WHY
- PRECIPITATION PROCESSES AND ATMOSPHERIC CLEANSING

WEATHER MODIFICATION ELEMENT
- SCAVENGING

OBJECTIVE
- DETERMINE RELATIVE IMPORTANCE OF THERMAL (T), DIFFUSION (V_P) AND BROWNIAN (B) FORCES

APPLICATION
- QUANTITIES OF SEEDING MATERIAL NECESSARY TO ACCOMPLISH DESIRED MODIFICATION

SPECIFIC KNOWLEDGE REQUIREMENT SATISFIED
- EFFICIENCY

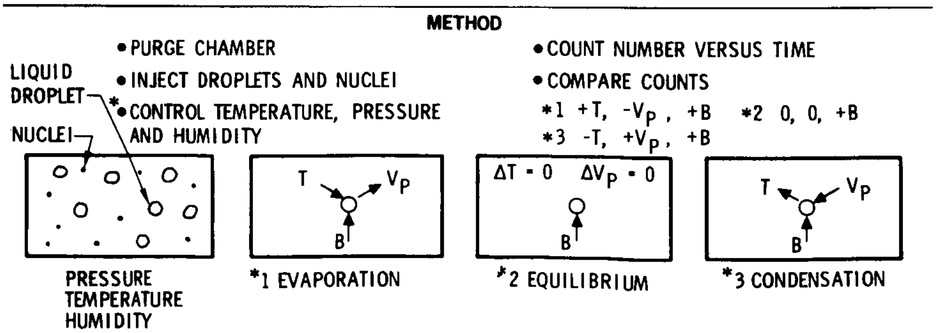


Figure 5

Condensation: The temperature and vapor conditions are now reversed from the evaporation case.

The analysis would consist of the evaluation of the counts obtained under the three basic conditions given above. The equilibrium condition provides effectiveness of Brownian motion. The subtraction of these counts from the evaporation experiment results will give a number indicating the relative importance of temperature and diffusion. A positive number indicates that the temperature difference is more important that the negative effect of vapor diffusion. Similar comparison between the equilibrium and condensations would indicate in complementary form the relative importance between temperature and vapor effects with a positive number indicating the greater importance of vapor diffusion.

These experiments would be performed with different conditions of supercooling, humidity and pressures to obtain the force dependence on these factors.

Laboratory Concepts and Requirements

An extensive analysis of the experiment suggestion was initiated with a view toward developing the requirements for zero-gravity cloud physics laboratory equipment and apparatus. MDAC scientists studied each experiment suggestion in order to determine the requirements and to identify the problems associated with the performance of the experiment. In some cases additional information regarding requirements was requested from the original suggesters and the replies were incorporated into the analysis. The various requirements were then grouped into common areas which evolved into the subsystems of the total zero-g cloud physics facility. These subsystems are chambers, generators, environmental controls, motion control, composition control, observations, data management and charge control.

It was recognized that parallel efforts regarding platform interface and total system integration would have to be undertaken.

The establishment of requirements in each subsystem was followed by an analysis to determine potential components that would meet subsystem requirements and have the capability for operation in zero-gravity conditions. As an example in the observations area, there are a wide range of requirements.

Table 6 presents an analysis of how the various phenomena of cloud physics are currently observed and potential techniques for future observations.

The next analysis step was to establish priorities and schedules for the definition work necessary for each of these subsystem components. Some components will require long-lead time definition and development. Other components will require less time. The identification of the long-lead time requirements and developing plans for meeting them was an important accomplishment.

Preliminary analysis is currently underway to study each of the potential components. University consultants are and will be heavily involved during this step especially in the chamber and environmental control areas. Expert in-house capabilities exist and are being utilized in platform interface and observation areas. MDAC is emphasizing generation and motion control subsystems and parts of the observation subsystem. Basic calculations to determine if requirements can be met are the first part of this analyis. If the component has the necessary capabilities it must be examined in terms of weight, power, volume, special controls and instrumentation requirements.

Table 6
OBSERVATIONS
(Present and Possible Techniques)

Phenomenon (to be observed)	Observation Technique (now)	Possible Obs. Tech. (Future)
Diffusion	Rate and points of growth from photographs	a. Holographic interferometry b. Vapor profile - spectroscopy (Raman and others) c. Temp. of droplet (IR scan) d. Temp. profile around drop e. Drop temperature control by absorption heating f. Holographic volume recording of changes in a cloud and ice propagation studies g. Evolution of cloud drop/crystal size spectra-diffusion and competition.
Coalescence	Photographic	a. Hologram of single and multiple events b. Collision process with interference hologram - deformation, etc.
Break-up	Freeze-try to detect splinters	a. Holographic (and video) and photo of volume - sequence of times to permit detection by growth of small ejected particles. b. Hologram - clouds - ice propagation. c. Raman impurity evaluation.
Scavenging	Freezing distribution vs evaporation, equilibrium condensation and particle size, type, and temperature	a. Raman scan to give particle concentration around droplet. b. Particle concentration and diffusion rate in droplet. c. Vapor and temperature profile (IR, UV and Raman)
Nucleation	Grow nuclei to a few micrometers size to observe	Monitor from 0.1 μm size and up if possible with size distribution given.
Charge Separation	Physical contact measurements.	Remote charge detection ac, dc, and sound fields.

V. EARLY FLIGHT OPPORTUNITIES

Throughout the course of the zero-gravity cloud physics program, consideration has been given toward utilizing pre-Shuttle flight opportunities for concept testing and scientific research. This testing approach is highly desirable considering the potential involvement of the final Shuttle atmospheric cloud physics laboratory and in light of the lack of experience of working in a zero-gravity environment. Several planned man-in-space missions have been preliminarily examined for their suitability as potential carriers for small portable cloud physics experiments. These portable experimentation and testing modules (PETM) have two objectives: 1) to provide a significant contribution to a relevant scientific objective, and 2) to testing one or more subsystem components being developed for zero-g laboratory. To this end, the Skylab, Apollo and the early Shuttle test flights have been examined and have been found to have PETM carrier potential. However, the flight vehicle, hardware and support systems are fixed several years in advance due to their complexity and required reliability. In addition, vehicles such as the Apollo were designed for space travel and not for experimental laboratory research.

The basic premise is to design the PETM's so that they are nearly self-sufficient in order to minimize integration impact. Weight, volume and crew safety are the primary factors and the major integrative linkage would be power. However, advantage will be taken of all existing support facilities within these carriers.

The Skylab system includes experiment and support facilities that could be utilized for preliminary cloud physics experimentation. Design constraints involve keeping the volume small enough for the Skylab storage units and keeping power requirements within the specified limits. The following are examples of two special facilities available aboard the Skylab for experiments.

A Materials Processing Facility (MPF) is located in the Multiple Docking Adapter of the Skylab, contains a 41.28 cm diameter sphere with a 15.24 cm port, and is provided with vacuum and temperature control. This facility can be used for vacuum and temperature studies of aerosols, ice crystals and particulates. Fig. 6 shows the M512 MPF integrated in the Skylab Orbital Workshop.

There are also food chillers and freezers provided for the storage of food and could be utilized for cloud physics experiment purposes. The freezer maintains a temperature of -12 ±5 degrees Centigrade and the chiller a temperature of +4 ±3 degrees Centigrade.

The Apollo Command Service Module (CMS) has room for demonstration type experiments and small PETM's. Cameras, video and water guns might all be utilized for fundamental cloud physics and laboratory engineering experiments.

There is also the possibility of placing PETM's aboard early test Shuttle flights. Although these test flights may require lower altitudes a great deal of component testing and checkout could be accomplished.

About midway through the feasibility and concept study, a set of five experiments were submitted to a MDAC/Skylab evaluation group to determine the

ORBITAL WORKSHOP
MDA INTERNAL VIEW (RIGHT SIDE)

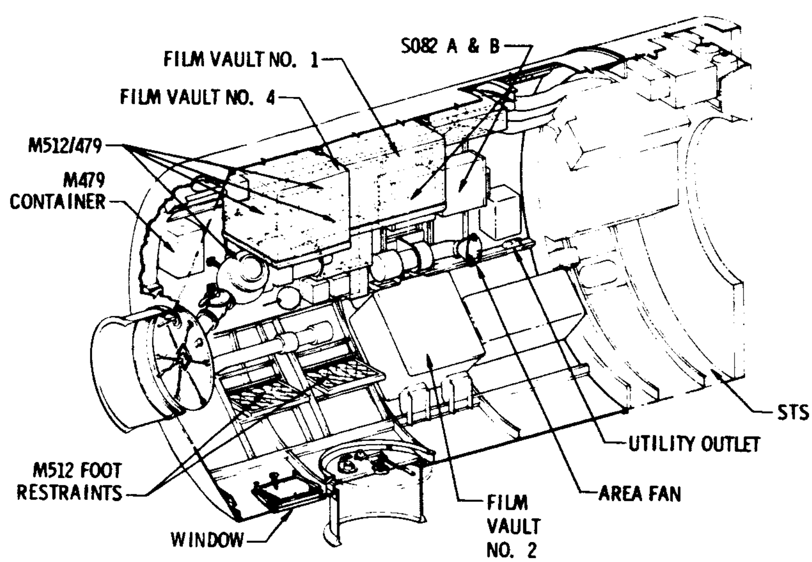


Figure 6

compatibility between experiment and vehicle. These experiments were to meet the Skylab requirements of "Simple Engineering/Manufacturing Tests to Exploit Zero-Gravity Environment."

Appendix C contains a two page form for each submitted experiment along with a sheet summarizing the priorities of the experiments. In addition to the material submitted to the Skylab group, Appendix C contains a short description of the need for the experiment as well as a brief example procedure for each experiment. A few notes are also included relative to simplified "carry-on" versions of the experiments.

Appendix C experiments that are suitable for early flight opportunities include the following: single water droplets colliding with larger water surfaces in order to study collision processes, droplet dynamics and droplet break up; evaporation of ice or water in a vacuum to determine important accommodation coefficients involved in precipitation processes and studies of vapor pressure over super cooled water.

The information of Appendix C is preliminary and is to be used only as guidelines for future concept developments.

VI. PAYLOAD INTEGRATION CONCEPTS

A continuous effort will be made throughout the course of this study to prepare and maintain up-to-date experiment program definition data for use in integrated payload planning activity. The NASA maintains a Candidate Experiment Program which consolidates information regarding experiment requirements, payload analysis, operational constraints, and candidate missions. Standard experiment program definition format sheets continuing data for cloud physics experiments are included in Appendix D. The first experiment is the ultimate laboratory for the Shuttle of the 1980's, the other two are typical experiments that could utilize the laboratory or be candidates for pre-Shuttle flight opportunities. The data on these format sheets represent the May 1972 concept and they are subject to change throughout the course of the program.

Figure 7 is a picture that represents a concept of the zero-gravity cloud physics laboratory. The zero-gravity cloud physics facility will be a laboratory available to the entire cloud physics community in which a wide range of

ZERO-G CLOUD PHYSICS FACILITY

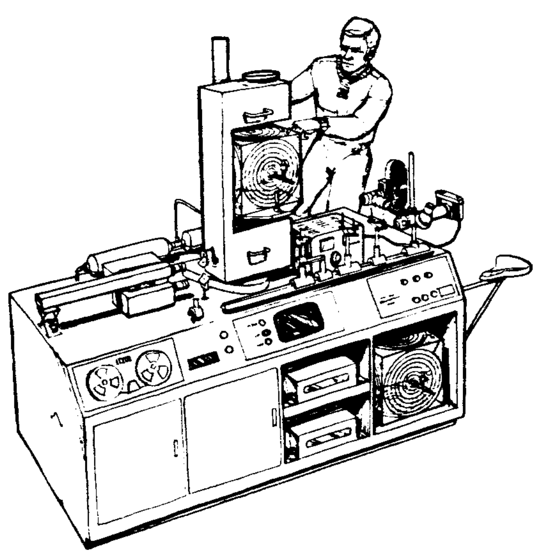


Figure 7

experiments can be performed. The laboratory will be an independent, complete, pallet-type facility which can be integrated into any of a number of space flight opportunities. Man's involvement is important and will become progressively more so, starting with elementary manipulations and data gathering, and moving toward decision making capabilities requiring a substantial education background in cloud physics.

This laboratory will be versatile enough to accommodate a wide variety of experiments. The operational concept involves individual experiments on Sortie type missions, conducted initially by scientifically trained astronauts, and eventually by the experiment scientist himself.

The Shuttle Sortie mode is ideally suited for the conduct of research within a cloud microphysics laboratory as it provides the necessary combination of relatively short term turnaround for conduct of the experiment and receipt of the results, accommodations for required volume and weight needed for the multiexperiment laboratory, availability of man to conduct experiments and the required levels of a near zero-gravity environment.

