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# ZERO-GRAVITY CLOUD PHYSICS LABORATORY-CANDIDATE EXPERIMENTS DEFINITION AND PRELIMINARY CONCEPT STUDIES

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**16. ABSTRACT**


This report covers (July 1972 - April 1973) the candidate experiment definition studies on the Zero-G Cloud Physics Laboratory. This laboratory will be an independent self-contained Shuttle Sortie payload. Several critical technology areas have been identified and studied to assure proper consideration in terms of engineering requirements for the final design. Areas include chambers, gas and particle generators, environmental controls, motion controls, change controls, observational techniques, and composition controls. This unique laboratory will allow studies to be performed without mechanical, aerodynamics, electrical, or other type techniques to support the object under study. This report also covers the candidate experiment definitions, chambers and experiment classes, laboratory concepts and plans, special supporting studies, early flight opportunities and payload planning data for overall Shuttle payload requirements assessments.

The results of the first phase of effort (September 1971 - July 1972) on this program are described in NASA CR-128998 entitled, "Feasibility Study of Zero-Gravity (Orbital) Atmospheric Cloud Physics Experiments Laboratory."



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## FOREWORD

The work reported herein encompasses study efforts during the period July 1972 through April 1973. This report is a sequel to NASA CR-128998 "Feasibility Study of a Zero-Gravity (Orbital) Atmospheric Cloud Physics Experiments Laboratory," November 1972. The main goal of this effort is to provide a multi-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 Science Department of McDonnell Douglas Astronautics Company was supported for this reported effort by NASA, involved the following tasks:

Task I - Maintain communications with the atmospheric cloud physics community relative to candidate experiments and ideas.

Task II - Work with the Senior Scientific Board to review and evaluate experiments, ideas and concepts for the Cloud Physics Laboratory.

Task III - Conduct studies for Space Shuttle applications of the Zero-G Cloud Physics Laboratory components involving the (a) Diffusion Chamber Thermal Control System, (b) Expansion Chamber Sub-System, and (c) selected flight payload concepts.

Task IV - Assess the mission requirements based on schedules of potential low gravity payload carriers. This includes studies of aircraft zero-g programs, unmanned ballistic rockets, SAT and laminar flow techniques.

Task V - Conduct an indepth analysis of all candidate experiments selected by the NASA/MDAC Senior Scientific Board as recommended by members of the cloud physics community.

Task VI - Determine the observational, data recording requirements, and preliminary laboratory concept utilizing documentation developed under Task V and results obtained in the feasibility study. (NASA CR-128998)

This program is being conducted on behalf of NASA's Office of Application and Office of Manned Space Flight. The progress on this Space Shuttle payload definition effort has been due primarily to the enthusiastic response and support provided by members of the cloud physics community and their recognition of the significant potential

that such a payload could provide further research and application work. Comments on the contents of this report will be welcomed. Copies of this report are available from:

Aerospace Environment Division
Aero-Astrodynamics Laboratory
NASA-Marshall Space Flight Center

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## I. SUMMARY

This study summarizes work accomplished during July 1972 - April 1973 on Zero-Gravity Atmospheric Cloud Physics Laboratory. This program involves the definition and development of an atmospheric cloud physics laboratory and accomplishing a set of candidate experiments that must utilize the unique environment of zero-gravity or near zero-gravity.

General objectives of the Zero-Gravity Atmospheric Cloud Physics Laboratory program are to significantly increase the level of knowledge in atmospheric cloud physics research by placing at the disposal of the terrestrial-bound atmospheric cloud physicist a laboratory that can be operated in the environment of zero-gravity or near zero-gravity. This unique laboratory will allow studies to be performed without mechanical, aerodynamics, electrical, or other type techniques to support the object under study. Terrestrial experiments tend to mask data results such that some identical experiments are not repeatable and divergence in the data will occur.

Scientific objectives of the Zero-Gravity Atmospheric Cloud Physics Laboratory program are: To advance the state-of-the-knowledge in atmospheric cloud microphysics, to provide an unique laboratory for cloud physics researchers, and to develop techniques in weather control and modification.

Cloud physics research under zero- or low-gravity conditions offers an opportunity to answer many problems that cannot be solved in earth-based laboratories. By taking advantage of zero-gravity to define many of the processes in clouds that are not yet fully understood, man could influence weather by changing, for example, drop distributions and nuclei concentrations, or by adding pollutant compositions. Under zero-gravity, an experimenter can suspend a drop in a chamber and observe its nature for the actual time required for various processes and forces to take effect. The droplet can be frozen and thawed out, and another drop can be propelled into it. Observations can be made of the migration and collection of particulate matter that may be near or around the drop. These characteristics cannot be investigated on earth because of gravity and, in some instances, because of effects of measures

taken to offset gravity. Thus, numerous experiments that cannot be done on earth can be performed in this unique environment.

Participation of the scientific community was encouraged, supporting research was done at universities and many valuable suggestions by scientists in industry, government, and universities were incorporated in the concept. In addition, a Senior-Scientific Board was formed early in the study to act in an advisory capacity. Its members were: Drs. C. L. Hosler, L. J. Battan, P. Squires, and H. Weickmann. The board continues its participation in the program.

In Section II of this report, the first phase of the feasibility study (NASA CR-128998), conducted from September 1971 to July 1972, is reviewed. This phase of the study accomplished the following: (1) Developed scientific community support, (2) selected high-priority experiments, (3) determined the program feasibility, and (4) identified a concept for the multi-experiment cloud physics laboratory, including its subsystems and components, with particular emphasis on long-lead-time research and development.

The remainder of this report presents the results of the investigation from July 1972 to date. The results of this study were: (1) experiments suggested by the scientific community were defined; (2) 20 classes of such experiments that require zero- or low gravity were identified, (3) laboratory requirements were determined, based on these 20 experiment classes, and (4) a multi-experiment laboratory concept was established to accommodate nearly all these experiments. Experiment mission hours were determined by analyzing the 20 experiment classes, the specific experiments in each class, the experiment parameter variations, and the iterations needed for validity.

The laboratory will be made available to the entire cloud physics community so that a wide variety of important experiments can be performed.

Section III describes the in-depth analysis of the experiment. Each of the 20 classes of experiments is described in detail. Engineering requirements based on the 20 experiment classes are also given, and subsequent mission workload analysis are described.

Section IV describes the conceptual design selected, based on the cloud physics experiment engineering requirements. This concept utilizes common subsystems and five interchangeable chambers. The laboratory is self-contained and interfaces with the Shuttle-Sortie laboratory for operational power, heat rejection, and for limited data management and communications. Section IV also discussed the results of the engineering analysis on subsystem requirements and commonality. Many of the subsystems and ancillary systems associated with the laboratory are used in common.

The laboratory concept accommodates 19 of the 20 identified experiment classes and was selected because it best satisfied the long-range research objectives, was most responsive to the scientific community, and satisfied both the technical guidelines and design features agreed upon by MDAC, the Senior Scientific Board, and NASA.

Section V discusses supporting research for the experiment and engineering analysis in long-lead technology areas. The University of Missouri at Rolla performed an extensive cloud chamber and supporting subsystem study. The major emphasis of their work was on expansion chambers and the applicability of expansion chambers to zero-gravity research. The Desert Research Institute of the University of Nevada completed an analysis of chamber operation under zero-gravity conditions, with emphasis on diffusion chambers. The Donald W. Douglas Laboratories studied the applications of heat-pipe technology for thermal control and cloud chamber subsystems. McDonnell Douglas Electronics Company studied holography applications for observation purposes in the zero-gravity cloud physics laboratory. MDAC in-house efforts were concentrated on thermal transport and thermal control development. Heat-pipe technology was studied in relation to continuous flow diffusion chambers and Raman cells. Additional MDAC efforts evaluated alternative means of achieving low gravity for design, testing, and experiment purposes. Techniques such as drop towers and aircraft programs appear possible for equipment and component testing; however, space platforms appear to be the only means of achieving sufficient time to provide for significant cloud physics research.

Throughout the investigation, consideration was given to using pre-Shuttle flight opportunities for concept testing and scientific research. Section VI discusses two of these opportunities, the Apollo-Soyuz Test Program and the Apollo-Skylab Experiment, and also describes potential experiments aboard early Shuttle test missions.

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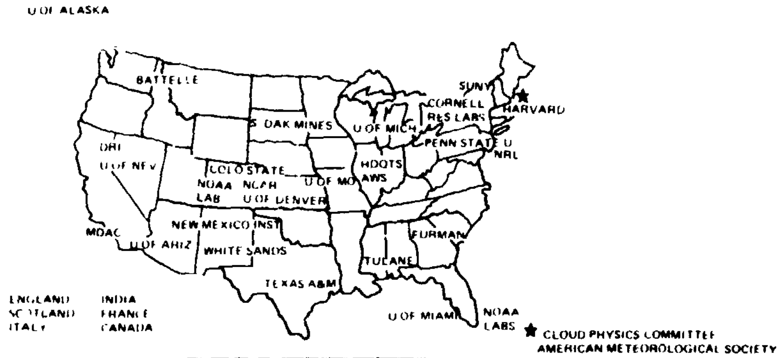
## II. FEASIBILITY STUDY STATUS (SEPTEMBER 1971 TO JULY 1972)

A primary objective of the September 1971 to July 1972 phase of the feasibility and concepts study was to encourage suggestions for experiments from every institution where cloud physics laboratory work is underway. A parallel objective was to inform everyone working in the discipline about the objectives of this program. Agencies involved in weather modification and field experimentation, and cloud-seeding commercial firms were invited to submit their ideas. Letters were sent to scientists in the field of cloud physics and weather modification who had articles published in meteorological journals from the period 1968 to 1971. Letters were also sent to those who had presented papers at the American Meteorological Society cloud physics meetings including individuals associated with universities, Government laboratories and private research organizations. A limited solicitation was made to scientists outside the United States. An explanation of the zero-gravity cloud physics program was sent to each addressee, including 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.

In addition to the mail solicitation, visits were made to universities and Government laboratories where major cloud physics laboratory research programs were underway, and individual and group conferences were held with many 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, Volume 52, December 1971.

The response to this solicitation was gratifying (Figure 1) and served as the basis for further analysis to prepare and clarify the experiment suggestions for detailed study by the NASA-MDAC Senior Scientific Board. The board independently evaluated 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 serve on this board: Drs. C. L. Hosler, L. J. Battan, P. Squires, and H. Weickman.




**INSTITUTIONAL ANALYSIS**

| | SOLICITATIONS SUBMITTED | REPLIES 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 |

49 INDIVIDUALS CONTRIBUTED 82 EXPERIMENT SUGGESTIONS

30

Figure 1. Solicitation

At its first meeting, held on 3 and 4 February 1972, the Senior Scientific Board selected and classified a set of experiments that met the major program requirements of relevance and scientific merit, as well as the 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.

Engineering problems and requirements associated with the development of a zero-gravity cloud physics laboratory were then identified. 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 to delineate the long-lead-time requirements of the various laboratory subsystems.

Two major briefings were prepared during the feasibility study. The first was 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 NASA Headquarters on 24 February 1972. The second was presented to the Applications Committee of NASA's Space Program Advisory Council on 5 April 1972 at Goddard Space Flight Center, Greenbelt, Maryland.

The briefings established the feasibility of the laboratory and the very important support of the scientific community. There was also general agreement 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 were given on such topics as "Zero-Gravity Cloud Physics," "Zero-Gravity Research in Cloud Physics and Weather Modification," and "Summary Description of the Zero-Gravity Cloud Physics Experiment." The substance of the material covered is included in the summary report (NASA CR 128998).

Thus, the significant accomplishments of this study included (1) 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.

Figure 2 summarizes the MDAC presentation to the Senior Scientific Board at its first meeting: it compares cloud constituents (liquid, liquid-ice, ice, nuclei, and gas) with the various cloud physics phenomena, such as nucleation, growth, scavenging, charge separation, and absorption. These constituents and phenomena can be combined into experiment classes, which have individual experiment groups, parameter variations, iterations, and discrete events.

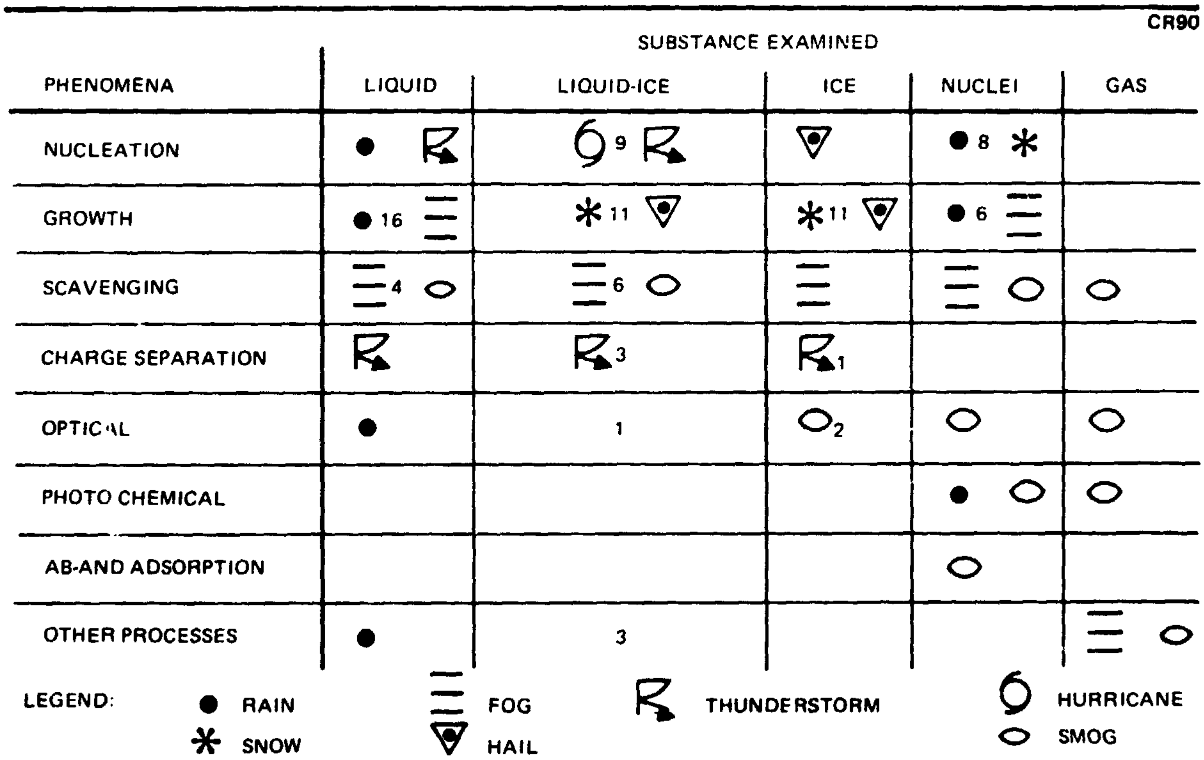



Figure 2. Experiment Classification Reply Statistics and Applications

Figure 2 also categorizes the various phenomena by area, including modification of rain, snow, fog, hail, thunderstorms, hurricanes, and smog. For example, experiments with nuclei and gases will help in understanding the process of scavenging. This process is critical in the analysis of fog and smog conditions. The numbers in Figure 2 indicate the frequency of the individual areas of experiments suggested.

The Senior Scientific Board indicated three areas of importance – optical properties, charge separation involving ice, and scavenging – where gravity was such a deterrent that little or no research was currently underway, and where very little had been completed in the past. The Senior Scientific Board also analyzed each suggested experiment to determine the operational ease or difficulty of performing each experiment. The two major factors considered were hardware requirements and man-involvement requirements.

Hardware considerations included the type of chamber, environmental ranges, motion control, and supporting equipment. Manpower considerations dealt with the educational background needed for the research, and the manipulative and observing skills requirements during the experiment. It was established that some very important and significant research can be made by an astronaut using off-the-shelf hardware. Other experiments, however, are more involved, and could require an astronaut with several years of graduate training in cloud physics.

The Senior Scientific Board reviewed the scientific analysis completed by MDAC to establish experiment importance and difficulty. The conclusions of this analysis were that (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 in zero gravity, and (3) some very important cloud physics research could be accomplished with relatively simple equipment carried by a non-scientist astronaut, but the majority of important experiments will require sophisticated apparatus and a trained experimenter.

The Senior Scientific Board agreed with the conclusion that cloud physics research progress has reached a plateau in certain areas due largely to laboratory restrictions imposed by gravity-induced motion and that these restrictions can be overcome by the use of a zero-gravity environment for certain experiments. These experiments involve particles with diameters between 0.01 μm and 20 μm, where the primary forces involved in nucleation, growth and scavenging are not aerodynamic (e.g., diffusive and electrical).

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## III. BASELINE CHAMBERS AND EXPERIMENT CLASSES

All experiments received during the feasibility study were grouped into the 20 classes of experiments shown in Table 1. Each class represents a group of experiments that are designed to study similar processes.

Five cloud chambers were determined as the optimum number needed for the experiments. The chambers, as shown in Figure 3, were selected for each experiment class on the basis of achieving maximum information from a given expenditure of experiment time. In many cases, the experiment could be performed in one or more chambers that would emphasize certain aspects of the experiment. Descriptions of these chambers and their code designations follow.

General-Purpose Chamber (G)

This chamber will be a 30-cm cube with transparent walls. Provisions will be made for generating various electric fields, positioning devices (sound, optical, electrical), and remote droplet sizing. This chamber will be used for many experiments that require a relative humidity below 100 percent and minimum temperature control.

Static Diffusion Liquid (SDL)

This is a Twomey type of chamber, 1.5-cm deep and 15 cm in diameter. It will be used for experiments requiring above-freezing temperatures and supersaturation of the liquid relative to water. Supersaturation is controlled by the temperatures of the water covering the upper and lower surfaces of the chamber.

Static Diffusion Ice (SDI)

This is also a basic Twomey type of chamber, but it utilizes ice surfaces to provide controlled supersaturation relative to ice. Its dimensions are 10 cm deep by 40 cm in diameter.

Continuous-Flow Diffusion (CFD)

The chamber dimensions are 1-cm deep by 30-cm wide by 30-cm long. The supersaturation is controlled as in the Twomey chamber and provides continuous data readout. It will be used for cloud condensation nucleation experiments, and have the capability for size distribution determinations.

Table 1

EXPERIMENT CLASSES

EXPERIMENT CLASSES

| | |
|---|---|
| 1. CONDENSATION NUCLEATION | 11. SATURATION VAPOR PRESSURE |
| 2. ICE NUCLEATION | 12. ADIABATIC CLOUD EXPANSION |
| 3. ICE MULTIPLICATION | 13. ICE NUCLEI MEMORY |
| 4. CHARGE SEPARATION | 14. TERRESTRIAL EXPANSION CHAMBER EVALUATION |
| 5. ICE CRYSTAL GROWTH HABITS | 15. CONDENSATION NUCLEI MEMORY |
| 6. SCAVENGING | 16. NUCLEI MULTIPLICATION |
| 7. RIMING AND AGGREGATION | 17. DROPLET COLLISION BREAKUP |
| 8. DROPLET-ICE CLOUD INTERACTIONS | 18. COALESCENCE EFFICIENCIES |
| 9. HOMOGENOUS NUCLEATION | 19. STATIC DIFFUSION CHAMBER EVALUATION |
| 10. COLLISION-INDUCED FREEZING | 20. UNVENTILATED DROPLET DIFFUSION COEFFICIENTS |

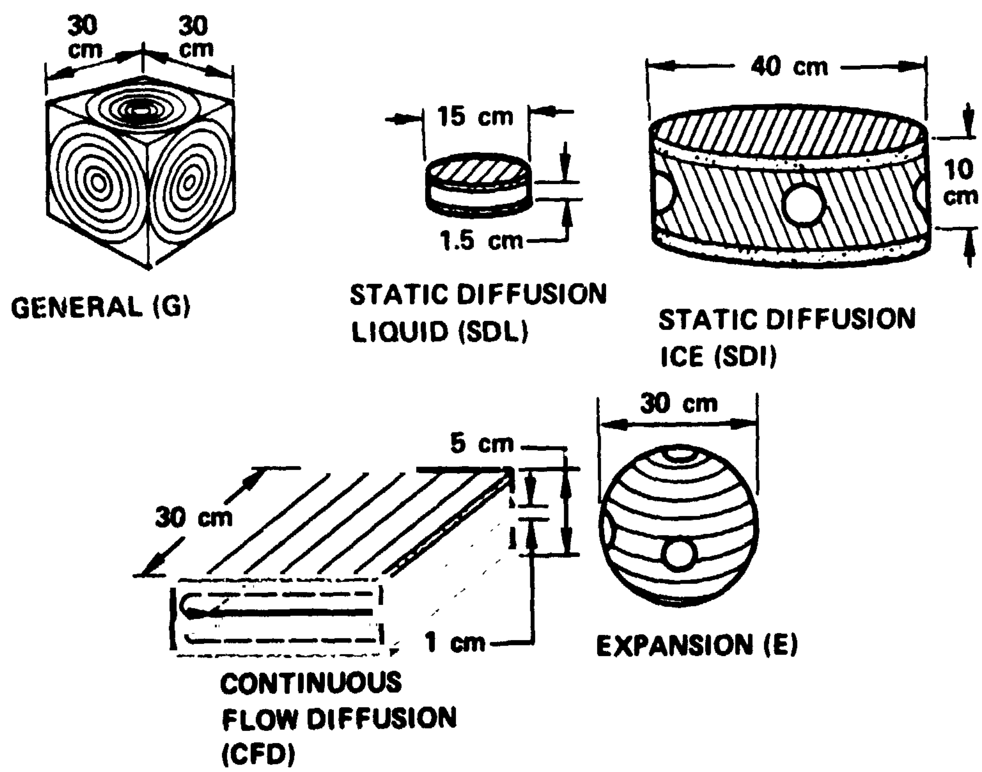


Figure 3. Atmospheric Cloud Physics Chambers

## Expansion Chamber (E)

This chamber will be a 30-cm-diameter sphere. The cooling of the walls will be synchronized with the expansion cooling of gas, thus providing for long-term, natural cloud, adiabatic expension simulation. Figure 4 briefly summarizes the chamber characteristics.

## Zero-G Laboratory Advantages

Figures 5 and 6 compare several aspects of natural cloud physics processes with terrestrial laboratory capabilities.

Figure 5 indicates that observations in terrestrial chambers are limited to a few seconds by gravity-induced convection and particle fallout. Extremely large chambers have been and are being used in an attempt to overcome the fallout factor, but these chambers still do not provide the desired results for many experiments. Gravity is the limiting factor for both convection and fallout. Under low-gravity conditions (e.g., $10^{-3}$ g), the complete atmospheric time scale can be covered.

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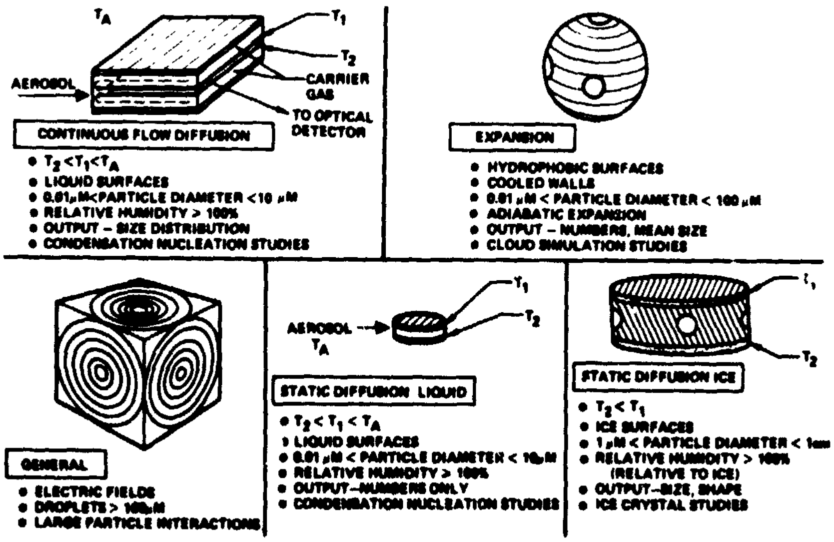


**Figure 4. Atmospheric Cloud Physics Chambers**

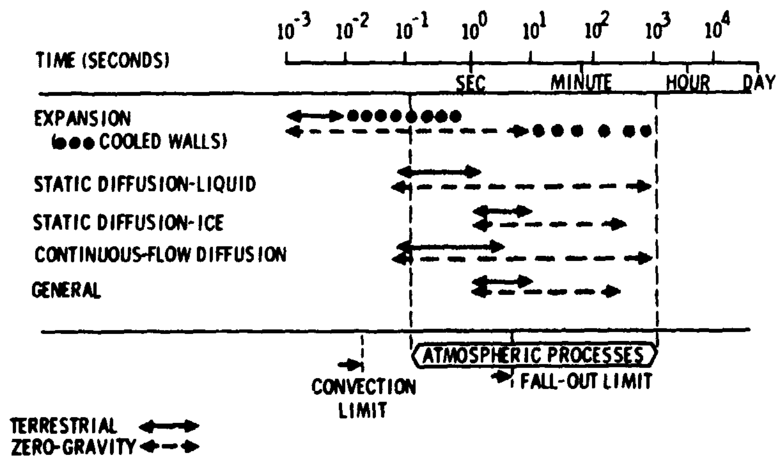


Figure 5. Chamber Utilization Times

Figure 6 relates important atmospheric particle sizes with some of the significant phenomena in precipitation and pollution processes. Particles range from Aitken nuclei at the lower end to hail stones at the upper end, representing a range of over eight decades.

The processes involving particles below a few micrometers are independent of gravity. As the particles become larger, both gravity-dependent and independent forces become active. At the upper diameter range, gravity-driven aerodynamic forces are of prime importance as in coalescence, aggregation, droplet distortion, and breakup. Many of the important observations (e.g., ice crystal growth habits) cannot be made with a normal optical imaging device until a particle grows to a few micrometers in dimensions. This is in contradiction to many of the atmospheric experiments. Low supersaturations (below 0.3 percent) require growth times that cannot be accommodated in a terrestrial laboratory without fallout.

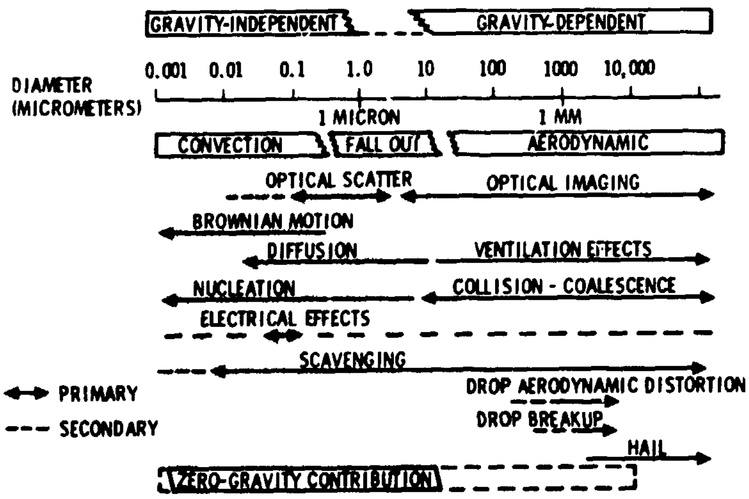


Figure 6. Zero-Gravity Cloud Physics Applications

A low-gravity environment permits the gravity-dependent forces to be separated from independent forces, and will provide much needed data. The shaded area in Figure 6 represents those processes which will function the same in a low-gravity environment as in the Earth's atmosphere. The results would therefore be directly compatible with the atmospheric environment.

In addition, certain dynamic inertial processes can be studied. The low-gravity environment would permit precise control of droplet-droplet impact energy and would permit "slow"-motion, aerodynamically scaled experiments. There are therefore a number of areas throughout the eight-decade dimension range that would benefit from use of low-gravity environment.

Figure 7 illustrates an adiabatic cloud expansion involved in a convective cloud growth cycle. This particular situation can be simulated in an expansion chamber under zero-gravity conditions. As a parcel of air containing condensation and ice nuclei rises in the atmosphere, it cools due to adiabatic expansion. Soon after the dew point (100 percent relative humidity) has been

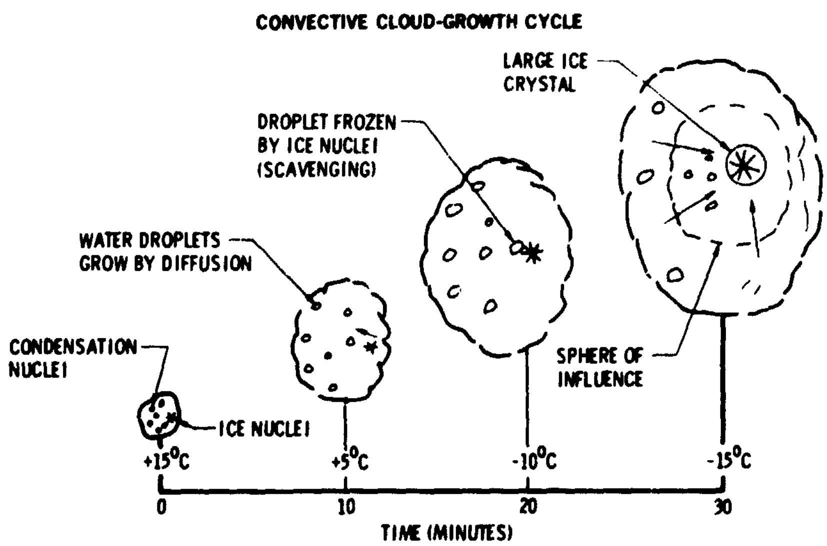


Figure 7. Adiabatic Cloud Expansion Using Expansion Chamber

passed, droplets form on condensation nuclei and start their diffusional growth. As the air rises higher, a lower temperature is reached, at which point the ice nuclei become active. Once a supercooled droplet freezes and becomes ice, its surface vapor pressure drops. The ice then draws the vapor from surrounding unfrozen droplets, resulting in the ice growing at the expense of the droplets. The nucleation, ice propagation, scavenging, and sphere of diffusional growth influence are only a few of the phenomena that must be understood in order to develop improved techniques of weather modification and control.

The major microphysical requirements are: (1) natural growth cycles take tens of minutes, and (2) many processes, such as those occurring in stratus clouds and fogs, have very low supersaturation conditions that require seconds to minutes just for the nucleation phase. The only way to achieve these natural times and supersaturations is in a zero-gravity environment.

## Experiment Class Descriptions

A description of each class of experiments given in Table 1 follows. Most of the methods, equipment, and procedures are presently being used in terrestrial laboratories. Refinements and revisions will take place as the program develops and the low-g laboratory environment is further established

The introductory sections explain the experiment objective, its importance to man, and the experiment method. The discussion section presents in detail the significance of the problem being studied. It also presents the current difficulties in terrestrial laboratory experiments along with the advantages and potential of low-gravity experimentation.

The remaining parts of the description are tailored to a specific experiment, given as an example for simplicity and clarity. Each class actually includes many experiments that may be performed in the same chamber but would require variations in method, procedure, and data requirements. These variations have been found to have minimal impact on the physical requirements of any laboratory facility. The remaining material gives some brief statements concerning experimental method, instrumentation, and data requirements. Further information concerning commonality of all the experiment classes along with unified weight, power, and volume requirements are given in Section IV. The procedural section specifies representative event times, but it does not include times for setup, calibration, and shutdown. These items are included with the engineering analysis in Section IV.

Acknowledgments are given in each experiment to persons who contributed suggestions in the 1971 phase of the study. Our appreciation is extended to the many other persons who made significant contributions to the experiments in later phases of the program. A list of contributors is shown in Table 2.

Table 2

SCIENTIFIC PARTICIPATION

**PRINCIPAL EXPERIMENT CONTRIBUTORS**

| | | | | | |
|---|---|---|---|---|---|
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| BATTAN, L. R. | U. OF ARIZ. | JAYAWEERA, K. O. L. F. | U. OF ALASKA | PRODI, V | ITALY |
| BLANCHARD, D. C. | SUNY | JIUSTO, J. E. | SUNY | RUHNKE, L. H. | ONR |
| BRAZIER-SMITH, P.R. | ENGLAND | KAMRA, A. K. | INDIA | RUS[illegible] | ONR |
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# 1. CONDENSATION NUCLEATION

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# CONDENSATION NUCLEATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine the nucleation efficiencies and early growth properties of soluble, insoluble, and hydrophobic nuclei. This class of experiments encompasses a large range of nuclei types, size, distributions, and relative humidities.