Requirements include:

Length of Flights - 5 to 7 day sortie missions.

Orbit - No constraints on orbital altitude or inclination.

Data Requirements - Data - Return from orbit of photographic, digital/analog magnetic tape records, astronaut log (voice record) of experiment. Voice communication with control station on Earth with TV coverage desirable.

Role and Number of Personnel - One cloud-physics trained scientist/payload specialist required. Highly desirable to have assistance of one other payload specialist. Role is to conduct a series of cloud physics experiments, make necessary real time adjustments/decisions, and record results.

Stabilization and Pointing - No pointing accuracy requirements; stabilization requirements are those which are adequate to maintain less than 10^{-3}g condition for periods of approximately 20 minutes.

Power and Thermal - Approximately 200 watts peak power, 1 watt average operation power; 2 hrs/day average operation per sortie with occasional operation twice per day. Required Shuttle Sortie Laboratory ambient thermal environment, 10° to 30°C (cloud chamber internal environment will range from +35° to -35°C).

Weight and Volume - Estimated ≤225 kg weight for laboratory with volume approximately 0.9 m x 1.2 m x 2.4 m. Self-contained facility except for power requirement.

General Support Equipment - Experiment expendables and supporting equipment not in basic laboratory estimated at about 22 kg and 0.06 m^3.

Special Operating Constraints - No operational constraints at present time; however, astronaut motion should be minimal during experiments.

Contamination Requirements - Minimal, except inside cloud chambers which are an integral part of the experiment laboratory and, are therefore, controlled by the experiment.

Other - Shuttle Sortie Laboratory accommodations desired to permit easy access. Some experiments may require earlier activation (in the first 24 hrs. after shuttle lift-off).

In order to accommodate the multi-experiment concept the laboratory must possess certain adaptability features. The principal component of a cloud microphysics laboratory is the cloud chamber. Three different types of chambers are in general use in terrestrial research. These are thermal expansion chambers, diffusion chambers and general purpose chambers. Figure 7 shows the concept of interchangeable chambers. More than one chamber of a type may be desirable in order to avoid purging and contamination problems. It may be possible to design a single chamber in which both expansion and diffusion research can be done and this concept is under study.

Figure 7 also pictures a complex observational system whose components includes still and motion cameras, microscopes and a sophisticated laser holography system. Other observational components are under study and the ultimate laboratory may involve various combinations of observational equipment.

Other components shown on Figure 7 include an electrical droplet motion-control system, and storage units for the gases that will be used for chamber composition control and for chamber preconditioning. Not specifically shown are the very important environmental control systems for temperature, pressure and humidity.

The laboratory concept will remain fluid and changes in concept are expected to be the normal course of action. However, two precepts must be continuously considered: 1) the laboratory must be versatile enough to serve a large variety of experiments and 2) there are interface limitations of weight, volume and energy supplies.

VII. LONG-LEAD TIME PRELIMINARY DESIGN STUDIES

An important part of the preliminary analysis of the experiment suggestions was a determination of the kinds of equipment and apparatus required to accomplish these experiments in zero-gravity. Although the basic purpose of this laboratory development was to take advantage of the very low gravity, it was recognized that many pieces of laboratory equipment had working mechanisms and systems that were gravity dependent. This factor has been and will continue to be an important design consideration for the zero-g laboratory. Using the experiment suggestions as a base, MDAC developed a list of component equipment for each of the subsystem areas. Each of these potential components will be studied. University consultants are and will be heavily involved during this study especially in the chamber and environmental control areas. MDAC is emphasizing generation and motion control subsystems and parts of the observation subsystem. Basic calculations to determine if requirements can be met are the first part of this analysis. If the component has the necessary capabilities it must be examined in terms of weight, power, volume, special controls and instrumentation requirements.

The next phase of the analysis will be the selection of the minimum number of components necessary to meet the requirements and the examination of the compatibility of these selected components. This will be an iterative process leading to a final subsystem concept package. There will also be "whole system" analysis which essentially studies the compatibility of the various subsystems with each other.

The list of Subsystem Potential Components follows:

- CHAMBERS
  - Diffusion Chambers
  - Expansion Chambers
  - General-Purpose Chambers
- GENERATORS
  - Liquid Droplet Generators
  - Liquid Cloud Generators
  - Solids (ice)
  - Solids (Nuclei)
  - Gases

ENVIRONMENTAL CONTROLS

- Temperature
- Pressure
- Dew Point Temperature
- Gas Composition
- Electric Field

MOTION CONTROLS

- Electric Fields
- Magnetic Fields
- Air Jets
- Acoustic Waves
- Photon Forces
- Laminar Air Flow
- Thermophoresis
- Diffusiophoresis
- Photophoresis
- Probes (Physical Contacts)

CHARGE CONTROLS

- Charging Probes
- Contact Charging
- U. V. Ionization
- Alpha Particle Ionization
- Ion Guns

COMPOSITION CONTROL

- Premixed Gases
- Internal Mixing
- Droplet Coatings
- Single Particle Contacts

OBSERVATIONS

- Visual
- Still Photography
- Motion Photography
- T. V. Video
- Microscopes
- Laser Holography

Raman Spectroscopy

I. R. Spectroscopy

Lidar

Optical Scattering Properties

MDAC developed a study program plan based on these component requirements. Those components requiring the longest lead time analysis were to be started early. The program component definition study plan is pictured in Fig. 8.

One large research area not previously explained is experiment in-depth definition. This definition involves an extensive detailed description of equipment and performance-time-lining for each experiment approved by the Scientific Board. The definition must be completed before all hardware and supporting equipment requirements can be determined.

Two long-lead time chamber studies were completed. Dr. James L. Kassner and staff of the University of Missouri at Rolla completed a study of cloud

PROGRAM PLAN

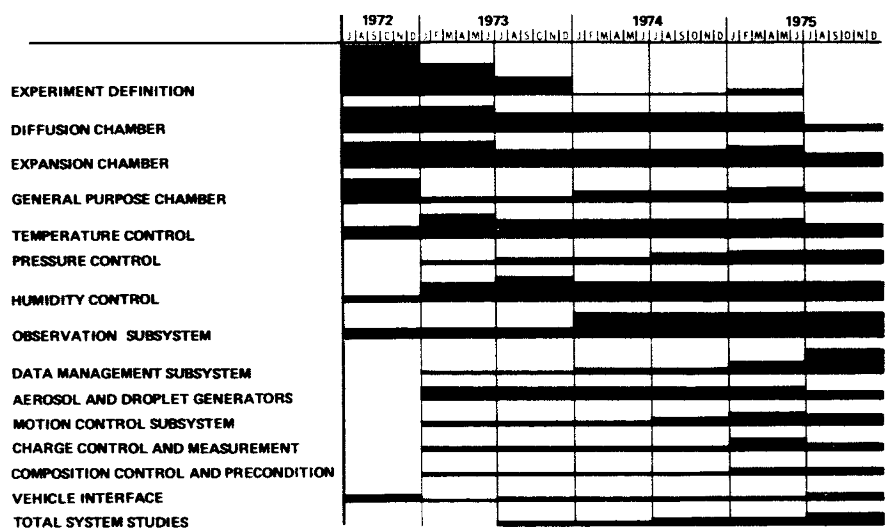


Figure 8

simulation chambers with the emphasis on thermal expansion chambers. This study also dealt with the special problems of operating a thermal expansion chamber under zero-g conditions. He concluded that a cloud simulation chamber such as the one under development at the Graduate Center for Cloud Physics Research at the University of Missouri-Rolla is well suited for applications in a zero-gravity environment. He pointed out that although the basic concept is valid most of the hardware would have to be redesigned to meet the space, weight and power limitations. The emphasis of the second consultant study was on diffusion chambers. Dr. Patrick Squires and associates of the Desert Research Institute at University of Nevada studied the special problems of zero-gravity operation upon both continuous-flow and static diffusion chambers. Special emphasis was placed on determining what types of experiments could best be done in each of the different chambers.

VIII. DEVELOPMENT AND TESTING FACILITIES

A low gravity environment presents a totally new dimension to research and manufacturing. Very little experience has been accumulated concerning the requirements and conditions of performing experiments under low-g conditions. A number of demonstrations have been performed on the various Apollo missions. Electrophoresis, composite casting, liquid transfer and thermal diffusion demonstrations were performed on Apollo 14. A general discussion concerning the potentials of manufacturing in space is given by Hans Wuenscher (to be published in Sept. 1972, Astronautics and Aeronautics).

Because of the "remoteness" of these potential laboratory facilities, it is highly desirable to utilize all available terrestrial and terrestrially controlled means to test various concepts that are to be used in a space laboratory.

Several methods are presently available for obtaining various levels of low gravity conditions. These are:

- Drop tower (300 ft giving 4 sec of low-g, MSFC)
- Aircraft zero-g maneuver (KC-135 research aircraft delivers 15-20 sec of low-g)
- Sounding rocket (Aerobee delivers 3-6 min. of low-g)
- Suborbital rocket (up to 30 min of low-g)
- Zero-g bubble simulation chamber (minutes to days).

The first four methods have been used extensively during the space program to develop systems and to train astronauts. These techniques offer relative low cost and rapid turnaround time for the development and testing of concepts for use in the low-g environment of a space laboratory.

Atmospheric physics experiments that can benefit from a zero-gravity condition will require acceleration levels below 10^{-3} of the earth's gravitational acceleration (g_o) (10^{-4} to 10^{-6} being desirable) and have durations from tens of seconds to tens of minutes.

The drop tower approach drops a container in free fall inside a second container. The outer container acts as a drag shield to minimize aerodynamic drag on the experimental components. Figure 9 illustrates the Marshall Space Flight Center (MSFC) drop tower which is located in one corner of the Saturn V Dynamic Test Stand. The tower's capabilities are summarized in the Figure. The drop tower's 4 seconds can potentially be used to test such concepts as drop injection, charging and positioning. The rapid turnaround time and low cost is attractive.

The KC-135 research aircraft has been extensively used to train astronauts for space conditions. The KC-135 is a specially modified Boeing four engine jet U. S. Air Force air refueling tanker comparable in size to the 707 commercial airliner. Figure 10 gives the characteristics of the parabolic zero-g KC-135 trajectory as well as the required acceleration pattern beofre and after the low gravity segment. Around 40 such trajectories can be flown in a two to three hour flying session. Experience has shown that the level of g for the aircraft fluctuates considerably during any given maneuver thus limiting actual uniform periods with very low acceleration to something less than 14-20 sec.

The sounding and suborbital rockets indicate significant time periods of near zero-g are available. As with the other methods, the actual acceleration levels from second to second must be evaluated to see if the technique is usable for a given concept test. In the case of rockets, spin about their long axis is used for stabilization. The required spin will then limit the lower total acceleration level attainable. Figure 11 is a typical trajectory for an Aerobee sounding rocket. As mentioned, the "near-zero"-g period must be evaluated. For some cases this amounts to less than 0. 01 g due to residual spin after the indicated "despin."