### Applications

Nucleation processes are the key to weather modification. Condensation nuclei are used to modify and dissipate warm fogs and other warm precipitation processes. A thorough understanding of nuclei properties and their roles in cloud formation will permit better local forecasting on the basis of measurements or observations of the particulate matter in the air, whether from natural or artificial sources. The data from these experiments will contribute to the "what" (type and size of seeding material) and "how much" decisions of warm-weather modification and pollution control.

### Specific Knowledge Requirement Satisfied

Provide activation conditions of various nucleating agents for use in a specific weather modification and permit prediction of precipitation conditions associated with given particulate observations.

### Approach

Various nuclei types will be studied using a continuous-flow diffusion chamber with various temperatures, relative humidities, and pressure, and utilizing the low-gravity conditions of a space platform. Measurements of nucleation efficiencies and initial growth rates will be compared with nucleation theory and will also be used to determine the heat and vapor accommodation coefficients during the early growth period.

## DISCUSSION

### Significance

Kohler's theory of the interaction of small hydroscopic particles with water vapor (1926) has been applied with some success to explain the behavior of atmospheric clouds. Thus, it is known that the ease and rapidity with which rain forms by coalescence is related to cloud microstructure, and that this in turn is largely controlled by the size distribution and composition of cloud nuclei.

In some respects, however, the theory does not appear to agree very well with observation: numerical calculations of the cloud-forming process predict more monodisperse cloud droplet spectra than are commonly observed. One possible explanation for this difference is that the accommodation coefficient for condensing water vapor molecules (usually assumed to be 100 percent) is not known. As discussed by Rooth in 1957, a small value of this coefficient could explain heterogeneity in the droplet sizes resulting from aerosols of mixed constitution. Influences of trace gases may also cause the condensation coefficient to vary, even among nuclei of the same type.

Thus, "poisoning" of cloud nuclei may occur in nature; moreover, it may prove to be technologically feasible to use such means to produce desired changes in cloud microstructure and behavior (i. e., weather modification).

Zero-Gravity

Terrestrial cloud chambers for the study of cloud nuclei rely on the assumptions that all individual droplets grow at the same rate (e.g., in a standard Twomey static diffusion chamber) and all nuclei are assumed to reach a diameter of 2 μm at the same time so that they can be photographed before fallout. In reality, this assumption is not true. Terrestrial diffusion chambers are restricted to a depth of 1 cm by thermodynamic considerations and as a result, their performance is seriouslv limited by fallout. Nuclei which grow more slowly than others would still be unobservably small when the faster-growing nuclei have formed droplets large enough to fall out of the region of observation.

The study of droplet growth rates, as affected by condensation kinetics, is therefore one class of experimental investigation for which zero-gravity conditions offer distinct advantages.

## METHOD

A continuous-flow thermal diffusion chamber will be used to study the activation and critical growth properties of soluble (e.g., NaCl), insoluble (e.g., DOP, dioctyl phthlate), and hydrophobic (e.g., Teflon) particles.

High-purity air will be passed through a desiccator, absolute filter, and into a conditioning chamber (collapsible metallized mylar bag). Once the bag is approximately two-thirds full, nuclei of the desired chemical composition will be generated and introduced into the bag. The amount of time that the aerosol is allowed to reside in the bag will partly determine the size distribution due to coagulation; long residence times will result in nuclei of up to a few tenths of a micrometer in diameter, while very short coagulation times will produce nuclei in the hundredths of a micrometer diameter range. For certain experiments, a natural aerosol will be taken into space.

After nuclei of the desired type and size are introduced into the conditioning chamber, samples can be drawn into an aerosol size analyzer and at the same time admitted into the diffusion chamber and total nucleus counter. Depending on the aerosol type and the conditions of supersaturation in the chamber, nucleation may take place in several seconds to several minutes. For most atmospheric nuclei, droplet growth to micrometer sizes occurs in six to seven seconds. The aerosol can be collected into a holding system for later disposal.

The continuous flow diffusion chamber is especially suited for the investigation of condensation nucleation and growth of droplets at small supersaturations (condensation coefficient, nucleus constitution, nucleus poisoning, etc.). Droplet and particle sizes down to 0.3 μm can be measured using the auxiliary optical counter. The residence time of the growing droplets in the supersaturated area can be controlled by the flow velocity of particle-free air.

## INSTRUMENTATION

The diffusion chamber is shown in Figure 1-1. Significant dimensions are the separation of the horizontal plates $P_1$ and $P_2$ (h = 1.3 cm), their length along the stream (28 cm), and their breadth (b = 29 cm). The sample is injected through a manifold (8 cm wide, 2 mm deep) with a preconditioned sheath

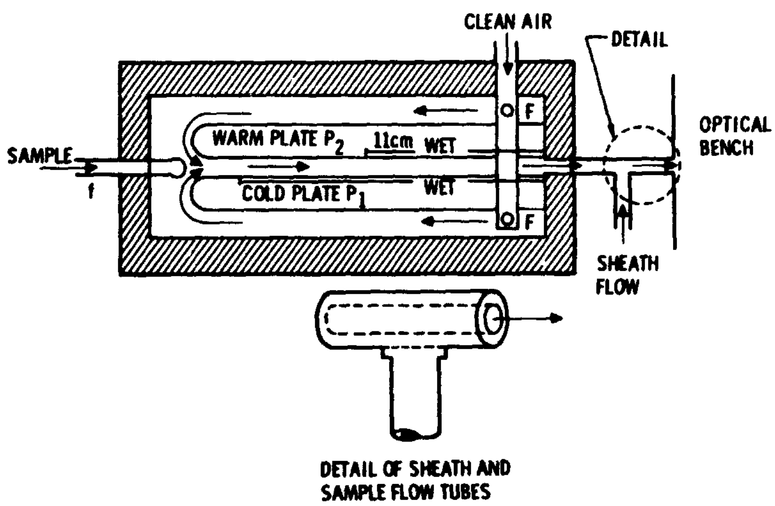


Figure 1-1. Continuous-Flow Diffusion Chamber

flow, thus confining the sample within the central 2-mm constant-supersaturation region of the chamber. The aerosol sample volume flow is between 0 and 1 $cm^3/sec^{-1}$. The droplets exit from the chamber into an optical counter (Royco 225 or equivalent).

The overall pattern of air flow is shown in Figure 1-2. The pump associated with the particle counter drives a circulating stream of air some 330 $cm^3/sec^{-1}$, most of which forms an almost particle-free sheath surrounding the droplet-carrying stream from the diffusion chamber. A stream of 42 $cm^3/sec^{-1}$ is vented to the atmosphere through an orifice (B), the pressure at B being controlled by a flow resistor downstream. This flow is partly replaced by the metered bypass inflow (A), which consists of room air. The remainder of the 42 $cm^3/sec^{-1}$ required to replace the air exhausted at B passes through the diffusion cloud chamber; it consists mostly of the main flow (F), a metered flow of filtered room air, with some sample flow f. The pump unavoidably

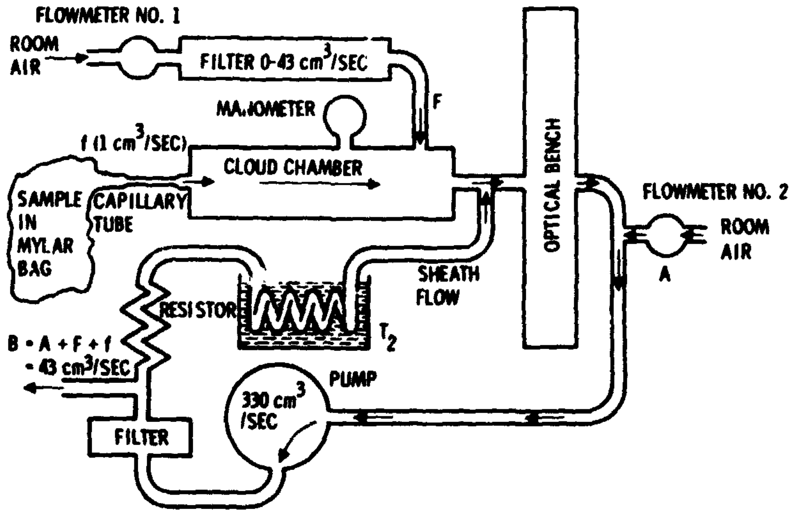


Figure 1-2. Continuous-Flow Diffusion Chamber Air Flow

heats the air. To avoid particle counterheating and possible droplet evaporation, the sheath flow air is cooled to the temperature of the top plate, $T_2$. The temperature of the two plates is measured to 0.05°C.

The chamber operates at a deficit pressure (1 cm mercury) relative to the air supply pressures. In an experiment where it is desired that the supersaturation be constant to within 0.02 percent, the maximum rate of change of pressure which can be tolerated in a chamber 1-cm deep (1/2-sec time constant) is around 0.5 mb/sec relative to a total pressure of 800 mb. For the zero-gravity cloud physics laboratory, the main air flow would be derived from stored air compressed in a cylinder (flow rate up to 5 cu ft per hour at one atmosphere) and all exhausted air would be delivered to a sump tank.

## MEASUREMENTS AND DATA REQUIREMENTS

Measurements and control of the upper and lower plate temperatures ($T_1$, $T_2$) and chamber pressure will be used to calculate the supersaturation profile between the plates. Nuclei residence (growth) time within the chamber is given by the measured air flow rates. Nuclei sizes and numbers are obtained by the optical particle counter located external to the chamber. This counter utilizes the optical Mie scattering properties of particles to size and count one particle at a time. Digital records of time, plate temperatures ($T_1$, $T_2$), chamber pressure, and air flow rates would be made along with records of droplet size spectrum from the optical counter. Voice-recorded commentary would be utilized at appropriate points during the experiment.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Generate aerosol and precondition | 30 |
| • Start continuous flow chamber and permit plate temperatures to reach equilibrium (while aerosol is being generated) | |
| • Inject aerosol into chamber air flow and obtain size distribution | 2 to 20 |
| • Change chamber flow rate (residence time 5 settings) | 5 |
| • Change plate temperature settings and stabilize (saturation levels, 4 settings) | 15 |
| • Recycle to new aerosol | |

**This class of experiments will involve between 140 and 500 min of operating time for each type of nuclei. At least three types of nuclei and several kinds of each type should be considered along with several conditions of "contaminating" environments. These experiments can be conveniently divided into sessions of a few hours duration.**

ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
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# 2. ICE NUCLEATION

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# ICE NUCLEATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine the relative importance of contact, internal, and sublimation nucleation of ice. Absolute nucleation efficiencies will also be studied as a function of nuclei types and size.

### Applications

These data are important in efforts to modify weather for all cold precipitation processes such as occur, for example, in snow, hail, and cold fogs. Proper seeding decisions will permit the redistribution of snow (e.g., over watershed control areas, recreation areas, and away from lake-located metropolitan areas such as Buffalo, New York). These experiment data will contribute to the "what" (type of seeding material), "when" (in the precipitation cycle), and "how much" (seeding material) decisions involved in weather modification.

### Specific Knowledge Requirement Satisfied

Provide nucleation mechanism and conditions for optimum nucleation effectiveness and provide nucleation efficiencies for various nuclei types.

### Approach

The ice-crystal phase will be initiated (nucleated) for various types of ice nuclei in a static ice diffusion chamber under various temperatures, pressures, and relative humidities utilizing the low-gravity conditions of a space platform. The plate temperatures and chamber pressure determine the relative humidity distribution and when combined with the photographic data of the number of ice crystal versus time, will provide the nucleation efficiencies and nucleation mode.

## DISCUSSION

### Significance

Among the population of atmospheric aerosol particles, ice-forming nuclei occupy a minute fraction· they are important because they form ice crystals in supercooled clouds and trigger a thermodynamically supported change

(i. e., glaciation). This process frequently leads the cloud to develop precipitation. Ice-phase weather modification is based on this phenomenon. Whenever the natural ice-forming process is inefficient in supercooled clouds or cloud systems, introduction of artificial ice nuclei helps to initiate the thermodynamic change and modifies the cloud structure, often leading to additional precipitation.

In order to understand the cloud process and to modify it further, we must have exact knowledge of the complex process of ice nucleation. The macroscopic modes of ice nucleation are of our direct concern when we are to apply our knowledge to the atmospheric processes, although the micromechanisms are indirectly connected.

Some answers for the long-standing puzzles of ice nuclei behavior at different saturation ratios will be provided by this study. In other words, this study will be able to tell the extent of (1) sublimation nucleation which is macroscopically defined to occur below water saturation, (2) condensation freezing which is macroscopically defined to happen above water saturation, and (3) contact freezing nucleation which is considered to take place when the ice nucleus particle collides with a supercooled water droplet. The contact ice nucleation may be analyzed by the behavior of ice nucleation above water saturation (droplets coexist).

<u>Zero-Gravity</u>

When ice nucleation takes place on the ground, ice crystals formed move away from the points of nucleation due to the gravitational settling. This factor makes the analysis of nucleation modes difficult.

For this study, the low-gravity condition in a space laboratory helps the nucleated ice crystals stay in the original positions and presents an opportunity to perform accurate experiments. There is no need to say that a study of this kind depends solely on its accuracy, since the questions to be answered are "to what extent"? or "how many percent"?

## METHOD

The sample smoke nuclei will be kept in a conditioning chamber and will be introduced into the thermal diffusion ice chamber while it is at room temperature. The ice chamber will be cooled to the temperature of investigation without having a temperature gradient inside (temperatures on both plates are the same).

When the chamber is uniformly cooled to the temperature of the study, the bottom plate will be cooled and the top plate will be warmed at a slow but constant rate (e.g., 0.25°C $min^{-1}$). The starting temperature will be maintained in the center of the chamber. The supersaturation at the center can be calculated from the temperatures of both plates. This will continue until fog droplets form and reach about 10 µm in diameter. The number of ice crystals formed in a unit volume will be measured by photographing the number of ice crystals in a known volume illuminated with a laser beam.

Since this study will suggest possible mechanisms of ice nucleation, it is desirable to run the same experiment at several temperatures between the nuclei nucleation threshold and a low temperature (e.g., -25°C) where the number of natural ice nuclei increases sharply. The integral number of ice nucleates will be plotted with respect to the water saturation ratio with a mark at ice saturation, and the temperature will be considered as a parameter in the graph.

The range of the bottom-plate temperature of the chamber will be between 0° and -32°C. The internal saturation ratio will range from ice saturation to 2-percent water supersaturation for several ambient temperatures. Representative nuclei samples are 1, 5-dihydroxynaphthalene and metaldehyde for organics, AgI and one clay material (Kaolinite) for inorganics, and one or two soil samples.

## INSTRUMENTATION

### Nuclei Generators

A simplified LaMer-Sinclair monodispersed aerosol generator can be used. The generator consists of a nuclei source (normally a heated wire), an evaporator of the nuclei compound with a dilution gas inlet, a mixing mechanism for the nuclei and vapor, and a cooling tube for gentle nucleation and growth. This generator uses a molten chemical to increase the vapor pressure. It may be necessary to use woven fiber glass to confine the liquid under low-gravity conditions.

Another way to attack the problem is to use a simple organic smoke nuclei generator of the Cloud Physics Laboratory, University of Denver. The smoke generator consists of an ordinary electric soldering iron with 1/16-in. copper tube wound around it. A small amount of sample organics (about 1 mg or less) is placed at one end of the tube, protruding from the hot soldering iron in order to prevent heating. A flexible plastic tubing with a syringe is then attached to the other end. A puff of air is sent through the hot copper tubing around the soldering iron by a pumping action of the syringe. The sample powder is blown in the hot spiral copper tube, and the centrifugal force keeps the particles rubbing against the hot wall while they move; it lets them evaporate quickly. As the vapor-laden air comes out of the tube, smoke particles form by condensation. Clay minerals must be ground and put in a plastic bottle while they are on the ground. The plastic container has a coarse filter and a tube. For smoke nuclei generation, the bottle will be shaken vigorously and then squeezed. The filter will retain large particles in the bottle. Spacecraft air is another possible nuclei source for this study. Other generation concepts are being investigated that are compatible with zero gravity.

Low-Temperature Thermal Diffusion Chamber

For this study, a static ice thermal diffusion chamber will be used at subfreezing temperatures. The temperature between the top and bottom plates will be adjustable. The diffusion chamber for this study is basically the same as that used for the ice crystal habit studies.

## MEASUREMENT AND DATA REQUIREMENTS

For a given air composition, the chamber plate temperatures and pressure define the relative humidity distribution in the chamber. Photographic data provide the numbers of ice crystals per unit of chamber volume as a function of time and ambient conditions. A recorded commentary will be utilized at appropriate points during the experiment along with digital recording of time, temperatures, and pressure.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Prepare nuclei in conditioning chamber | 60 |
| • Purge diffusion chamber | 10 |
| • Establish thermal equilibrium at $\Delta T = 0$ | 20 |
| • Inject aerosol nuclei | 5 |
| • Cool chamber to desired temperature ($\Delta T = 0$) | 20 |
| • Record plate temperature and time (continuous) | |
| • Time-lapse photographs of ice crystal formation | |
| • Establish $\Delta T$ (c.f., METHOD) at 0.25°C/min | 10 |
| • Recycle for new mean temperature (5 values) | |
| • Recycle for various nuclei | |

The variables to be considered are nuclei types, size distributions, temperature, relative humidity, pressure, and gas contaminants. These experiments can be conveniently divided into segments of a few hours duration.


## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

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- T. L. Ogden — Institute of Occupational Medicine Edinburgh, Scotland
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# 3. ICE MULTIPLICATION

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# ICE MULTIPLICATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine the conditions under which ice fragments are generated during atmospheric precipitation processes and the extent to which they are generated.

### Applications

The limited number of ice nuclei relative to the condensation nuclei provides a key by which man can modify certain weather conditions. The extent and conditions of the natural seeding by ice breakup (multiplication) must be known before the "when" (in the life cycle), "how much" (added seeding material), and "where" (in cloud system) of weather modification can be decided. These data are applicable to the control of hail and the redistribution of snow, among other phenomena.

### Specific Knowledge Requirement Satisfied

Provide information concerning the conditions and extent of self-seeding in the cold precipitation processes.

### Approach

Studies of droplet-shattering during freezing and crystalization processes (including melting) will be performed in a static ice diffusion chamber utilizing the low-gravity conditions of a space platform to provide the necessary experiment time without mechanical supports. The chamber surface temperatures define the relative humidity while photographic data will supply the desired particle sizes and numbers from the experiments. Infrared measurements of the surface temperature of droplets and ice crystals are also desirable.

## DISCUSSION

### Significance

Ice-forming nuclei are a minute fraction of the population of atmospheric aerosol particles. They form ice crystals in supercooled clouds and trigger a thermodynamically supported change (i.e., glaciation). This process frequently leads the cloud to develop precipitation; consequently, ice-phase weather modification is based on this phenomenon. Whenever the natural ice-forming process is inefficient in supercooled clouds or cloud systems, introduction of artificial ice nuclei helps to initiate the thermodynamic change and modifies the cloud structure, often leading to additional precipitation.

The processes involved in the rapid glaciation that is often observed in a cloud are of concern in these experiments. The rate and conditions of this glaciation have an impact on the decision as to how much artificial seeding material should be added. Improper seeding (e.g., overseeding during a rain enhancement project) could result in not obtaining the desired goal.

Zero-Gravity

In many of these experiments, fallout in a terrestrial laboratory does not provide the necessary observation time to study the processes in detail. For example, the freezing process itself of a freezing supercooled drop, while influenced by ventilation factors as it falls in a gravity field, is not directly dependent on gravity. Thus, a low-gravity environment would permit the main droplet and any fragments to be localized for a long enough time to detect and measure them, thereby eliminating the gravity-induced restrictions and permitting observation of the gravity-independent processes.

METHOD

The representative experiment described herein is droplet breakup during freezing. A droplet of water will be supercooled in a static diffusion ice chamber with controlled relative humidity, pressure, and temperature. Freezing will then be induced by an ice nucleus or another ice crystal (Figure 3-1). Initial sizes of all ice particles over a few micrometers in dimension will be obtained and the resulting smaller fragments will then be permitted to grow until photographic records can be obtained of these fragments. The process will be repeated for various temperatures, pressures, and relative humidities. The experiment is to determine those conditions which are conducive to droplet breakup during freezing. Other experiments deal with ice and snow type crystal breakup during conditions of collision or melting.

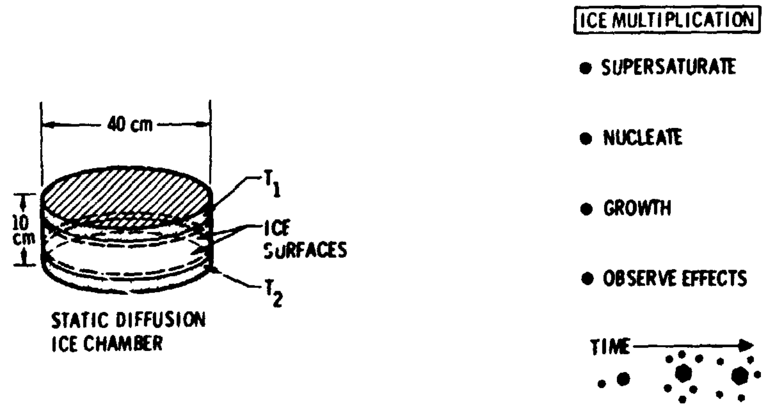


Figure 3-1. Typical Experiment – Droplet Breakup

## INSTRUMENTATION

A static diffusion ice chamber will be utilized for these experiments. A few details of a chamber are given in Figure 3-2 with representative dimensions. Square or cylindrical geometry is acceptable. Optical windows are required on the side for visual and photographic observations. The upper plate temperature ranges from +10°C to -40°C and the lower plate from -10°C to -40°C. Cooling requirements at -40°C will theoretically be around 50 watts, not accounting for equipment inefficiencies. Optical illumination will require 25 to 80 w.

## MEASUREMENT AND DATA REQUIREMENTS

The temperatures of the chamber plates and the chamber gas pressure will be measured. These quantities define the relative humidity distribution in the chamber. Photographic data will provide the droplet position and motion and resulting crystal numbers and sizes. Commentary will be recorded for

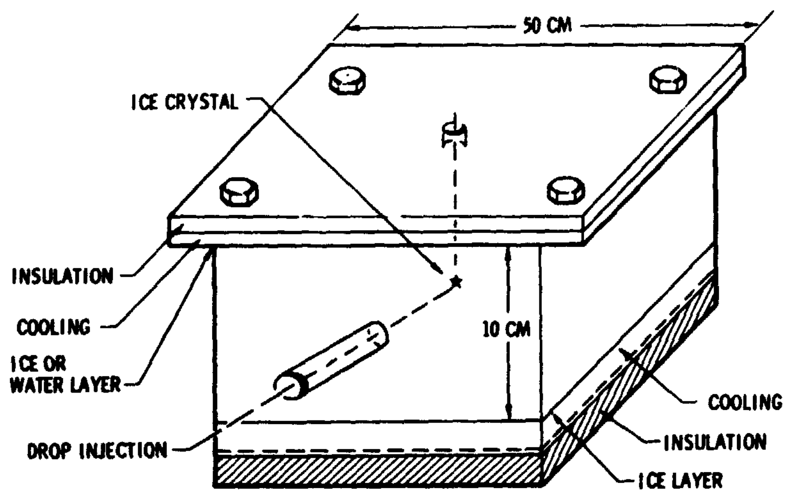


Figure 3-2. Static Diffusion Ice Chamber

appropriate points during the experiment along with digital recording of time, temperature, pressure, and computed relative humidity.

PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge Chamber | 5 |
| • Establish thermal and vapor equilibrium | 10 |
| • Photograph (time lapse) | |
| • Insert droplet(s) | 1 |
| • Freeze droplet (e.g., insert nuclei) | 2 |
| • Allow submicrometer fragments to grow | 3 |
| • Record temperatures and pressure | |
| • Recycle with a given droplet diameter (50 events) | |

- Recycle with three other droplet diameters (50 events)
- Recycle with other humidity levels (5 levels)
- Recycle with other temperature levels (4 values)
- Recycle with other pressure levels (3 levels)
- Recycle with other gas (e.g., pollutant) composition (6 types)

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The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study

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# 4. CHARGE SEPARATION (ELECTRIFICATION)

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# CHARGE SEPARATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine quantitative values for charge transfer occurring during several important atmospheric processes.

### Applications

Particle-to-particle charge transfer mechanisms are believed to be responsible for the production of charge separation in thunderstorm clouds that results in lightning. An understanding of these mechanisms may permit certain weather control efforts to minimize lightning and associated fires and strike damage to buildings, forests, and aircraft. This understanding will aid in deciding "where" in the cloud system and "when" in the cloud life to modify weather during lightning-associated precipitation.

### Specific Knowledge Requirement Satisfied

Provide information concerning the mechanisms, conditions, and extent of various charge separation processes.

### Approach

Studies of droplet and ice interactions in various combinations will be performed in a static ice diffusion chamber, utilizing the low-gravity conditions of a space platform to provide the necessary time and electrical isolation from mechanical support surfaces. The quantity of interest is how much charge has been transferred from one ice (droplet) particle to another ice (droplet) particle as a result of their interaction under given conditions of electric field, temperature, pressure, and relative humidity.

## DISCUSSION

### Significance

Lightning causes much damage to forests, buildings, and homes through fires. Also of concern is the direct loss of life from lightning strikes and the ever present threat of such loss from strikes on aircraft and space vehicle launches. An increased emphasis has been placed on finding what mechanisms are important to the electrification processes within thunderstorm clouds.

A number of interactions involving ice and droplets have been shown to produce varying degrees of particle electrification. Among these interactions are freezing of supercooled water drops, melting of snowflakes and hailstones, the disintegration of large raindrops, and collisions between ice crystals, water droplets and hail pellets. An understanding of the relative importance of these processes with respect to particle electrification is important if any attempt is to be made to minimize lightning conditions.

These electrification phenomena involve a number of very different mechanisms of charge transfer (e.g., by ion segregation at the ice-water interface during freezing, by proton migration in ice down a temperature gradient, by conduction of charge between ice crystals and water drops colliding with and rebounding from hail pellets, and by the shearing of the electrical double layer at the surfaces of air bubbles bursting in water and of water drops bursting in air).

Most of the above processes occur for hydrometeors (ice, water) which are greater than 100 μm in diameter. Thus, the physical separation of the charge once electrification has taken place is a function of gravity and convective updrafts within a cloud. But a number of electrification processes themselves, which is of concern here, are a function of thermal and electrical properties of the particles, which in turn are not a function of gravity. As a consequence of the ice and droplet particle size and resulting fallout due to gravity, most terrestrial laboratory experiments have utilized mechanical supports to provide sufficient time for the necessary experimental observations. The conductivity of even the best supports modifies the resulting charge measurements to such an extent that qualitative measurements are obtained, but quantitative measurements are nearly impossible.

## Zero-Gravity

Under low-gravity conditions, the various interactions can be studied without the need for physical supports. Techniques are presently available for the measurement of charge on a freely floating spherical droplet by the use of static and alternating electric fields. A low-gravity environment would permit quantitative measurements to be made for those electrification processes which are not strictly gravity-dependent. Even certain aspects of the processes such as electrification during the disintegration of large droplets could be studied to advantage under such conditions.

## METHOD

Electrification during the impingement and rebounding of cloud droplet with hail pellets will be used as a representative example of this class of experiments.

A neutrally charged, 1-cm ice pellet will be placed near the center of a thermally controlled, static ice diffusion chamber. The plate temperatures of the chamber will define the relative humidity within the chamber from exact saturation with respect to ice up to several percent supersaturation as required. Humidity values below 100 percent can be provided by utilizing dry walls and plates and preconditioning the air before entry into the chamber.

A uniform electric field will be applied across the diffusion chamber. This field will electrically polarize the ice pellet as would happen in a natural cloud.

Single droplets between 100 to 1, 000 μm in diameter will then be impinged at a glancing angle onto the ice pellet so that the droplets will rebound from the surface. The motion of the droplet (and of the ice-pellet to a lesser degree due to its mass) under the influence of a static electric field or an applied alternating field will be used to deduce the acquired charge. Particles of irregular shape would require auxiliary calibration to determine their drag coefficients.

These measurements would be performed for various particle sizes, temperatures, pressures, relative humidities, and purities (and therefore electrical conductivities) of ice and water. Observations would be made to related processes such as droplet shattering and resulting charging.

## INSTRUMENTATION

A static diffusion ice chamber will be utilized for these experiments. A few details of the chamber are given in Figure 4-1 with representative dimensions. Square or cylindrical geometry is acceptable. Optical windows are required on the sides for visual and photographic observations. The upper plate temperature ranges from +10°C to -40°C and the lower plate from -10°C to -40°C.

## MEASUREMENT AND DATA REQUIREMENTS

The temperatures of the chamber plates and the chamber gas pressure will be measured. These quantities define the relative humidity distribution within the chamber. Photographic data will provide the droplet and ice pellet sizes, positions, and electric field-induced velocities, thus providing a measurement of the induced charge. Voice recorded commentary will be utilized at appropriate points during the experiment along with digital recording of time, temperature, pressure, and computed relative humidity.

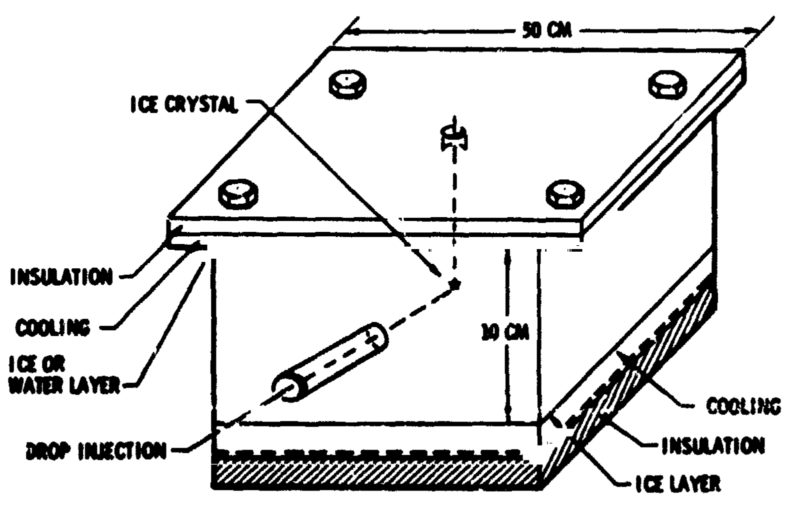


Figure 4-1. Static Diffusion Ice Chamber

PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 5 |
| • Establish thermal and vapor equilibrium | 10 |
| • Photograph (time lapse) | |
| • Insert pellet and position | 5 |
| • Apply static polarizing electric field | |
| • Impinge droplet | 1 |
| • Apply appropriate charge measuring electric field (resulting motion being photographed) | 2 |
| • Turn off charge measuring fields | |
| • Recycle with other droplets (50 events) (purge when necessary) | |
| • Recycle with other droplet diameters (3 sizes) | |
| • Recycle with other humidity levels (5 levels) | |
| • Recycle with other temperatures (4 values) | |
| • Recycle with other impurities in ice and water | |

ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

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# 5. ICE CRYSTAL GROWTH HABIT

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# ICE CRYSTAL GROWTH HABIT EXPERIMENTS

## INTRODUCTION

### Objective

Determine the temperature, pressure, and relative humidity conditions which dictate ice crystal geometry and growth rate under pure diffusion (non-convective) conditions.

### Applications

These data will contribute to the control and distribution of snow and cold rain precipitation. A goal is to distribute snow in mountain areas above runoff-controlled watersheds for the purpose of enhancing the water supplies utilized for irrigation, domestic and industrial use, recreation and wildlife. Another application is the redistribution of snow away from lake-located cities (e.g., Buffalo, N.Y.) to the surrounding non-urban areas to prevent crippling snowfall within an urban area. The understanding of crystal growth habits (rate of growth and fall velocity as a function of crystal type) will also be applied to the minimization of blizzard conditions. These experiment data govern the "when" (in the crystal growth cycle that a given system would be modified) and "where" (what temperature, relative humidity regions) decisions of weather modification involving cold precipitation processes.