An alternate approach to the generation of a zero or low-g environment is that of simulation. A bubble chamber simulation technique has been independently developed by MDAC-W. This concept utilizes neutrally buoyant polymer soap bubbles to simulate a droplet in zero-gravity conditions. These bubbles are capable of surviving for days to years depending mainly on the internal gas and the use of dust free gases. The bubbles have a fluid surface and electrical properties similar to water and thus react to electric fields

THE MSFC 300 FOOT DROP TOWER

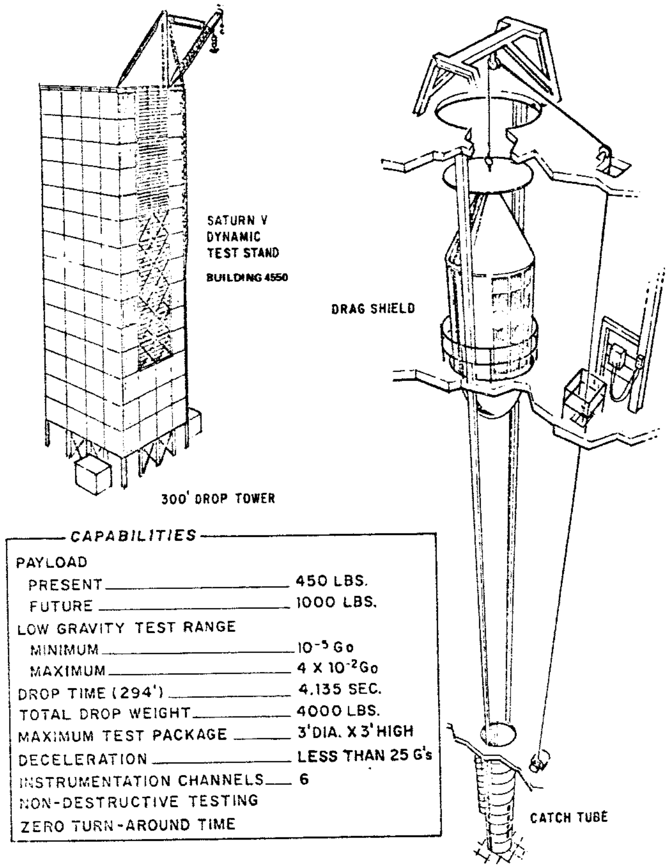
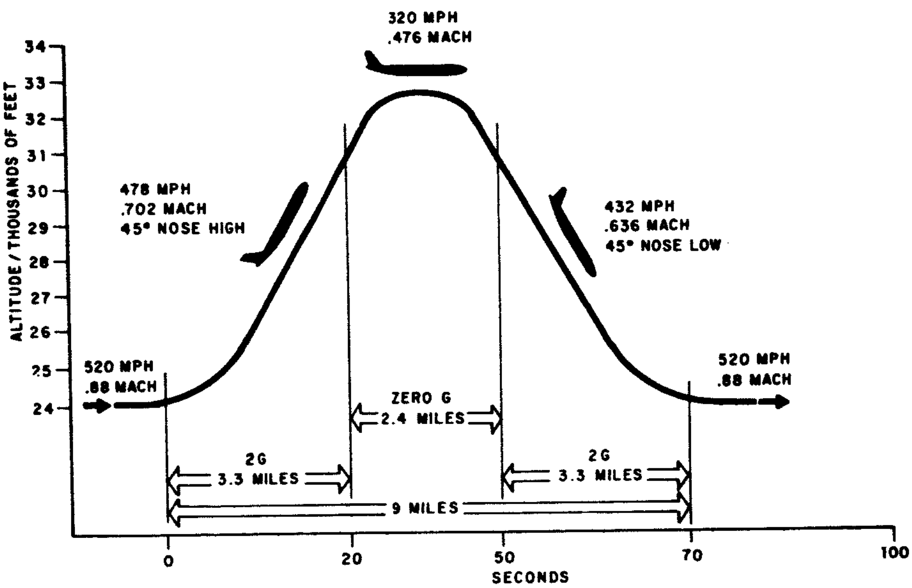


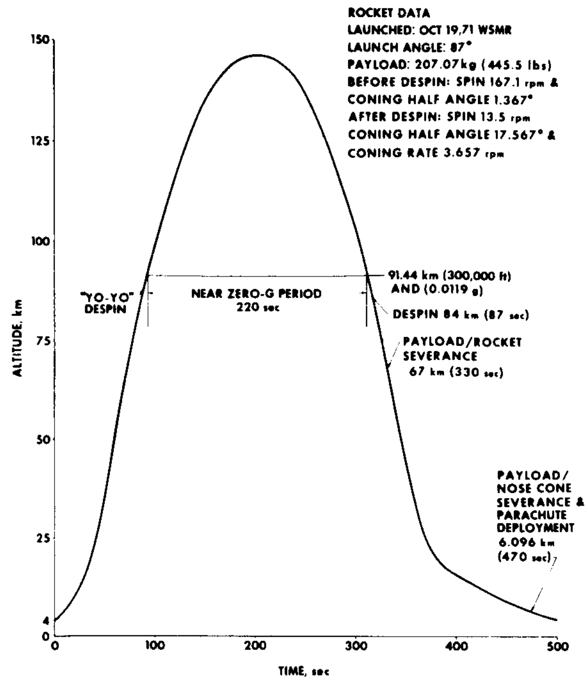
Figure 9

KC-135 RESEARCH AIRCRAFT TRAJECTORY



ZERO GRAVITY MANEUVER

Figure 10



Altitude versus time for Aerobee 170A NASA 13.113.

Figure 11

and sound fields in a way that is similar to a water drop. Various zero-g generation, charging and positioning concepts for water drops can be tested using this zero-g simulation technique. Figure 12 illustrates an early version of this technique using electric fields for bubble position control.

Questions arise regarding the use of rockets and other unmanned spacecraft as vehicles for cloud physics research. Briefly stated, the cloud physics experiments presented in this report are not experiments in which sensors are used to observe phenomena beyond our control such as remote sensing of the earth, the moon and Mars. The proposed cloud physics experiments dealt with in this feasibility study are laboratory experiments where the ambient conditions are controlled as well as observing what happens. As with most research of this type, a significant part of the experiment is the direct observation by a scientist who is able to perceive and analyze events

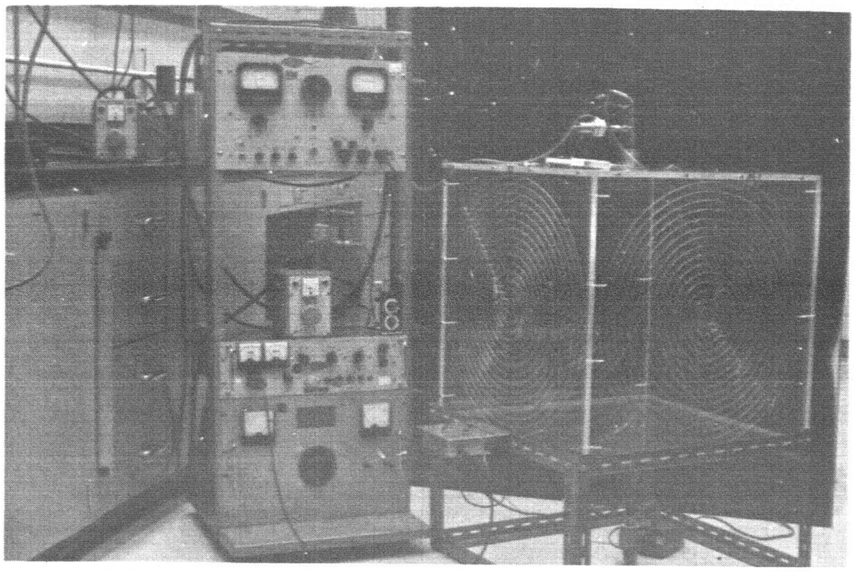


Figure 12

that were unexpected. Such events would generally be missed if the experiment was fully automated. In addition to this, the cost of the equipment for appropriate full automated rocket experiment would be considerably more than the cost of a semi-automated experiment aboard the Space Shuttle.

From the above considerations, some of the various available short-term low acceleration techniques show potential as concept testing and development techniques. Further analysis and consideration will be given to each and they will be utilized where appropriate.

IX. PROJECTION

This study established that the concept of accomplishing significant cloud microphysics research in low or zero gravity was clearly feasible. MDAC-W emphasis will continue toward the definition, design, development and testing of a reuseable cloud physics laboratory to be operated on manned Space Shuttle flights in the early 1980's.

NASA and MDAC-W will continue to examine pre-Shuttle space flight opportunities as carriers of portable cloud physics experiments. Various degrees of experiment complexity may be attainable dependent on the carriers physical and power capabilities and the astronauts time availability

There are a number of important experiments that will be compatible with early shuttle missions. These experiments have spacecraft requirements which are between those requirements of the Apollo and the full Shuttle laboratory.

The ultimate product, the Zero-Gravity Atmospheric Cloud Physics Laboratory will be a carefully designed, cost effective facility capable of serving a large portion of the cloud physics community. This laboratory combined with the continuing important terrestrial laboratory and field research programs can provide the means for major breakthroughs in weather modification.

Appendix A

NASA-MDAC SENIOR SCIENTIFIC BOARD BIOGRAPHIES

Chairman, Dean Charles L. Hosler, Jr., b. Honey Brook, Pa., June 3, 1924; Meteorology. B. S., Pa. State, 47, M. S., 48 Ph. D. (Meteorology), 51. Inst. Meteorology, Pa. State, 48-51, Asst. Prof., 51-54, Assoc. Prof., 54-58, Prof., 58-, Head, Meteorology Department, 60-65, Dean, Col. Mineral Industries, 65-, Hydrographer, Pa., Dept. Forests and Waters, 49-59. Consult., President's Adv. Cmt. on Weather Control, 54-57; Nuclear Sci. and Eng., 60-64; Hazelton Nuclear Sci., 62-65; HRB-Singer, Inc., 58-64; Esso Research and Engineering Co., 64-, Law Firms, 51-, U. S. N., 43-46, AAS; Meteorology Advisory Committee of the Environmental Protection Agency; NAS-NAE Committee Advisory to NOAA; Chairman of the Panel on Weather Modification for NAS-NAE Committee Advisory to NOAA; Storm Fury Advisory Committee; Chairman of the AMS Radio and TV Board; Councilor and Secretary of the Executive Committee for the AMS.

Dr. Louis J. Battan, 5141 E. Rosewood Ave., Tucson, Ariz. Meteorology, New York, N. Y., Feb. 9, 23; B. S. N. Y. Univ., 46, Harvard: Mass. Inst. Tech: M. S., Chicago, 49. Ph. D. (Meteorology), 53. Radar Meteorologist, U. S. Weather Bureau, 47-51; Res. Meteorologist, Chicago, 51-58; Dir. Inst. Atmospheric Physics and Prof. Meteorology and Climate, Ariz., 58-, Consult., U. S. Weather Bureau; National Science Foundation; U. S. Air Force; U. S. Army - 42-43; U. S. A. F. 44-46; American Meteorology Society (Meisinger Award 1962; Brooks Award 1971); President of AMS, 66-67; Commissioner Scientific and Technological Activities of the AMS; Vice President of Meteorology Section of AGU (as of 1972); Section Secretary, Section on Atmospheric and Hydrospheric Sciences of the AAAS; Vice Chairman, Committee of Atmospheric Sciences of the National Academy of Sciences; Panel on Weather Modification of NAS.

Dr. Patrick Squires, b. Melbourne, Australia, July 12, 14; Meteorology. B.A., Melbourne, 33, M.A. 35, D.Sc. (Meteorology), 59. Research Meteorologist, Australian Weather Bureau, 37-46; Commonwealth Sci. and Indust. Res. Orgn., Australia, 46-62; Nat. Center Atmospheric Research 62-66; Dir. Lab. Atmospheric Physics, Desert Res. Inst., Univ. Nevada, 66-, American Meteorology Society Cloud Physics.

Dr. Helmut K. Weickmann, b. Munich, Germany, Mar. 10, 15; U.S. Citizen; Atmospheric Physics, Meteorology. Leipzig, 34-36; Ph. D. (Geophysics), Frankfurt, 39. Flight Meteorologist, German Flight Inst., 39-45; Dir., High Altitude Observatory, German Weather Service, 45-49; Physicist, Atmospheric Physics Br., U.S. Army Electronics Command, 49-61, Chief, 61-65; Dir., Atmospheric Physics and Chem. Lab., Environmental Sci. Serv. Admin., 65-, Co-ed, J. Atmospheric Sci., Mem., Int. Union Geod. and Geophys. Tech. Achievement Award, Signal Corps, U.S. Army, 61, Cert. of Achievement, Electronics Command, 62, American Meteorology Soc.; Geophys. Union; Int. Asn. Meteorol. and Atmospheric Physics. Meteorological Research; Cloud and Weather Modification; Geophysics.

APPENDIX B - NASA/MDAC SENIOR SCIENTIFIC BOARD STUDY MATERIAL

The following material was prepared and given to the Senior Scientific Board a couple of weeks prior to their February 3-4, 1972 meeting. This condensed information concerning the submitted zero-gravity cloud physics experiment was used as the basis for experiment discussions, analysis and evaluations.

NASA SCIENTIFIC BOARD STUDY MATERIAL

General Information

On the following pages are included several types of information.

A. Condensation of experimental advantages:

This serves as a rough idea of the advantages concerning zero gravity given by those who have suggested cloud physics experiments.

B. Zero-Gravity Relevance:

A brief example of an earth laboratory restriction that may be resolved under zero gravity conditions.

C. Classification - Zero-Gravity Cloud Physics Experiments:

Experiments are listed by phenomena versus basic phase of material of interest (liquid, ice).

No optimization has been attempted at this time concerning overlaps in this classification (e.g. break-up of droplets and ice is also involved in charge separation).

The arrangement and associated numbers (indicating number of individual contributions for that experiment) in the chart serve to summarize the range of response and areas of greatest interest.

D. Experiment Suggestions:

This is a very rough listing of suggestions according to material (liquid, ice, etc.). Overlap has not been eliminated in such items as diffusion growth rate and accommodation coefficient determinations.

E. Experiment Description:

This listing is by phenomena and in general is not a true procedure description. It is more along the line of general statements of possible information one might want to obtain concerning a given phenomenon.

F. Problem Analysis:

This is a very brief outline of general problem area breakdown. Much more detailed breakdowns in each area have been prepared and certain problems are now being investigated.

All of this information is tentative and is presented to serve as a basis for further discussion and analysis in connection with possible cloud physics experiments on a zero-gravity platform.

CONDENSATION OF EXPERIMENTAL ADVANTAGES FOR CLOUD PHYSICS EXPERIMENTS UNDER ZERO GRAVITY CONDITIONS AS GIVEN BY EXPERIMENT SUGGESTORS

A. Elimination of mechanical supports of material under investigation which result in the elimination of:

   a. thermal conduction through supports
   b. mechanical obstruction to heat and mass transport
   c. surface modification or contamination or fluid interface
   d. electrical conduction through supports
   e. optical interference of supports
   f. mechanical damping of supports.

B. Separation of gravity from other forces of interest by eliminating:

   a. convection
   b. settling or fallout
   c. relative motion between particles

   thus providing better observation of:

   a. electrical forces
   b. diffusiophoresis (motion due to vapor flow)
   c. thermophoresis (motion due to temperature differences)
   d. Brownian motion.

C. The above results permit extended observation times so that gravity independent processes can be observed under conditions that more nearly approximates natural atmospheric conditions and times.

ZERO-GRAVITY RELEVANCE TO CLOUD PHYSICS

A. Basic Requirements

1. More time
2. Separation of gravity induced phenomena from other, such as
   - Turbulence
   - Sounding
   - Electrical
   - Optical?
   - Chemical

B. Earth: Methods for Holding in Fixed Position to Obtain More Observation Time and Easier Observation

1. Mechanical supports - modify heat and electrical processes involved in phenomena
2. Acoustical / Electrical - impose unwanted forces on particles
3. Free fall - need more time at position of observation

C. Zero-G

1. Minimal gravity induced motion thus no support mech. necessary. Give time and free from physical contact.
2. Clouds exist in a g field but zero-g permits separation of g from electrical effects.

An Example of Earth Laboratory Restrictions

Growth

Diffusion: To obtain natural growth condition of less than 0.5% super saturation (100.5% relative humidity) - must have 0-g to prevent fallout.
" " convection.

a) Lower natural cloud saturation requirements much longer growth times (minutes).
b) Gravity settling causes small particle to fall out in seconds for small diff. chambers (1 cm).
c) Equilibrium of diffusion too long for greater depths.
d) Expand chamber - Have gravity induced convection within a second.

Coalescence: No simulation technique or material available for liquid drop in air during collision and coalescence - must use reduced g to give more time to study interaction; theory cannot handle all parameters involved (internal circulation, surface slip, non-linear eq.)

Zero-G: No convection or "fallout".

B

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS

- A. Classification -

			1 Liquid	2 Liquid-ice	3 Ice	4 Nuclei	5 Gas	6 Combination
Growth	Diffusion (Condensation Evaporation)	A	5	2	8	6		
	Coalescence (aggregation riming)	B	10	1	1	(G)		
	Break-up (Liq. osc. Freeze-shatter Crystal Break-up	C	1	7	1			
Nucleation	Homogeneous	D		1				
	Inhomogeneous (Sources and characteristics including memory	[illegible]						
	Liquid	E	(Nuclei)			3		
	Ice (sublimation cond-freeze Bulk surface contact)	F		8		5		
Scavenging		G	4	6	(A)	(A)		
Charge Separation		H	(C)	3	1			
Optical		I		1	2			
Photo Chemical		J						
Ab & Adsorption		K				1		
Other		L		3				

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS

- Suggestions -

State of Substance Investigated: Liquid (1)

Growth:

(A.1) Diffusion (Condensation Evaporation)

a) Determine the effect of surface curvature on the heat of mass transfer from an isothermal sphere

b) Measurement of condensation and thermal accommodation coefficients of water droplet growth kinetics

c) Obtain the ventilation coefficient for moving, evaporating droplets by the measurement of the non-ventilated evaporation rate and comparing results with ventilated data.

d) Experimental verification of the theoretical saturation vapor pressure over supercooled water (droplets of various size)

e) Pure diffusional growth in various electric fields (e.g., DC, at various strengths, AC at various strengths and frequencies.)

(B.1) Coalescence (aggregation riming)

a) Scaled down acceleration: collision and coalescence experiments

b) Surface impurities effect on coalescence

c) Environmental gas effects on coalescence (including pure water vapor)

d) Turbulence (or sound waves) on coalescence

e) Charge and electric fields (DC, AC, etc.) - collision and coalescence

(C.1) Break-up

a) Study of large droplet oscillations with particular emphasis on type of break-up (above critical amplitude) as a function of drop size and surface tension. (Study collision of oscillating drops)

(G.1) Scavenging

a) Study of magnitudes and relative importances of Thermophoretic, diffusiopheretic, electrical, brownian motion and inertial capture (mainly-first three).

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS (cont.)

- Suggestions -

State of Substance Investigated: Liquid-Ice (2)

Growth	(A.2)	Diffusion (Condensation Evaporation)	a) Evaporation studies of ice or liquids in a high vacuum, possibly leading to some estimate of the accommodation coefficients.
			b) Rates of growth in populations of nuclei, drops or ice crystals and mixtures of these; differential growth rates (various concentrations), thresholds of nucleation, evolution of cloud droplet/crystal size spectra.
	(B.2)	Coalescence (aggregation riming)	a) Measurement of collision and coalescence due to electrical fields and charges on droplets and ice crystals.
	(C.2)	Break-up	a) Freezing-splintering or shattering studies: number of pieces and sizes versus: 1. Single droplets 2. Clouds - study of ice phase propagation (various concentration) 3. Various surface forces (sound, etc., electric field) 4. Impurities in ambient gas and in and on surface of droplet
			b) Blow-out from evaporation of salt solution
Nucleation	(D.2)	Homogeneous	a) To investigate the functional relationship between the degree of supercooling, time of exposure and radius of the uncontaminated water droplets.
		Inhomogeneous	
	(F.2)	Ice	a) Seeding individual drops (delay time?) 1. length of time at constant temperature to freeze. 2. shattering if present
			b) Contact nucleation vs. bulk nucleation and sublimation (some indications that particles below 0.01 microns are active) 1. Various ambient conditions 2. Size and type of nuclei (AgI, PbI, CdI, etc., silicates, carbonates, etc., typical of earth's surface). 3. Brownian (scavenging) contact nucleation

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS (cont.)

- Suggestions -

State of Substance
Investigated: Liquid-Ice (2)

4. Ice phase propagation (nuclei scavenging) (include indirect effects as nuclear radiation.)

5. Nucleation (multiplication and propagation?) with and without electric fields.

Scavenging (G.2)

a) Use of the freezing process to study the Facey effect, Brownian capture, thermophoresis, diffusiophoresis, electric fields, etc.

b) The above items relative to the liquid and ice phase scavenging.

Charge Separation (H.2)

Evaluation of the charge separation processes

a) Crystal growth and drop freezing

b) Charge separation upon freezing and splintering

c) Measure possible localized domains of charge on a neutral unshattered droplet.

d) Measure the role of the workman electrical double layer in the charge separation process.

(Optical) (I.2)
(Remote Sensing)

a) Optical properties (e.g. polarization and albedo); in particular, the way in which these quantities might be influenced by local sources of pollution.

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS (cont.)

- Suggestions -

State of Substance Investigated: Ice (3)

Growth	(A.3) Diffusion	a)	Determination of the contribution of pure diffusion (no ventilation) on the growth rate and growth mode of ice crystals at different temperatures and vapor gradients.
		b)	Electric field effects (AC, DC) on the diffusion growth
		c)	Measure deposition and thermal accommodation coefficients
	(B.3) Aggregation riming	a)	Ice crystal collisions - including effects of temp, charge, field intensity and riming or coalescence efficiency of collection kernels.
	(C.3) Break-up	a)	Determining whether melting snowflakes break-up

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Charge Separation (H.3)	A)	Study charge separation (and ion diffusion rates) by such things as suspending a single crystal in a temperature gradient and measure rate and amount of charge separation.
Optical (I.3)	a)	Measure the polarization and scattering coefficient of ice crystals.

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS (cont.)

- Suggestions -

	State of Substance Investigated	Nuclei (4)
Growth		
(D.4) Diffusion		a) Droplet size distributions of unseeded and hygroscopically seeded fogs. (Emphasis on giant salt nuclei (diam > 5μ). (as related to warm cloud seeding)
		b) Accommodation coefficients in early stages of growth as a function of 1. environmental conditions; T, P, RH, and trace gases 2. condition of nuclei: surface impurities
		c) Study of growth of particulates used to investigate the nucleation behavior of both liquid and solid phases.
Nucleation		
(E.4) Liquid		a) Study of condensation numbers, rates and properties under very low supersaturations (<0.1 percent)
		b) Memory effect of cloud condensation nuclei.
(F.4) Ice		a) Memory effect (capillarity vs adsorption)
		b) Activation time delay of hydrophobic particles - why activated, comparison measured vs theoretical numbers and size distributions.
		c) Nucleation properties of soluble and insoluble (also hydrophobic) nuclei (>1 micron).
		d) Contact nucleation vs bulk nucleation
Adsorption (K.4)		a) Study of temperature related effects of adsorption (as absorption) of gases onto nuclei

ZERO GRAVITY CLOUD PHYSICS EXPERIMENTS (cont.)

- Suggestions -

State of Substance
Investigated: General

General:

(L) Electrical

a) Electric mobilities of small and large particles (ions to hail stones)

b) Investigation of the influence of space charges on flow dynamics of air. In particular, the influence on viscous losses and gravity waves can be studied.

c) Corona emission from ice crystals.

(L.4) ION Production

a) Measure air conductivity and relaxation times at compositions in a spacecraft environment.

ID No. A

EXPERIMENT DESCRIPTION

Phenomenon: Growth (diffusion)

PURPOSE:

Study the contribution of diffusion to various growth processes in the absence of gravity and thermally induced convection and ventilation.

DESIRABILITY FOR ZERO-G:

a. Elimination of free convection.
b. No thermal conduction through mechanical supports.
c. No fall-out or relative motions.
d. No extraneous surface effects as capillary and impurities due to contact with mechanical supports.
e. Long usable observation times.

DESCRIPTION:

a. Observation of single liquid or ice particles.
b. Observation of populations of nuclei, droplets or crystals and combinations of them - relative competition.
c. Ice and water thermal diffusion chambers for low supersaturations.
d. Provisions for various electric field configurations.

SPECIAL REQUIREMENTS:

a. Cancellation of motion due to net charge or non-uniform electric field for some experiments.
b. Vacuum (space about 10^{-7} mmHg available).
c. Mass of crystal versus time.
d. Rapid response R.H. probe (<5 sec.).

COMMENTS:

ID No. B

EXPERIMENT DESCRIPTION

Phenomenon: Growth (coalescence, riming)

PURPOSE:

Studies of various factors involved with collision, coalescence and riming under conditions which separates out the inertial factor due to gravity (electric fields, turbulence, low (10^{-5}g) acceleration observations.

DESIRABILITY FOR ZERO-G:

a. Separation of gravitational forces from other forces (electrical, etc.).
b. Longer observation times.
c. Scaled (reduced Re) permitting realistic preservation of Re number before and during collision.
d. Low ($<10^{-4}$g) acceleration permits better observation of collision.

DESCRIPTION:

a. Use of unsaturated, saturated and supersaturated environments.
b. Variables: surface and bulk impurities
   environmental gas (including pure water vapor)
   charge or electric field (AC, DC, uniform, nonuniform)
   turbulence (sound, other)
c. Distribution of cloud drops or ice with and without electric field versus time.

SPECIAL REQUIREMENTS:

a. Position and charge control on particles.
b. Provide known (10^{-4} to 10^{-6} g) acceleration $\pm$ 10% for 40 to 1,000 sec.
c. AC-DC fields.
d. Measurement of residual net charge distribution on droplets and crystals.

COMMENTS:

ID No. C

EXPERIMENT DESCRIPTION

Phenomenon: Break-up

PURPOSE:

Studies of various mechanisms contributing to particle multiplication (liquid, ice, nuclei, etc.).

DESIRABILITY FOR ZERO-G:

a. No mechanical support necessary (heat, vapor transport unmodified).
b. Controlled turbulence factor available.
c. No fallout, permits time to observe very small splinters (by diffusion growth if necessary) if they exist.