### Specific Knowledge Requirement Satisfied

Provide diffusional growth parameters of ice crystals in cold precipitation processes.

### Approach

Ice crystals will be grown unsupported in a static ice diffusion chamber under various conditions of temperature, pressure and relative humidity, utilizing the low-gravity conditions of a space platform. Crystal growth rates, mass, surface temperature, and geometry (types) will be measured and correlated with ambient conditions surrounding the crystals.

## DISCUSSION

### Significance

Ice crystals are responsible for releasing much of the precipitation (snow, rain, hail) from clouds in the high- and mid-latitudes. The growth properties of ice crystals form an important aspect in the area of weather modification. The cold precipitation mechanism depends on the conversion of water vapor into ice crystals. The rate of this conversion is controlled by the growth rate of ice crystals, which in turn is governed by the distribution of water vapor and temperature around the crystals.

Needle and dendritic ice crystals have been found to grow very rapidly at temperatures of -3°C to -5°C and -12°C to -16°C, respectively. At other temperatures, the linear growth rates are much slower. Certain crystal types enhance collision and riming processes while the potential breakup of crystals becomes important in the cold precipitation process of conversion of supercooled water droplets to ice. Ice breakup may also play an important role in thunderstorm electrification. Ice crystal growth rates and their controls need to be better understood before this knowledge can be efficiently utilized in the "when and where" decisions of weather modification. These are only a few of the many areas where detailed knowledge about crystal growth habits are needed.

### Zero-Gravity

Past and present terrestrial laboratory experiments have shown the complexity of the precipitation ice growth phase within a cloud. Important questions remain as to just what critical parameters of pressure, temperature, and vapor concentrations determine the transitions between crystal growth types.

Present laboratory investigations of the pure diffusion mechanisms involved in the crystal growth are hampered by gravity-induced convection currents and restricted by the need of mechanical supports. These restrictions modify the heat and vapor transport characteristics sufficiently to mask the observation of the desired physical processes. Ventilation is important in the growth of ice crystals and the contribution of this factor can be better evaluated by comparing terrestrial wind tunnel data with the low-gravity diffusional growth data.

A low or zero-gravity platform would greatly enhance the study of ice crystal growth habits. Gravity-induced convection would be reduced by a factor related to the reduction of the residual acceleration (gravity and vehicle motion) and at the same time permit extended periodsof time for crystal growth with no physical supports.

## METHOD

Long-term growth of ice crystals would be done using an ice thermal diffusion chamber. The supersaturation relative to ice would be controlled by the absolute temperature at a given point within the chamber and the temperature gradient between the two parallel surfaces of such a chamber. The time available for unsupported crystal growth would be a function of crystal mass, shape, and residual acceleration level. For extended times, the crystals may be automatically positioned by utilizing optical, sound or electrical servo devices.

Variables of interest besides pressure, temperature, and supersaturation relative to ice include electric fields (ac, dc), effects of controlled crystal motion through air, and effects of atmospheric "contaminants" on crystal growth habits.

As an alternate approach, short-term (tens of seconds) crystal growth could be studied by use of an expansion chamber. The chamber could utilize continued expansion to make available more moisture for growth and thus simulate the process which occurs in a natural convective atmosphere (c. f., 12. Adiabatic Cloud Expansion). The use of an expansion chamber with walls that are cooled at a controlled rate would be very desirable. Although this approach would be pushing the state of the art, long-term goals should give this approach further consideration.

## INSTRUMENTATION

A thermal diffusion chamber requires that the plate surface temperatures be controlled. The spacing of the plates, their temperature difference, and mean temperature will determine the level of supersaturation from less than 1 percent to 10 percent. A water surface on the warmer, upper plate would provide high local supersaturation within the chamber relative to the ice crystals, while covering this plate with ice would provide lower supersaturation values. In both cases, the lower plate is ice covered.

Crystals in a diffusion chamber (Figure 5-1) typically grow to 1 mm in a few tens of minutes. Crystals 1 mm in length may be conveniently examined during growth by a long-working-distance (about 10 cm) microscope. This arrangement sets the design limits for the chamber to be greater than 2 cm in depth. To examine the temperature range 0°C to -30°C, a chamber at least 10 cm deep is desirable to distinguish between growth in different temperature regimes. A width/height ratio (aspect ratio) of at least 4 is desirable to prevent significant depletion of the downward diffusing vapor by growing crystals and to minimize wall effects, Hence, preliminary design criteria may be established:

A. Height, 10 cm
B. Diameter, 40 cm
C. Horizontal cross section cylindrical with optical viewing ports
D. Upper plate temperature range, +10 to -40°C
E. Lower plate temperature range, -10 to -40°C
F. Total heat load, 60 w
   Power required by illumination system, 25 w
   The efficiency of the refrigeration system must also be considered. It may be necessary to program the wall temperature to prevent ice crystal growth around the chamber. This will have to be done empirically, but a temperature variation to give only a very slight saturation at each level should be sought (Figure 5-2), resulting in an additional heat load of about 20 w. Alternatively, the walls may be maintained at the top temperature, and the aspect ratio increased to about 8.
G. Time constant. Once the chamber is cooled, its diffusional equilibrium time constant, $\tau_d$, is given by approximately

$$\tau_d \simeq \frac{h^2}{\pi^2 D}$$

   Where h (height) = 10 cm and D (thermal diffusivity) = 0.2 $cm^2\ sec^{-1}$, the resulting equilibrium time constant $\tau_d$ = 20 sec. Hence, to approach 0.5 percent of equilibrium for a given change in conditions would take five time constants or about 100 sec.

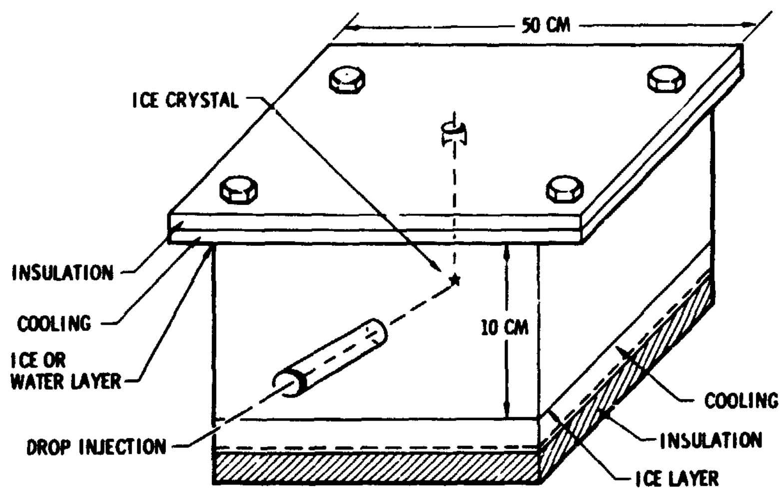


Figure 5-1. Static Diffusion Ice Chamber

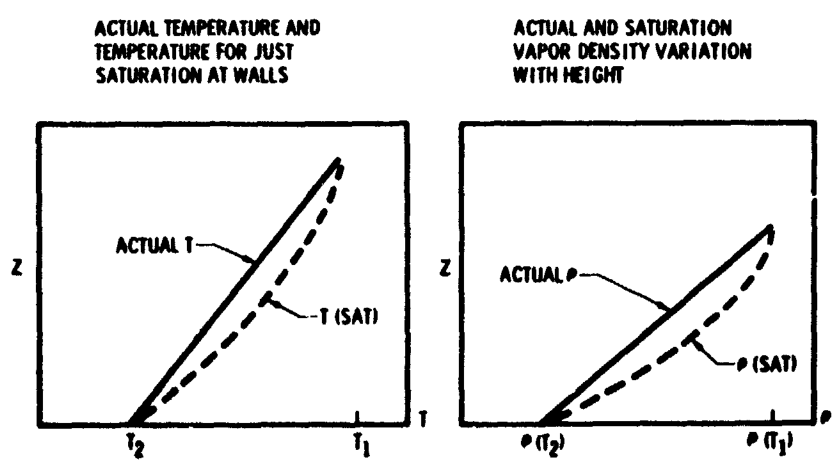


Figure 5-2. Saturation Temperature and Density as a Function of Chamber Position

H. Crystal may take 10 minutes to 2 hours to grow depending on conditions; temperatures must therefore be maintained to 0.2°C (to give saturation ratios to 1/2%) over at least a three-hour period.

I. Construction: Silver top and base
Plexiglas walls
Cooling by thermo-electric servo loop system.

## MEASUREMENTS AND DATA REQUIREMENTS

Time lapse photographs will provide ice crystal geometric shape and size versus time and thus growth rates. Temperature measurements of the upper and lower chamber plates and internal chamber pressure along with a known gas composition will be used to compute the ambient relative humidity as a function of position within the chamber. Voiçe recorded commentary would be utilized at appropriate points during the experiment along with digital recording of time, temperature, pressure, and relative humidity.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 2 |
| • Establish temperature profile between plates, $\Delta T$ | 2 |
| • Insert ice or ice nuclei within chamber* | 3 |
| • Record plate temperatures and time | |
| • Time lapse photography of crystal growth | 10 - 100 |
| • Recycle for various $\Delta T$ | |

*High supersaturations would give large ice crystals in minutes while low supersaturations may take hours.

ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

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# 6. SCAVENGING

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# SCAVENGING EXPERIMENTS

## INTRODUCTION

### Objective

Determine the relative and quantitative importance of thermal (thermophoresis), diffusional (diffusiophoresis), and Brownian forces in the collection of submicrometer aerosol particles by cloud droplets.

### Applications

Scavenging is an important mechanism that is active in cleansing the atmosphere of submicrometer aerosol particles. This mechanism is also the process which unites man's cloud seeding nuclei with the desired cloud elements in the modification or control of rain, snow, hail, and fog and is a very important link between man and weather modification. These experiments will also contribute to the understanding of the scavenging mechanisms involved in the cleansing of the atmosphere. Experimental data will aid in the determination of the quantity of seeding material necessary to accomplish a specific weather modification goal (associated with precipitation processes) and in a better understanding of the atmospheric cleansing processes occurring to reduce air pollution.

### Specific Knowledge Requirement Satisfied

Provide collection efficiencies of seeding material and air pollutants by droplets under various atmospheric conditions.

### Approach

Supercooled droplets and silver iodide particles will be suspended in a measured and controlled temperature, pressure and humidity environment, utilizing the low-gravity conditions of a space platform. Numbers of droplets freezing per unit time (from photographs) under conditions of droplet evaporation, condensation, and non-growth will be used to determine the relative effectiveness of thermal, diffusional, and Brownian forces.

## DISCUSSION

### Significance

Scavenging of aerosol particles by larger droplets and ice crystals is important in three areas: cloud physics, air pollution, and weather modification studies. The cloud microphysics concern is to study the method by which aerosol particles transform cloud droplets to ice crystals. In air pollution problems, precipitation scavenging within a cloud is considered the most important method by which aerosol particles, natural and artificial, are removed from the atmosphere. In weather modification research, one of the optimizing parameters is the size distribution of the seeding aerosol particles, since this influences the seeding effectiveness. In all three of these facets, there are details of the processes by which aerosol particles attach to the cloud droplets which require additional study.

Five major scavenging mechanisms are aerodynamic interception, electrical interactions, Brownian motion, diffusiophoresis, and thermophoresis. The last three are of interest in this experiment while electrical effects will be considered later.

### Zero-Gravity

Terrestrial laboratory studies of the scavenging forces usually are performed using mechanically supported water drops due to the need for long times and microscopic observations. Freely falling droplets in a terrestrial laboratory are not compatible with the necessary observation requirements. As a consequence, thermally conductive mechanical supports introduce uncertainties about the droplet temperature change resulting from evaporation or condensation. Thus, laboratory measurements have been made of the diffusiophoretic forces, but these experiments did not permit the evaluation of thermophoretic forces. Theoretical considerations are divided as to which of these forces are more important and their relative importance to the ever-present Brownian motion.

Zero-gravity would permit free suspension of both aerosol and droplets. This situation will provide undisturbed vapor and thermal fields around the droplets, and thus permit the evaluation of the relative importance of the scavenging forces.

## METHOD

The freezing of supercooled water drops will be used as the detector of aerosol capture where the aerosol will consist of submicron silver iodide particles. A chamber will be controlled to -10°C. Droplets (a few/$cm^3$) and aerosol will be injected within this chamber and the number of droplets freezing per unit time will be determined under conditions of droplet evaporation, condensation, and non-growth. A comparison of the resulting numbers will give the relative effectiveness of the scavenging forces. The analysis is shown in Figure 6-1.

Condition 1 in Figure 6-1 indicates that when a droplet is evaporating the thermal gradient force (T) is inward, the vapor gradient force ($V_p$) is outward, and the Brownian force is inward. The results for condition 2 are for Brownian forces alone and condition 3 reverses the thermal and vapor gradients. Results of condition 2 permit the elimination of the Brownian effects from conditions 1 and 3. A comparison of conditions 1 and 3 permits an evaluation of their relative importance and subsequent comparison of these with condition 2 determines the relative importance of the three forces.

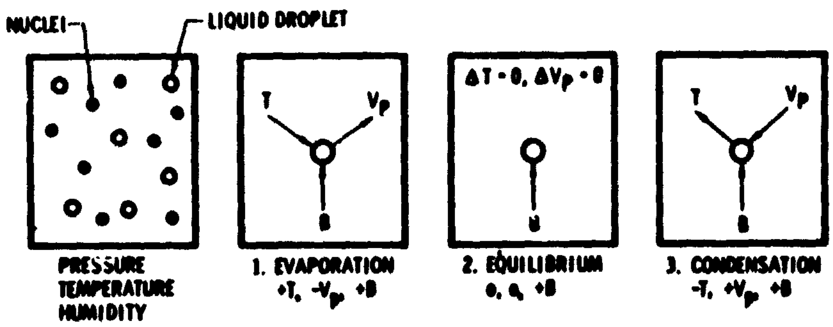


Figure 6-1. Configurations for Determining Scavenging Mechanism

These same experiments will permit some study of the contact nucleation properties of silver iodide. Under appropriate conditions, certain simple aspects of droplet shattering and charge separation may also be included.

## INSTRUMENTATION

The experiments will be performed in a thermal ice diffusion chamber, 10 cm high and 40 cm in diameter. Data collection will be in the form of time lapse photographs which will give the number of droplets freezing as a function of time. The chamber humidity will also be controlled to give the three conditions stated in the Methods section.

## MEASUREMENT AND DATA REQUIREMENTS

Measurements of the plate temperatures and chamber pressure will determine the average relative humidity distribution within the chamber. As droplets freeze, their optical properties change. This change is captured on photographic film along with elapsed time. Analysis of the photographs will provide the numbers and times necessary for the evaluation of the relative importance of the scavenging processes. Time lapse photography of droplet freezing rates will be used along with voice recorded commentary at appropriate points during the experiment. Digital records and displays of temperature, pressure, and relative humidity will be used.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 5 |
| • Establish temperature, pressure and humidity | 10 |
| • Inject nuclei and droplets | 2 |
| • Photograph droplets | 20 |
| • Stop when all droplets frozen | |
| • Recycle 3 times at same conditions | |
| • Recycle with new chamber conditions (Evaporation, condensation, equilibrium) | |
| • Recycle with other nuclei types | |

## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
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# 7. RIMING AND AGGREGATION

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# RIMING AND AGGREGATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine interaction between a supercooled water droplet and an ice surface during events associated with riming and graupel formation.

### Applications

This process is important in crystal multiplication, cloud electrification, and riming on aircraft and stationary objects. These data will contribute toward lightning control in addition to reduction of damage due to riming of stationary objects such as trees and power lines. These data govern the "when" (in the life cycle) and "where" (in the cloud system) decisions of weather modifications involving cold precipitation processes.

### Specific Knowledge Requirement Satisfied

Provide conditions contributing to the adhesion of the supercooled water droplet to an ice crystal surface.

### Approach

Supercooled droplets will be projected at very low velocities toward an ice surface or ice crystal within an ice diffusion chamber under various conditions of temperature, pressure, and relative humidity. This study, through the use of low relative velocities, will be possible by utilizing the low-gravity conditions of a space platform. Photographic data will supply the interaction data while temperature and pressure measurements define the chamber conditions.

## DISCUSSION

### Significance

Graupel and rime form by the accretion and freezing of supercooled water drops on a falling ice crystal or on a fixed obstacle in the wind. The nature of this interaction is of importance for a number of atmospheric processes including crystal multiplication and any associated electrification phenomena. The interaction involves the approach of a supercooled drop to the ice surface and its subsequent freezing. There are reports that small supercooled drops move around for a period of time on an ice surface without freezing.

Zero-Gravity

Terrestrial laboratory experiments are complicated because of the need for the control of the relative velocity between the ice and droplet. Also, the droplet on the ice must be supported if microscopic observations are to be made. A low-gravity environment will permit slow approach velocities between the droplet and ice, thus permitting detail studies of the interactions between the droplet and ice. This will also permit the study of the postulated supercooled droplet motion upon an ice surface.

METHOD

The droplet-ice interaction processes can be studied in detail in the static thermal diffusion ice chamber in the following way:

Supersaturation: Uncharged drops (e. g., 10, 100 mm) are injected at low velocity and allowed to come to thermal equilibrium, at appropriate supercooling. The detailed interaction of the drop is of interest; namely, velocity of approach, instant of freezing, and the freezing mechanism itself. If ice satellite particles are produced, they would be revealed in the prevailing high supersaturation.

Undersatuation: The top and bottom of the chamber are maintained at one temperature (say, -15°C) and the ice crystal is radiantly heated by 2°C to 3°C. The drop is injected as above. This study is of particular interest for small drops which may be inhibited in entry by vapor flux away from evaporating crystal.

A prelimimary experiment may also be considered at an earlier opportunity: A drop is injected with very low velocity onto an ice surface. Interaction is examined by successive strobe photography, with a microscope (Figure 7-1).

The microscope views drop interactions edge on. Drop impaction velocity should be on the order of 10 μm/sec or less. Its trajectory will be studied by stroboscope and the interaction by direct photography.

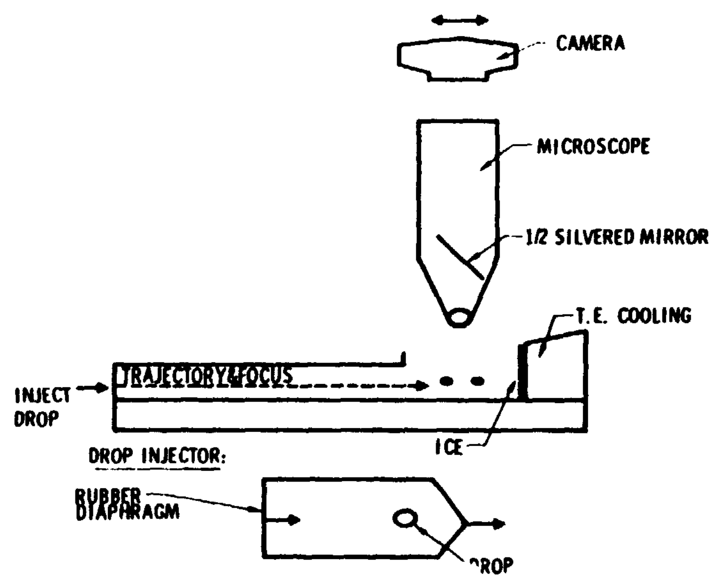


Figure 7-1. Low Velocity – Drop Impaction Study

These studies, carried out at different temperatures, will give valuable information on the nature of the "liquid" layer on the ice. Precautions must be taken to use high-purity, single-crystal ice. Initial laboratory studies should examine processes occurring as a suspended supercooled drop is brought close to an ice surface at constant velocity; high-speed camera studies may also be required.

## INSTRUMENTATION

Crystals in a diffusion chamber (Figure 7-2) typically grow to a millimeter in a few tens of minutes. Crystals of millimeter size may be conveniently examined by a long working distance (~10 cm) microscope during growth. This factor sets the design limits for the chamber, that cannot be less than ~2 cm deep as crystals cannot be conveniently studied. To examine the temperature range between 0°C to - 30°C, a chamber at least 10-cm deep is desirable to distinguish between growth in different temperature regimes. A width/height ratio of >5 is desirable to prevent significant delpetion of the diffusing vapor by growing crystals. Crystals may take 10 min to 2 hr to grow depending on conditions; temperatures must therefore be maintained to 0.2° C (to give saturation ratios to 1/2%) over at least a 3-hr period.

MEASUREMENT AND DATA REQUIREMENTS

Of specific interest is whether a supercooled droplet moves around on an ice surface. Photographic film will provide this information versus time, as well as the time to freeze. The ice chamber plate temperatures determine the relative humidity distribution within the chamber. The data will be time lapse photographs of droplet-crystal interactions and voice recorded commentary during appropriate points of the experiment along with digital recording of time, temperature, pressure, and relative humidity.

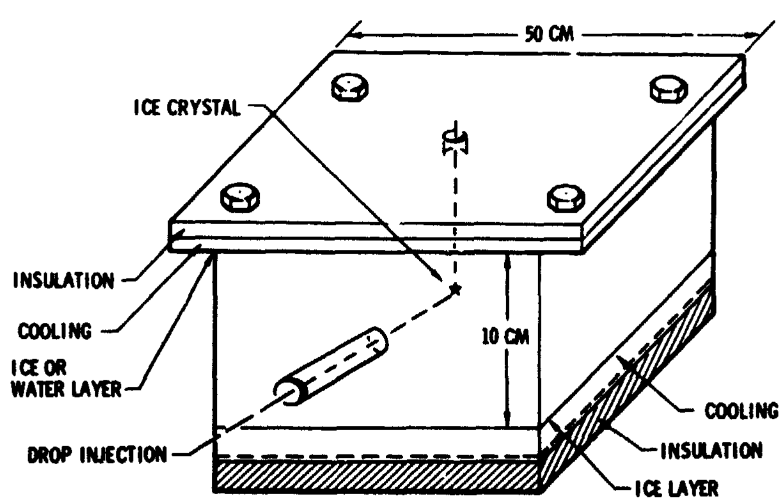


Figure 7-2. Static Diffusion Ice Chamber

PROCEDURE

| Activities | Minutes |
|---|---|
| • Generate ice surfaces and ice crystal | 30 |
| • Purge chamber | 5 |
| • Establish desired thermal equilibrium | 20 |
| • Inject and position ice crystal | 5 |
| • Project droplet diameter $d_1$ at crystal | 2 |
| • Photograph interaction | |
| • Reposition crystal | 1 |
| • Recycle with another droplet $d_1$ (10 times) | |
| • Recycle with droplet $d_2$ (10 times) | |
| • Recycle with new thermal profile (5 values) | |

The thermal profile will include supersaturated and undersaturated conditions. Effects of superimposed electric fields will also be studied.

ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity-Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
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| • T. Ohtake | University of Alaska |

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# 8. DROPLET-ICE CLOUD INTERACTIONS

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# DROPLET-ICE CLOUD INTERACTIONS EXPERIMENTS

## INTRODUCTION

### Objective

Determine the modes and extent of the interactions of ice crystals and supercooled water droplets, including the propagation of the ice phase through a supercooled droplet cloud and the diffusional growth of ice crystals within a cloud of supercooled droplets under varying conditions of temperature, pressure, and droplet/crystal concentrations.

### Applications

The growth of ice crystals and their propagation is important in all attempts to modify cold precipitation processes (e.g., snow, hail, sleet and thunderstorms). The generation of natural ice crystal nuclei has a bearing on the quantity of nuclei that may be needed to achieve a specific weather modification goal. Overseeding and underseeding can defeat the original objective.

### Specific Knowledge Requirement Satisfied

Provide information concerning the rate and conditions of the ice crystal growth and propagation within clouds representing natural concentrations and times.

### Approach

A cloud of supercooled droplets will be generated within a cooled chamber under various conditions of temperature, pressure, and relative humidity. The low-gravity environment of a space platform will provide the necessary time for atmospheric realistic diffusional growth of ice crystals within a supercooled droplet cloud without the normal terrestrial limitation of fallout. Photographic information will provide size and numbers of ice and droplets versus time. The effects of electric, sound and optical fields will also be studied.

## DISCUSSION

### Significance

The propagation of ice throughout the upper levels of clouds (e.g., thunderstorm cumuli) has extreme relevance to all attempts to modify weather. Aircraft observations have indicated that the numbers of ice nuclei near a cloud base are often several decades lower than the number of nuclei necessary to explain the rapidity with which the ice phase moves through the upper parts of a supercooled cloud as determined by radar. An explanation of this rapid propagation of the ice phase is the multiplication of ice particles (e.g., by droplet breakup upon freezing and ice crystal breakup during collisions). These fragments then serve as ice nuclei resulting in the cascading of the ice phase through the cloud. The extent and conditions for natural ice nuclei production must be known before decisions can be made concerning the quantity of seeding material that is injected for a specific modification objective. For some rain and snow processes, too many nuclei cause competition for the available water among the generated ice crystals. This results in small crystals which have less probability of forming rain-size precipitation. At the other extreme, too few seeding nuclei would not release the thermodynamics of a precipitation system that would result in precipitation. Each precipitation process has different seeding requirements, and a knowledge of the total natural and man-injected nuclei properties must be available.

Another important aspect of the cold precipitation process is the growth of ice crystals within a cloud of supercooled water droplets. The crystal types and rate of growth of multiparticles must be studied. Such studies will provide an indication of the conditions and times under which seeding must be done to have maximum effectiveness for a specific weather modification goal.

The two examples above are representative of the many processes which take place during the ice phase of precipitation growth. Each aspect of these processes must be studied separately involving only a few particles under very controlled laboratory conditions before a process can be fully understood in relation to its complex interaction with the environment. For this reason, many of the classes of experiments proposed for zero-gravity, as in a terrestrial laboratory, deal with single or few particles to isolate specific processes for detailed studies.

A necessary step in understanding the complete atmospheric precipitation process is to simulate a large parcel of particles for the study and observation of several microphysical processes proceeding simultaneously. It is this latter aspect to which this experiment is directed. Once individual processes such as diffusion growth and conditions for droplet splintering are understood, then the complex interaction studies can better be approached. Effects of sound, optical, and electrical fields will also be studied in relation to the ice-droplet interactions.

These experiments also will be used to provide knowledge as to the extent to which inadvertent weather modification takes place due to man (e.g., through pollution and urban development).

Zero-Gravity

Observations in the terrestrial laboratory are limited by particle fallout and to some extent convection, which are both gravity-driven. Observation times are limited to milliseconds in small expansion chambers, seconds in diffusion chambers, and tens of seconds in very large chambers. With the large chambers, convection prevents the continuous observation of specific particles, while for the smaller chambers, the seconds available are not enough compared to the minutes available within natural atmospheric clouds. A low-gravity environment would permit the observation of individual crystals and droplets for times that are representative for atmosphere-relevant processes.

METHOD

The nucleation of ice and ice crystal growth within a supercooled cloud of droplets is used as representative experiments of this class.

A cloud of supercooled droplets will be injected into a thermally controlled chamber. Ice or water surfaces will provide an appropriate humidity-controlled environment. For a number of the observations, the chamber will be raised to near saturation at or above freezing temperature by the use of a purge and humidification system. A cloud of water droplets will then be injected into the chamber. As the chamber is then cooled below freezing, the air will become saturated and the supercooled droplets will grow or evaporate as a function of the initial relative humidity and pressure, as well as the final temperature and pressure. At a selected final condition of temperature and relative humidity, some ice nuclei will be injected to produce a few ice crystals. As the supercooled droplets freeze, visual and photographic observations will be made of the freezing of adjacent droplets and the resulting ice phase propagation, as a consequence of droplet splintering (ice multiplication). The application of sound, optical, and electric fields will also be studied in relation to their influence on the ice phase propagation (e.g., due to electric field-driven charged particles generated by freezing supercooled droplets).

Observations will also be made of the ice crystal type and growth rate at the expense of adjacent supercooled droplets as a function of ambient pressure, temperature, and relative humidity. These observations will include, e.g., the rates of evaporation of adjacent droplet and a measure of the sphere of influence for an ice crystal (i.e., that volume from which an ice crystal draws water vapor at the expense of the surrounding supercooled water droplets). The variables of interest include droplet and crystal concentrations and sizes, rates of growth, ambient temperature, pressure, relative humidity along with presence and magnitude of electric, sound and optical fields.

INSTRUMENTATION

The ice chamber geometry with a depth of 10 cm and diameter of 40 cm will be suitable for these experiments. In this case, both controlling surfaces will be cooled to the same temperature to provide a saturated atmosphere. Vibrating needle droplet generators will provide the necessary droplets with controlled surface charge. Vibrating orifice aerosol generators are available that produce aerosols from tens to below 0.01 micrometer diameter nuclei with a diameter spread of less than 1 percent for a fixed generation setting. Aerosol mass and size distributions can be determined with a Whitby instrument, while photographic and optical detectors will provide size, position, and ice/liquid determinations.

## MEASUREMENTS AND DATA REQUIREMENTS

Time lapse photographic data will provide information concerning the physical properties and changes of the ice-droplet cloud. Vocal recorded commentary will be utilized at appropriate points during the experiment in addition to the digital recording of time, temperature, pressure, and relative humidity. Holographic and single-exposure and multiple-exposure interferometry would both be very beneficial due to the desired depth of field and the rate of change information that is needed.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 5 |
| • Establish humidity and thermal equilibrium (+5°C) | 15 |
| • Start time-lapse photographs (1/second) | |
| • Inject droplets (1 to 1,000 per $cm^3$) | 3 |
| • Cool chamber to subfreezing temperature | 15 |
| • Inject ice nuclei | 3 |
| • Visually observe freezing and growth of ice crystals | 20 |
| • Stop camera | |
| • Recycle to other final relative humidity and temperature | |
| • Recycle other droplet sizes | |
| • Recycle other droplet/crystal concentrations | |
| • Recycle with electric, optical, sound fields | |


## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • H. A. Appleman | USAF Air Weather Service |
| • A. N. Dingle | University of Michigan |
| • T. G. Kyle | National Center for Atmospheric Research |
| • G. Langer | National Center for Atmospheric Research |
| • T. L. Ogden | Institute of Occupational Medicine, Edinburgh, Scotland. |

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## 9. HOMOGENEOUS NUCLEATION (ICE)

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# HOMOGENEOUS NUCLEATION (ICE) EXPERIMENTS

## INTRODUCTION

### Objective

Determine the homogeneous freezing distribution of droplets as a function of time, degree of supercooling, and droplet diameter under conditions of no physical supports.

### Application

Cloud droplets in the atmosphere often exist at temperatures to -20°C and sometimes to -35°C before freezing. Most indications are that -40°C is the lower limit at which a small supercooled droplet can exist before it will spontaneously freeze. While the question of heterogeneous freezing (using ice nuclei) is very germane to weather modification, the phenomena of homogeneous freezing is of theoretical interest and sets the framework for the important heterogeneous freezing. Also in arctic cities (e.g., Nome, Alaska), ice fogs occur when temperatures fall below -35°C and thus, in such locations, the properties of homogeneous nucleation are of great interest.

### Specific Knowledge Requirement Satisfied

Provide information concerning freezing probabilities versus free-floating droplet diameters under atmospheric conditions.

### Approach

A monodispersed layer of droplets will be injected into a thermally controlled chamber which can be cooled slowly but steadily down to temperatures of at least -40°C. The low-gravity condition of a space platform will eliminate all uncertainties about contaminations arising from various methods of suspension as used in terrestrial laboratories. Photographic recording will provide data on numbers of ice and droplets versus temperature and time. The optical scattering properties of ice are used to distinguish it from liquid droplets.

## DISCUSSION

### Significance

The formation and behavior of clouds are, in part, regulated by the micro-physical processes active in the formation, development, and behavior of the individual droplets. The mechanisms by which atmospheric nuclei become activated and grow to cloud size droplets is not completely understood. The heterogeneous nucleation process is complicated by the presence of a foreign particle which is usually of unknown composition and possesses surface properties which are not readily characterized. Even the simplest of nucleation processes, the homogeneous nucleation of liquid droplets from the vapor, is not fully understood. Although homogeneous nucleation does not occur in the atmosphere, the concepts established through its study will form a foundation upon which an understanding of the heterogeneous nucleation process can be developed. Therefore, a quantitative understanding of the homogeneous nucleation process must precede our comprehension of the more complex heterogeneous nucleation process.