DESCRIPTION:

a. Oscillation with collision breakup - fragment size distribution function of surface tension.
b. Blow-out due to evaporation of saturated salt solution.
c. Break-up of melting snow flakes.
d. Nucleation of individual droplets - measure number of splinter particles (let grow to larger size if necessary) as function of ambient conditions and droplet size.
e. Propagation of ice phase due to break-up during freezing process.
f. Holographic observation.

SPECIAL REQUIREMENTS:

a. Electric field stresses, sound fields.
b. Electric and sound fields used for motion.
c. Possibly low gas pressures (down to pure water vapor) to amplify splintering propagation and observation.

COMMENTS:

EXPERIMENT DESCRIPTION

Phenomenon: Nucleation (Homogeneous)

PURPOSE:

Studies of the functional relationship between the degree of supercooling, time of exposure and radius of the uncontaminated water drops.

DESIRABILITY FOR ZERO-G:

a. Eliminates contamination arising from methods of suspension.
b. Permits observation time with sufficiently realistic low cooling rates.

DESCRIPTION:

a. 0.3 meter cube chamber.
b. Monodispersed or polydispersed droplets (~100, a few micron to few mm diameter).
c. Cool chamber slowly.
d. Observe number frozen versus size, temperature, time.

SPECIAL REQUIREMENTS:

a. Possibly a two dimensional lay of droplets for ease of observation.
b. No icing on wall permitted.

COMMENTS:

EXPERIMENT DESCRIPTION

Phenomenon: Nucleation
Inhomogeneous Liquid

PURPOSE:

Studies of condensation nuclei properties under low supersaturation conditions (including memory).

DESIRABILITY FOR ZERO-G:

a. No mechanical supports that might contribute to the memory effect (capillary effects between particles and support surface).
b. No gravity induced convection - extended observation time for more realistic supersaturation conditions.
c. No fallout, giving total counts of activated nuclei.
d. Controlled air motion could be used.

DESCRIPTION:

a. Thermal diffusion chamber.
b. Reactivation of nuclei to measure memory effect.
c. Use low supersaturations (below 0.2%).
d. Study role of giant nuclei (>1 micron) by condensation and competition in a cloud of droplets.

SPECIAL REQUIREMENTS:

COMMENTS:

ID No. F

EXPERIMENT DESCRIPTION

Phenomenon: Nucleation
Inhomogeneous-ice

PURPOSE: Studies of various properties and freezing modes of freezing nuclei including memory effects (capillary versus adsorption)

DESIRABILITY FOR ZERO-G:
a. No physical supports to give capillary conditions.
b. No fall out - extended observation time.
c. No convection - stationary particles.
d. Nearer natural supersaturations for extended times are possible.

DESCRIPTION:
a. Observe freezing due to various modes: (silicates, carbonates, AgI, PbI, CaI) contact, bulk, sublimation

due to various forces:

electrical, brownian motion, nuclear radiation and various phoretic forces

due to various types:

silicates, carbonates, AgI, PbI, CdI (hydropholic, soluble insoluble).
b. Freezing during equilibrium, growth, evaporation.
c. Nucleation by <0.01 micron particles.
d. Reactivation under various conditions - memory effect.
e. Possible measurement of activation time lag.
f. Possible splintering - numbers and sizes.

SPECIAL REQUIREMENTS:

COMMENTS:

ID No. G

EXPERIMENT DESCRIPTION

Phenomenon: Scavenging

PURPOSE:

Studies of the relative importance of various possible scavenging mechanisms in relation to natural earth atmospheric processes. (Brownian motion, thermophoresis, diffusiophoresis and electrical) by the liquid and ice phases.

DESIRABILITY FOR ZERO-G:

a. No suspension mechanism to modify heat or vapor flow.
b. No fall-out or other gravity induced relative motion.
c. Extended observation times available.

DESCRIPTION:

a. Attachment of particles 0.01 micron to 1.0 micron to liquid and ice.
b. Use two chambers - fill both same - activate one - collect activated particles - activate both - compare activities.
c. Use of relative freezing characteristics during evaporation, equilibrium and condensation to determine relative importance of diffusiophoresis and thermophoresis.

SPECIAL REQUIREMENTS:

a. Removal of droplets without disturbing remaining smoke or other particles.

COMMENTS:

ID No. H

EXPERIMENT DESCRIPTION

Phenomenon: Charge Separation

PURPOSE:
Studies of various possible charge separation mechanisms and their relative importance to electrical properties of natural clouds.

DESIRABILITY FOR ZERO-G:

a. No electrically conductive supports.
b. No gravitational settling.

DESCRIPTION:

a. Cloud chamber with high voltage plates.
b. Freezing of droplets, melting of crystals in electric fields.
c. Stripping of the water electric double layer by various means (surfactents, etc.).
d. Study electircal ion diffusion rates in ice-liquid particles.

SPECIAL REQUIREMENTS:

a. Remote measurement of charge and charge separation.

COMMENTS:

ID No. I

EXPERIMENT DESCRIPTION

Phenomenon: Optical

PURPOSE:

Studies of the optical properties of liquid and ice phases (particularly - polarization and scattering coefficients of complex ice shapes).

DESIRABILITY FOR ZERO-G:

a. No optically scattering mechanical support.
b. No relative motion during measurements.

DESCRIPTION:

a. Scattering produced by clouds of drop and/or ice.
b. Observe (change in light scattering properties) number of frozen versus size, temperature and time as droplets are frozen.
c. Scattering properties of individual particles.

SPECIAL REQUIREMENTS:

a. Possibly a two dimensional layer of droplets for ease of observation.

COMMENTS:

ID No. L

EXPERIMENT DESCRIPTION

Phenomenon: General

PURPOSE: Low production and electrical conductivity of spacecraft environment. Also electrical mobility of ions to hail stones under various environmental conditions.

DESIRABILITY FOR ZERO-G: Eliminates gravity induced motion, permits evaluation of electric field forces.

DESCRIPTION:

a. Measure large particle mobility with maximum electric fields strengths that are thought to occur in electrical storms.

b. Measure background ionization rate and ion accumulation levels (important relative to electrical cloud physics experiments).

c. Measure space charge influence on viscous losses and on gravity waves (use of small wind tunnel with pressure transducers and space charge generators).

SPECIAL REQUIREMENTS:

COMMENTS:

PROBLEM ANALYSIS

SYSTEMS	COMPONENTS (Partial List)
CHAMBERS	Diffusion Expansion General Purpose
GENERATION	Droplets, Ice Crystals, Nuclei
ENVIRONMENTAL CONTROLS	Temperature Pressure Dew Point Temp. Electric Field Composition
MOTION CONTROL	Electric Fields Air Jets Photon Forces Laminar Air Flow Miscellaneous
CHARGE CONTROL	Charging Neutralization Background Radiation
COMBINATION AND MODIFICATION CONTROL	Mixing Systems Droplet Coatings
OBSERVATIONS	Visual Photographic Microscopic Raman Spectroscopy Laser Holography Lidar
SPACECRAFT ACCOMMODATION	Cabin Environment Waste Heat Disposal G Levels
MISCELLANEOUS	New Technologies

The relationship of each component to the five parameter states; liquid, liquid-ice, ice, particles and gases, is considered a separate problem during the initial analysis.

The development of the concepts leading to a preliminary design for the zero-gravity cloud physics chamber is an iterative process as follows:

a. Theoretical development and calculations for each line item in the component-parameter phase.

b. System concepts for solution of component-parameter problem.

c. Selection of concept for component-parameter solution.

*d. Selection study of components within each system.

*e. Compatability study of components within each system.

**f. System analysis for compatability.

**g. System - spacecraft accomodation studies.

h. Total laboratory concepts.

*Problems at this point may require restart at point b or c.

**Problems at this point may require restart at point d or e.

APPENDIX C - "CARRY-ON" EXPERIMENTS

This appendix includes five examples of cloud physics laboratory type experiments which were submitted to a MDAC/Skylab evaluation team for vehicle compatability analyses. Two of the experiments contain two parts. The coalescence experiment also includes a droplet dynamics (e.g., oscillation break up) experiment and the splintering of freezing water droplets includes the special case of NaCl break up during salt water evaporation.

A summary sheet is included which ranks the proposed experiments with respect to scientific need, equipment complexity and astronaut involvement.

The first two pages of each experiment deal with Skylab constraints. Also indicated is the utilization of available Skylab facilities such as the M512 manufacturing chamber. A brief procedure description for each experiment has been added to the initial forms. These descriptions were very preliminary and included minimal engineering evaluation. The descriptions are to be used only as a basis for further experiment concept development.

Experiments can be found on following pages:

ZERO-GRAVITY CLOUD PHYSICS CARRY-ON EXPERIMENT

SUMMARY

Experiment	Astronaut Involvement	Equipment Complexity	*Scientific Importance	**Special Req. and Comments
A. Coalescence (& Dynamics)	2	3	2	work bench
B. Evaporation	1	1	1	Mfr. chamber
C. Splintering (& NaCl)	3	4	1	refrigerator, vacuum
D. Saturation	2	2	1	refrigerator, vacuum
E. Circulation	4	5	3	none

*All of these areas are important, but the timing on which ones should be done first is indicated by the numbers. These rankings apply only relative to the simple carry-on type of experiment.

**The first four items become easier to perform in proportion to the reduction of the acceleration level. Levels of 10^{-3} can be used but values less than 10^{-4} during experiments would be desirable.

The initial contributors of the above experiments to the zero-gravity cloud physics program are listed below. Organization affiliations of these contributors are listed in Table 2.

A. Dr. J. W. Telford (coalescence), Dr. D. C. Blanchard (drop dynamics)

B. Dr. John Hallett

C. Professor H. R. Byers

D. Dr. T. E. Hoffer

E. Dean C. L. Hosler

CLOUD PHYSICS CARRY-ON EXPERIMENTS

The following can be implemented as pre-Shuttle experiments.

Experiment

A. Collision processes: single water droplets (mm size) colliding with a plane water surface. Use optical interference patterns to observe the collision-coalescence process during the last fraction of a millimeter before and during collision. Movie camera data recording. Included here would also be droplet dynamics and droplet breakup. The final collision and coalescence process is important in warm cloud precipitation processes as also is the droplet breakup mechanism.

B. Evaporation: evaporation of ice or water in a vacuum (free floating). Photograph rate of evaporation. EVA or vacuum chamber. Important in the physics (accommodation coefficients) of ice and water precipitation processes in clouds.

C. Splintering: freeze water droplet and count number of fragments caused by splintering. This ice nuclei "multiplication" process is very important in cold precipitation processes and is relevant to weather modification procedures. This would be carried out in a cooled box between 0 and -40^{o}C. Control of temp. pressure and humidity. Along these same lines but with only humidity control, salt (NaCl) droplets could be evaporated to determine if the NaCl crystal fragments into several parts (i.e., "multiply") or remains in a single crystal.

D. Saturation: Vapor pressure over supercooled water. This value has not been measured experimentally but is extrapolated from above freezing vapor pressures. This quantity provides the driving force for vapor between liquid water and ice in a below freezing cloud. A chamber with silicone coated walls and droplet of pure water at its center. Evacuate chamber of all air and then let vapor pressure build to equilibrium and measure. Do for temperatures from +20^{o}C to -40^{o}C.

E. Circulation: Three-dimensional atmospheric circulation could be studied by the use of a fluid covered sphere. Two-dimensional rotating "dish pan" experiments are being done at the present to study the on set of atmospheric Rosby waves.

SKYLAB CONSTRAINTS AND

INFORMATION REQUIRED FOR SCREENING

PROPOSED SECOND SKYLAB SUITCASE EXPERIMENTS

Experiment
Title: Coalescence Processes of Liquid (Water) Droplets (also droplet dynamics)

A. Hard Physical Constraints: (Skylab requirements in brackets; please record this experiments requirements)

*1. Size and Geometry: (≤30" x 40" x any reasonable length)
(1 - Stowage Ring Container) Basic part 1 ft cube

*2. Weight: (≤150 pounds, including container)
<45 lbs (≈150 with items c)

3. Power: (28 v.d.c., ≤1000 watts (≤500 watts preferred)

How much? 200 watts Duration? 30 minutes

4. Toxicity: (No toxic materials permitted)
Water

5. Temperature Range/Control: (55^{o} to 92^{o} F range)
Ambient

6. When Available? (Launch ready by mid 1975)
1974-1975

B. Priority Criteria

1. Benefits: (Why is experiment important, and to whom?) Major item in warm precipitation processes. Important to Atmospheric Physics & Weather Modification.