Homogeneous nucleation is a function of time and temperature, as well as of the characteristics of the "pure" water such as the specific surface free energy of the crystal/liquid interface. A possible result of homogeneous nucleation experiments is the determination of the free energy of this crystal/liquid interface which cannot be accurately measured or calculated in any other way. Various physical supports and errors in droplet surface temperature determinations due to free fall have not yet given a reliable determination of this quantity.

### Zero-Gravity

Many of the homogeneous nucleation experiments have been performed with the water droplets on polished metallic plates between two immiscible liquids or with the liquid sealed within the glass or quartz tube. All of these methods involve surface contact which can modify the surface free energy of the droplet and, thus, the support media can serve as nucleation sites. Of these methods, the two liquid approach appears to be the best. Small droplets can be frozen while free-falling through a temperature gradient. Some difficulty is experienced here in knowing the actual droplet temperature at the time of freezing. A potential solution to a number of these problems is the free suspension of droplets in air under low-gravity conditions (e.g., $10^{-3}$ g), as available on a space platform. These experiments can then be performed over extended time periods with slow rates of cooling to eliminate thermal time lag problems and performed without surface contact with a foreign material.

METHOD

A cloud of pure water droplets will be injected into a thermally controlled chamber while the chamber is above freezing (e.g., +5°C). Then the chamber will be cooled slowly, less than 0.5°C per minute, and photographic data taken at 0.1°C intervals. Because of volume of data required, holographic techniques would be ideally suited. These data would provide sizes and numbers of droplets and crystals versus time, temperature, and rate of cooling. Cooling continues until all droplets have frozen which will take place by about -40°C depending on droplet characteristics (such as volume). Surface area and volume dependence of this statistical freezing will be studied by inserting clouds which all have the same total liquid volume but different droplet diameter (i.e., different surface areas). Consideration must be given to the maximum allowable droplet/crystal density that will avoid diffusion interaction of adjacent particles. Other clouds with the same surface areas but different total liquid volumes will provide further information concerning volume and surface area dependence of homogeneous freezing. At present, most results favor the volume dependence, but experimental uncertainties and difficulties leave room for some question about this.

INSTRUMENTATION

The thermally controlled chamber will be capable of being slowly and uniformly cooled to temperatures as low as -40°C. Special precautions must be taken to prevent ice nucleation on the walls of the chamber. Non-nucleating fluids show the most promise below -20°C, while special teflon surfaces are adequate above this temperature. Droplet injection techniques are available which permit placement of individual droplets within a few millimeters of a desired location. In this way, a single layer of droplets appropriately spaced to prevent interactions, can be provided to conform to the depth of field limitations of a normal camera system. Holographic techniques would remove this restriction, permitting much more information to be collected at a given time because of its volume recording capabilities.

## MEASUREMENT AND DATA REQUIREMENTS

Photographic records will provide the basic information on droplet and crystal numbers, spacing, and sizes which is to be correlated with cooling rates, temperature, time, and ambient relative humidity. Vocal recorded commentary will be utilized throughout the experiment along with digital recording of time, temperature, pressure, and relative humidity. Analog displays of these variables will also be available during the experiment.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber (very clean) | 30 |
| • Establish thermal equilibrium (+5°C) | 15 |
| • Start time lapse camera | |
| • Inject droplet cloud (1 per $cm^3$) | 3 |
| • Cool chamber slowly (0.5°C/min) | 90 max. |
| • Stop camera when all droplets have frozen | |
| • Recycle for other total liquid droplet volume (4) | |
| • Recycle for other total droplet surface areas (4) | |
| • Recycle for other cooling rates | |

## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • C. L. Hosler | Pennsylvania State University |
| • K. O. L. F. Jayaweera | University of Alaska |
| • T. Ohtake | University of Alaska |

# 10. COLLISION-INDUCED FREEZING

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# COLLISION-INDUCED FREEZING EXPERIMENTS

## INTRODUCTION

### Objective

Determine the conditions and frequency of droplet freezing due to collisions of supercooled droplets as a function of droplet size, impact energy, and various ambient conditions of temperature, pressure, and relative humidity. Effects of electric and sonic fields will also be investigated.

### Application

The ice propagation through supercooled clouds has been observed to be rapid and has not been accounted for by measurements of ice nuclei at cloud base. An understanding of all mechanisms contributing to the "rapid glaciation" of clouds has important impact on all attempts to modify clouds producing hail and snow. An understanding of this propagation of the ice phase would permit more realistic estimates of how much seeding material is needed for weather modifications of hail- and lightning-associated precipitation processes.

### Specific Knowledge Requirement Satisfied

Provide information concerning the relationship between supercooled droplet collisions and the ice phase propagation within a cloud.

### Approach

Experiments of supercooled droplet freezing during collision will be studied in a static ice diffusion chamber, utilizing the low-gravity environment of a space platform to provide time and lack-of-physical droplet support. Photographic data will provide velocity and impact parameters. Chamber plate temperature will determine the relative humidity and temperature of the chamber. Observations will also be made for droplet splintering whenever freezing does occur.

## DISCUSSION

### Significance

The propagation of ice throughout the upper levels of clouds (e.g., thunderstorm cumuli) has extreme relevance to all attempts in weather modification.

Aircraft observations have indicated that the number of ice nuclei near cloud bases are often several decades lower than the number of nuclei necessary to explain the rapidity with which the ice phase moves through the upper parts of a supercooled cloud as determined by radar. A contribution to this rapid propagation of the ice phase could be through supercooled droplet freezing as a result of droplet-droplet collisions. Any fragmentation due to freezing would further accelerate the glaciation process since these fragments would then serve as ice nuclei, resulting in the cascading of the ice phase through the cloud.

The extent and conditions for natural ice nuclei production must be known before a decision can be made concerning the quantity of man-injected seeding material that is needed for a specific modification objective. For some rain and snow processes, too many nuclei cause competition among the generated ice crystals for the available water, resulting in small crystals which have less probability of forming precipitation. At the other extreme, too few seeding nuclei would not release the thermodynamics of a precipitation system that would result in precipitation. Each precipitation process has different seeding requirements and a knowledge of the total natural and man-injected nuclei must be available.

Any process which causes a change in the surface free energy or other characteristics of a droplet can potentially contribute to the initiation of the freezing process. Collision processes are known to play an important role in the growth cycle of ice and liquid particles and, thus, the aspect of the collision-induced freezing must be considered.

Zero-Gravity

Gravity-induced motion hinders precise control of droplet-droplet interaction studies in a terrestrial laboratory. Experiments performed within a wind tunnel do not permit the simultaneous suspension of large particles and the detection of any resulting fragmentation of the freezing droplets. Wind tunnel experiments at the University of California at Los Angeles have conclusively shown that droplet distortion does often occur upon freezing, but any possible determination of loss of mass is masked by the unknown change in aerodynamic drag from liquid to distorted solid particle. Droplets of a given mass have a single fall velocity in a terrestrial laboratory; consequently, collisions with controlled impact energy are very difficult. This control is necessary if the physical process is to be understood.

The low-gravity environment of a space laboratory will permit controlled motion and placement of large supercooled water droplets. Impact velocity (i.e., energy) can be varied over a large range for various droplet diameters to determine under what conditions collision-induced freezing may occur. The low-gravity environment will permit detailed observations of the droplet surface before, during, and after the collision. The low-gravity environment will also permit any resulting small ice fragments to be grown to detectable dimensions, which is presently either very difficult or impossible.

METHOD

Supercooled droplets will be placed within an ice diffusion chamber. The chamber will provide thermal and relative humidity control. Other droplets will be injected on a collision course with various velocities and impact parameters. Photography will provide the data acquisition for droplet sizes, velocity, and surface characteristics before, during, and after collision. The chamber will also provide the necessary supersaturation for growth of any resulting ice fragments, providing numbers and possibly crystal characteristics. The addition of sound and electric fields will also contribute to the study of this potential freezing mechanism and associated electrification processes.

INSTRUMENTATION

The static diffusion ice chamber 10 centimeters in depth and 40 centimeters in diameter will provide the necessary temperature and relative humidity controls. Droplet production techniques are available that permit individual droplets to be accurately placed within the designated area. Thus, an array of target droplets, appropriately spaced to prevent interactions, would permit efficient utilization of experiment time. There are several potential techniques available for the projection of droplets with precise velocity and direction control for collisions. The demands on the optical resolution of the medium-speed camera are greatly relaxed in a low-gravity environment since larger droplets can be used to simulate the dynamics of smaller droplets.

Electric field plates and acoustical sources will be placed within the chambers providing acoustical waves from a few hertz to a few kilohertz and electric fields to several kilovolts per centimeter.

## MEASUREMENTS AND DATA REQUIREMENTS

The ambient relative humidity will be computed from the physical laws governing static diffusion chambers. The plate temperatures and presence of ice or liquid surfaces control the relative humidity within the chamber. Stroboscopic and/or medium-speed photography will provide the necessary droplet characteristics before, during, and after collision including relative velocities and drop dimensions. Commentaries will be recorded throughout the experiment along with digital records for time, temperatures, pressure, and relative humidity. Digital and analog displays of these variables will also be available for experiment monitoring and decision making.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 10 |
| • Thermal and vapor equilibrium (+5°C) | 15 |
| • Start camera | |
| • Insert and position target drops | 3 |
| • Cool to subfreezing operating temperature | 10 |
| • Inject droplet at target | 2 |
| • Grow any ice fragments generated | 5 |
| • Determine any particle electrification charge | 3 |
| • Recycle with other droplets (100) | |
| • Recycle with other temperatures (5) | |
| • Recycle with electric fields (3) | |
| • Recycle with sound fields (3) | |

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The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • A. N. Dingle | University of Michigan |
| • K. O. L. F. Jayaweera | University of Alaska |
| • J. E. Jiusto | State University of New York (Albany) |
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| • H. Weickmann | Environmental Research Laboratory, NOAA, Boulder, Colorado |

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## 11. SUPERCOOLED-WATER SATURATION VAPOR PRESSURE

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# SUPERCOOLED-WATER SATURATION VAPOR PRESSURE EXPERIMENT

## INTRODUCTION

### Objective

Determine the saturation vapor pressure of supercooled water.

### Applications

Vapor pressure controls the driving force for ice crystal growth within a supercooled droplet cloud. This quantity is inherently vital to the modification of all cold precipitation processes involved in such weather as hail, snow, and cold fogs. These data govern the "when" (in growth cycle) and "where" (in cloud system) decisions of weather modification involving these cold precipitation processes.

### Specific Knowledge Requirement Satisfied

Define diffusional growth parameters of ice within a supercooled water cloud.

### Approach

Unsupported water drops will reach thermal and vapor equilibrium within a temperature-controlled chamber utilizing the low-gravity conditions of a space platform. Measured vapor pressures as a function of droplet temperature will be compared with theory. X-ray measurement of molecular ordering within supercooled water should also be made.

## DISCUSSION

### Significance

The measurement of this vital parameter, the saturation vapor pressure over supercooled water, will verify or correct the theoretical values obtained through integration of the Clasius-Claperyon equation. The tabulated values of this vapor pressure are not corrected for departures due to nonideality. A more complete knowledge of the vapor pressure parameters will facilitate the computations of ice crystal and droplet growth at temperatures below freezing, thereby permitting a closer approximation to the diffusional growth of ice crystals, which is of vital importance to weather modification.

Zero-Gravity

The measurement of the saturation vapor pressure over supercooled water becomes tractable under zero-gravity conditions, since normal terrestrial limitations of mechanical supports or containing mechanisms can be eliminated. This lack of physical support greatly reduces the probability that a drop will freeze, and hence eliminates the major terrestrial obstacle of measurement of the vapor pressure over liquid water at subfreezing temperatures.

## METHOD

The equilibrium vapor pressure over supercooled water will be measured by injecting a number of liquid water droplets into a temperature-controlled chamber. The chamber gas will consist only of water vapor at a pressure near the initial equilibrium vapor pressure at +5.0°C. The vapor pressure and droplet temperature (infrared measurement) will be measured at 1°C intervals between +5.0°C and -30°C.

## INSTRUMENTATION

A special chamber 30 cm in diameter will be used. The walls of the chamber must not nucleate ice or water; that is, there can be no deposition on the walls of the chamber. This is especially true for ice which has a lower vapor pressure than water. The inside surface of the chamber will be coated with a thin film of teflon or polethylene for temperatures to -20°C and a silicone fluid film below -20°C to prevent nucleation. The chamber walls must also be isothermal. The temperature of the chamber will be electronically lowered in steps, with sufficient duration at each temperature, to permit thermal and vapor equilibrium. The equilibrium temperature and vapor pressure will then be recorded. The pressure transducer will have a resolution of one part in $10^5$ and temperature readout and control of 0.01°C.

## MEASUREMENT AND DATA REQUIREMENTS

The chamber internal temperature and pressure will determine the desired vapor pressure versus temperature, as long as wall condensation is not taking place. Photographs utilizing the change in optical scattering from liquid to ice determine when droplets freeze. Periodic photographs of droplet size and distribution will be taken. Voice recorded commentary will be utilized at appropriate points during the experiment along with digital recording of time, temperature, and pressure Digital and analog visual displays will also be used during the experiment.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Evacuate chamber | 5 |
| • Pressurize to 25 millibars with water vapor | 5 |
| • Establish temperature equilibrium (initial +5°C) | 10 |
| • Inject a number of droplets (200 micron diameter) | 5 |
| • Establish temperature and vapor equilibrium | 10 |
| • Record temperature and pressure | |
| • Lower temperature (in 1.0°C steps) | 5 |
| • Recycle (until droplets freeze) | |
| • Recycle with new droplets | |


## ACKNOWLEDGMENTS

The following individual submitted this idea during the 1971 period of the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributor | Affiliation |
|---|---|
| • T. E. Hoffer | Desert Research Institute, University of Nevada |

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# 12. ADIABATIC CLOUD EXPANSION SIMULATION

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# ADIABATIC CLOUD EXPANSION SIMULATION EXPERIMENT

## INTRODUCTION

### Objective

Duplicate in time and conditions the early portion of the life cycle of a parcel of air involved in an atmospheric precipitation process.

### Application

A better understanding of how nuclei and early growth processes react to actual adiabatic expansions will give a better insight to precipitation processes. This insight will then contribute to directing man's attempt in modifying weather. These early adiabatic growth phases are important in convective cloud formation under both warm and cold conditions and set the stage for the determination of the resulting precipitation form (e.g., rain, hail, and lightning).

### Specific Knowledge Requirement Satisfied

Provide nucleation and early droplet growth characteristics of a complete adiabatic expansion life cycle under more realistic conditions of water vapor supply and temperature.

### Approach

A cloud of nuclei in a 1/15 cubic meter volume will be nucleated and grown through one or more life cycles of expansion and compressions within a thermally cooled-wall expansion chamber. The low-gravity conditions of a space platform will be utilized to provide the necessary time without fallout and convection. Photographic data will provide cloud droplet size and numbers versus time. Cooling the chamber walls at the same rate that the air is cooled by expansion will assure adiabatic conditions for the five to 20 minute expansion cycles.

## DISCUSSION

Knowledge of nucleation and early growth history of cloud droplets plays an important role in all weather modification attempts. This early history and the resulting droplet size distribution determines the later growth pattern (e.g., whether a cloud will produce rain or whether there are too many droplets with too narrow a size distribution resulting in a cloud but no precipitation). Small changes in the nuclei characteristics caused by natural or man-produced pollution products could change the initial nucleation and early growth characteristics of cloud droplets, resulting in inadvertent weather modification.

Nucleation and early growth are representative of the many processes which take place during precipitation growth cycles. Each aspect of these processes must be studied separately involving only a few particles under very controlled laboratory nditions before a process can be better understood in relation to its complex interaction with the environment. For this reason, many of the classes of experiments proposed for zero-gravity, as in a terrestrial laboratory, deal with single or few particles in order to isolate specific processes for detailed studies.

A necessary step in understanding the complete precipitation cycle is to simulate a large parcel of particles for the study and to observe several processes proceeding simultaneously. It is this latter aspect to which this experiment is directed. Once individual processes such as nucleation and early diffusion growth are understood, then the complex interaction studies can better be approached. Effects of sound, optical and electrical fields will also be studied in relation to the droplet-droplet and droplet-environment interactions.

A slow adiabatic expansion of a parcel of air containing condensation and ice nuclei will simulate an actual growth cycle within a cumulus cloud. Effects of electrical, optical, and electrical fields will also be studied as the same parcel of air is taken through several growth cycles.

Zero-Gravity

Expansion chambers in terrestrial laboratories are greatly restricted by gravity-induced convection and fallout. Convection driven by thermal gradients around the walls is being controlled somewhat by cooling the chamber walls at the same rate as the expanding chamber air. This approach has the potential of extending experiment observation from tens of milliseconds to a few seconds. The new limit is determined by a droplet s fall velocity and chamber dimensions. These restrictions dictate the use of larger supersaturations to obtain shorter growth times which are in turn generally not representative of the processes in the earth's atmosphere. These initial processes of nucleation and growth are not gravity-dependent; thus, the performance of these studies in a low-gravity environment would provide a potential solution to the above terrestrial limitations. Because of the importance of this step in studying multi-process interactions, this experiment has been proposed to be performed in a low-gravity laboratory facility.

## METHOD

Ice and condensation nuclei will be placed in varying numbers and compositions in a spherical expansion chamber about 30 cm in diameter. The walls of the chamber will be cooled in synchronization with the expanding adiabatic cooling of the chamber air. The condensation nuclei will activate and grow. Some of the studies will include expansion to subfreezing temperatures to include the ice phase. Nucleation and growth characteristics of droplets and ice will be studied in relation to expansion rates, nuclei concentrations and compositions, and initial relative humidities, and will consider the variables of electrical, optical, and acoustical fields. The effects on nucleation and growth of various "pollutants" injected into the system will also be studied. The prime advantage of a low-gravity environment is that slow expansion representative of fogs can be studied under more realistic supersaturation and elapsed time conditions. Visual and photographic data will provide the necessary data for analysis. Holographic volume recording techniques would be ideally suited for this study for particles greater than a few micrometers in diameter. Optical scatter measurements would provide some information concerning the particle growth from 0.3 to 3 micrometers. Auxiliary equipment is available to provide initial aerosols (nuclei) and their size distributions.

## INSTRUMENTATION

For observation and realism purposes, the chamber should be spherical with provisions for expansion to a radially symmetric form about the viewed volume. These considerations would provide for minimal movement of the particles at the center of the chamber. For expansions of tens of seconds duration

(e. g. , in the study of the nucleation phase involving many particles), the walls of the chamber would not have to be cooled. For the main part of this study, the walls do need to be cooled at a rate equal to the adiabatic cooling of the chamber air due to its expansion. This process would easily provide tens of minutes of observation time. The lack of fallout also permits the same nuclei to be cycled several times, providing information concerning history and memory effects on collection of particles and the resulting effects on the droplet size distribution within the realistic growth environment of an adiabatic expansion.

MEASUREMENTS AND DATA REQUIREMENTS

Photographs, possibly holography, will provide the droplet-ice concentration, position, and motion information. Optical scattering data will provide some information for submicrometer particles. The Raman technique shows promise for providing molecular identification and concentrations of the air and pollutants within the chamber. Recorded vocal commentaries will be made during appropriate points of the experiment along with the digital recording of temperature, pressure, time, and relative humidity. Digital and analog displays will also be available for experimenter monitoring and decisions.

PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 10 |
| • Thermal equilibrium (+25°C) | 15 |
| • Inject nuclei | 5 |
| • Start expansion rate | |
| • Photograph periodically | |
| • Expand to designated temperature | 5 to 30 |
| • Contract | 5 to 30 |
| • Repeat cycle | |
| • Recycle with other concentrations | |
| • Recycle with other nuclei | |
| • Recycle with pollutants | |
| • Recycle with electric, optical and acoustical fields | |

## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • L. J. Battan | University of Arizona |
| • C. L. Hosler | Pennsylvania State University |
| • J. Kassner | University of Missouri |
| • P. Squires | Desert Research Institute, University of Nevada |
| • H. K. Weickmann | Environmental Research Laboratory, NOAA, Boulder, Colorado |

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# 13. ICE NUCLEI MEMORY

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# ICE NUCLEI MEMORY EXPERIMENTS

## INTRODUCTION

### Objective

Determine the effect of an ice nuclei's history on its ability to initiate (nucleate) the ice phase.

### Applications

These data are important in weather modification efforts of all cold precipitation processes such as occur in snow, hail, and cold fogs. Proper seeding decisions will permit the redistribution of snow (e.g., over watershed control areas, recreation areas, and away from lake-located metropolitan areas such as Buffalo, New York). These experiment data will contribute to the "where" (in the cloud system) decisions of weather modification.

### Specific Knowledge Requirement Satisfied

Determine necessary nuclei pre-conditioning (natural and/or artificial) for optimum utilization toward a specific weather modification goal.

### Approach

Nuclei activation efficiencies will be studied within a thermally controlled expansion chamber under various cycles of temperature, relative humidity, and pressure utilizing the low-gravity conditions of a space platform. The relative humidity is determined by the initial and final temperature and pressure of the chamber. Analysis of photographs containing numbered ice crystals versus time in conjunction with the cycled ambient conditions will determine many of the history effects.

## DISCUSSION

### Significance

The formation of ice phase in the atmosphere and particularly in supercooled clouds is of great importance in understanding the evolution of the clouds and in modifying them. In order to estimate the number of ice nucleations in the clouds, the concentration of ice nuclei particles can be measured by introducing warm air samples into proper cold chambers. However, it is known that some ice nuclei can retain "memory" on their surfaces under a dry condition if ice nucleation has previously occurred on them or the particles have experienced a very low temperature. Therefore, the nuclei with memory can form ice crystals at higher temperatures. This memory effect disappears if the sample is warmed before testing.

In order to understand the phase change of a supercooled cloud, the number of ice crystals, as well as the mechanism of formation, needs to be clarified with respect to the cloud condition. Measurements of ice nuclei in warmed sample air do not take into account the ice nuclei with memory nor ice crystals formed by fragmentations of ice crystals or other mechanisms.

Concerning the memory effect of ice nucleation, the proposed mechanisms are controversial. Fukuta suggests a capillary mechanism for the memory effect for a strongly cooled sample, although he does not deny the possibility of the surface memory mechanism. This study is directed to clarify this controversial memory mechanism.

<u>Zero-Gravity</u>

The settling of aerosol particles as well as formed ice crystals presents a serious problem when the experiment cycling must be repeated more than once for the same aerosol sample. It may be expected that the number of ice nuclei with the surface memory will decrease in proportion to the smoke coagulation and the number with capillary memory will increase with respect to the extent of the coagulation, at least at the beginning. The particle settling acts toward reducing the number. If the settling is allowed, it induces an additional complication. The low-gravity condition of the space platform is ideal and allows one to perform a clear-cut experiment without convection and particle fallout.

## METHOD

Samples are mostly organic ice nuclei compounds, but some inorganic compounds such as lead and silver iodide can be used. Soil samples of various kinds should also be tested. The soil sample test allows determination of whether or not there is any memory effect in freely suspended particles in air, but does not serve the purpose of distinguishing the possible mechanism of the memory effect.

The experimental procedure is as follows. Organic smoke particles prepared by a LaMer-Sinclair Generator or the Denver University Smoke Generator are introduced into the conditioning chamber. The smoke particles in the chamber will age by coagulation with each other and with the wall. The smoke particle concentration should be about $10^5$/cc so that the coagulation proceeds at a proper rate. At a given time interval, approximately an hour, a small amount of smoke sample is introduced into the cold expansion chamber. The expansion chamber is kept at a subfreezing temperature $T_1$ (see Figure 13-1) with a supercooled fog created by injecting the steam from the steam source. The ice nucleation proceeds in the fog. After photographing and confirming the number and concentration of nucleated ice particles by the light beam method (illuminate a small, known volume of the cold chamber and

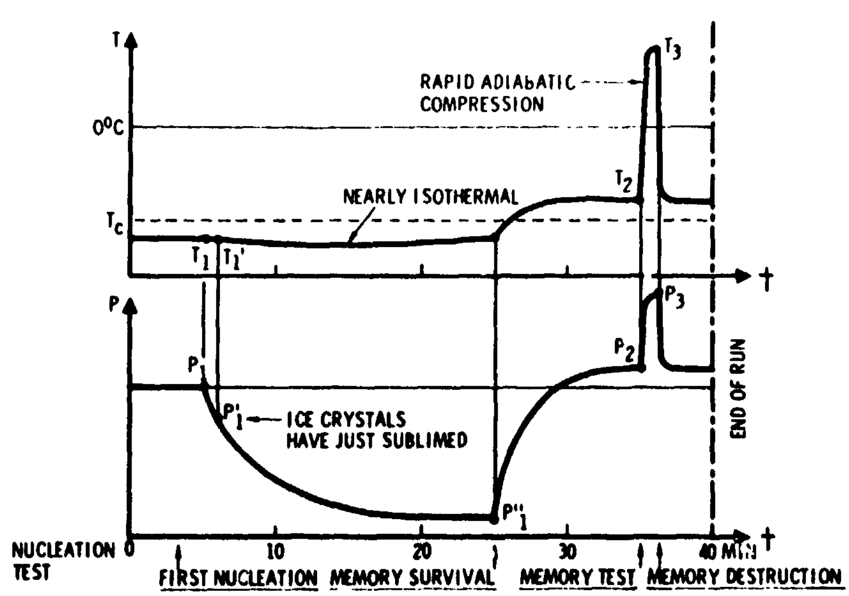


**Figure 13-1. Process of Adiabatic Expansion Chamber for Memory Study**

count the number of ice crystals with the naked eye), the chamber is quasi-isothermally and therefore relatively slowly expanded by maintaining the same temperature at the wall until the pressure reaches a predetermined value $P''_1$ from the initial value of $P_1$. During this course, both the total pressure of the chamber at which the ice crystals have just sublimed, $P'_1$, and the temperature of air, $T'_1$, will be measured. This point is under ice saturation. Therefore, from $P'_1$, $T'_1$, $P''_1$, and $T_1$ one can estimate the relative humidity of the air (RH) at the $P''_1$ position. This dry condition of the chamber will last for about 20 minutes. Then the chamber wall temperature will quickly be raised slightly above the threshold temperature of the ice nucleation $T_2$ (about 2°C warmer than the threshold), and the chamber air will slowly be compressed until the predetermined ice saturation point is reached at temperature $T_2$. A small amount of moisture will be introduced from the steam source and the number of ice crystals formed in the given volume of the light beam will be counted.

If any ice crystals are detected here, it is a sign that the memory exists. In order to confirm the memory effect, the air will be heated up to temperature $T_3$, say to 10° C, by a rapid adiabatic compression coupled with the chamber wall warming. After holding the warm condition for one minute, the system will be quickly cooled back to the previous condition by adiabatic expansion coupled with the wall cooling. The number of ice crystals formed will be checked and compared with that found before this warming process.

After this, the chamber air will be replaced with clean, filtered air and be ready for the next run.

The same experiment will be repeated for a duration sufficient to determine whether the ratio between the number of ice nucleation by memory effect and that of the first nucleation increases with respect to time. Such an increase is a sign of a capillary memory effect.

The chamber temperature needs to be reduced to a level as low as -60° C. The pressure will have to be lowered at least to 1/2 atmosphere. One experimental run will take several hours due to the required aerosol aging.

For this study, there are three main factors under which the experimental runs will have to be made (i.e., $T_1$, RH at $P''_1$, and the sample). Since there are many possible combinations of these variables, the number of levels of the variables must be kept to a minimum. The suggested levels of the variables are:

$T_1$: -60, -20, and $(T_c-3)$°C

$T_c$: the nucleation threshold temperature

RH: 80 and 40%

Sample: 1, 5-Dihydroxynaphthalene for organics,
AgI for inorganics,
and one soil sample

In order to save time, two relative humidity levels may be taken alternately for the runs in the same day.

INSTRUMENTATION

In order to clarify the mechanism, it is necessary to create a capillary-free condition and test the memory effect in it. If the nucleus compound is supported by a surface, capillaries form at points of contact. Therefore, the compound must be suspended in air in order to avoid capillary formation. The compound should not carry any capillaries in itself, and the smoke particles formed by slow condensation should satisfy this requirement if they are kept apart to prevent the coagulation. Once the capillary-free particles of ice nuclei are formed, it would be easy to conduct a suitable experiment making use of the 30-cm spherical expansion chamber with additional vapor supply for mixing and a simple stirrer.

A simplified LaMer-Sinclair Monodispersed Aerosol Generator can be used. This generator consists of a nuclei source (normally a heated wire) evaporator of nuclei compound with dilution gas inlet, mixing mechanism of the nuclei and vapor, and a cooling tube for gentle nucleation and growth. This generator uses a molten chemical to increase the vapor pressure. It may be necessary to use woven fiber glass to restrain the liquid in order to prevent the liquid from floating.

Apart from the expansion chamber operation, electric power of 200 to 300 w is required. Of course, as general supporting equipment, an air filter is necessary to remove aerosol particles and vapor. An activated charcoal method may be appropriate. It is also advisable to have a smoke nuclei box which can be cleaned by the filtered air. The desirable carrier gas is air under 1 atm or slightly less.

## MEASUREMENT AND DATA REQUIREMENTS

Chamber pressure, temperature, and relative humidity will be measured. Photographs will provide data storage of ice crystal numbers versus various chamber condition cycles. Commentary will be recorded at appropriate points during the experiment along with digital recording of time, temperature, and pressure.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Generate nuclei within conditioning chamber | 30 |
| • Purge expansion chamber | 5 |
| • Cool expansion chamber to subfreezing temperature (Figure 13-1) | 20 |
| • Establish pressure $P_1$ | |
| • Generate supercooled fog using steam source | 5 |
| • Inject nuclei sample | 5 |
| • Photograph nucleated droplets and following events | |
| • Quasi-isothermally expansion to pressure $P''_1$ | 20 |
| • Record temperature and expansion | |
| • Raise chamber wall temperature to $T_2$ | |
| • Compress chamber to $P_2$ | 10 |
| • Introduce moisture and photograph resulting ice crystals | 3 |
| • Raise temperature to $T_3$ (+10°C) by rapid compression | 1 |
| • Expand to pressure $P_2$, temperature $T_2$ | |
| • Photograph resulting ice crystals | |
| • Recycle with another aged nuclei sample | |
| • Repeat for other nuclei types. | |

ACKNOWLEDGMENTS

The following individual submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study

- N. Fukuta — Denver University

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# 14. TERRESTRIAL EXPANSION CHAMBER EVALUATION

# TERRESTRIAL EXPANSION CHAMBER EVALUATION EXPERIMENTS

## INTRODUCTION

### Objective

To measure condensation and ice nuclei activation efficiencies under operating conditions similar to those utilized in terrestrial laboratories, but without gravity-induced convection.

### Application

The expansion chamber has been used to study nucleation properties of condensation and ice nuclei. Corrections for the nuclei counts under gravity-induced convection and fallout would permit more accurate studies of atmospheric nuclei and how they participate in atmospheric precipitation processes. This knowledge would be used in weather modification efforts involving rain, snow, and fog.

### Specific Knowledge Requirement Satisfied

Provide information concerning the effects of convection on the measurements of nuclei properties in terrestrial expansion chambers.

### Approach

Standard aerosols will be nucleated, grown, and measured within a expansion chamber using the same procedures of a terrestrial laboratory, except that these experiments will utilize the low-gravity environment of a space platform. The low-gravity results will be compared with terrestrial laboratory results to determine corrections for terrestrially obtained numbers resulting from fallout and convection. This procedure could then be extended to slower, more realistic expansion rates, thus providing an extended range of usefulness for the terrestrial expansion chambers. Utilization of slower expansion rates is described in the experiment class involving adiabatic cloud expansion simulation.

## DISCUSSION

### Significance

The expansion chamber is a very important instrument often used for the studies of ice and condensation nuclei properties which are present in the atmosphere. This chamber provides the necessary supersaturation for nucleation by adiabatic expansion cooling. Working above freezing provides information concerning the condensation nuclei which participate in the precipitation processes, while below freezing temperatures are used for ice nuclei studies. The characteristics of natural and artificial nuclei under representative atmospheric conditions must be known before cloud seeding can be used to redistribute rain and snow, diminish the damage due to hail and lightning, and moderate the effects of hurricanes. The effects of pollutants on atmospheric processes and man's health are also important and can be studied in the expansion chamber.

Most present expansion chambers are limited by convection to a few tens of milliseconds, whereas atmospheric-important processes range from a few tenths of a second to minutes in duration. This convection is a result of non-uniform cooling of the air near the chamber walls. Gravity then causes the heavier air to move downward, resulting in convection. Past attempts to cool the walls of the chamber have been made with little success. Chambers now under development promise to solve part of this convection problem as well as thermal diffusion problems by cooling the walls of the chambers at the same rate that the air is being cooled. If these chambers are successful, the observation times can be extended to a few seconds with this new limit being imposed by gravity-induced fallout. While this extension will provide much needed data, even longer times are needed.

### Zero-Gravity

The low-gravity conditions of a space laboratory would reduce the convection and fallout limitations of an expansion chamber by an amount related to the reduction of the acceleration level. Experiments in these conditions would provide unambiguous numbers relative to specific expansion rates and initial and final conditions. These numbers can then be compared with terrestrially obtained data to determine errors due to convection and fallout. Using such a procedure of comparison for low-g and 1-g chamber results, correction factors can be obtained that would permit the expansion chamber to be operated at lower expansion rates which are more representative of atmospheric conditions (i.e., the useful range of an expansion chamber operating in a terrestrial environment can be extended).

METHOD

Two (or pairs of) identical expansion chambers will be used, one operating in a terrestrial laboratory and the other operating in a low-gravity environment. A series of nucleation experiments would be performed in both chambers using standardized nuclei sources and following presently accepted operating procedures. Recommendations for terrestrial chamber modifications and operating procedures may result from the comparisons of these chambers. Next the chambers will utilize slower expansions than are normally acceptable in a terrestrial laboratory. The results will be used to see if consistent correction factors can be applied to the terrestrial laboratory chambers so that some future experiments could be performed on the ground with repeatable results, rather than being conducted in space. These chambers will incorporate the latest expansion and cooled-wall techniques to obtain the maximum operating times.

INSTRUMENTATION

Initial expansion chamber and supporting subsystems will be similar to those presently used in terrestrial laboratories. This similarity is needed to satisfy the goal of evaluating the numbers obtained in a terrestrial laboratory. Future designs for both terrestrial and low-gravity chambers will incorporate changes in geometry and procedure as improvements are specified. Present small chambers are usually cylindrical in form, about 30 cm in diameter and 45 cm in height. The initial pressure, temperature and relative humidity, and final pressures must be measured to accuracies of 0.05 percent or better. These requirements are pushing the state of the art, especially in the area of relative humidity or total water content measurements. Optical techniques utilizing light scattering and absorption techniques are being developed to detect the water content within the chamber. Optical scattering techniques are also being refined for the detection of submicrometer diameter particles within the chamber, thus monitoring their growth with time.

Raman spectroscopy may permit quantitative monitoring of the gas composition for those experiments involving "pollution" gases.

## MEASUREMENT AND DATA REQUIREMENTS

Photographic data are presently being used to record the numbers of activated nuclei per unit volume. Holographic and other optical techniques that would provide information over a large volume and information concerning submicrometer droplet sizes and gas composition are under development. These techniques will be utilized as they become available. Commentary will be recorded during the experiments in addition to digital recordings of temperature, pressure and relative humidity. Analog and digital displays will be provided for experimenter monitoring and decision making.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 10 |
| • Establish initial pressure, temperature and relative humidity | 15 |
| • Inject nuclei | 5 |
| • Start camera, optical detectors and T, P, RH recording | 2 |
| • Start expansion | |
| • Expand and observe formed cloud | $10^{-4}$ to 30 |
| • Compress and recycle as required | $10^{-4}$ to 30 |
| • Recycle with other expansion rates and final values | |
| • Recycle with other initial T, P, RH values | |
| • Recycle with other nuclei concentrations and types | |


## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • J. L. Kassner | University of Missouri |
| • R. E. Ruskin | Office of Naval Research, Washington, D. C. |

# 15. CONDENSATION NUCLEI MEMORY

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# CONDENSATION NUCLEI MEMORY EXPERIMENTS

## INTRODUCTION

### Objective

Determine the effect of a condensation nuclei's history on its ability to initiate (nucleate) the liquid phase.

### Applications

The possible condensation nuclei memory effects must be considered in the modifications of warm precipitation processes (e.g., warm and polluted fogs). These data will contribute to the "where" (in the cloud system) decisions of weather modification.

### Specific Knowledge Requirement Satisfied

Determine necessary nuclei pre-conditioning (natural and/or artificial) for optimum utilization toward a specific weather modification goal.

### Approach

Nuclei activation efficiencies will be studied within liquid static diffusion chambers under various cycles of temperature and relative humidity, utilizing the low-gravity conditions of a space platform. The relative humidity is determined by the plate surface temperatures in the chambers, and photographs provide the activations numbers. The low-gravity condition permits the same nuclei sample to go through several conditioning cycles.

## DISCUSSION

### Significance

Some cloud condensation nuclei are known to show memory effect in nucleation. There is a possibility that the trained nuclei in the residual air mass of previous clouds may change the nature of the cloud to form later when the air mass is entrained. Of course, the coagulation among the aerosol particles (particularly scavenging of aerosol particles by cloud droplets carrying cloud condensation nuclei inside) changes the nature of the particles and one must also be cautious about this effect.

Although this memory effect is not expected to be as strong as that for ice nucleation, it must be described quantitatively in order to understand cloud processes.

Zero-Gravity

In studying the memory effect, a stable and reproducible condition of the nuclei activation is necessary. For such a purpose, the supersaturation field inside the thermal diffusion chamber appears best suited. However, the particle settling in the chamber after activation presents a serious problem. The low-gravity condition in the space laboratory is advantageous for this reason.

METHOD

The experimental procedure is simple. The smoke sample will be stored in a pre-conditioning chamber. The smoke sample will be taken out of this chamber into the pre-processing chamber by suction, and will flow through the series of chambers. (See Figure 15-1.) The temperature of the pre-processing chamber is the same as that of the drying chamber, and it is

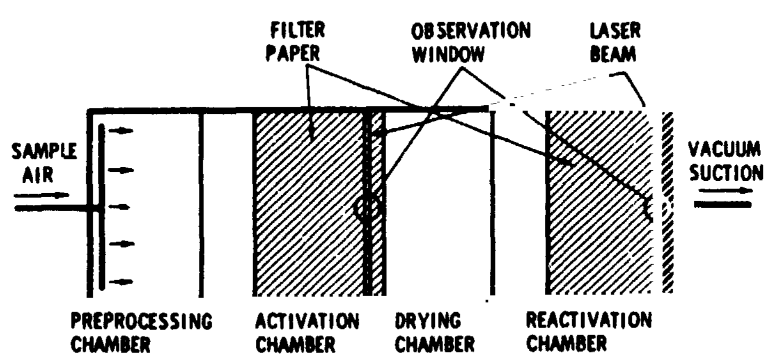


Figure 15-1. Apparatus Design for Nuclei Memory Experiment

higher than that of the diffusion chambers. The first diffusion chamber activates the nuclei at a set supersaturation. The number of nuclei activated will be photographed and counted by means of the microscope attached at the observation window. Then the activated sample or droplets formed on the cloud condensation nuclei will evaporate in the drying chamber.

Since the size of droplets formed is small, the amount of water vapor evaporated from the droplets is negligible. The relative humidity in the drying chamber can be directly estimated from the supersaturation, temperature in the midpoint of the diffusion chamber, and the temperature in the drying chamber.

The dried air will be reactivated when it goes through the second diffusion chamber. The supersaturation in the second diffusion chamber is exactly the same as that of the first diffusion chamber. The number of reactivated nuclei will be measured in the same way. The data of the nuclei active for the first time and the second time will be recorded with respect to the relative humidity of the drying chamber.

It is recommended that humidifying filter papers on the walls in the downstream sides of diffusion chambers be used, leaving the upstream sides uncovered, in order to avoid transient supersaturation.

The diffusion chamber temperature needs to be controlled at about 25°C to 30°C. The drying chamber should be about 0°C to 10°C higher than that of the diffusion chambers. Supersaturation in diffusion chambers will range between 0 and 2 percent.

Proper combinations for the level of variables can be made considering the time limitation and the significance of the experiment.

The memory effect on condensation nuclei is expected to be weaker than that of ice nuclei. It may be necessary to control the relative humidity (no lower than 90 percent) in the drying chamber. It will be interesting to see if the memory effect appears as the aerosol of insoluble particles ages or as the particles coagulate. This can be checked in a similar manner as described in the Ice Nuclei Memory Experiments. Concerning the activity spectrum of cloud condensation nuclei, there is some evidence that the aging or coagulation helps to shift the spectrum towards lower supersaturation.

INSTRUMENTATION

The memory effect can be interpreted in terms of the shift of nucleus spectrum shape in thermal diffusion chambers after treatment under a dry condition. The dryness is a measure for memory survival. The smoke generators mentioned in the Ice Nuclei Memory Experiments can be used. Clay minerals must be ground and put in a plastic bottle while they are on the ground. The plastic container has a course filter and a tube. For aerosol generation, the bottle will be shaken vigorously and then squeezed. The large particles will not come out of the bottle. For burning wood, coal, or other kinds of solids, the Denver University Smoke Generator will be used. Room air is another possible sample for this study.

The experimental apparatus consists of two identical thermal diffusion chambers, separated by a drying chamber. A pre-processing chamber for the sample air, which is identical to the drying chamber, is attached to this apparatus. The tops of the drying chamber and the pre-processing chamber are heated. (Although the chambers do not have a top or bottom, the term is used for the sake of convenience.) This allows the nuclei carrying air to experience low relative humidities. A sketch of the apparatus is shown in Figure 15-1.

Water can be supplied by a wick to the filter paper at the top of each diffusion chamber. The filter paper covers the entire inside of the diffusion chambers. Water condensed on the "bottom" plate will be returned by capillary action to the top plate, supplementing the wick action. The top metal plate of each diffusion chamber has an observation window made of glass. The dark field illumination method will be employed using a good laser beam, and a low magnification microscope will be used for counting.

The sample air is slowly but continuously sucked into the pre-processing chamber. In order to obtain the nucleus air sample in the form of a flat, uniform width sheet, a slit with a slightly larger opening at the end will be used for introduction. The sample air will be sucked out of the chamber through a slit covered with a fine filter paper. This procedure helps to create a uniform air flow into the end wall.

## MEASUREMENT AND DATA REQUIREMENTS

Various chamber temperatures and pressures will define the relative humidity profiles within these chambers. Photographic data will provide the activated nuclei numbers before and after drying. Voice recorded commentary will be utilized at appropriate points during the experiment along with digital recordings of time, temperature, and pressure.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Generate nuclei sample | 30 |
| • Purge chambers | 10 |
| • Establish thermal equilibrium in the chambers | 10 |
| • Inject samples into preprocessing chamber | 2 |
| • Move sample into first diffusion chamber | 2 to 10 |
| • Record plate temperatures | |
| • Photograph activated nuclei | |
| • Move sample to drying chamber | 2 to 5 |
| • Record temperature of this chamber | |
| • Move sample to second diffusion chamber | 2 to 10 |
| • Record plate temperatures | |
| • Photograph activated nuclei | |
| • Recycle at other supersaturations (5 cycles) | |
| • Recycle for other nuclei | |


## ACKNOWLEDGMENTS

The following individual submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

- N. Fukuta Denver University

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# 16. NUCLEI MULTIPLICATION

# NUCLEI MULTIPLICATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine the processes and extent of nuclei material breakup.

### Application

The extent of nuclei breakup is important in the shaping of the nuclei size distribution in the atmosphere. Salt particles, e.g., are an important nucleating agent in oceanic and shoreline haze problems. Better understanding of the breakup process and conditions could lead to improved haze forecasting and to eventual haze and fog modification and control techniques. This breakup also has ecological importance in relation to brine cooling towers and highway salting.

### Specific Knowledge Requirement Satisfied

Provide quantitative determination of the extent of nuclei breakup under specific terrestrial representative conditions.

### Approach

Solution droplets will be injected into a temperature, pressure, and humidity controlled expansion chamber that will utilize the low-gravity conditions of a space platform to provide sufficient observation time. Photographic data will provide time-sequence recording of the processes along with the desired quantitative numbers.

## DISCUSSION

### Significance

The precipitation processes are a function of available nuclei size and number. Large (0.1 μm to 1 μm) and giant (1 μm to 10 μm) NaCl nuclei in particular play a major role. The oceans are the main source of salt nuclei which are produced as a result of the formation and subsequent evaporation of droplets formed by the breakup of waves and bubbles at the ocean surface. The large

NaCl particles are known to exist at much lower concentrations over land masses than over the oceans. A number of processes, including the particle breakup during evaporation, are believed to contribute to this decrease. Knowledge of the depletion processes causing this loss of large NaCl particles would provide a link to the understanding of the nuclei size and mass distribution in the atmosphere. Better understanding of this break-up mechanism could also play an important role in the weather modification technique of dispersing NaCl where precise size and particle numbers are required. Salt particles are important nucleating agents for oceanic and shoreline haze problems. Better understanding of the breakup process would lead to improved forecasting capabilities and to eventual haze and fog modification and control techniques.

Brine cooling towers are considered a method of avoiding the thermal pollution of lakes and rivers during the generation of electrical power. One aspect of brine towers is the significant loss of the saturated solution to the ambient air. The rate of accumulation of the salt from the brine depends on droplet size and fall velocity. Present theoretical considerations, neglecting particle breakup, indicate that an undesirable salt accumulation could occur in an area around the towers. If salt particle breakup existed during the rapid evaporation of the brine droplets, the salt would be dispersed over a greater area. The concentration accumulation decreases by as much as the fourth power of the particle diameter. Thus, if the particle diameter decreased by a factor of 2, the concentration would fall by a factor between 4 and 16 depending on particle size. Thus, the ecological impact depends on the dispersion processes and determines the non-use, use, and design of towers versus other cooling methods.

There has been concern about the damage done by salt wash-off from highways. Another aspect of this problem is the generation of salt mist due to vehicle motion over salt laden highways. The distance that this salt mist disperses depends on salt size and numbers. Salt particle breakup during the evaporation of the salt droplets would be important in the determination of the ecological impact of the use of salt on highways.

Zero-Gravity

Present investigation of this important research problem has reached a plateau because the Earth's gravitational field prevents the observation of this sea-salt breakup process. Small particles are lost when vertical wind tunnels are used to investigate this phenomena. Mechanical supports modify the heat, electrical, and vapor processes and thus do not provide realistic answers. Even with mechanical support, small particles are lost due to gravity-induced "fallout." Thus, a low-gravity environment provides the time to study the primary particle and resulting smaller particles.

METHOD

A given size of droplet with the nuclei material in solution (e.g., NaCl or ocean water) will be inserted into an expansion chamber of specified relative humidity below 80 percent. For low enough humidities, the droplet will evaporate and the nuclei material will crystallize. It is during the crystallization, which is believed to be very rapid, that the number of very small fragments may break away from the main particle. After crystallization, the appropriate expansion will cool the chamber, giving a supersaturation which will result in the nucleation and growth of any small nuclei that were generated. Nuclei counts will be obtained by photography.

An alternate approach after breakup would be to pass the air through a continuous flow diffusion chamber for nuclei growth and then into an optical counter to provide information on size as well as numbers.

An early opportunity version of this experiment depends on photography and Nuclepore filters to provide the qualitative numbers for this type of experiment.

INSTRUMENTATION

Chamber Subsystem

An analysis indicates that a chamber with total internal dimensions of 30 cm by 30 cm by 30 cm will be sufficient for a duration of 2 min, assuming acceleration values of $< 10^{-3}$ g as determined from Apollo 14 demonstration experiments. This chamber will have the following:

A. Purge inlet and outlet.

B. Interior blackened to minimize scattered light.

C. Observation windows 20 cm by 25 cm on two opposite walls.

D. Droplet injection mechanism.

E. Sensors for temperature, pressure, and relative humidity.

Purge Subsystem

This subsystem is used to remove unwanted salt particles from the chamber and to control the RH of the chamber (Figure 16-1). Two three-way valves will be used to control flow:

Position a. Air Bypass. This is used to filter out the salt particles from the chamber, but leaves the relative humidity unchanged.

Position b. Dryer. The total water vapor in the chamber at 20° C, 80 percent relative humidity is $2.1 \times 10^{-4}$ gm. Assuming twice this value to include the purge system gives $4.2 \times 10^{-4}$ gm of water. A

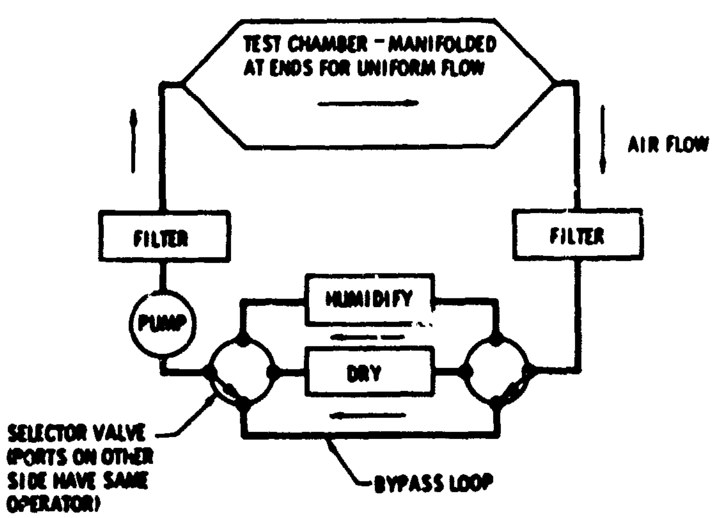


Figure 16-1. Purge System Schematic

desiccant such as molecular sieve can adsorb 0.2 gm of water per gram of its own weight and the sieve material has a packing density of 0.6 gm/$cm^3$. These values indicate that 3 $cm^3$ of molecular sieve would be needed to completely dry the system. One hundred $cm^3$ of desiccant is a reasonable value which permits the chamber subsystem to be purged a number of times.

Position c. Humidifier. The humidifier would utilize surface tension and capillary action to maintain a moist outer surface of a ceramic tube. For proper humidification the air passage should not be greater than 2 mm, with enough length for several seconds of air residence time. The concept is shown in Figure 16-2.

Position d. The addition of a venting/intake valve will permit the necessary expansion and compression.

Pre- and post- 1 μm absolute filters (e.g., millipore filter) will be used to prevent salt particles from entering the humidity control section and also to prevent particles from entering the chamber.

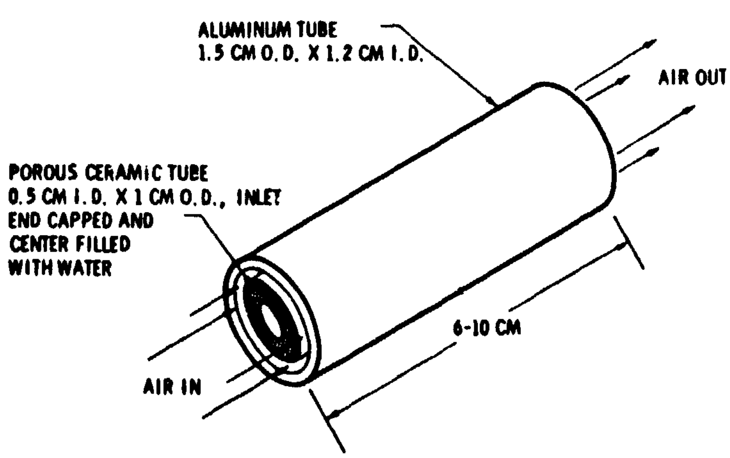


Figure 16-2. Humidifier

## MEASUREMENT AND DATA REQUIREMENTS

The initial relative humidity level must be established and measured to a few percent accuracy. The initial and final temperatures and pressures will be measured. The exact supersaturation is not critical for this application, since it is used only to "activate" the small particles so that they can grow to above a few micrometers in size. In an alternate diffusion chamber approach, the plate temperatures define the relative humidity. Photographs (or the optical counter) will provide numbers of particles generated. Voice recorded commentary will be utilized at appropriate points during the experiment along with digital records of time, temperature, pressure, and relative humidity.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 5 |
| • Establish temperature, pressure and relative humidity | 20 |
| • Insert solution droplet(s) | 1 |
| • Photograph evaporation rate and motion | |
| • Expand to supersaturation | 1 |
| • Photograph resulting droplets | |
| • Recompress-evaporate droplets | 2 |
| • Expand photograph droplets | 1 |
| • Recycle with more droplets of the same size (5 times) | |
| • Recycle for other droplet sizes (3 sizes) | |
| • Recycle for other humidity values (4 values) | |
| • Recycle for other temperatures (3 values) | |
| • Recycle for other pressures (3 values) | |


## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • C. L. Hosler | Pennsylvania State University |
| • J. P. Lodge | National Center for Atmospheric Research |
| • J. L. Kassner | University of Missouri |
| • J. E. Jiusto | State University of New York (Albany) |

# 17. DROPLET COLLISION BREAKUP

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# DROPLET COLLISION BREAKUP EXPERIMENTS

## INTRODUCTION

### Objective

Determine the energy requirements of large droplet-droplet collision-induced breakup as a function of fluid properties, droplet diameters, and external field conditions (sound and electrical).

### Applications

Droplet breakup and the resulting upper limit to droplet size have an important impact on shaping the cloud droplet size distribution. Other areas of concern are associated with soil erosion and heavy rain-induced crop damage. A better understanding of the role of droplet breakup in cloud physics processes would result in increased understanding of the droplet growth mechanisms within clouds, which in turn contributes to man's ability to modify precipitation processes.

### Specific Knowledge Requirement Satisfied

Provide data concerning energy requirements and thus the extent and importance of droplet breakup upon the droplet growth mechanisms within clouds.

### Approach

Droplets with accurately controlled diameter, kinetic energy, and direction will be collided within a general experiment chamber, utilizing the low-gravity environment of a space platform. Surface active agents and electric and sound fields will also be studied in relation to droplet breakup. Time lapse photography will provide data concerning position, size, and number of droplets versus time. Ambient temperature, pressure, and relative humidity will also be monitored and controlled.

## DISCUSSION

### Significance

The initial phases of precipitation formation involve the diffusional growth of submicrometer nuclei particles to a few micrometer diameter liquid (water) spheres. Although this initial growth by diffusion involves only a few seconds to a few minutes of time under normal atmospheric conditions, diffusional growth from 10 or 20 μm diameter to millimeter "precipitation" sizes under non-freezing conditions would take hours, whereas in nature this process is known to take place in 20 to 60 minutes. This growth problem can be resolved by considering collision and coalescence of water droplets. Theory indicates that in order for the coalescence processes to take place, droplets of different diameters must coexist. One of the possible important sources for this range of droplet sizes is the breakup of millimeter size drops due to collisions.

P. R. Brazier-Smith et. al. (Proc. R. Soc. London A 326, 393-408 (1972)) summarized the possible modes of interaction when a pair of water drops collide while falling through air: (1) they may bounce apart, contact of the two surfaces being prevented by the intervening air film; (2) they may coalesce and remain permanently united; (3) they may coalesce temporarily and separate, apparently retaining their initial identities; (4) they may coalesce temporarily, with the subsequent separation accompanied by satellite drops; or (5) with very high-energy collisions, spattering may occur, in which numerous tiny droplets are expelled radially from the periphery of the interacting drops. The type of interaction depends upon the sizes of the drops, their velocities, their angular momentum, the existing electrical forces and other parameters.

Item (2) above is droplet growth by collision, while items (4) and (5) provide a spreading of droplet size distribution permitting item (2) to progress more actively. In addition to these two (or more) body interactions, droplets above a few millimeters in diameter can also break up due to aerodynamic forces during their gravity-induced free fall in the Earth's atmosphere. These various breakup mechanisms are very important in the precipitation processes and an understanding of them will contribute to weather prediction and modification efforts on the micro and macro weather scale.

Droplet breakup can also contribute to the electrification and charge separation in clouds. This charging process can in turn influence the coalescence processes. Neutral droplets containing impurities, breaking up in an electric field and/or with temperature differences can produce multiple droplets that possess net charges. The understanding of these electrification processes will contribute to the prediction, modification, and prevention of electrical storms that cause forest fires and other electrical damage. Precipitation enhancement may also be possible. Knowledge of the breakup processes will contribute to the understanding of the electrification processes.

Zero-Gravity

Present development of this important problem is extremely difficult because the earth's gravitational field hampers detailed observations of the liquid droplet breakup process. Although the free-fall aerodynamics in a gravity field is important, the determination of the physical breakup processes would be greatly enhanced by the application of known forces on the droplet. Thus, the study of other variables such as surface tension and viscosity changes would be greatly simplified. Zero-gravity conditions would permit the application of a wider range of forces and conditions to liquid spheres without the constraints of a wind tunnel or of mechanical supports. This low-gravity environment permits controlled droplet energy conditions, prolonged observation times, and detailed observation of the droplet surface before, during, and after the collision. Measurements of electrification and numbers of generated droplets would then be rendered possible.

METHOD

A general chamber with controls for temperature, pressure, and relative humidity will be used. Experiments that require relative humidities above saturation could be performed in a large diffusion chamber (e.g., the static ice diffusion chamber).

A millimeter target drop(s) will be placed within the field of view of the camera. Other droplets of varying diameters will be projected toward the target droplet with various kinetic energies and impact parameters. Photographs will provide the droplet velocities, surface characteristics during collision and resulting droplet size distribution and positions after collision. The studies will include the use of surface active agents to modify the surface tension, as well as the use of other viscosity fluids. These variations are necessary to determine the form of the governing dynamic equations, and thus determine the effects of pollution and potential weather modification materials on droplet breakup. The influence of electric and sound fields on the collision breakup and resulting droplet electrification will also be studied.

INSTRUMENTATION

A cubic thermally-controlled chamber 30 centimeters on a side will be used to contain the necessary environment. Purge and humidification subsystems will be used to remove particles and to establish the humidity level in the chamber. The thermal and humidity requirements for these experiments are not critical, with a few readings satisfying most requirements.

The generation of droplets above a millimeter in diameter can easily be accomplished. The critical requirement is the projection of droplets with fixed velocity and direction. Several promising generation techniques are being investigated to satisfy this requirement. The experiment procedure can be greatly simplified by the use of acoustical fields to precisely position the target droplet(s) initially. The fields would usually be removed during the collision process. The experiments on the interaction of acoustical fields during collision breakup will require continuous acoustical fields. The acoustical field has been used in the terrestrial laboratory and is even more suitable for the low-gravity environment.

MEASUREMENT AND DATA REQUIREMENTS

Basic data on droplet dynamics will be obtained visually and photographically. Strobe and holographic techniques will be used where appropriate. Holographic interferometry would provide ideal recording of droplet surface distortions due to collisions. Commentary will be recorded during the experiment along with digital records of temperature, pressure and relative humidity. Analog and digital displays of these variables will also be used for experimenter monitoring and decision making.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 1 |
| • Establish T, P, RH | 10 |
| • Inject and position target droplet(s) | 3 |
| • Start cameras and data recorders | |
| • Impinge droplet with fixed velocity (10 droplets) | 2 |
| • Recycle with other velocities, diameters and trajectories (five values each) | |
| • Recycle with various surface tension and viscosities (three values each) | |
| • Recycle with sound and electric fields (four values each) | |


## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • D. C. Blanchard | State University of New York (Albany) |
| • J. E. Jiusto | State University of New York (Albany) |
| • J. P. Lodge, Jr. | National Center for Atmospheric Research |
| • J. D. Spengler | Harvard University |

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# 18. COALESCENCE EFFICIENCIES

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# COALESCENCE EFFICIENCIES EXPERIMENTS

## INTRODUCTION

### Objective

Determine the coalescence efficiencies of small (< 50 μm) cloud droplets under varying impact conditions with specific attention toward what happens at the droplet-droplet interface just before and during collision.

### Application

Droplet collision and coalescence is necessary in the warm precipitation process. The onset of this process at the 10- to 30-micrometer diameter region is of particular interest as it relates to the rain precipitation process and the possibility of altering this initial process for the purpose of weather modification. Atmospheric cleansing of large particulates by internal scavenging is also of interest.

### Specific Knowledge Requirement Satisfied

Provide information concerning the mechanism of coalescence as a function of impact parameters and ambient conditions of relative humidity, pressure, and electrical and acoustical fields.

### Approach

Aerodynamically scaled droplet collision experiments will be performed in air within a general chamber utilizing the low-gravity conditions of a space platform. Under these conditions, millimeter diameter droplets representing 10-μm droplets will be collided under aerodynamically scaled conditions permitting observations and motion control that are presently impossible for this size range in a terrestrial laboratory. Photographic data will provide the necessary motion and time information.

## DISCUSSION

### Significance

An important problem in cloud physics is the study of the growth of raindrops by coalescence. Condensation processes provide clouds with a fairly narrow size distribution with a mean droplet radius of about 10 μm. The spread in sizes produces relative motion in a gravitational field and hence droplet trajectories occasionally lead to collision paths. If these paths produce actual droplet contacts, coalescence of the drops often occurs, leading to a larger drop with a greater fall speed and increased probability of further coalescence. It is believed this process often leads to the formation of rain.

However, a problem occurs in providing an accurate quantitative explanation since, at the droplet sizes generated by condensation, the air appears very viscous and apparent collisions often involve droplets deflecting one another without touching.

Experimentally, this is a very difficult area (a 10-μm radius drop falls about 1 cm $sec^{-1}$ or about 1000 radii/sec). The drops cannot be seen without magnification, and generation procedures do not permit two such drops to be accurately positioned relative to each other or generated in sufficient numbers to allow pairs of interacting drops to be continually kept in a microscope field of view. Moreover, the event occurs too rapidly to allow visual study; in addition, any small convection currents in the air distort the motion quite seriously.

Thus, much attention has been given to analog simulation since numerical simulation is difficult and still involves unverified assumptions (like surface slip and droplet circulation). However, simulation needs to maintain Reynolds numbers at each instant. Thus, simulation by solid balls or bubbles in oil, which allow large (1 cm) drops to maintain Reynolds numbers at terminal velocities, fails to maintain the Reynolds numbers during collision because the density of the oil relative to the simulated drop is far too large.

Zero-Gravity

The only practical medium to maintain the correct density ratio for the suspending medium is air since no other fluid except a gas has a density approaching 1/100th that of water. Thus, the only practical analog accurately simulating the motion with large drops involves reducing gravity.

An analog to reduce gravity by using only a small component of it and by towing the simulated drops with a wire with a servo-controlled small slope from the vertical was attempted by Telford and Cottis (1964), but met many difficulties.

Recent work has suggested the mathematical model would give the correct answer when rerun with the correct density, providing information about the coalescence process when the drops are almost touching. Here, the nature of the water surface may be important; very little information is available on the details of this motion at present.

## METHOD

To simulate the events leading to collisions, the Reynolds number at terminal velocity must be correct and the density ratio must also be correct.

The terminal velocity of a Stokesian droplet is derived from

$$F = 6\pi \eta r v = 4\pi (\rho - \rho') r^3 g/3$$

$$v = 2 (\rho - \rho') g r^2 / 9\eta$$

$$Re = 4 (\rho - \rho') g r^3 / 9 \nu^2 \rho'$$

Where

$\nu = \eta / \rho'$ = kinematic viscosity of air

$\eta$ = dynamic viscosity of air

$\rho'$ = density of air

$\rho$ = density of water

$r$ = drop radius

$g$ = acceleration due to gravity

$Re$ = Reynolds number

Thus, in simulation with reduced g, the subscript e referring to normal atmospheric conditions on Earth,

$$\frac{Re}{Re_e} = \frac{g}{g_e} \frac{r^3}{r_e^3}$$

Thus, if $r = 1000\mu m$ to simulate the behavior of $10\mu m$ droplets, the required value of g is $10^{-6} g_e$, where $g_e$ = gravity on Earth.

Also,

$$\frac{v}{v_e} = \frac{g}{g_e} \frac{r^2}{r_e^2} = 10^{-6} \times 10^{+4} = 10^{-2}$$

so that in the simulated situation the velocities will be much smaller; about $10^{-2}$ cm $sec^{-1}$.

Thus, a droplet will move one radius in 10 sec; in a sustained gravitational field of $10^{-6}g_e$, a 1-mm drop will fall 1 cm in 100 sec.