**2. Is There a Champion?
NASA-MDAC (Zero-Gravity Cloud Physics) Senior Scientific Board

***3. Complexity: (How simple to set up, operate? How straight forward is final analysis?)
Simple latch assembly, check list operation, simple manual adjustment of droplet position and velocity.

4. Time Requirements:

- Total 30 minutes operating (minimum)
- Astronaut's
- Port, Airlock? NA
- Event Criticality? Non-critical

5. Unique Skylab Facilities Interface? (Airlock, Mfg. chamber, cooling system, etc.)
Work bench if available (see C)

6. Data Recording: (Quantity? Analog? Digital? Film, other)
Film: 5 rolls movie; Verbal and/or written description of events plus ambient T, P, R, H, if available.

7. Other Special Requirements: (EVA? Scientist Astronaut? $\leq 10^{-4}g$? Orbital? etc.)
$\leq 10^{-3}g$ for one minute or less during actual coalescence event.

8. Payload Return Requirements: (wt. and vol.) 5 rolls of film + taped events.

C. General Purpose Workbench/Equipment: Would a workbench be beneficial to the astronaut in performing the experiment? What ancilliary equipment/ tools does the experiment require that may be common to other suitcase experiments and, if provided by the workbench, could be shared? (e.g., voltmeter, optical bench, digital tape recorder, A-D converter, microscope, movie camera, d.c./a.c. converter, heater, etc.)

Light Source (laser if available)
Bench area to mount equipment
Cameras (2) (Possibly (?) one high speed >1,000 fps and one movie)

D. Space for Continued Comments:

*Items C could be supplied in a single stowage ring container with basic experiment if not available separately.

**This experiment is a part of the zero-gravity cloud physics program study and committments have been made to maintain suggestor's names with each experiment. These individuals are represented by the stated Board.

***The basic requirements are fairly simple, bench mounting could be used but free floating may permit -ower gravity (acceleration) values.

The droplet generator would be adjusted so that droplets strike the second surface at different velocities and possibly for several angles based on astronaut observations.

Coalescence-Liquid

Collision and coalescence of liquid droplets is the method whereby warm cloud droplets greater than 20 microns grow to precipitation sizes above 100 microns. Gravity is a first-order influence in the collision processes. The collision processes have been studied from many approaches including free fall and wind tunnel studies. The quantity of interest here is the coalescence efficiency. Even though two droplets collide, they may not coalesce. Theoretical fluid dynamic considerations break-down when the droplets approach a separation on the order of the mean free path length of air molecules. It is what happens to this thin film of air and water vapor between two approaching droplets and the initial coalescence process that is of prime importance. Normal collision events in terrestrial laboratories happen rapidly, making close detailed observations of the collision and coalescence processes extremely difficult or impossible.

Low or zero gravity conditions would permit the collision and coalescence process to be observed in "slow-motion." The approach velocity could be regulated without the use of mechanical supports.

A droplet could be fired toward a water surface and high speed camera would record interference patterns produced by the two liquid surfaces when their approach is within a few wavelengths of light (a few microns). A second camera would record approach velocity and position and gross distortion during collision.

The full system could be free floating during a given sequence of pictures to minimize accelerations due to crew motion. A plastic or equivalent enclosure may be used around the droplet path to minimize effects due to air movement from laboratory air conditioning units.

Equipment:

- Fluid surface (flat or curved).
- Cameras and optical systems.
- Droplet projection and source.
- Controls for T, P, R.H.

Procedure:

- Prepare flat or curved water surface (e.g., new fluid?).
- Establish T, P, R.H.
- Adjust distance between droplet source and fluid surface to obtain desired impact velocity.
- Project droplet toward fluid surface.
- Photograph interference pattern during impact.
- Photograph impact distortion from side.
- *Repeat for various conditions.

*Approaches:

- Double pulse holography interferometry could possibly be used.
- If a curved fluid surface is used, vary impact parameter also.

General:

- Impact velocities of 10^{-2} cm/sec and larger (10^{3} cm/sec max).
- Atmospheric pressure from vacuum to one atmosphere.
- Several fluids with various surface tension, vapor pressure and viscosities could be used to better establish theory.

Carry-on Version:

Basic procedure and equipment would be as given above.

The only change would be that ambient conditions of T, P, and R.H. would be used and measured.

SKYLAB CONSTRAINTS AND

INFORMATION REQUIRED FOR SCREENING

PROPOSED SECOND SKYLAB SUITCASE EXPERIMENTS

Experiment
Title: Evaporation of ice and water in a vacuum (accommodation coefficients)

A. Hard Physical Constraints: (Skylab requirements in brackets; please record this experiments requirements)

1. Size and Geometry: (≤30" x 40" x any reasonable length)
<1/2 cubic ft - fluid supplies & dispensers

2. Weight: (≤150 pounds, including container)
≤30 lbs

3. Power: (28 v.d.c., ≤1000 watts (≤500 watts preferred)

How much? 150 Duration? 5-10 minute periods

4. Toxicity: (No toxic materials permitted)
Water - ice

*5. Temperature Range/Control: (55^o to 92^o F range)
Ambient

6. When Available? (Launch ready by mid 1975)
   1973

B. Priority Criteria

1. Benefits: (Why is experiment important, and to whom?) Provide basic information concerning diffusion accommodation coefficients as related to atmospheric physics and weather modification.

**2. Is There a Champion?
   NASA-MDAC: Zero Gravity Cloud Physics, Senior Scientific Board

3. Complexity: (How simple to set up, operate? How straight forward is final analysis?)
   Injection of a water droplet or ice crystal into manufacturing space chamber. Photograph with time lapse camera.

4. Time Requirements:

• Total	up to one hour.
• Astronaut's	
• Port, Airlock?	Vacuum line to manufacturing space chamber.
• Event Criticality?	Non-critical

***5. Unique Skylab Facilities Interface? (Airlock, Mfg. chamber, cooling system, etc.)
   Use of mfg. chamber - no modification. Cooling could be used if available but not necessary in initial experiments.

6. Data Recording: (Quantity? Analog? Digital? Film, other)
Film, astronaut's comments & notes, post-flight debriefing.

***7. Other Special Requirements: (EVA? Scientist Astronaut? 10^{-4}g? Orbital? etc.)
As low g as possible so that droplet or ice stays near center of chamber.

8. Payload Return Requirements: (wt. and vol.) 3 rolls of film & recorded

C. General Purpose Workbench/Equipment: Would a workbench be beneficial to the astronaut in performing the experiment? What ancilliary equipment/tools does the experiment require that may be common to other suitcase experiments and, if provided by the workbench, could be shared? (e.g., voltmeter, optical bench, digital tape recorder, A-D converter, microscope, movie camera, d.c./a.c. converter, heater, etc.)

1. Light source (for camera)
2. time lapse camera (movie - slow framing)

D. Space for Continued Comments:

*Item A.5, cooling could be used down to -40^{O}F but would not be necessary for initial experiments.

**This experiment is a part of the zero-gravity cloud physics program study and committments have been made to maintain suggestor's names with each experiment. These individuals are represented by the stated Board.

***A free floating chamber less than 1 ft on a side could be used in connection with the vacuum lines from the lower body negative pressure device in place of the space manufacturing chamber.

Accommodation Coefficients

When a water molecule strikes a surface (liquid or solid) the molecule may or may not "stick" (remain on) to the surface. The accommodation coefficients are a measure of this adherence efficiencies. For non-growth conditions, as many molecules leave the surface as come into the surface. Under conditions of condensation, there is a flux of water molecules to the surface. The surface properties (e.g., type of material, surface energies, curvature) play important roles in this diffusional growth. The region of growth from nuclei (0.01 to 1μm) diameters to few micron cloud droplets or crystals are of particular interest. In this area of research, gravity is incidental and only enters the laboratory through experimental difficulties resulting from convection or fallout.

Laboratory measurements of initial particle size distribution from diffusional growth using supersaturations above 0.3 percent indicate a monodispersed cloud of particles, fairly independent of particle characteristics. These results are in contradiction with the polydispersed measurements observed in natural clouds. A polydispersed distribution is necessary to initiate the important coalescence processes which result in precipitation.

The quantity of interest here is the initial diffusion growth rates under very low supersaturations ($<$0.1 percent). A comparison of actual growth rates with theory would provide the accommodation coefficients.

Equipment:

- 30 cm cube chamber (expansion).
- Controls for temperature (T), air pressure (p) and water vapor pressure (p_w), particle injection.
- Camera and/or holographic systems.

Procedure:

- Purge chamber. (60 sec)
- Establish initial conditions (T_o, p_o, p_{wo}). (120 sec)
- *Inject particles to be studied (15 sec)
- Expansion to obtain desired final conditions (T_F, p_F, p_{wf}) (30 sec)
- *Observe size and shape versus time. (variable)
- Recycle with same or new conditions (T, P, P_w, particle type).

*Approaches:

- Condensation nuclei growth studies.
  - -- $p_{wf} < 1\%$ supersaturation, $T_F > 0$. (final values)
  - -- Growth rate at 0.05% supersaturation: 0.1μm to 1μm in 1 sec. (thus 10^{-3} to 10^{-2} sec resolution time in initial seconds)
  - -- Monodispersed cloud or individual particles
  - -- Analog record Mie scattering during 0.1 to 2 m diameter growth.
  - -- Holographic recording may supply the same scatter information.
- Droplet or ice greater than a few microns
  - -- Holography for volume recording of size distribution.
  - -- Interferometry (including holographic) to record changes in size.

General Comments:

- Growth rates of a few microns/sec.
- Special conditions might be larger but usually a factor of ten less.

Carry-on version:

An initial experiment would involve the evaporation of a liquid or ice particle in vacuum.

- Purge and evacuate chamber.
- Inject water droplet(s) to ice crystal(s).
- Maintain vacuum as particle evaporates.
- Photographically record size versus time.
- Recycle for same or, if available, other conditions.
- Data reduction consists of dimension measurements versus time from the photographs--to be done in a terrestrial laboratory.

Possible alternatives (separate or in appropriate combinations)

- Ejection of crystals into space outside space vehicle.
- Photograph sizes versus time.
- Small 30 cm cube chamber using a vacuum line.
- Free float chamber and camera to minimize residual acceleration.

SKYLAB CONSTRAINTS AND

INFORMATION REQUIRED FOR SCREENING

PROPOSED SECOND SKYLAB SUITCASE EXPERIMENTS

Experiment Title: Splintering of freezing water droplets (also NaCl Breakup)

A. Hard Physical Constraints: (Skylab requirements in brackets; please record this experiments requirements)

1. Size and Geometry: (≤30" x 40" x any reasonable length)
   1 - Stowage Ring Container: 16" x 20" x 28" 1 ft cube chamber plus control equipment

2. Weight: (≤150 pounds, including container)
   ~140

3. Power: (28 v.d.c., ≤1000 watts (≤500 watts preferred)

   How much? 300 Duration? 1 hour

4. Toxicity: (No toxic materials permitted)
   Water

5. Temperature Range/Control: (55^{o} to 92^{o} F range)
   -14 to ambient acceptable (-40 to +20 desired)

6. When Available? (Launch ready by mid 1975)
   1975

B. Priority Criteria

   1. Benefits: (Why is experiment important, and to whom?) A factor of major importance directly related to how much, where, and what is cloud seeding for weather modification.

   **2. Is There a Champion?
   NASA-MDAC Senior Scientific Board, Zero-Gravity Cloud Physics Facility

   3. Complexity: (How simple to set up, operate? How straight forward is final analysis?) Fairly self-contained, simple to set-up. Operation would be check list type but decisions would be required of astronaut as to when to progress to next step or terminate particular step. Final analysis would be fairly simple during first experiments, a yes or no sometimes being sufficient.

   4. Time Requirements:

      - Total
      - Astronaut's 1 hour minimum
      - Port, Airlock?
      - Event Criticality? Non-critical

   5. Unique Skylab Facilities Interface? (Airlock, Mfg. chamber, cooling system, etc.) Use of refrigeration systems. Vacuum line could be utilized.

6. Data Recording: (Quanity? Analog? Digital? Film, other) Visual and voice recordings. Photographs of chamber contents (one picture 110 secs), post-flight debriefing.

*7. Other Special Requirements: (EVA? Scientist Astronaut? $\leq 10^{-4}$g? Orbital? Minimal g desired.) Particle size can be adjusted over certain limits to accommodate g levels up to 10^{-3} but $< 10^{-4}$ would be desired.

8. Payload Return Requirements: (Wt. and Vol.) Film and written and taped notes.

C. General Purpose Workbench/Equipment: Would a workbench be beneficial to the astronaut in performing the experiment? What ancilliary equipment/ tools does the experiment require that may be common to other suitcase experiments and, if provided by the workbench, could be shared? (e.g., voltmeter, optical bench, digital tape recorder, A-D converter, microscope, movie camera, d.c./a.c. converter, heater, etc.)