Such drops would be big enough to be generated with accurate positioning, and big enough to be easily seen with low magnification and large depth of focus. Events would occur slowly enough to allow the observer to see what was going on.

For a simulated drop of radius 1/5mm, which is about as small as would be convenient, the required value of g would be about $10^{-4}g_e$; it would fall at about 0.05cm $sec^{-1}$; that is, about two radii/sec.

The air would have to be enclosed and saturated. The value of gravity would need to be maintained within about 20 percent for periods corresponding to fall distances of about 100 radii (1,000 and 40 sec in the two cases considered above).

The variables that will be studied include surface active agents, temperature, pressure, relative humidity, electric, and sound fields. The actual interaction and the effect of these variables on the coalescence process are of prime interest here. These experiments will be aimed at the realistic simulation for collisions of droplets down to equivalent diameters of a few micrometers. Other experiments are designed for larger droplets where breakup and electrification are the important process.

## INSTRUMENTATION

A cubic thermally controlled chamber 30 cm on a side will be used to contain the necessary environment. Purge and humidification subsystems will be used to remove particles and to establish the humidity level in the chamber. The thermal and humidity requirements for these experiments are not critical with a few readings satisfying most requirements.

The generation of droplets above a millimeter in diameter can easily be accomplished. The critical requirement is the projection of droplets with fixed velocity and direction. Several promising generation techniques are being investigated to satisfy this requirement. The experiment procedure can be greatly simplified by the use of acoustical fields to precisely position the target droplet(s) initially. The fields would usually be removed during the collision process. The experiments on the interaction of acoustical fields during collision breakup will require a continuous acoustical field. The acoustical field has been used in the terrestrial laboratory and is even more suitable for the low-gravity environment.

## MEASUREMENT AND DATA REQUIREMENTS

The primary data will be collected by the use of a medium-speed camera. This data would include droplet diameters, approach velocity, impact parameters, surface characteristics during impact (e.g., surface waves, propagation velocity and amplitude), and final results of coalescence or non-coalescence. Optical interference techniques are available that may be used to supply fine detail of the liquid-liquid surface during coalescence. Commentaries and digital records of temperature, pressure, and relative humidity will be made. Analog and digital displays will be provided for monitoring and decision making.

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Purge chamber | 10 |
| • Insert and position target droplet(s) | 5 |
| • Start camera(s) | |
| • Project droplet(s) at target droplet | 3 |
| • Record ambient conditions and comments | |
| • Recycle | |

These experiments will include the variation of a number of variables including temperature, pressure, relative humidity, gas composition, droplet diameter, viscosity and surface tension, relative kinetic energy, electric and acoustical fields. A number of events (e.g., at least 10 to 20) is needed for each set of variables to assure statistical significance of results.


ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contractors | Affiliations |
|---|---|
| • H. S. Appleman | USAF Air Weather Service |
| • H. R. Byers | Texas A&M University |
| • W. R. Cotton | Experimental Research Laboratory NOAA, Miami, Florida |
| • N. Fukuta | Denver University |
| • A. K. Kamra | University of Roorkee, India |
| • L. H. Ruhnke | Office of Naval Research, Washington, D. C. |
| • W. D. Scott | National Hurricane Center, NOAA Miami, Florida |
| • J. W. Telford | Desert Research Institute, University of Nevada |

# 19. STATIC DIFFUSION CHAMBER EVALUATION

# STATIC DIFFUSION CHAMBER EVALUATION EXPERIMENTS

## INTRODUCTION

### Objective

Determine the absolute nucleation efficiencies of standardized nuclei sources utilizing zero fallout conditions.

### Applications

Static diffusion chambers are presently extensively used to measure relative numbers and activation characteristics of atmospheric condensation nuclei. The study of natural and artificial nuclei materials is important in the quest for materials that can be effectively used for weather modification (e. g., warm fog dispersion) and in the understanding of the effects of man-made air pollutants on man and on natural precipitation processes (inadvertent weather modification). These evaluations may provide correction factors that can be utilized to extend the useful operating range of the static diffusion chamber to lower relative humidity values within the terrestrial environment.

### Specific Knowledge Requirement Satisfied

Provides fallout-free nucleation efficiencies for standard nuclei which can be compared with fallout-limited terrestrial chamber results.

### Approach

Condensation nucleation experiments of standard aerosols will be performed in a commonly used static liquid diffusion chamber, utilizing the low-gravity conditions of a space platform to provide the necessary droplet fallout-free environment. Standard procedures of photographically recorded activated nuclei numbers will be utilized. Identical procedures are to be used in a low-g and a 1-g environment. Comparisons of these results will determine the errors due to droplet fallout under terrestrial laboratory conditions.

## DISCUSSION

### Significance

The numbers, types, and activation characteristics of atmospheric condensation nuclei and other pollution particles are important in weather modification processes, both inadvertent and planned. Present attempts to dissipate the warm fog-smog combination in the Los Angeles International Airport area have failed. Nuclei measurements have shown that the condensation nuclei concentration over land is two to five times higher than over ocean areas. As a consequence of this and the respective nuclei type, droplet growth over land is much more competitive, resulting in a narrower droplet size distribution. The resulting size and numbers of cloud droplets have an important role in setting the stage for hail and thunderstorm conditions.

Static liquid diffusion chambers have been utilized for many years in the measurement and determination of nuclei types and characteristics. Problems have been identified concerning the lack of comparability between chambers of different design. Thus, the validity of nuclei concentration measurements over the last twenty or more years are in question. Comparison and evaluation experiments were performed at the Second International Workshop on Condensation and Ice Nuclei (IWCIN), Ft. Collins, Colorado, August 1970. The resulting data relating to fairly nonactive nuclei tested at the workshop were in error by a factor of 17 too high. Their conclusion was that data already in the literature, using expansion-type counters to measure increases in what were purported to be cloud condensation nuclei in pollution, are unreliable and may be as much as 17 times too high when the pollution contains many fairly nonactive Aitken nuclei, as is frequently the case. Similar problems have existed for diffusion chambers, especially as related to low humidity growth conditions representative of fogs.

### Zero-Gravity

Terrestrial cloud chambers for the study of cloud nuclei rely on the assumption that all individual droplets grow at the same rate (i. e., in a standard Twomey static diffusion chamber, all nuclei are assumed to reach a diameter of 2 μm at the same time so that they can be photographed before fallout). In reality, this is not true. Terrestrial diffusion chambers are restricted to a depth of 1 cm by thermodynamic considerations and as a result their performance is seriously limited by fallout. Nuclei which grow more slowly than others would still be unobservably small when the faster-growing nuclei have formed droplets large enough to fall out of the observing region. The photographic data thus results in counts that are too low by an unknown amount.

The "calibration" of static liquid diffusion chambers under low-gravity conditions using standardized nuclei sources would permit numerical corrections to be applied to terrestrial condensation nuclei measurements and possibly result in the extension of the lower operating range of a terrestrially operated static diffusion chamber.

METHOD

A complete sample flow diagram is given in Figure 19-1. The requirements for certain parts of this system will depend on the exact requirements of a given experiment. When a heated wire is used as an aerosol generator, a coagulation tube may be necessary in order to obtain the desired nuclei diameters. There are vibrating orifice aerosol generators presently available that should eliminate the need for such a tube for certain experiment goals.

The plate temperatures and the internal pressure of the static diffusion chamber determine the relative humidity distribution within the chamber. A portion of a pre-conditioned standard nuclei is admitted to the static thermal diffusion chamber to be activated while another part of the nuclei sample is passed to an aerosol analyzer which can provide total mass per unit volume of air. As the nuclei grow in the static diffusion chamber, photographs are obtained to provide numbers versus time. Experiments will be made with several standard aerosol types using several temperatures, relative humidities, and activation durations. An identical set of experiments will be done in a terrestrial laboratory with a droplet fallout limitation. Comparisons between zero and 1-g data will provide the desired "calibration" corrections as a function of nuclei type and size.

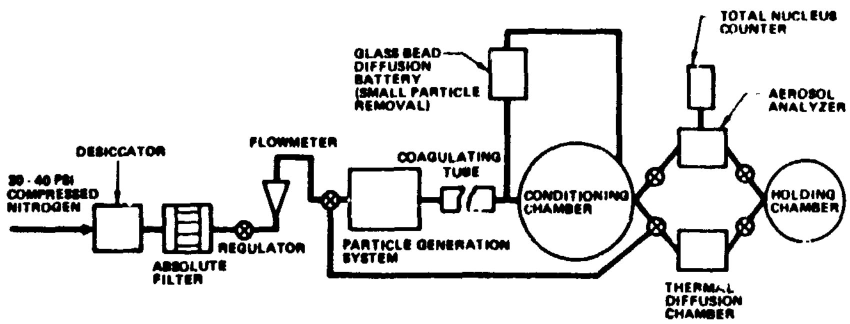


Figure 19-1. Thermal Diffusion Flow Diagram

INSTRUMENTATION

A terrestrial static thermal diffusion chamber with representative dimensions as used by the Cornell Aeronautical Laboratories is given in Figure 19-2.

The upper and lower plates are wetted. A temperature gradient is applied across the chamber by controlling the upper plate at $T_2$ and the lower plate at $T_1$. This $\Delta T$ ($1^{\circ}C$ to $10^{\circ}C$) and the moist surfaces establishes the relative humidity profile between the plates. The time constant to establish the thermal and vapor equilibrium within the chamber dictates a spacing between the plates of around 1 cm, which is independent of gravitational considerations. Thus, these dimensions basically apply also in a low-acceleration environment.

A Whitby-type aerosol analyzer uses electrostatic techniques to provide a total mass or diameter versus numbers distribution of submicrometer particles in the nuclei sample. A vibrating orifice aerosol generator would be used to produce the nuclei sample. Bottled nitrogen or air provides the gas supply. A holding chamber will be provided so that the used aerosol and purge gases would not have to be dumped into the laboratory or overboard.

## MEASUREMENTS AND DATA REQUIREMENTS

Temperatures and pressures of the thermal diffusion chamber and conditioning chamber will be measured. The diffusion plate temperatures and chamber pressure will be used to calculate the internal supersaturation. Analog data from the aerosol counter will provide the necessary initial aerosol distribution while photographs provide the activated nuclei numbers as a function of temperature, pressure, relative humidity, and time. An additional optical counter could provide activated nuclei size distribution down to 0.3 μm instead of a the non-size discerning limit of 2 μm for photographic film detection. Time-lapse photography of the droplet growth and numbers and voice-recorded commentary would be utilized at appropriate points during the experiment along with digital recording of time, temperature, pressure, and relative humidity.

CR90

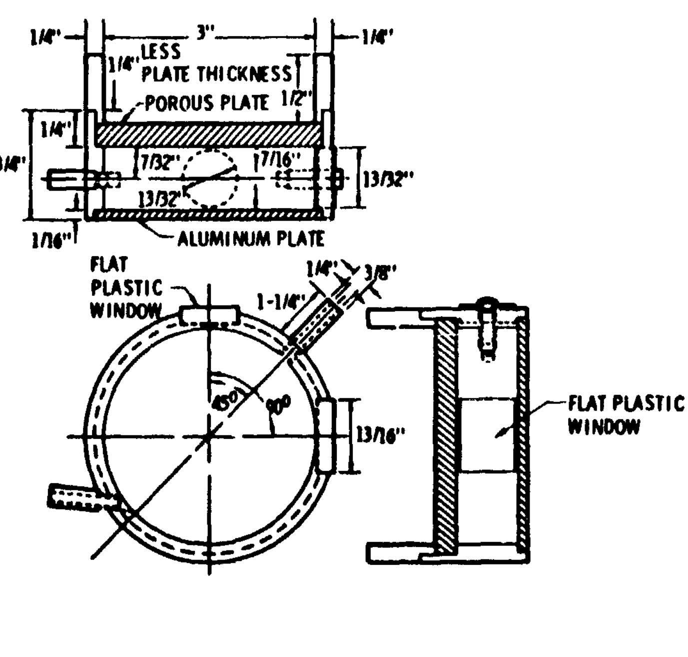


**Figure 19-2. Cornell Aeronautical Laboratories' Thermal Diffusion Chamber**

## PROCEDURE

| Activities | Minutes |
|---|---|
| • Establish thermal equilibrium | 5 |
| • Purge diffusion chamber and aerosol analyzer | 2 |
| • Generate standard aerosol | 3 |
| • Start time-lapse camera | |
| • Introduce sample into chamber and aerosol analyzer | 1 |
| • Photograph growth of droplets and numbers | 3 to 30 |
| • Recycle with same nuclei (5 times) | |
| • Recycle with different relative humidities (5 values) | |
| • Recycle with different standard nuclei (4 types) | |


## ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • W. C. Kocmond | Cornell Laboratories |
| • R. E. Ruskin | Office of Naval Research, Washington, D. C. |
| • P. Squires | Desert Research Institute, University of Nevada |

# 20. UNVENTILATED DROPLET DIFFUSION COEFFICIENT

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# UNVENTILATED DROPLET DIFFUSION COEFFICIENT EXPERIMENTS

## INTRODUCTION

### Objective

Determine the undisturbed diffusion (nonconvective) heat and mass transfer coefficients for growing and evaporating droplets (diameter greater than 10 μm) under various conditions of temperature, pressure, and relative humidity and for various droplet diameters. This class of experiments will include the effects of various atmospheric contaminants on these coefficients.

### Applications

These data are important in the dissipation of fogs from military and commercial airports and major highways. Diffusional growth plays a very important role in the early phases of precipitation cloud growth and thus is important in weather modification efforts. These data contribute the "when" (in growth cycle) and "where" (in cloud system) decisions of weather modification involving warm precipitation processes.

### Specific Knowledge Requirement Satisfied

Determine diffusional growth parameters for water drops in warm precipitation processes including effects of certain contaminants.

### Approach

Unsupported water droplets will be alternately grown and evaporated in a static diffusion (liquid)chamber under various conditions of temperature, relative humidity, and pressure utilizing the low-gravity conditions of a space platform. Measured droplet growth rates (from photographs or scattered light detection) and surface temperature (infrared) will be compared with theory to obtain values for the thermal and mass accommodation coefficients. Comparison of these results with terrestrial wind tunnel measurements will yield the ventilation coefficient associated with aerodynamic growth.

## DISCUSSION

### Significance

Once nucleation has occurred, liquid droplets grow 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 diffusional growth phase for the understanding of the modification of fogs and clouds.

For the large droplets, a diffusion ventilation factor is important due to the gravity-induced relative motion between droplet and air. An important aspect of the growth mechanisms in fogs and clouds is the evaluation of this ventilation factor. The evaluation of the true ventilation factor requires a knowledge of the static diffusion coefficients. These coefficients must be evaluated in an environment lacking gravity-induced convection and acceleration. Also important is the study of the effects of atmospheric contaminants (e.g., smog) on the diffusion coefficients.

### Zero-Gravity

Normal diffusion growth measurements in a terrestrial laboratory require a physical (e.g., spider web), electrical, or acoustical support of the droplet because of gravity. These support techniques cause unnatural surface effects and modify the vapor and heat transfer patterns. Both forced and free convection must be eliminated before nonconvective diffusion measurements can be made. Comparison of theoretical values with these nonconvective diffusion experiments would provide values for the heat and vapor accommodation coefficients, and in turn, comparison of the zero-g data with terrestrial wind tunnel results would provide values for the ventilation coefficient.

## METHOD

The evaporation and condensation rates of large droplets will be studied in a static diffusion chamber. Normal chamber operation will provide various levels of supersaturations and corresponding condensation while a dry chamber will provide evaporation conditions. The need for positioning devices depends on the droplet size, relative humidity, and residual vehicle acceleration.

A droplet will be injected into a pre-conditioned environment and time-lapse photography used to obtain droplet size versus time. Voice commentary and digital readouts of time, temperature, pressure, and relative humidity would be recorded.

Consideration must be given to droplet size, growth times, residual acceleration, lighting, data collection, and droplet injection techniques.

Variables to be controlled are;

- Relative humidity above and below saturation relative to water
- Tempera.ure
- Pressure (Total).

The study of initial growth by diffusion from submicrometer to 10-micrometer sizes is also very important but such measurements can be combined with nucleation experiments.

INSTRUMENTATION

The experiments will be performed in a 10-cm-deep by 40-cm-diameter thermal diffusion chamber whose surfaces are temperature-controlled. The plate spacing, temperature difference (electronically controlled) and local temperature will determine the level of supersaturation from a small fraction of 1 percent to several percent.

MEASUREMENT AND DATA REQUIREMENTS

The plate temperatures and chamber pressure will determine the ambient relative humidity profile within the chamber. Infrared measurements will provide the droplet surface temperature and photographs will provide size versus time for the droplets. Time-lapse photography of the droplet growth or evaporation and voice-recorded commentary would be utilized at appropriate points during the experiment along with digital recording of time, temperature, pressure, and relative humidity.

PROCEDURE

| Activities | Minutes |
|---|---|
| • Establish temperature and humidity conditions | 20 |
| • Inject droplet(s) | 2 |
| • Photograph droplet size versus time | 1-20 |
| • Purge Chamber | 5 |
| • Recycle to new parameters (three temperatures, four humidities) | |
| • Inject "contaminant" | 3 |

ACKNOWLEDGMENTS

The following individuals submitted ideas related to this experiment class in 1971 for the Zero-Gravity Cloud Physics Program Feasibility Study.

| Contributors | Affiliations |
|---|---|
| • A. N. Dingle | University of Michigan |
| • T. E. Hoffer | Desert Research Institute, University of Nevada |
| • K. O. L. F. Jayaweera | University of Alaska |
| • T. Ohtake | University of Alaska |
| • H. H. Sogin | Tulane University |
| • R. G. Soulage | University of Clermont, Clermont, France |
| • P. Squires | Desert Research Institute, University of Nevada |

## CLOUD PHYSICS SCIENTIFIC-COMMUNITY INVOLVEMENT

Throughout the study, special emphasis has been placed on gaining participation by the cloud physics community and keeping the community informed. The Cloud Physics Feasibility Study Summary Report (NASA CR-128998) was given extensive distribution. Significant events involving the community are shown in Table 3. Maintenance of scientific community participation was accomplished by convening the Senior Scientific Board for review and critique of study progress and results.

Table 3

ZERO-GRAVITY ATMOSPHERIC CLOUD PHYSICS SIGNIFICANT EVENTS

| | |
|---|---|
| 1967 – 1968 | OCEANOGRAPHY AND METEOROLOGY SYSTEMS ANALYSIS |
| APR 1968 – SEPT 1971 | MDAC PRELIMINARY EFFORTS |
| SEPT 1971 | INITIATION OF FEASIBILITY STUDY CONTRACT |
| SEPT 1971 – JAN 1972 | SCIENTIFIC COMMUNITY CONTACTS |
| DEC 1971 | ZERO-G CLOUD PHYSICS PROGRAM ANNOUNCEMENT, BULLETIN OF AMS |
| FEB 1972 | FIRST SCIENTIFIC BOARD MEETING |
| FEB 1972 | BRIEFING HDQTRS NASA, (OA AND OMSF) AND MSFC |
| APR 1972 | BRIEFING-APPLICATIONS COMMITTEE OF THE SPACE PROGRAM ADVISORY COUNCIL |
| MAY 1972 | PAPER-INTERNATIONAL COMMITTEE ON SPACE RESEARCH (COSPAR) |
| MAY 1972 | PAPER-AIAA/AMS INTERNATIONAL CONFERENCE |
| JULY 1972 | DEFINITION STUDY FOR ASTP COMPLETED |
| AUG 1972 | INTERNATIONAL CLOUD PHYSICS CONFERENCE, LONDON, ENGLAND |
| AUG 1972 | DEFINITION STUDY FOR DROPLET DYNAMICS EXPERIMENT DEMONSTRATION COMPLETED |
| NOV 1972 | CLOUD PHYSICS FEASIBILITY STUDY SUMMARY REPORT DISTRIBUTED |
| DEC 1972 | APOLLO 17 DROPLET DYNAMICS DEMONSTRATION |
| FEB 1973 | SECOND SCIENTIFIC BOARD MEETING |
| MAR/APR 1973 | MANAGEMENT BRIEFING-HDQTRS NASA (OA AND OMSF) |

The Senior Scientific Board, at its second meeting in February 1973, reviewed the study progress, giving particular attention to the in-depth experiment definition. The board analyzed each experiment class with regard to scientific priority, chamber requirements, operational difficulty, and application to zero-gravity. The board also evaluated the laboratory proposals in terms of the chambers and subsystems required. The laboratory recommended by MDAC and approved by the board includes five interchangeable chambers sharing common subsystems. The preliminary laboratory guidelines established by MDAC and endorsed by the board stated that the laboratory should (1) have multi-experiment capability, (2) be designed to utilize existing or planned space transportation systems (e.g., the Shuttle Sortie laboratory),

(3) be reusable for at least 20 missions, (4) provide for one or two astronauts, (5) have minimum effects on space transportation system operations, and (6) utilize compatible zero-g and 1-g subsystems whenever possible.

## EXPERIMENT CLASS EVALUATION

MDAC recommended 20 experiment classes and chamber selections to the Senior Scientific Board at the 27 and 28 February 1973 meeting. The board concurred with the recommendations and made suggestions that have been incorporated into the experiment description writeups. The board also evaluated each of the experiment classes with regard to scientific priority, achievability and zero-g applicability. The results of the analysis are shown on Table 4 and the rationale for this evaluation follows.

### Scientific Priority

Under the scientific priority factor, an A designates those experiments that the board felt were the most important, of greater interest, and requiring

Table 4
SCIENTIFIC BOARD ANALYSIS

| CLASS OF EXPERIMENTS | PRIORITY FACTOR | CHAMBER ASSIGNMENT | ACHIEVEMENT ABILITY | APPLICABILITY TO ZERO-G |
|---|---|---|---|---|
| 1. CONDENSATION NUCLEATION | A | CFD | B | A |
| 2. ICE NUCLEATION | A | SDI | B | A |
| 3. FREEZE SPLINTERING | A | SDI | A | A |
| 4. CHARGE SEPARATIONS | A | SDI | C | A |
| 5. ICE CRYSTAL GROWTH HABITS | A | SDI | A | A |
| 6. SCAVENGING | A | SDI | B | B |
| 7. RIMING AND AGGREGATION | A | SDI | B | B |
| 8. DROPLET-ICE CLOUD INTERACTION | A | SDI | B | B |
| 9. HOMOGENEOUS NUCLEATION | B | SDI | B | A |
| 10. COLLISION-INDUCED FREEZING | B | SDI | B | A |
| 11. SATURATION VAPOR PRESSURER | B | SDI | C | B |
| 12. ADIABATIC CLOUD EXPANSION | A | E | B | A |
| 13. ICE NUCLEI MEMORY | A | E | B | A |
| 14. TERRESTRIAL EXPANSION CHAMBER EVALUATION | A | E | B | A |
| 15. CONDENSATION NUCLEI MEMORY | C | E | B | C |
| 16. NUCLEI MULTIPLICATION (NaCl BREAKUP) | B | G (E) | A | A |
| 17. DROPLET COLLISION BREAKUP (>0.5 mm) | B | G | C | C |
| 18. COALESCENCE EFFICIENCIES (<100 $\mu$m) | A | G | C | B |
| 19. TERRESTRIAL STATIC DIFFUSION CHAMBER EVALUATION | A | SDL | B | A |
| 20. UNVENTILATED DROPLET DIFFUSION COEFFICIENTS | B | SDL | B | A |

accomplishment as soon as possible. The B priority classes are also important, but they have less priority than A. The rating C is for those experiments that would provide interesting and useful information, but their performance is not as pressing as the other two classes.

### Achievability

Assuming that all necessary equipment were available, an achievability factor was assigned to each experiment. That is, each experiment was evaluated as to how difficult it would be to perform because of such factors as required manipulations. The ratings are A, easiest; B, medium; and C, hardest.

### Zero-Gravity Applicability

A rating was applied to the appropriateness or anticipated contribution of zero-gravity to each experiment. The rating A means that zero-gravity is appropriate for specific goals of the experiment and the low-gravity would greatly enhance certain aspects of performing the experiment which are presently difficult to accomplish in a terrestrial laboratory. The rating B indicates that zero-gravity would contribute information but the problem is not totally gravity-independent.

The C rating was given to those experiments where the phenomena were definitely gravity-dependent and thus possibly not appropriate to zero-gravity experimentation. A number of experiments that were definitely not appropriate to zero-gravity experimentation were deleted from the classes.

## EXPERIMENT REQUIREMENTS ANALYSIS

Each of the 20 experiment classes was analyzed as to the experimental requirements for its performance. A flow chart describing the rationale for this analysis is shown in Figure 8. The first step in the experiment requirement analysis is the selection of the appropriate chamber. Figure 8 shows that the controlling factors for chamber selection are relative humidity, size distribution, and expansion requirements. Figure 9 lists the chambers and assigned experiments.

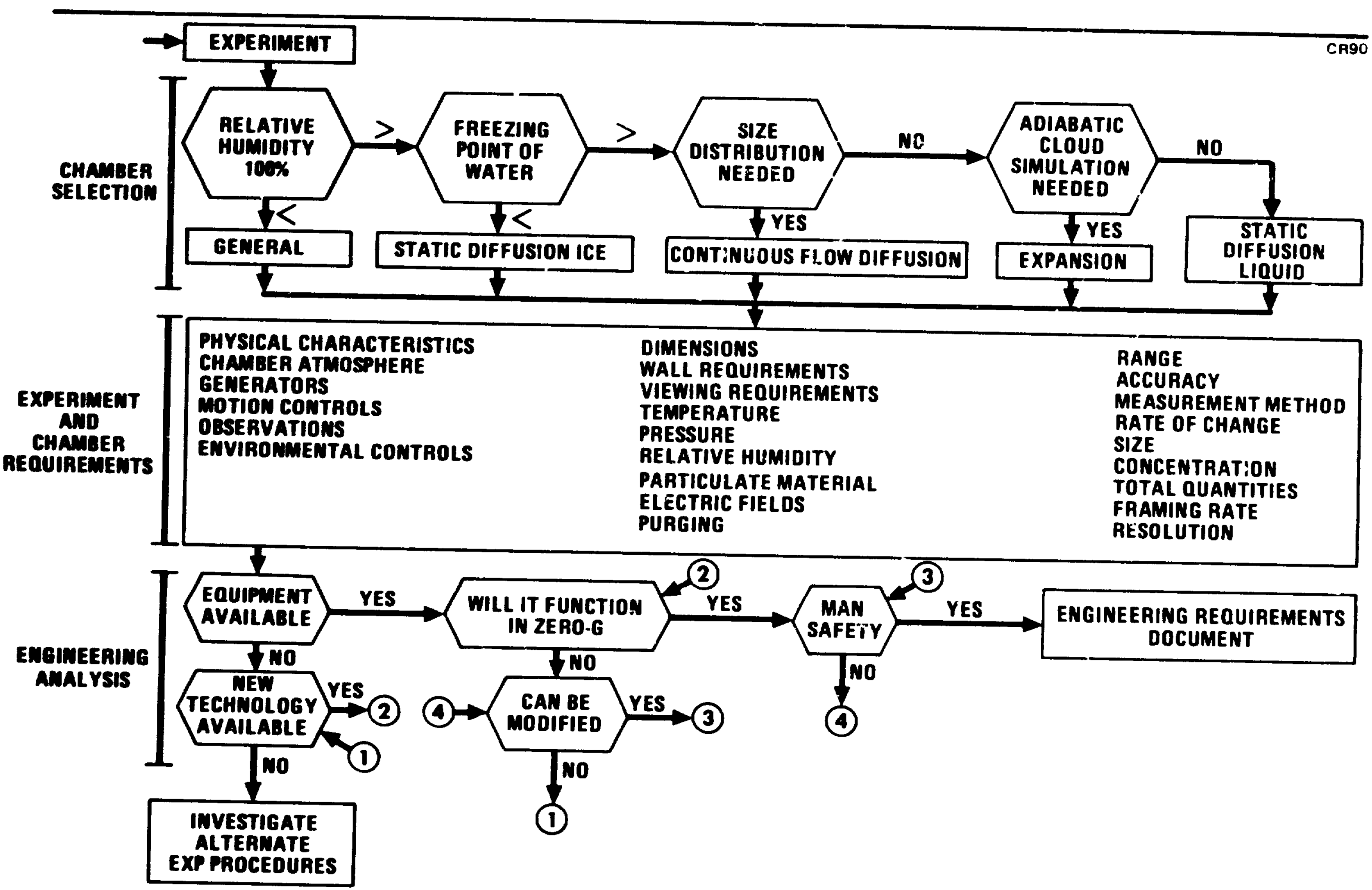
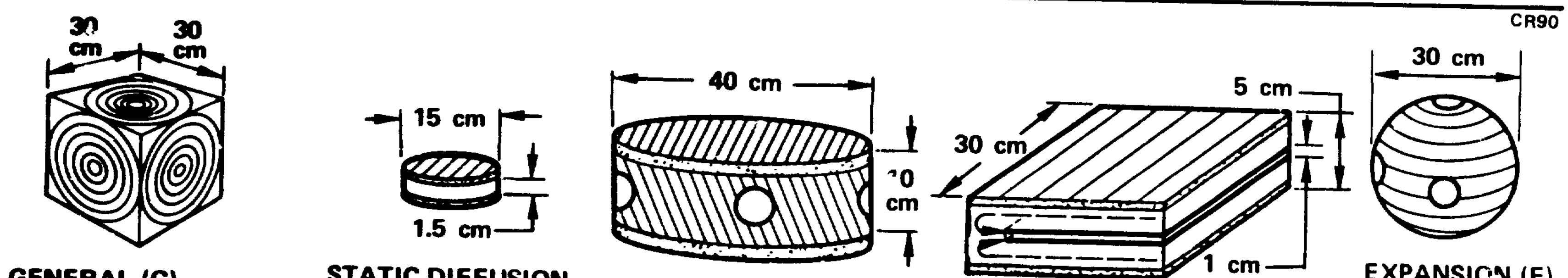



Figure 8. Experiment Requirements Analysis




GENERAL (G)

16. NUCLEI MULTIPLICATION
17. DROPLET COLLISION BREAKUP (ABOVE 0.5 MM)
18. COALESCENCE EFFICIENCIES (BELOW 50 $\mu$M)

STATIC DIFFUSION LIQUID (SDL)

19. TERRESTRIAL STATIC DIFFU-SION CHAMBER EVALUATION
20. UNVENTILATED DIFFUSION COEFFICIENTS

STATIC DIFFUSION ICE (SDI)

2. ICE NUCLEATION
3. ICE MULTIPLICATION
4. CHARGE SEPARATION
5. ICE CRYSTALS GROWTH HABITS
6. SCAVENGING
7. RIMING AND AGGREGATION
8. DROPLET–ICE CLOUD INTERACTION
9. HOMOGENEOUS NUCLEATION
10. COLLISION INDUCED FREEZING
11. SATURATION VAPOR PRESSURE

CONTINUOUS FLOW DIFFUSION (CFD)

1. CONDENSATION NUCLEATION

EXPANSION (E)

12. ADIABATIC CLOUD EXPANSION
13. ICE NUCLEI MEMORY
14. TERRESTRIAL EXPANSION CHAMBER EVALUATION
15. CONDENSATION NUCLEI MEMORY

Figure 9. Candidate Experiment Classes

One major point must be stressed. This program is aimed toward supplying a support facility incorporating many of the common subsystems utilized in cloud physics research. The present concept permits the construction of special chamber geometries and characteristics to fit special experiment requirements. In these cases, these tailored chambers would still use the basic thermal, pressure, and humidity controls of this experiment support facility. Thus, the versatility permits an innovative individual to tackle a complex problem without dissipating efforts in the areas that are common to all experiments.

Once a chamber has been selected, the next area as indicated in Figure 8 is the experiment and chamber requirements. The first step is specification of special physical requirements (e.g., non-wetting or ice nucleating walls). Also taken into consideration are the parameters to be measured and controlled and the ranges and accuracies required for each parameter.

After subsystem component requirements are identified, decisions must be made as to whether present equipment is available. If so, will the equipment function in zero-gravity and is it safety qualified for space operations? New technology areas and potential modifications are identified where applicable. If a given requirement cannot be met (e.g., size distribution in a static diffusion chamber), then the experiment must either be moved to the continuous flow diffusion chamber or the size analysis be deduced indirectly.

PRELIMINARY MISSION ASSESSMENT

Each class of experiments is composed of one or more experiment groups. Within each group a number of parameter variations must be considered. If a given run is a single ice crystal growing, then a number of interactions or repeats must be made with the same conditions to provide experiment validity statistics. A given event will have one to several data points. This multi-experiment and experiment complexity is illustrated in Figure 10.

During the experiment analysis, a list of variable parameters (Table 5) was developed. In addition, the representative number of variations of each parameter (e.g., four discrete droplet diameter sizes) is listed. These parameter variations are used to estimate the total experiment time required for each

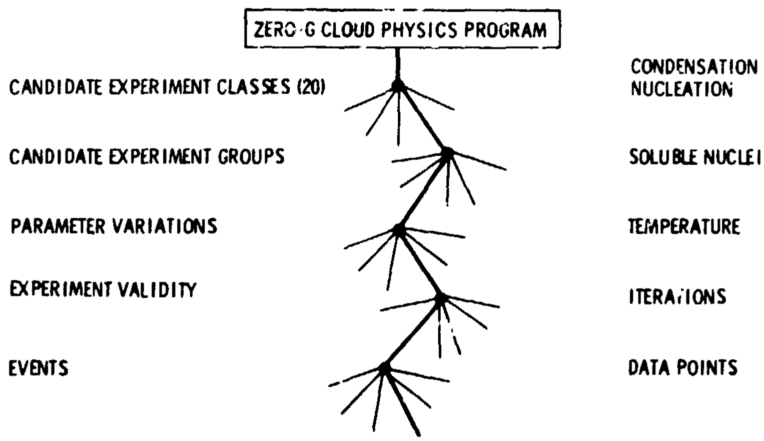



Figure 10. Candidate Experiment Definition Program Tree

Table 5

ASSIGNMENT OF VARIATIONS/PARAMETER

| PARAMETER | VARIATIONS |
|---|---|
| SIZE (DIAMETER) | 4 |
| TYPE (MATERIAL, COMPOSITION, NUCLEI) | 6 |
| POLL(UTANT) (GAS, SOLUTION) | 3 |
| P (PRESSURE) | 3 |
| T (TEMPERATURE) | 4 |
| R.H. (RELATIVE HUMIDITY) | 4 |
| CHARGE | 3 |
| RATE OF COOL(ING) | 4 |
| TIME | 6 |
| SOUND | 3 |
| E (ELECTRIC FIELD) | 3 |
| NUC(LEAR) R(ADIATION) (IONS) | 3 |
| ABSORP(TION) | 3 |
| TURB(ULENCE) | 3 |
| VENT(ILATION) | 3 |
| OPTICAL (POLARIZATION, INTENSITY) | 4 |
| SHAPE | 4 |
| ORIENT(ATION) | 3 |
| CONC(ENTRATION) | 3 |
| VEL(OCITY) | 4 |
| LWC (LIQUID WATER CONTENT) | 3 |
| SURF(ACE) TEN(SION) | 3 |
| A (AEROSOL) | 3 |
| HISTORY (OF NUCLEI) | 3 |
| ION LEV(EL) | 3 |
| INITIAL COND(ITIONS) (EXP. CHAMB.) | 4 |
| K(INETIC) E(NERGY) | 5 |
| GASES (AMBIENT) | 3 |

experiment class as a whole. Table 6 lists the parameter assignments for each experiment class. The total parameter variations are calculated by combining Table 5 with these assignments and they are also listed in Table 6.

Table 7 gives the experiment hours and missions required to perform all of the experiment classes. The chamber assignment, numbers, and application priority correspond to the values assigned during the Senior Scientific Board analysis. The total parameter variations comes from Table 6. The iterations are the estimated experiment repeats for fixed variables that would be required to provide the desirable statistical significance for the results. A very conservative look at the experiment time/iteration requirements provides the factor to convert iterations to man hours. During an actual experiment, these times can be significantly reduced if continuous time is committed to each experiment. The times presented include allowances for calibration, periodic setup, and storage time. The total experiment hours and the translation to missions are also given in Table 6.

Table 6

EXPERIMENT PARAMETER VARIATION ASSIGNMENTS

| CHAMBERS | CLASSES | PARAMETERS | | | | | | | | | | | | | | | | | | | | | | | | | | | | TOTAL PARAM VARIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SIZE | TYPE | POLL. | P | TEMP | RH | CHARGE | RATE OF COOL | TIME | SOUND | E | NUC R | ABSORP | TURB | VENT. | OPTICAL | SHAPE | ORIENT. | CONC | VEL | LWC | SURF. TEN. | AGE | HISTORY | ION LEV | INITIAL COND | KE | GASES | |
| CONTINUOUS FLOW DIFFUS | 1. CONDENSATION NUCL | X | X | X | X | X | X | | | X | | | | | | | | | | | | | | | | | | | | 34 |
| STATIC DIFFUSION ICE | 2. ICE NUCLEATION | X | X | | | X | X | | | X | X | X | X | X | X | | | | | | | | | | | X | | | | 42 |
| | 3. ICE MULTIPLICATION | X | X | X | X | X | X | X | X | | | X | | | | X | | | | | | | | | | | | | | 37 |
| | 4. CHARGE SEPARATION | | X | | X | X | X | | | | X | X | | | | | | | | | | | | | | | | | | 23 |
| | 5. ICE CRYSTAL GROWTH HABITS | X | X | | X | X | X | | | | | | | | | X | X | X | X | X | | | | | | | | | | 38 |
| | 6. SCAVENGING | | X | | X | X | X | | | X | | X | | | X | | | | | X | | | | | | | | | | 32 |
| | 7. RIMING AND AGGREGATION | | X | | X | X | X | X | | | | X | | | | | | | | X | X | | | | | | | | | 30 |
| | 8. DROPLET - ICE CLOUD INTERACTION | | X | | X | X | | X | | X | | X | | | | | X | | | | | | | | | | | | | 29 |
| | 9. HOMOGENEOUS NUCL | X | | | | X | X | | X | X | X | | | | | | | | | | | | | | | | | | | 29 |
| | 10. COLLISION INDUCED FREEZING | X | | X | X | X | X | X | | | X | X | | | | | | | | | X | | | | | | | | | 31 |
| | 11. SATURATION VAPOR PRESSURE | X | X | | | X | | | | | | | | | | | | | | | | | | | | | | | | 14 |
| EXPANSION | 12. ADIABATIC CLOUD EXPAN | | X | | | | | | X | X | | | | | | | | | | X | | X | | | | | | | | 22 |
| | 13. ICE NUCLEI MEMORY | X | X | | X | X | X | | | X | | | | | | | | | | | | | | X | X | | | | | 33 |
| | 14. TERRESTRIAL EXPANSION CHAMBER EVALUATION | | X | | | | | X | | | | | | | | | | | | | | | | | | X | X | | | 17 |
| | 15. CONDENSATION NUCLEI MEMORY | | X | | X | X | X | | | X | | | | | | | | | | | | | | | X | | | | | 28 |
| GENERAL | 16. NUCLEI MULTIPLICATION | | X | | X | X | X | | | | | | | | | | | | | | | | | | X | | | | | 20 |
| | 17. DROPLET COLLISION BREAKUP ( > 0.5 mm) | X | | | X | X | X | | | | | | | | | | | | | | X | | X | | | | | X | | 27 |
| | 18. COALESCENCE EFFICIEN ( < 50 μm) | X | | X | X | X | X | X | | | | X | | | | | | | | | X | | | | | | | X | X | 38 |
| STATIC DIFFUSION LIQUID | 19. STATIC DIFFU CHMBR EVALUATION | | X | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | 17 |
| | 20. UNVENTILATED DROPLET DIFFU COEFFICIENTS | X | X | | X | X | X | | | | | X | | | | X | | | | | | | | | | | | | | 27 |

Table 7

PRELIMINARY MISSION ASSESSMENT

| CHAMBERS | CLASSES | APPLICATION PRIORITY | TOTAL PARAMETER VARIATIONS | ITERATION | MINUTES/ ITERATION | EXPERIMENT HOURS | MISSIONS (40 EXPMT HR TYPICAL) |
|---|---|---|---|---|---|---|---|
| CONTINUOUS FLOW DIFFUSION | 1. CONDENSATION NUCL | A | 34 | 5 | 60 | 170 | |
| STATIC DIFFUSION ICE | 2. ICE NUCLEATION | A | 42 | 5 | 60 | 210 | |
| | 3. ICE MULTIPLICATION | A | 37 | 10 | 60 | 370 | |
| | 4. CHARGE SEPARATION | A | 23 | 15 | 60 | 345 | |
| | 5. ICE CRYSTAL GROWTH HABITS | A | 38 | 5 | 60 | 190 | |
| | 6. SCAVENGING | A | 32 | 10 | 60 | 320 | |
| | 7. RIMING AND AGGREG | A | 30 | 20 | 30 | 300 | |
| | 8. DROPLET-ICE CLOUD INTERACTION | A | 29 | 10 | 60 | 290 | *A 102 |
| | 9. HOMOGENEOUS NUCL | B | 29 | 5 | 60 | 145 | |
| | 10. COLLISION INDUCED FREEZING | B | 31 | 20 | 30 | 310 | *B 24 |
| | 11. SATURATION VAPOR PRESSURE | B | 14 | 10 | 60 | 140 | *C 2 |
| EXPANSION | 12. ADIABATIC CLOUD EXPANSION | A | 22 | 5 | 60 | 110 | |
| | 13. ICE NUCLEI MEMORY | A | 33 | 20 | 60 | 660 | |
| | 14. TERRESTRIAL EXPANSION CHAMBER | A | 17 | 15 | 30 | 178 | |
| | 15. CONDENSATION NUCLEI MEMORY | C | 26 | 5 | 30 | 65 | |
| GENERAL | 16. NUCLEI MULTIPLICATION | B | 20 | 15 | 30 | 150 | |
| | 17. DROPLET COLLISION BREAKUP (>0.5 MM) | B | 27 | 20 | 15 | 135 | |
| | 18. COALESCENCE EFFIC. (<50 μM) | A | 36 | 100 | 10 | 600 | |
| STATIC DIFFUSION LIQUID | 19. STATIC DIFFUSION CHAMBER EVALUATION | A | 17 | 10 | 30 | 85 | |
| | 20. UNVENTILATED DROPLET DIFFUSION COEFF. | B | 27 | 5 | 30 | 68 | |

*PRIORITY

## IV. LABORATORY CONCEPTS AND PLANS

The purpose of the envisioned zero-gravity cloud physics laboratory is to supplement and/or complement the cloud physics research done in terrestrial laboratories. The major capability of the laboratory will be to eliminate gravity-induced relative motion between particles and cloud chambers, thus providing a longer observation time to study the important forces and processes in nature. In nature, droplets fall and the resulting aerodynamic effects influence droplet behavior and interaction. However, there are a number of important cloud physics phenomena in which aerodynamics does not play a prominent role, and which cannot be studied on earth because of gravity or artificial measures taken to prevent gravity effects. The envisioned zero-gravity atmospheric cloud physics laboratory will make a significant number of these vital experiments executable.

A zero-gravity atmospheric cloud physics laboratory is relevant to all aspects of meteorology in the space application program goals, as defined by the following priority research objectives of the National Research Council[1]:

(1) Extend the capability for useful prediction of the weather and atmospheric processes.

(2) Contribute to the development of the capability to manage and control the concentrations of air pollution.

(3) Establish mechanisms for the rational examination of deliberate and inadvertent means for modifying weather and climate.

(4) Substantially reduce human casualties, economic losses, and social dislocations caused by weather.

Workable weather modification and climate control require an accurate and detailed understanding of the microphysical processes of clouds. Adequate information for some of these processes is difficult and in certain cases impossible to obtain in terrestrial laboratories. Micro-cloud physics executed in a zero-gravity cloud physics laboratory will help provide the required experimental data.

[1] "The Atmospheric Sciences and Man's Needs: Priorities for the Future," National Research Council, May 1971.

As will be shown, many experiments are envisioned for the zero-gravity atmospheric cloud physics laboratory and they may take several thousands of hours to complete. Evaluation of the contemplated experiments also showed that manned laboratories provide the best opportunity for the attainment of the experiment objectives; man can provide experiment flexibility and the decision-making capability required for the varied experiment operations.

Because experimentation in atmospheric cloud physics is potentially of great value for mankind can be accomplished in a near-zero-gravity environment, and is enhanced by manned manipulation, it is deemed applicable to the Shuttle-Sortie laboratory.

The Shuttle-Sortie laboratory provides a relatively benign launch and reentry environment for sensitive cloud physics chambers, their ancillary subsystems, and imaging devices. The low-gravity, low-vibration environment in earth orbit permits extended experiment observational time. The Shuttle-Sortie laboratory resources simplify the cloud physics laboratory concept by use of the inherent capabilities of the laboratory. The initial five-day orbital experiment time is sufficient to accomplish the envisioned experiment program in logical increments and a growth in the mission duration to 30 days can be effectively utilized with only minor increases in the weight and volume of expendables such as gas samples and liquids.

In addition to compatibility with the Shuttle-Sortie laboratory, the zero-gravity atmospheric cloud physics laboratory is compatible with a wide variety of other experiments and payloads. The cloud physics laboratory does not require equipment external to the Shuttle-Sortie laboratory, imposes no constraints on orbital orientation other than near-zero-gravity ( $\sim <10^{-3}$ g) and low vibration, does not produce contaminating effluents, and is not influenced by contaminating effluents of other payloads or experiments. Further equipment and subsystems of the cloud physics laboratory can be developed on a schedule that will permit availability for initial operational use on a 1980/81 Shuttle-Sortie laboratory mission.

The following sections provide the rationale for the development of a zero-gravity atmospheric cloud physics laboratory, for the conceptual design, and give the planned schedule for initial usage with a Shuttle-Sortie laboratory in the 1980/81 time period. The laboratory conceptual design was formulated for Shuttle-Sortie Laboratory utilizing the cloud physics experiment requirements to establish design guidelines. Laboratory subsystem requirements were derived from an assessment of the experiment program requirements: they included considerations of flexibility and commonality (both with the experiment program and between the zero-gravity laboratory and terrestrial laboratories). Consideration was given to various laboratory concepts, some austere and others comprehensive. The selected conceptual design provides a laboratory that accommodates or satisfies the requirements of almost the full range of experiments envisioned and all cloud chambers, with only a minor increase in equipment over the most austere version considered.

The conceptual laboratory design is shown in Figure 11. The total laboratory is 1.2 m (4 ft) in depth, 3.1 m (10 ft) high, and 2.5 m (8 ft) long. The laboratory is self-contained and interfaces with the Shuttle-Sortie laboratory for operational power, heat rejection, and data management and communications. All equipment is stowed in the laboratory or mounted on the work bench. Maximum launch weight, including gas samples and expendables, is 468 kg (1,032 lb). The average power required is 132 w with a peak-power requirement of 580 w.

The conceptual laboratory design has been assessed as a low-risk project (i.e., essentially using state-of-the-art technology). All subsystem equipment requires modification for astronaut safety, time-effective experiment operation, zero-gravity compatibility, and flexibility to perform the defined experiment program. The laboratory will contain equipment not presently found in any individual terrestrial cloud physics research laboratory.

The conceptual design of the zero-gravity multi-experiment atmospheric cloud physics laboratory will accommodate experiments from diverse research areas presently being conducted in terrestrial laboratories and enhance the

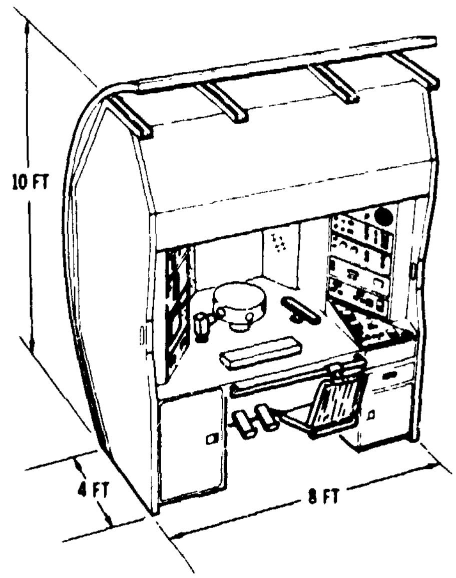



Figure 11. Conceptual Design of Zero-Gravity Cloud-Physics Laboratory

experiment by the unique near-zero-gravity environment. Envisioned usage of the cloud physics laboratory by the scientific community will permit experimental data to be accumulated and hence greatly increase the understanding of micro-physical processes of clouds. This accumulation of knowledge will raise research in this vital area from the plateau imposed by terrestrial laboratory gravity conditions and permit advancement toward attainment of the research objectives defined by the National Research Council.

Experiment/Experiment Program Requirements

The applicable cloud physics research can be conducted in a zero-gravity environment in the 20 experiment classes shown in Table 8. An expanded definition of individual experiments in each of the experiment classes is presented in Section III of this report. The experiment classes were evaluated in depth and the experiment groups, experiment parameter variations, experiment iterations to establish their validity, and discrete experiment events for each class were assessed. As a result, each experiment class was assigned to a specific cloud chamber and mission hours were established for each experiment class.

Table 8

EXPERIMENT CLASSES

| | |
|---|---|
| 1. CONDENSATION NUCLEATION | 11. SATURATION VAPOR PRESSURE |
| 2. ICE NUCLEATION | 12. ADIABATIC CLOUD EXPANSION |
| 3. ICE MULTIPLICATION | 13. ICE NUCLEI MEMORY |
| 4. CHARGE SEPARATION | 14. TERRESTRIAL EXPANSION CHAMBER EVALUATION |
| 5. ICE CRYSTAL GROWTH HABITS | 15. CONDENSATION NUCLEI MEMORY |
| 6. SCAVENGING | 16. NUCLEI MULTIPLICATION |
| 7. RIMING AND AGGREGATION | 17. DROPLET COLLISION BREAKUP |
| 8. DROPLET-ICE CLOUD INTERACTIONS | 18. COALESCENCE EFFICIENCIES |
| 9. HOMOGENOUS NUCLEATION | 19. STATIC DIFFUSION CHAMBER EV[illegible]TION |
| 10. COLLISION-INDUCED FREEZING | 20. UNVENTILATED DROPLET DIFFUSION COEFFICIENTS |

The cloud chambers establish the requirements used to formulate the conceptual design for a cloud physics laboratory. Figure 12 identifies the five primary cloud chambers and their specific features. Further definition with regard to physical characteristics and environmental conditioning requirements (e.g., pressure, temperature, and relative humidity) of both the cloud chamber and the gas samples contained therein are shown in Table 9. The chambers, with their environmental control, sensors, and imaging devices, establish the subsystem requirements for the cloud physics laboratory. As shown, there are significant physical characteristic differences between cloud chambers and that, as defined, they incorporate inherent capabilities for the evaluation of complex cloud physics phenomena.

The results of the assessment relating experiment classes and cloud physics chambers are summarized in Table 9 and detailed in Table 10. Also shown are the mission hours for each experiment class. The mission hours for

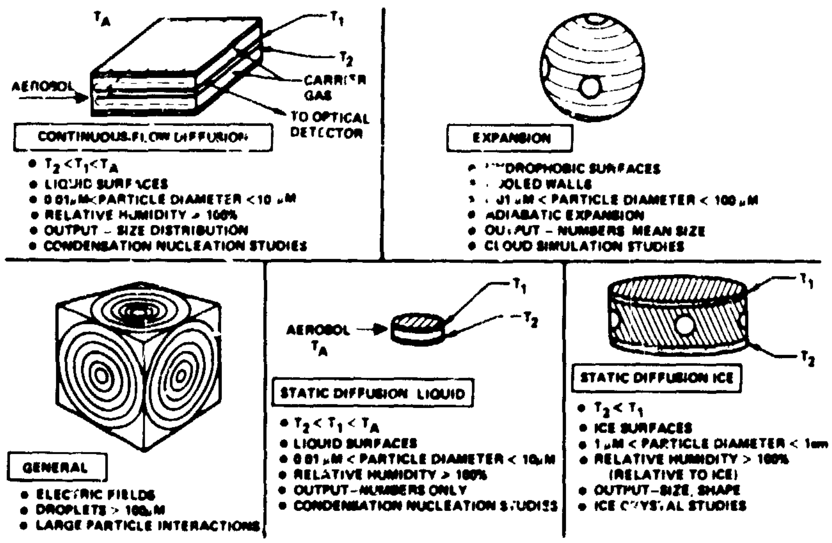



Figure 12. Atmospheric Cloud Physics Chambers

each experiment class were determined by evaluation of the cloud physics experiment tree (discussed in Section III) and by preliminary discrete experiment event timelines.

The typical timelines for minimum, nominal, and maximum experiment events are shown in Figure 13. It should be noted that the experiment timelines show significant variations in experiment setup and shutdown times. Variations in these times can alter the experiment mission hours required. The experiment timelines were predicted not only on the physical manipulations of an astronaut but also on the anticipated transient response capability of the laboratory subsystems to provide the cloud chamber and sample gas. The mission timelines shown in Figure 13 are for a single cloud physics laboratory installed in the Shuttle-Sortie laboratory. The minimum timeline corresponds to a condition where other payloads required the predominant portion of the laboratory resources and astronaut time. The nominal mission and maximum mission timelines assume an increasing use of laboratory resources and astronaut time.

Table 9

CLOUD CHAMBER REQUIREMENTS/CHARACTERISTICS

| REQUIREMENT \ CHAMBER | CONTINUOUS FLOW DIFFUSION | EXPANSION | GENERAL | STATIC DIFFUSION LIQUID | STATIC DIFFUSION ICE |
|---|---|---|---|---|---|
| CONFIGURATION/INTERNAL VOLUME | RECTANGULAR 30 CM X 30 CM X 1.3 CM | SPHERICAL 30-40 CM DIA | CYLINDRICAL 30 CM DIA X 40 CM DEPTH | CYLINDRICAL 10 CM DIA X 1 CM DEPTH | CYLINDRICAL 40 CM DIA X 10 CM DEP |
| SIZE $M^3$ ($FT^3$) | 0.011 (0.4) | 0.042(1.5) | 0.057(2.0) | 0.006(0.2) | 0.034(1.2) |
| WEIGHT KG (LB) | 13.61 (30) | 22.68(50) | 27.22(60) | 4.54(10) | 27.22(60) |
| VIEWING PORTS | CLEAR CYLINDRICAL WALLS | 4 TOTAL 90° APART, 10 CM DIA ON CENTERLINE | ALL SIDES CLEAR | CLEAR CYLINDRICAL WALLS | CLEAR CENTERLINE CYLINDRICAL VIEWING STRIP |
| ENVIRONMENTAL CONTROL TEMPERATURE | -20° TO +30°C ± 0.1°C | -20° TO +30°C ± 0.1°C* | 0° TO + 30°C ± 0.1°C | 0° TO + 30°C ± 0.1°C | -40° TO + 30°C ± 0.1°C |
| PRESSURE | 1/4 TO 1 ATM ± 0.01 ATM | 1/4 TO 1 ATM* ± 0.01 ATM | 1/4 TO 1 ATM ± 0.01 ATM | 1/4 TO 1 ATM ± 0.01 ATM | 1/4 TO 1 ATM ± 0.01 ATM |
| RELATIVE HUMIDITY | 100 TO 103% ± 0.05% | 80 TO 103% ± 0.05% * | 0 TO 80% ± 0.05% | 100 TO 103% ± 0.05% | 100 TO 103% ± 0.05% |
| INHERENT FEATURES | WETTED SURFACES<br>ELECTRIC FIELD<br>ACOUSTICAL FIELD<br>SECONDARY FLOW INJECTION | ELECTRIC FIELD<br>ACOUSTICAL FIELD<br>ADIABATIC EXPANSION & SEQUENCED WALL TEMP. | ELECTRIC FIELD<br>ACOUSTICAL FIELD | WETTED SURFACES<br>ELECTRIC FIELD<br>ACOUSTICAL FIELD | WETTED SURFACES<br>ELECTRIC FIELD<br>ACOUSTICAL FIELD |
| EXPERIMENT CLASSES | 1 | 3 + 1 * | 3 | 2 | 10 |
| EXPERIMENT CLASS MISSION HOURS | 170 | 836 + 178 ** | 886 | 153 | 2620 |

*TOLERANCE RANGE COMPATIBLE WITH ALL BUT ONE EXPERIMENT CLASS. ** MORE STRINGENT TOLERANCE REQUIREMENTS.

Table 10

PRELIMINARY MISSION ASSESSMENT

| CHAMBERS | CLASSES | APPLICATION PRIORITY | PARAMETERS | MISSION HOURS | MISSIONS (40 EXPERIMENT HRS TYPICAL) |
|---|---|---|---|---|---|
| CONTINUOUS FLOW DIFFUSION | 1. CONDENSATION NUCLEATION | A | 7 | 170 | |
| STATIC DIFFUSION ICE | 2. ICE NUCLEATION | A | 11 | 210 | |
| | 3 FREEZE SPLINTERING | A | 10 | 370 | |
| | 4. CHARGE SEPARATION | A | 6 | 345 | |
| | 5. ICE CRYSTAL GROWTH HABITS | A | 10 | 190 | |
| | 6. SCAVENGING | A | 8 | 320 | |
| | 7 RIMING AND AGGREGATION | A | 8 | 300 | |
| | 8. DROPLET-ICE CLOUD INTERACTION | A | 7 | 290 | |
| | 9. HOMOGENEOUS NUCLEATION | B | 7 | 145 | |
| | 10. COLLISION INDUCED FREEZING | B | 9 | 310 | |
| | 11. SATURATION VAPOR PRESSURE | B | 3 | 140 | A 102 |
| EXPANSION | 12. ADIABATIC CLOUD EXPANSION | A | 5 | 110 | B 26 |
| | 13. ICE NUCLEI MEMORY | A | 8 | 660 | C 2 |
| | 14. TERRESTRIAL EXPANSION CHAMBER EVALUATION | A | 4 | 178 | TOTAL 130 |
| | 15. CONDENSATION NUCLEI MEMORY | C | 6 | 66 | |
| GENERAL | 16 NUCLEI MULTIPLICATION | B | 5 | 150 | |
| | 17. DROPLET COLLISION BREAKUP (>0.5 MM) | B | 7 | 136 | |
| | 18. COALESCENCE EFFICIENCES (<80 μM) | A | 10 | 600 | |
| STATIC DIFFUSION LIQUID | 19. TERRESTRIAL STATIC DIFFUSION CHAMBER EVALUATION | A | 4 | 86 | |
| | 20. UNVENTILATED DROPLET DIFFUSION COEFFICIENTS | B | 7 | 68 | |

CR90

| | TYPICAL MISSION TIMELINE | TYPICAL EXPERIMENT TIMELINE |
|---|---|---|
| MINIMUM<br>(1 ASTRONAUT/EXPERIMENTER) | 2-5 HRS EXPERIMENT CYCLE<br>2-3 TIMES/MISSION<br>4-15 EXPERIMENT HOURS | EXPERIMENT SEQUENCE<br><br>T = 14 MIN.<br>SETUP – 10 MIN<br>SECURE (BETWEEN CYCLES) – 2 MIN<br>SHUTDOWN – 20 MIN |
| NOMINAL<br>(1+ ASTRONAUT/EXPERIMENTER) | 5-8 HRS EXPERIMENT CYCLE<br>5 TIMES/MISSION (DAILY)<br>25-40 EXPERIMENT HOURS | EXPERIMENT SEQUENCE<br><br>T = 32 MIN<br>SETUP – 20 MIN<br>SECURE (BETWEEN CYCLES) – 6 MIN<br>SHUTDOWN – 30 MIN |
| MAXIMUM<br>(2 ASTRONAUT/EXPERIMENTERS) | TWO 8 HR EXPERIMENT CYCLES<br>5 TIMES/MISSION<br>80 EXPERIMENT HOURS | EXPERIMENT SEQUENCE<br><br>T = 63 MIN.<br>SETUP – 30 MIN<br>SECURE (BETWEEN CYCLES) – 10 MIN<br>SHUTDOWN – 40 MIN |

= CHECKOUT   = CALIBRATION   = EXPERIMENT TEST   = EXPERIMENT EVALUATION

Figure 13. Typical Experiment Program Timelines

Astronaut participation was established after many experiment events were considered. It should be noted that each individual experiment event can be accomplished by a single astronaut. There are however, experiment events where use of a second astronaut permits reduced setup and shutdown times and otherwise promotes "time-effective" experiment operation.

As a result of the evaluation of the atmospheric cloud physics experiment program tree and the definition of experiment timelines, it was established that a large number of laboratory missions would be required to complete the entire experiment program. Realizing that basic research is not fully predictable and that research plans must be continually modified and updated, the experiment classes and priorities (listed in Table 10) were assessed in terms of potential variations. This assessment showed that the number of experiment missions would remain in excess of 100.

The conduct of cloud physics research in a multi-experiment orbital laboratory is dependent on the capabilities and resources of the Shuttle-Sortie laboratory, but imposes minimum constraints on the Shuttle systems. The primary requirement imposed by the envisioned experiments is for low vibration levels and near-zero-gravity ( $<10^{-3}$ g) environment. This applies only to the portion of the experiment involving calibration and experiment testing ($\approx 10$ to 40 min). Between individual experiment events, higher gravity and vibration levels can be tolerated.

Resources to be utilized include operational power, heat rejection, and limited communications and data management. In addition, the physical volume and weight of the cloud physics laboratory must be accommodated, and an astronaut is required to operate the laboratory. As discussed elsewhere in this section, the cloud physics laboratory can be easily accommodated in the Shuttle-Sortie laboratory and the resources required for its operation are well within the capability envisioned for the laboratory.

## Laboratory Guidelines and Design Features

The experiment requirements defined above, the suggestions of the Senior Scientific Board, other pertinent efforts in this study, and the results of MSFC, European Space Research Organization (ESRO) and MDAC Shuttle-Sortie laboratory studies were utilized to establish technical guidelines and design features for the cloud physics laboratory.

The Level 1 laboratory technical guidelines are defined in Table 11. These guidelines were established in concert with the overall philosophy of the NASA and the long-range objectives of conducting cloud physics research to aid in improving weather predictions, and ultimately to enable man to control and modify weather.

Features to provide for man's safety will be built into the laboratory. The operation of the laboratory presents no unusual hazards, and safety provisions for astronaut protection can be easily incorporated.

Table 11

LABORATORY TECHNICAL PROGRAM GUIDELINES

| | | |
|---|---|---|
| • SAFETY | - | NO CRITICAL ASTRONAUT/EXPERIMENT HAZARDS |
| • LOW COST | - | MINIMIZE OVERALL PROGRAM COST |
| • FLEXIBILITY | - | ACCOMMODATE ALL CLOUD CHAMBER CONCEPTS AND MAXIMUM NUMBER OF EXPERIMENTS |
| • AUTONOMY | - | UTILIZE SORTIE LAB RESOURCES WITH MINIMUM SORTIE LAB TO CLOUD PHYSICS LABORATORY INTERFACES |
| • PAYLOAD COMPATIBILITY | - | DESIGN CLOUD PHYSICS LABORATORY AND ITS OPERATION TO MINIMIZE CONSTRAINTS ON SORTIE LAB AND OTHER PAYLOADS. |
| • DESIGN LIFE | - | 20 MISSIONS OR 5 YEARS, WITH GROUND REFURBISHMENT |
| • GROWTH | - | TO 30 DAY MISSIONS AND/OR ADVANCED SUBSYSTEMS |

Minimization of the overall program cost was considered in terms of both the experiment program and the potential benefits to mankind. For a multiexperiment laboratory with envisioned reusage, minimizing the overall cost is more cost-effective than minimizing the costs to attain initial operational capability (IOC) only to find operational costs were increased in the process. Considerations of laboratory operation by an astronaut who was a cloud physicist or a cloud physicist who was not an astronaut lead to a more sophisticated laboratory design to enhance both the quality and the time-effectiveness of cloud physics research. Such features would raise the project cost at IOC, but would reduce operational costs and hence minimum overall program cost.

Flexibility to accommodate all cloud chamber concepts and attain a maximum number of experiments is consistent with both the cost guidelines and the recommendation of the Senior Scientific Board. Such flexibility enhances achievement of a long-range goal, reduces the cost of a mission experiment hour, and enhances the potential for participation by the scientific community.