1. Vacuum line

2. Refrigeration system -14^{o}F or less

D. Space for Continued Comments:

*Chamber could be free floating (with appropriate constraints) to obtain the lower desirable acceleration values.

**This experiment is a part of the zero-gravity cloud physics program study and committments have been made to maintain suggestor's names with each experiment. These individuals are represented by the stated Board.

Freeze-Splintering

Many natural clouds form precipitation by the cold or ice processes. Due to the relative abundance condensation nuclei, these clouds are found to have 30 to 500 supercooled droplets (0 to -15°C) per cm^3 below 20 microns in diameter. Radar and aircraft observations have indicated that under certain conditions these supercooled droplet clouds can turn to ice in a matter of minutes. Field measurements have shown that the number of special nuclei available in these clouds which can cause the freezing are too few in number by several decades to explain this rapid conversion to ice. One proposed explanation to this rapid ice conversion is that under certain conditions supercooled water droplets splinter during the freezing. The ice pieces or splinters act as freezing nuclei and thus multiply. The resulting cascading effect could produce the observed phenomenon.

Laboratory investigations have indicated splintering but the results still are a couple of orders of magnitude from being sufficient to explain the natural process. Gravity induced settling is the major factor which has limited laboratory investigations. Although ventilation probably plays a role in this process, the basic heat and vapor flow around freezing droplets could be meaningfully studies in a zero-gravity environment.

Equipment:

- Controls of T, P, R, H, and T change rate.
- Camera, holography, visual data recording

Procedure:

- Purge chamber.
- Establish initial T, P, R, H.
- Inject liquid droplet(s).
- Cool chamber at a controlled rate (+5^{o}C to -30^{o}C).
- Note (record-photographic, manual) if any small ice particles have been produced.
- Observe time of freezing (T, P, R, H).
- Provide humidity and time for any possible small crystals to grow to detectable sizes.
- Re-establish initial T, P, R, H.
- Recycle same particles several times.
- Recycle using same or different conditions.

Approaches:

- Slight supersaturation can be established after freezing to enhance small crystal growth.
- Expansion chamber (with appropriately cooled walls) could be used to provide known cooling cycle throughout chamber.

General:

- Cooling rates: 0.1C/min (1 M/sec)
10.0C/min (100 M/sec)
- Determine effects of CO_2 levels.
- Vary rates of evaporation and concensation during cooling.

Carry-on Version:

Basic procedure would be as given in general description. Available refrigerator units could be utilized to provide necessary cooling.

For initial experiments, a temperature step could be used in place of controlled cooling.

NaCl Break-up

Common salt (NaCl) from the ocean is a very important source of large and giant nuclei. The numbers and sizes of these hygroscopic nuclei exert a large influence on cloud droplet size distributions and resulting precipitation potentials. Because NaCl plays such an important role in the precipitation process, an understanding of the airborne particle size distribution is very important. Salt particle break-up has been suggested to explain the salt particles producing atmospheric haze over the oceans, and the propagation of salt particles over land. The possible break-up of salt particles also plays a vital role in the design of brine cooling towers for electricity production as well as what happens to the salt used to de-ice freeways.

Gravity prevents the terrestrial laboratory observation of this phenomena without physical supports. A zero-gravity condition would permit a study of large evaporating salt solution droplets.

Equipment:

- T, P, R, H controls.
- Camera and visual records.

Procedure:

- Purge chamber.
- Establish initial T, P, R, H.
- Inject saturated NaCl solution droplet(s).
- Adjust R, H to cause evaporation.
- Photograph crystallization processes.
- Observe time of solidification or crystallization.
- Note if multiple particles are formed (number, size).

- Increase humidity so that any small NaCl pieces might grow to detectable sizes.
- When all particles are in solution again recycle processes.
- Recycle same or different conditions.

Approaches:

- Zero-gravity would permit small and large particles to remain stationary. High humidity can then be used to determine the number of particles present without the use of a microscope.
- Slight motion or sound waves may be needed to separate pieces if they are not ejected with an initial motion.

General:

Evaporation rates - adjust R.H. between 0 and 70 percent.

Carry-on Version:

Same basic approach. Use ambient T, P. Use a space vacuum source to maintain evaporation rate.

SKYLAB CONSTRAINTS AND

INFORMATION REQUIRED FOR SCREENING

PROPOSED SECOND SKYLAB SUITCASE EXPERIMENTS

Experiment Title: Saturation vapor pressure over supercooled water.

A. Hard Physical Constraints: (Skylab requirements in brackets; please record this experiments requirements)

1. Size and Geometry: ($\leq$ 30" x 40" x any reasonable length)

   $\simeq$1 ft cube

2. Weight: ($\leq$150 pounds, including container)

   <50 lbs. (+autorecording if not done by hand)

3. Power: (28 v.d.c., $\leq$1000 watts ($\leq$500 watts preferred)

   How much? <100 Duration? 1 hour

4. Toxicity: (No toxic materials permitted)

   Water

5. Temperature Range/Control: (55^{o} to 92^{o} F range)

   <-14 to ambient

   (-40^{o}F ultimate)

6. When Available? (Launch ready by mid 1975)

   1974

B. Priority Criteria

1. Benefits: (Why is experiment important, and to whom?) Primary importance in the diffusional growth of ice crystal among supercooled droplets. Presently, data is extrapolated from above 32F data.

**2. Is There a Champion?

   NASA-MDAC Senior Scientific Board

3. Complexity: (How simple to set up, operate? How straight forward is final analysis?) Simple to set up (install in refrigerator), check list operation (set refrigerator temp. in steps) and record chamber pressure temp.

4. Time Requirements:

   - Total 1 hr. after set-up
   - Astronaut's
   - Port, Airlock?
   - Event Criticality?

5. Unique Skylab Facilities Interface? (Airlock, Mfg. chamber, cooling system, etc.)

   Cooling System (refrigerator)

   Vacuum line to initially evacuate chamber.

6. Data Recording: (Quantity? Analog? Digital? Film, other) Visual and written or spoken; Analog if available (Temp, pressure, time)

*7. Other Special Requirements: (EVA? Scientist Astronaut? $\leq 10^{-4}$g? Orbital? Minimal acceleration).

8. Payload Return Requirements: (Wt. and Vol.) Taped notes and analog info if used.

C. General Purpose Workbench/Equipment: Would a workbench be beneficial to the astronaut in performing the experiment? What ancillary equipment/ tools does the experiment require that may be common to other suitcase experiments and, if provided by the workbench, could be shared? (e.g., voltmeter, optical bench, digital tape recorder, A-D converter, microscope, movie camera, d.c./a.c. converter, heater, etc.).

Analog recording or A-D and digital tape
Desired but not necessary

D. Space for Continued Comments:

*The major concern of most cloud physics experiments is the movement of the substance under investigation to the walls of the chamber. The particle size can be adjusted over certain ranges to prevent this problem (smaller sizes move slower) but larger particles are desired in many cases when ever possible for ease of observation.

In a number of experiments the chamber can be free floating thus permitting 10^{-5} g or less for a few minutes at a time.

The refrigerator or space manufacturing chambers do not permit such freedom.

**This experiment is a part of the zero-gravity cloud physics program study and committments have been made to maintain suggestor's names with each experiment. These individuals are represented by the stated Board.

Saturation Vapor Pressure Over Supercooled Water

The controlling factor in the initiation of the cold precipitation process at a given temperature is the saturation vapor pressure difference between ice and supercooled water droplets. The few large particles necessary for the initiation of the collision process are formed by the vapor growth of a few frozen droplets in a field of many supercooled droplets. This rapid growth provides particle size differences which then starts the gravity inertial collision process.

Laboratory measurements of the saturation vapor pressure over supercooled water is hindered by water freezing induced by surface contact with any material support. On theoretical grounds, this saturation vapor pressure over supercooled water has been calculated and used to four decimal places.

Because of the importance of this vapor pressure, a zero-gravity experiment has been proposed that circumvents the physical contact problems of a terrestrial laboratory.

Equipment:

- 20 cm diameter chamber with hydrophobic inner surface (teflon or silicon oil)
- Temperature control ($+20>T>-40^{\circ}C$).
- Temperature and pressure recorders.

Procedure:

- Purge chamber and evacuate.
- Inject 1 cm diameter pure water droplet.
- Establish vapor pressure and temperature equilibrium between chamber and droplet.
- Measure and record T, P of gas in chamber.
- Decrease T of chamber (e.g., 1.0C increments).
- Terminate upon freezing of droplet.
- Recycle for statistics.

Approaches:

- Use teflon or silicon oil on inner surface of sphere to prevent premature ice formation on walls of chamber.
- Single fluid sphere will evaporate until the ambient water vapor pressure builds up to the saturation vapor pressure of the source (droplet).
- Uniform temperature is required throughout chamber and interior chamber surfaces.

General Comments:

- Ambient inert gas pressure may be needed to dampen any residual acceleration due to space laboratory movement.

SKYLAB CONSTRAINTS AND

INFORMATION REQUIRED FOR SCREENING

PROPOSED SECOND SKYLAB SUITCASE EXPERIMENTS

Experiment Title: Circulation: 3 dimensional simulation of the atmospheric circulation.

A. Hard Physical Constraints: (Skylab requirements in brackets; please record this experiments requirements)

1. Size and Geometry: (≤30" x 40" x any reasonable length)
   1 ft diameter sphere + 2 cubic ft of

2. Weight: (≤150 pounds, including container)
   <150 lbs.

3. Power: (28 v.d.c., ≤1000 watts (≤500 watts preferred)

   How much? 500 watts   Duration? >30 minutes

4. Toxicity: (No toxic materials permitted)

   No

5. Temperature Range/Control: (55^{o} to 92^{o} F range)

   Ambient

6. When Available? (Launch ready by mid 1975)

   After 1975 for full unit; basic concept could be tried as early as 1975.

B. Priority Criteria

1. Benefits: (Why is experiment important, and to whom?)
   Important to study cause and effects related to weather prediction.

**2. Is There a Champion? Dr. C. Hosler
   NASA-MDAC Senior Scientific Board

3. Complexity: (How simple to set up, operate? How straight forward is final analysis?) Simple set, check list operation, straightforward preliminary analysis. Film would be used for detailed analysis.

4. Time Requirements:

   - Total 30 minutes minimum
   - Astronaut's
   - Port, Airlock?
   - Event Criticality? Non-critical

5. Unique Skylab Facilities Interface? (Airlock, Mfg. chamber, cooling system, etc.) None

6. Data Recording: (Quantity? Analog? Digital? Film, other) Visual, voice & photographs.

7. Other Special Requirements: (EVA? Scientist Astronaut? $\leq 10^{-4}$g? Orbital? etc.) $\leq 10^{-3}$ g

8. Payload return Requirements: (wt. and vol.) Film & recorded notes.

C. General Purpose Workbench/Equipment: Would a workbench be beneficial to the astronaut in performing the experiment? What ancilliary equipment/tools does the experiment require that may be common to other suitcase experiments and, if provided by the workbench, could be shared? (e.g., voltmeter, optical bench, digital tape recorder, A-D converter, microscope, movie camera, d.c./a.c. converter, heater, etc.)

Camera - movie
voltmeter

D. Space for Continued Comments:

*As with most proposed cloud physics experiments, the primary value of a space platform is the low g acceleration values.

**This experiment is a part of the zero-gravity cloud physics program study and committments have been made to maintain suggestor's names with each experiment. These individuals are represented by the stated Board.

Circulation: 3 dimensional simulation of the atmospheric circulation

Concept: Under zero gravity conditions, the fluid surface tension would hold a fluid of appropriate characteristics onto the surface of a sphere. If the fluid were ferromagnetic (these are presently available) then localized electromagnetic sources within the sphere could be used to modify the effective viscosity at desired points in the rotating fluid. Thus perturbations could be initiated and the consequences could be observed.

APPENDIX D - PAYLOAD INTEGRATION CONCEPTS

The NASA maintains a Candidate Experiment Program which consolidates information regarding experiment requirements, payload analysis, operational constraints, and candidate missions. Standard experiment program definition format sheets containing data for three zero-g cloud physics experiments are included in this Appendix. The first experiment listed (ES-1H) is the complete laboratory concept. The data for the subgroup experiments (ES-1H-1 and ES-1H-2) is given for independent operation, eg. (pre-Shuttle flights). The experiments can also be performed within the complete laboratory.

The data on these format sheets represent the May 1972 concept and they are <u>subject to change</u> throughout the course of the program. Prior to using this information in any payload definition studies the originating office for this report should be contacted.

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

REQUIREMENTS / SORTIE PAYLOADS	LAUNCH WEIGHT KG (LB)	DIMENSIONS METERS (FEET)		SUPPORT EQUIPMENT NOT INCLUDED IN EXPERIMENT LAUNCH WEIGHT						REMARKS
		LAUNCH	DEPLOYED	DESCRIPTION	WEIGHT KG (LB)	DIMENSIONS METERS (FT)	OPERATION DURATION	AVG POWER WATTS	EXPENDABLES PER 30 DAYS KG (LB)	
ES-1H Atmos. Cloud Physics Exp. &Lab. 5 day Shuttle flt	272 (600)	1 x 1.3 x 2.7 (3x4x8)	Same	Cloud chambers & measuring instrumentation & supporting equipment	45 (100)	.8 x .8 x 1 (2x2x3)	5-15 hr per flight	150W	(70)	reuseable
Subgroup ES-1H-1 Freezing Droplet Experiment 5 day Shuttle flt	25 (55)	1 x ½ x 1 (3.2 x 1.5 x 3.2)	Same	Cloud chamber measuring & support equipment	4.5 (100)	.8 x .8 x 1	4-6 hrs per flight	50W	(70)	reuseable
Subgroup ES-1H-2 Droplet Charging Experiment 5 day Shuttle flt	40 (88)	1 x ½ x 1 (3.2 x 1.5 x 3.2)	Same	Cloud chamber measuring & support equipment	4.5 (100)	.8 x .8 x 1.0	4-6 hrs per flight	50W	(70)	reuseable

EXPERIMENT GROUP WEIGHT, SIZES, AND SUPPORT EQUIPMENT

Data given is preliminary and subject to revision as studies progress (May 1973)

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

SORTIE PAYLOADS / REQUIREMENTS	AVERAGE OPERATION POWER (EACH) WATTS	OPERATION DURATION OF DUTY CYCLE HOURS/DAY	DAILY AVERAGE POWER PER NUMBER DAYS PER CYCLE	PEAK POWER (WATTS)	PEAK DURATION OR DUTY CYCLE HOURS/DAY	REMARKS
ES-1H Atmos. Cloud Physics Exp. & Lab. 5 day Shuttle flt	150W per hr	4 hr/day	600W	200W	1 hr/day	
Subgroup ES-1H-1 Freezing Droplets Experiment 5 day Shuttle flt	50W per hr	2 hr/day	100W	100	1 hr/day	
Subgroup ES-1H-2 Droplet Charge Experiment 5 day Shuttle flt	50W per hr	2 hr/day	100W	100	1 hr/day	

POWER REQUIREMENTS

Data given is preliminary and subject to revision as studies progress (May 1972)

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

SORTIE PAYLOADS / REQUIREMENTS	SETUP/DEPLOY TIME (HR)		OPERATE TIME (HR) FOR EACH CYCLE	RETRIEVE/SHUTDOWN/ MAINTAIN/EVALUATE TIME (HR) PER CYCLE	TOTAL CYCLE DURATION	REPETITION CYCLE (DAYS OR MONTHS)	CYCLE/ MISSION (MISSION DURATION)	REMARKS
	INITIAL	SUBSEQUENT						
ES-1H Atmos. Cloud Physics Exp. & Lab. 5 day Shuttle Flt	0.5 hr	0.5 hr	2 hrs 2 times a day	0.5 hrs	4 hrs/ days	day	20/5 days	All experiments are not performed at one time. One experiment done at a time, then another the next time. Schedule to be furnished.
Subgroup ES-1H-1 Freezing Drop Experiment 5 day Shuttle flt	.5 hr	.5 hr	1 hr	.5 hr	2 hrs/ day	day	20/5 day	Repetative experimental runs for statistical data
Subgroup ES-1H-2 Droplet Charge Experiment 5 day Shuttle flt	.5 hr	.5 hr	1 hr	.5 hr	2 hrs/ day	day	20/5 day	Repetative experimental runs for statistical data

EXPERIMENT OPERATIONAL SEQUENCES

Data given is preliminary and subject to revision as studies progress (C[illegible])

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

REQUIREMENTS / SORTIE PAYLOADS	DATA ACQUISITION			OPERATION			DISPOSITION OF DATA (APPROX. PERCENT)					REMARKS
	MEASUREMENT SOURCE	OUTPUT FORM (D,A,FILM)	DATA RATE (BPS, Hz)	DURATION (MIN)	NO. OF OPERS. PER DAY	DAILY TOTAL (BIT KHZ, FRAME)	REAL TIME TRANSMIT	ONE ORBIT DUMP	1-7 DAYS RETURN	SHUTTLE RETURN	ON-ORBIT DISPLAY	
ES-1H Atmos. Cloud Physics Exp. & Lab. 5 day Shuttle flt	Photo electric	16 mm Film Mag Tape	32 tps $7\frac{1}{2}$ ips	3	4	$2.3 \times 10^4 t_1$ $5.4 \times 10^3 + t_1$	-	-				
Subgroup ES-1H-1 Freezing Drop Experiment	HOLOG Raphm	Film	TBD	5	5	TBD						
Subgroup ES-1H-2 Droplet Charging Experiment	HOLOG Raphm	Film	TBD	5	5	TBD						

EXPERIMENT DATA REQUIREMENTS

Data given is preliminary and subject to revision as studies progress ([illegible])

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

SORTIE PAYLOAD / REQUIREMENTS	EVA (HOURS)	SKILL TYPE	CREW TIME (HOURS PER OPERATING DAY)	CREW TIME (HOURS PER MISSION)	REMARKS
ES-1H Atmos. Cloud Physic Exp. & Lab. 5 day Shuttle flt	None	Atmospheric (cloud) Physics or General Scientific Training with Selected Course Work in Cloud Physics	4 hrs	5 to 15 hrs/ 5 days	Duty cycle based on granting each experiment for one set of data
Subgroup ES-1H-1 Freezing Drop Experiment 5 day Shuttle flt	None	General scientific training with cloud physicists	2 hrs	4 to 6 hrs/ 5 days	
Subgroup ES-1H-1 Droplet charging experiment 5 day Shuttle flt	None	General scientific training with cloud physicists	2 hrs	4 to 6 hrs/ 5 days	

CREW REQUIREMENTS

Data given is preliminary and subject to revision as studies progress

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

REQUIREMENTS / SORTIE PAYLOAD	ALTITUDE Km (n.mi)		INCLINATION RADIANS (DEGREES)		MANEUVERS	ATTITUDE (INERTIAL/ VELOCITY VECTOR, ETC.)	POINTING ACCURACY RADIANS (DEGREES)	STABILITY/ OBSERVATION TIME	REMARKS
	ACCEPTABLE	PREFERRED	ACCEPTABLE	PREFERRED					
ES-1H Atmos. Cloud Physic Exp. & Lab. 5 day Shuttle flt	any	any	any	any	normal	inertial	any	TBD	
Subgroup EH-1H-1 Freezing Drop experiment 5 day Shuttle flt	any	any	any	any	normal	inertial	any	TBD	
Subgroup EH-1H-2 Droplet charging experiment 5 day Shuttle flt	any	any	any	any	normal	inertial	any	TBD	

ORBIT REQUIREMENTS

Data given is preliminary [illegible] revision as studies progress [illegible]

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

SORTIE PAYLOAD / REQUIREMENTS	ALLOWABLE ORBITAL TEMP. °C (°F)	ALLOWABLE ATMOSPHERIC PRESSURE N/M^2 (PSIA)	ATMOSPHERE (GAS TYPE)	RELATIVE HUMIDITY	CLEANLINESS (CLASSIFICATION)	GRAVITY LEVEL (g's)	ALLOWABLE RADIATION EXPOSURE (REM or RADS)	REMARKS
ES-1H Atmos. Cloud Physic Exp. & Lab 5 day Shuttle flt	7-27°C (45-81°F)	$0\text{-}10^5$ n/m^2 (0-15 psia)	N/A self-contained	30-70%	space	$\leq 10^{-3}$	N/A	
Subgroup EH-1H-1 Freezing drop experiment 5 day Shuttle flt	same as above	same as above	N/A self-contained	N/A	space	$\leq 10^{-3}$	N/A	
Subgroup EH-1H-2 Droplet charging experiment 5 day Shuttle flt	same as above	same as above	N/A self-contained	N/A	space	$\leq 10^{-3}$	N/A	

ORBITAL OPERATING ENVIRONMENTAL REQUIREMENTS

Data given is preliminary and subject to revision as studies progress ([illegible])

Prior ot using this information in any payload definition studies, the originating office for this report should be contacted.

SORTIE / PAYLOAD	TEMPERATURE °C (°F)	PRESSURE N/M² (PSI)	ATMOSPHERE COMPOSITION	ACCELERATION	LAUNCH STATUS ACTIVE/PASSIVE	CONTAMINANTS	REMARKS
ES-1H Atmos. Cloud Physic Exp. & Lab. 5 day Shuttle flt	7-27°C (45-81°F)	0-10^5 N/m² (0-15 psia)	optional N_2 OK O_2 OK	$\leq 10^{-3}$	active cryogenics	sensitive to some contaminants	
Subgroup EH-1H-1 Freezing drop experiment 5 day Shuttle flt	N/A	N/A	N/A	N/A	active cryogenics	sensitive to some contaminants	
Subgroup EH-1H-2 Droplet charging experiment 5 day Shuttle flt	N/A	N/A	N/A	N/A	active cryogenics	sensitive to some contaminants	

NON-OPERATING ENVIRONMENTAL REQUIREMENTS (PRE-LAUNCH, LAUNCH AND ORBITAL STORAGE)

Data given is preliminary and subject to revision as studies progress ([illegible]

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

REQUIREMENTS / SORTIE PAYLOAD	OPERATIONAL CONSUMABLES							SPARES & MAINTENANCE CONSUMABLES						REMARKS
	TYPE	INITIAL		RESUPPLY (30 DAYS)		RETURN (30 DAYS)		INITIAL		RESUPPLY (30 DAYS)		RETURN (30 DAYS)		
		WT Kg (lb)	VOL. $M^3 (Ft^3)$	WT. Kg (lb)	VOL. $M^3 (Ft^3)$	WT. Kg (lb)	VOL. $M^3 (Ft^3)$	WT. Kg (lb)	VOL $M^3 (Ft^3)$	WT. Kg (lb)	VOL. $M^3 (Ft^3)$	WT. Kg (lb)	VOL. $M^3 (Ft^3)$	
ES-1H Atmos. Cloud Physics Exp. & Lab. 5 day Shuttle flt	Magnetic tape film	16 (36)	.04 (1.8)	N/A	N/A	16 (36)	.04 (1.8)	N/A	N/A	N/A	N/A	N/A	N/A	
Subgroup EH-1H-1 Freezing drop experiment 5 day Shuttle flt	Magnetic tape film	16 (36)	.04 (1.8)	N/A	N/A	16 (36)	.04 (1.8)	N/A	N/A	N/A	N/A	N/A	N/A	
Subgroup EH-1H-2 Droplet charging experiment	Magnetic tape film	16 (36)	.04 (1.8)	N/A	N/A	16 (36)	.04 (1.8)	N/A	N/A	N/A	N/A	N/A	N/A	

LOGISTIC SUPPORT REQUIREMENTS

Data given is preliminary and subject to revision as studies progress ([illegible])

Prior to using this information in any payload definition studies, the originating office for this report should be contacted.

REQUIREMENTS / SORTIE PAYLOAD	CHECKOUT MONITOR & CONTROL	AREA LOCATION & SIZE	TEMP °C (STORAGE)	HUMIDITY	CONTAM. SENSITIVITY	UTILITIES: FLUIDS	UTILITIES: ELECTRICAL POWER	UTILITIES: GAS	UTILITIES: OTHER	SERVICE & HANDLING	SPECIAL SUPPORT BUILDING	REMARKS
ES-1H Atmos. Cloud Physic Exp. & Lab. 5 day Shuttle flt	onboard check-out system	3'x4'x8'	7-27°C (45-81°F)	30-70%	N/A		150W	cryo-genics		regular	N/A	
Subgroup EH-1H-1 Freezing drop experiment 5 day Shuttle flt	onboard	3x4x8	7-27°C (45-81°F)	30-70%	N/A	distilled water	150W	cryo		regular	N/A	
Subgroup EH-1H-2 Droplet charging experiment	onboard	3x4x8	7-27°C (45-81°F)	30-70%	N/A	distilled water	150W	cryo		regular	N/A	

Data given is preliminary and subject to revision as studies progress (May 1972)