Laboratory autonomy, with utilization of Shuttle-Sortie laboratory resources, enhances candidacy for flight usage. With low weight, volume, and resources requirements, the cloud physics laboratory becomes a more probable concept. The simplified interfaces of the cloud physics laboratory with the Shuttle-Sortie laboratory combined with the flexibility of the experiment program enhance the cloud physics laboratory concept as a secondary flight objective; its operation will be consistent with available resources and thereby provides full utilization of the Shuttle-Sortie laboratory.

The autonomy and flexibility previously discussed combined with the minimum constraints on the Shuttle-Sortie laboratory result in a compatibility of the cloud physics laboratory with the greatest number of payloads. The cloud physics laboratory can be effectively utilized with earth resources, astronomy, or other payloads since the only operational constraint imposed is near-zero-gravity.

The guideline for design life was formulated to accommodate the envisioned experiment program. With over 100 potential missions, a design life of

20 missions or five years (with ground refurbishment) was established. This design life was found to impose no unreasonable component, assembly, or subsystem life requirements (100 on-orbit operating days) that would tend to counteract its low cost.

Growth capability to 30-day missions was imposed to ensure conformance with Shuttle-Sortie laboratory growth. The capability to accommodate advanced subsystems was established to utilize advancements in technology, incorporate experiment program modifications, and to improve the quality and quantity of cloud physics research, thereby reducing project losses due to obsolescence.

Design features for the cloud physics laboratory, identified in Table 12, satisfy the Level 1 technical guidelines. Common ancillary subsystems (including common imaging systems and sensors) with common displays and controls were established for cost-effectiveness reasons. Reduced subsystem development cost and reduced astronnaut training will result from these design features. Operation by one astronaut (with accommodations for two), real-time

Table 12
LABORATORY DESIGN FEATURES

- OPERATION BY 1 ASTRONAUT/EXPERIMENTER - ACCOMMODATION FOR 2
- COMPONENT AND MODULAR REFURBISHMENT
- GROWTH CAPABILITY TO INCLUDE ADVANCED SUBSYSTEMS
- AUTOMATED CONTROL WITH MANUAL OVERRIDE
- REAL TIME DATA TRANSMISSION (VIA SORTIE LAB/ORBITER)
- INTERCHANGEABLE CLOUD CHAMBERS AND CLOUD CHAMBER SUBSYSTEMS
- COMMON ANCILLARY SUBSYSTEMS
- COMMON DISPLAYS AND CONTROLS
- SIMPLIFIED SET-UP, MODIFICATION, SHUTDOWN OPERATIONS
- STORAGE FOR SENSITIVE INSTRUMENTS, SPARE PARTS AND TOOLS

data transmission via the Shuttle-Sortie laboratory, and interchangeable cloud chambers and cloud chamber subsystems enhance the experiment flexibility and reduce the cost. Storage for sensitive instruments, spare parts, and tools makes the cloud physics laboratory more autonomous and reduces the development cost of such equipment. Simplified laboratory setup, modification and shutdown, combined with automated controls (with manual override) provide for increased astronaut safety and reduce the operational costs. Component and modular refurbishment design features will be used to satisfy the design life guideline and, combined with the capability to include advanced systems, improve laboratory growth and flexibility.

Laboratory Subsystem Requirements and Commonality

An assessment of subsystems for a cloud physics laboratory was performed using the cloud chambers as the central equipment. The laboratory design features, previously described, were used in the concept formulation. For analysis purposes, laboratory subsystems were categorized into chamber subsystems and ancillary subsystems. The chamber subsystems included the specific cloud chamber, the generator (aerosol, liquid drop, and ice particle), the motion controller (electrical, acoustical, and optical), the aerosol particle counter, and the imaging devices (still camera, stereo microscope, motion picture camera, television camera, laser device, image intensifiers, and strobatac). These subsystems are all mounted on the laboratory work surface adjacent to the cloud chamber. The ancillary subsystems include the pressure, temperature, and dew point control (integrated environmental control), gas storage, data management, power distribution, displays and controls, and miscellaneous support subsystems. The ancillary subsystems are installed in the laboratory. These arbitrary categorizations were selected to facilitate laboratory subsystem evaluations, simplify the assessment of subsystem commonality, and provide the format for the work breakdown structure (WBS).

The categorization of subsystems to cloud chambers is shown in Figure 14. It should be noted that all ancillary subsystems were determined by each cloud chamber concept. The limited-motion controllers are also identified for each cloud chamber, but cannot be made as common equipment since design varies with each cloud chamber concept. The imaging devices are also common to each cloud chamber concept, but all imaging devices will not be used simultaneously, and only specific equipment will be flown on a given mission.

A preliminary evaluation of subsystem commonality was performed for each laboratory subsystem to a level of depth consistent with project feasibility phase status and the state-of-the-art development status of the subsystem. The results of this commonality analysis are presented in Figures 15 and 16 for the chamber subsystems and ancillary subsystems. Commonality between cloud chambers was also assessed; results are summarized in Table 9.

| | CHAMBER SUBSYSTEMS | | | | | | | | | | ANCILLARY SUBSYSTEMS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GENERATORS | | | LIMITED MOTION CONTROLLERS | | | | | | | INTEGRATED ENVIRONMENTAL CONTROL | | | | | |
| CLOUD CHAMBER | AEROSOL | LIQUID DROP | ICE PARTICLE | ELECTRICAL | ACOUSTICAL | OPTICAL | AEROSOL PARTICLE COUNTER | IMAGING DEVICES | PRESSURE | THERMAL | DEW POINT | GAS STORAGE | DATA MGMT | PWR DIST. | DISPLAYS AND CONTROL | MISC. SUPT. |
| GENERAL | | X | | X | X | X | | X | X | X | X | X | X | X | X | X |
| STATIC DIFFUSION LIQUID | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X |
| CONTINUOUS FLOW DIFFUSION | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X |
| STATIC DIFFUSION ICE | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X |
| EXPANSION | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X |

**Figure 14. Subsystem Categorization**

CHAMBER SUBSYSTEMS

| CHAMBERS | GENERATORS: AEROSOL GENERATOR | GENERATORS: LIQUID DROP GENERATOR | GENERATORS: ICE PARTICLE GENERATOR | LIMITED MOTION CONTROLLERS: ELECTRICAL | LIMITED MOTION CONTROLLERS: ACOUSTICAL | LIMITED MOTION CONTROLLERS: OPTICAL | AEROSOL PARTICLE COUNTER | IMAGING DEVICES |
|---|---|---|---|---|---|---|---|---|
| GENERAL | | COMPATIBLE | | INTEGRAL | INTEGRAL | INTEGRAL | | COMPATIBLE |
| STATIC DIFFUSION LIQUID | COMPATIBLE | | | OPTIONAL | OPTIONAL | OPTIONAL | COMPATIBLE | COMPATIBLE |
| CONTINUOUS FLOW DIFFUSION | COMPATIBLE | | | OPTIONAL | OPTIONAL | OPTIONAL | COMPATIBLE | COMPATIBLE |
| STATIC DIFFUSION ICE | COMPATIBLE | COMPATIBLE | COMPATIBLE | INTEGRAL | INTEGRAL | INTEGRAL | | COMPATIBLE |
| EXPANSION | COMPATIBLE | | | OPTIONAL | OPTIONAL | OPTIONAL | COMPATIBLE | COMPATIBLE |

NOTE: ALL CHAMBER SUBSYSTEMS REQUIRE DISPLAYS AND CONTROLS

(hatched circle) - COMPATIBLE (open circle) - OPTIONAL (solid circle) - INTEGRAL

Figure 15. Subsystems Commonality Assessment

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ANCILLARY SUBSYSTEMS

| CHAMBERS | PRESSURE | THERMAL | DEW POINT | GAS STORAGE | DATA MANAGEMENT | POWER DISTRIBUTION | DISPLAY AND CONTROLS | MISC SUPPORT |
|---|---|---|---|---|---|---|---|---|
| GENERAL | COMPATIBLE | COMPATIBLE | EXPANDED RANGE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE |
| STATIC DIFFUSION LIQUID | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE |
| CONTINUOUS FLOW DIFFUSION | COMPATIBLE | COMPATIBLE | COMPATIBLE | EXPANDED RANGE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE |
| STATIC DIFFUSION ICE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE |
| EXPANSION | COMPATIBLE / EXPANDED RANGE | COMPATIBLE / EXPANDED RANGE | COMPATIBLE / EXPANDED RANGE | EXPANDED RANGE | COMPATIBLE | COMPATIBLE | COMPATIBLE | COMPATIBLE |

NOTE: ALL ANCILLARY SUBSYSTEMS REQUIRE DISPLAYS AND CONTROLS

(hatched circle) - COMPATIBLE (solid circle) - EXPANDED RANGE (open circle) - CONTROL TOLERANCE CRITICALITY

Figure 16. Ancillary Subsystems Commonality Assessment

Differences in the shape and volume and viewing access between cloud chambers eliminate total commonality considerations. This advanced-development equipment can, however, utilize common material and fabrication concepts. Furthermore, the concepts for providing "wetted surfaces" can be common to the continuous flow diffusion and the static diffusion liquid chambers with partial commonality to the static diffusion ice chamber (Table 9). Similarly, a common design concept can be used to control the limited motion of the electrical and acoustical equipment for all cloud chambers. All cloud chambers will have common electrical power, heat rejection, and instrumentation interfaces with the laboratory subsystems.

Figure 15 identifies the cloud chamber subsystems and indicates the various degrees of commonality. It should be noted that the limited motion controllers are all integral to the cloud chamber and in some instances are optional (varying requirements between different experiment classes and/or varying requirements within an experiment class) All generator subsystems are to be mounted to the cloud-chambers. The ice-particle generator is an advanced development subsystem and is obviously applicable only to the static diffision ice chamber. The liquid-drop generator and the aerosol generator are common for the chambers specified. Both generators are considered to be within the state of the art; various design concepts already exist and are employed in terrestrial laboratories. The aerosol-particle counter and the imaging devices are subsystems employed to gather cloud physics research data. This equipment is within the state of the art and can be utilized with all chambers. The interfaces of these subsystems with the laboratory will be standardized.

The ancillary subsystems identified in Figure 16 constitute the major portion of the equipment in the cloud physics laboratory. Figure 16 further shows an extremely high degree of commonality for the ancillary systems. The integrated environmental control (pressure, temperature and dew point subsystems) exhibits only minor deviations between cloud chambers. These deviations are increased tolerance control (required for only one experiment class performed in the expansion chamber) and expanded dew point subsystem range for the general chamber. The expanded dew point range can be incorporated with minimum subsystem modification; however, increased tolerance control would result in a major impact on the laboratory. The increased temperature, pressure, and dew-point tolerance control would involve advanced sensors and control concepts requiring state-of-the-art advancement.

The gas storage subsystem includes the gas-sample storage and sump tankage. An increased quantity of gas samples is required for the continuous-flow diffusion chamber and the expansion chamber, but can be accommodated by increased pressure for storage of gas samples. Commonality of the data management and power distribution subsystems is easily achievable. These subsystems are within the state of the art, and sizing to accommodate maximum experiment requirements does not result in significant impact on weight, volume, or cost.

The displays and controls subsystem contains the visual displays and operational controls required by the laboratory. A standardized console enhances the cloud physics research and reduces the training requirements for astronauts. For specific missions certain equipment would be superfluous but it imposes a small penalty in weight, volume, and power.

The miscellaneous support subsystem is composed of laboratory-contained equipment for the cloud chamber subsystems and equipment linking laboratory subsystems to other subsystems and to the Shuttle-Sortie laboratory systems. Commonality of this equipment provides the advantages defined for the displays and controls subsystem.

## Laboratory Conceptual Design

A baseline conceptual design was formulated for a zero-gravity multi-experiment atmospheric cloud physics laboratory. The design accommodates all five cloud chambers, utilizes common ancillary subsystems, and accommodates 19 of the 20 experiment classes identified. The design was based on evaluation of candidate concepts from the most austere to the most advanced and comprehensive. Consideration was given to experiment class compatibility, cloud chamber compatibility, reliability, maintainability, and experiment mission flexibility, as well as to development, production, and operation costs. The concepts considered by MDAC, the Senior Scientific Board, and NASA, and the significant features in each concept are shown in Table 13.

The evaluation of the candidate concepts resulted in selection of Concept B' (Table 13) for the baseline conceptual design. This concept best satisfied the long-range research objectives, was most responsive to the scientific community, satisfied the technical guidelines, and had appropriate design features.

Concept A was formulated to represent the austere laboratory concept. This concept included the required ancillary systems and only the general and static diffusion liquid cloud chambers and their imaging systems. Concept A was compatible with five experiment classes involving 28 experiment missions (at 40 hours of experiment time per mission). Concept B expanded the laboratory to include two additional cloud chambers (static diffusion ice and continuous flow diffusion). It therefore involved costs associated with these chambers, an ice-particle generator, the aerosol-particle counter, and expanded the thermal range for the integrated environmental control system. This additional equipment permitted the laboratory to accommodate 16 experiment classes involving 103 missions.

The selected baseline conceptual design (Concept B') requires only the addition of the modified expansion cloud chamber (to Concept B). This expansion chamber concept is compatible with all but one experimental class to be performed in this chamber. The chamber concept, however, is compatible with the tolerance limits of the integrated environment control system. With a modified expansion chamber, the laboratory can accommodate 19 experiment classes involving 125 missions.

The advanced and comprehensive laboratory is represented by Concept C. This concept has the sophisticated expansion chamber and the improved tolerance temperature, pressure, and dew point subsystems. Additional advanced imaging devices can be provided (e.g., holography, Raman spectroscopy, x-ray diffraction, and infrared imaging). With this equipment, the laboratory would be most comprehensive and all envisioned research

Table 13
CANDIDATE LABORATORY CONCEPTS

| FEATURES \ CONCEPT | A | B | B′ | C |
|---|---|---|---|---|
| CHAMBERS | GENERAL<br>STATIC DIFFUSION LIQUID | GENERAL<br>STATIC DIFFUSION LIQUID<br>STATIC DIFFUSION ICE<br>CONTINUOUS FLOW DIFFUSION | GENERAL<br>STATIC DIFFUSION LIQUID<br>STATIC DIFFUSION ICE<br>CONTINUOUS FLOW DIFFUSION<br>EXPANSION (MODIFIED) | GENERAL<br>STATIC DIFFUSION LIQUID<br>STATIC DIFFUSION ICE<br>CONTINUOUS FLOW DIFFUSION<br>EXPANSION |
| EXPERIMENT CLASSES | 5 | 16 | 19 | 20 |
| EXPERIMENT MISSIONS | 28 | 103 | 125 | 130 |
| APPLICATION PRIORITIES | A – 18<br>B – 10<br>C – 0 | A – 77<br>B – 26<br>C – 0 | A – 97<br>B – 26<br>C – 2 | A – 102<br>B – 26<br>C – 2 |
| COST FACTOR | ~0.93 | ~0.99 | 1.0 | >1.3 |
| REMARKS | BASIC LAB WITH REQUIRED DISPLAYS AND CONTROLS | CONCEPT A +<br>● 2 CHAMBERS<br>● ICE PARTICLE GENERATOR<br>● EXPANDED THERMAL CONTROL RANGE | CONCEPT B +<br>● 1 CHAMBER | CONCEPT B′ +<br>● EXTREME TOLERANCE SUBSYSTEMS<br>● IMPROVED EXPANSION CHAMBER |

could be performed in it. This concept does require significant advanced development of both chamber and ancillary subsystems, but it can accommodate the complete experiment program shown in Table 10.

Comparison of the various concepts shows that the equipment required by the austere laboratory (Concept A) needs minimum supplements for Concepts B and B'. Concept C incorporates advanced subsystems and imaging devices. The cost factors shown in Table 14 for the laboratory concepts quantify the variations. Using the baseline conceptual design (Concept B') as the unit cost, it can be seen that reductions in capability are significant for Concepts A and B, but less than 10 percent of the cost is saved with the other concepts. Concept C significantly increases costs and accommodates only one additional experiment class (five experiment missions). It should also be noted that the cost factor variations are proportional to and representative of differences in weight, power, and volume required by the laboratory concepts.

The baseline conceptual design for the zero-gravity multiple experiment atmospheric cloud physics laboratory is shown in Figure 11. The laboratory was designed to be compatible with the Shuttle-Sortie laboratory, which accommodates all cloud chambers and experiments associated with 19 experiment classes. The laboratory incorporates features for operation by one or two astronauts and has a design life of 20 missions (5 days on-orbit) or five years. As envisioned, the laboratory is self-contained, provides storage for all equipment, tools, and expendables used, and has simplified interfaces with the Shuttle-Sortie laboratory for power, heat rejection, and data management and communications. An interface exists for emergency overboard dump, a safety feature. For a maximum-condition experiment mission, the laboratory would have a maximum launch weight of 468 kg (1,032 lb) and an average power requirement of 132 w with an associated peak power of 580 w. As configured, the laboratory encompasses a total volume of 8.78 $m^3$ (310 $ft^3$) and is 1.2 m (4 ft) in depth (maximum), 3.1 m (10 ft) high, and 2.5 m (8 ft) long. A model of the baseline conceptual design was fabricated; the front view is shown in Figure 17.

Table 14
(Sheet 1 of 2)

LABORATORY SUBSYSTEM CHARACTERISTICS

| CHAMBERS | GENERATORS | | | LIMITED MOTION CONTROLLERS | | | AEROSOL PARTICLE COUNTER | IMAGING DEVICES | CHARACTERISTICS |
|---|---|---|---|---|---|---|---|---|---|
| | AEROSOL GENERATOR | LIQUID DROP GENERATOR | ICE PARTICLE GENERATOR | ELECTRICAL | ACOUSTICAL | OPTICAL | | | |
| GENERAL | 0.01(0.4)<br>0.91(2)<br>5 | 0.01(0.3)<br>1.36(3)<br>2 | | 0.03(0.1)<br>0.45(1)<br>2 | 0.003(0.1)<br>1.36(3)<br>2 | 0.014(0.5)<br>4.54(10)<br>5 | | 0.07(2.4)<br>19.50(43)<br>380 | SIZE $M^3$ ($FT^3$)<br>WEIGHT KG (LB)<br>POWER WATTS |
| STATIC DIFFUSION LIQUID | | | | • | • | • | 0.28(1)<br>(60)<br>240 | | SIZE $M^3$ ($FT^3$)<br>WEIGHT KG (LB)<br>POWER WATTS |
| CONTINUOUS FLOW DIFFUSION | | | | • | • | • | 0.28(1)<br>(60)<br>240 | | SIZE $M^3$ ($FT^3$)<br>WEIGHT KG (LB)<br>POWER WATTS |
| STATIC DIFFUSION ICE | | | 0.01(0.3)<br>1.36(3)<br>10 | | | | | | SIZE $M^3$ ($FT^3$)<br>WEIGHT KG (LB)<br>POWER WATTS |
| EXPANSION | | 0.01(0.3)<br>1.36(3)<br>2 | | • | • | • | 0.28(1)<br>(60)<br>240 | | SIZE $M^3$ ($FT^3$)<br>WEIGHT KG (LB)<br>POWER WATTS |

*OPTIONAL

The geometry of the cloud physics laboratory was based on considerations of experiment usage, astronaut operations, human factor considerations, and maintenance and refurbishment considerations. The work surface area and volume reflect consideration of the various cloud chamber designs, the associated generators and limited motion controllers, and the various data gathering equipment. The displays and controls for all subsystems were arranged to facilitate experiment operation. The ancillary equipment was installed in the console for ease of maintenance and refurbishment. Storage areas were provided for equipment sensitive to acceleration and vibration during launch. The design provides sufficient free volume for new equipment or improved subsystems that might be developed over the long life of the laboratory.

Table 14
(Sheet 2 of 2)
ANCILLARY SUBSYSTEMS

| CHAMBERS | INTEGRATED ENVIRONMENTAL CONTROL | | | GAS STORAGE | DATA MGMT | POWER DISTRIB | DISPLAY AND CONT | MISC SUPPORT | CHARACTERISTICS |
|---|---|---|---|---|---|---|---|---|---|
| | PRESSURE | THERMAL | DEW POINT | | | | | | |
| GENERAL | 0.057(2)<br>11.34(25)<br>140 | 0.014(0.5)<br>20.41(45)<br>30 | 0.028(1)<br>2.72(6)<br>40 | 0.850(30)<br>90.72(200)<br>— | 0.042(1.5)<br>18.14(40)<br>50 | 0.014(0.5)<br>6.80(15)<br>10 | 0.071(2.5)<br>22.68(50)<br>15 | 0.085(3)<br>36.29(80)<br>25 | SIZE $M^3$ $(FT^3)$<br>WEIGHT KG (LB)<br>POWER WATTS |
| STATIC DIFFUSION LIQUID | | | | | | | | | |
| CONTINUOUS FLOW DIFFUSION | | | | | | | | | |
| STATIC DIFFUSION ICE | | | | | | | | | |
| EXPANSION | | | | | | | | | |

The baseline conceptual design is a conservative approach established by assessment of individual subsystems in terms of weight, power and volume (including shape factor). Wherever possible, existing ground equipment values were used; other subsystems were estimated using state-of-the-art values. No attempt was made to reduce weight, power, and volume by use of advanced aerospace techniques, since this would result in increased cost. The characteristics for the subsystems are shown in Table 14.

The characteristics for all subsystems in the cloud physics laboratory were established using the identified baseline conceptual design philosophy. This philosophy resulted in size, weight, and power variations for only the cloud chambers, specific could chamber subsystems (liquid drop generator, ice particle generator, and aerosol particle counter) and the quantity of expendables (films, gases and liquids). The characteristics of all ancillary subsystems, and miscellaneous equipment for all experiments (tools, instruments, etc.), and the control console structure are identical.

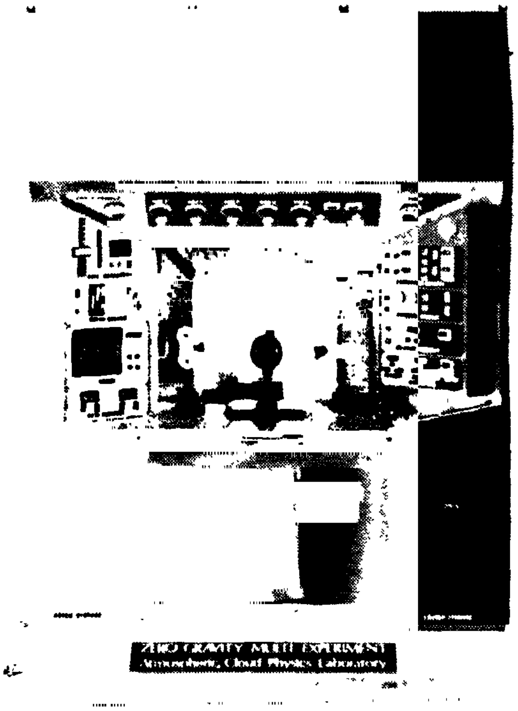


**Figure 17. Laboratory Conceptual Design**

The characteristics identified in Table 14 were specified for the subsystems described in the following sections.

Aerosol Generator

The cloud physics laboratory will be able to deliver aerosols at variable rates and with a high degree of repeatability over a range of particle diameters. This subsystem is a small electromechanical device requiring advanced development.

Liquid-Drop Generator

Various concepts are employed to produce droplets in terrestrial laboratories. The liquid-drop generator concept to be used in the cloud physics laboratory will produce a range of droplet sizes at a variable but controlled production rate. This generator is a small electromechanical device requiring advanced development (it has some commonality with the aerosol generator).

Ice-Particle Generator

This generator will employ either the aerosol or liquid-drop generator concept with additional cooling equipment needed to produce ice crystals. The ice-particle generator is an electromechanical device requiring advanced development (it has some commonality with the aerosol or liquid-drop generator).

Limited Motion Controller — Electrical

The subsystem consists of the electrical conductors installed on or within the cloud chambers to produce ac and dc fields. The dc field will provide the capability to sweep or position single or multiple particles. The ac field will provide the capability for positioning single particles. This electronic subsystem uses state-of-the-art technology and requires design variations conforming to the specific cloud chamber requirements and configuration.

Limited Motion Controller — Acoustical

The acoustical motion controller consists of the speakers and associated electrical equipment required for multi-axis control of droplets or for coagulation of aerosol droplets into larger droplets. The electromechanical system will be installed in the cloud chambers. It will exhibit design variations consistent with chamber requirements, and will require advanced development.

Limited Motion Controller — Optical

This subsystem will be a laser type and it will contain the optical sensors and servo controls required for single-particle positioning or motion (single beam) and for droplet confinement (dual beam). This optical subsystem requires advanced development.

Aerosol Particle Counter

This data-gathering optical subsystem will count particles and discriminates the particle size. The equipment uses state-of-the-art technology and is presently employed in terrestrial laboratories.

Imaging Devices

This subsystem is composed of state-of-the-art equipment used to obtain and record cloud physics research data. The equipment includes the following:

TV — Low-light-level vidicon with high resolution and zoom lens.

Image Intensifier — Optical illumination to enhance observation of low-light-level particles.

Laser — Polarized, collimated optical beam to assess optical scattering properties of ice crystals.

Stereo Microscope — Enhance observation of particles (used in conjunction with still camera and TV).

Motion Picture Camera — Variable frame speed (0 to 400 frames/sec) camera to record dynamic experiment phenomena.

Still Camera — High-resolution camera to record static experiment events (microscope mounting capability).

Strobatac — Enhance capability to optically view dynamic motion of particles through the microscope.

Integrated Environmental Control — Pressure
This subsystem includes all the laboratory gas sample pressure-control equipment, feed and transfer hardware and software between the gas sample supply tanks and the cloud chamber. It also includes the hardware for returning the gas samples to the sump tankage. The subsystem includes the conditioning chamber (positive expulsion-type tankage in which environmental conditioning of the gas sample is performed prior to its injection into the cloud chamber). The subsystem will be capable of supplying gas samples to the cloud chamber over a range of 1/4 to 1 atm and with a tolerance of ±0.01 atm. The subsystem utilizes state-of-the-art technology but requires development due to the need for tolerances and automated control and for complex and sophisticated interfaces with the integrated environmental control (i.e., temperature and dew-point) subsystems.

Integrated Environmental Control — Thermal
This subsystem contains equipment to provide for three major functions: (1) thermal control of electronics equipment, (2) thermal control for the cloud chambers, and (3) thermal control of the gas sample.

The thermal control of the electronics will minimize the heat released to the Shuttle-Sortie laboratory. The equipment uses state-of-the-art technology.

The thermal control of the cloud chambers includes equipment to provide high-tolerance (±0.1°C) thermal control over a range of -30°C to +40°C. This control is required for cloud chamber walls. In certain cases (static diffusion liquid and continuous flow diffusion chambers), two different temperatures must be maintained on the surfaces of different chamber walls.

Thermal control of the gas sample must be provided at the same tolerance and over the same range as for the cloud chambers. The thermal control of the gas sample is part of the integrated environmental control-pressure and dew-point subsystems.

The equipment required in the thermal subsystem is basically within the state of the art although advanced concepts employing heat pipes and thermoelectrics are under evaluation. Evaluation of the tolerances and thermal response needed to enhance experiment "time effectiveness", combined with the Shuttle-Sortie laboratory and cloud chamber interfac requirements places this subsystem as one requiring considerable development.

Integrated Environmental Control — Dew Point

The equipment for this subsystem utilizes state-of-the-art technology. The capability to add and remove water vapor to the gas sample is included in the design. Recirculation of the gas sample, provided by the pressure subsystem, is envisioned. The relative humidity range of 0 to 103 percent with a tolerance of ±0.05 percent and the transient response requirement identifies the dew-point subsystem as requiring long-lead-time development.

Gas Storage

This subsystem consists of the tankage and componentry associated with pressure vessels. As defined in the baseline laboratory conceptual design, this subsystem provides for (1) five 0.028 $m^3$ (1 $ft^3$) pressure vessels for storage of sample gases, (2) one 0.28 $m^3$ (10 $ft^3$) spherical storage tank for an earth sample, and (3) one 0.28 $m^3$ (10 $ft^3$) sump pressure vessel for storage of cloud chamber gases (after experiment usage). As envisioned, the earth sample will be stored at 1 atm and the gas samples will be stored at higher pressures consistent with the quantity of samples required for the particular experiment. The sump tank will be launched empty and will be pressurized by gas samples after experiment usage. A pump in the pressure subsystem will compress gases into the sump tank, eliminating the need for an overboard dump. However, the subsystem contains emergency dump equipment. This subsystem is within the state of the art.

Data Management
The equipment in this subsystem includes an analog/digital recorder and electronic equipment to permit acquisition and transmission (via the Shuttle-Sortie laboratory) of data pertinent to the laboratory status and of experiment data. Sensors from all laboratory subsystems will interface with the laboratory recorder. Provisions for voice recording and real-time data transmission to earth are envisioned (i.e., a Shuttle-Sortie laboratory interface). This subsystem is within the state of the art.

Power Distribution
Equipment of this subsystem interfaces with the Shuttle-Sortie laboratory and all other cloud physics laboratory subsystems. Both 115 vac and 28 vdc power will be utilized (if available). Power control and power conversion equipment required by the cloud physics laboratory subsystems is envisioned for this state-of-the-art subsystem.

Displays and Controls
The equipment for this subsystem is shown in Figure 18. This state-of-the-art subsystem includes equipment for both manual and automated experiments, with visual displays of laboratory subsystems and experiment status. As shown in the figure, mirrors are provided to enhance astronaut observation of experimental phenomena.

Miscellaneous Support
The equipment in this category includes the console-installed elements of the generators, the limited-motion controllers, and the imaging devices. State-of-the-art electronics will be used.

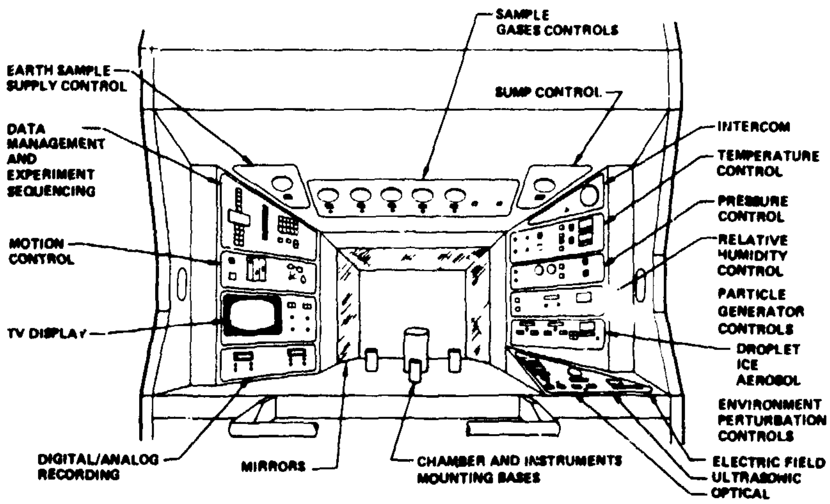



Figure 18. Zero-g Cloud Physics Laboratory Conceptual Displays and Controls

The characteristics of the cloud physics laboratory are given in Table 15, which covers the major equipment and subsystems in the laboratory. The control console characteristics are based on conventional (ground-type) structural design, and the laboratory concept (Figures 11 and 17) includes provisions for subsystem maintenance and refurbishment. As indicated, there is significant volume allowed for equipment access and for packaging sensitive equipment for stowage. The maximum envisioned launch weight of 468 kg (1,032 lb) includes expendables and miscellaneous equipment. The expendables include the gas samples and the film for the imaging devices. The miscellaneous equipment includes tools, packaging material, instruments, and spare parts (if required).

The peak power for the laboratory was assessed assuming a worst-case experiment operation sequence. The power required to operate all subsystem equipment is greater than the peak power specified; all equipment will not be operated simultaneously. The average operating power was also assessed

Table 15

CLOUD PHYSICS LABORATORY CHARACTERISTICS

| CHAMBERS | CLOUD CHAMBER | CHAMBER SUBSYSTEMS | ANCILLARY SUBSYSTEMS | CONTROL* CONSOLE | EXPEND-ABLES | MISC. EQUIP. | TOTAL LABORATORY | PEAK PWR | AVG OPER PWR | CHARACTERISTICS | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GENERAL | 0.057(2)<br>27.22(60) | 0.108(3.8)<br>28.12(62)<br>376 | 1.161(41)<br>254.47(561)<br>310 | 0.057(2)<br>90.72(200) | 0.028(1)<br>6.80(15) | 0.198(7)<br>31.75(70) | 1.608(56.8)<br>432.08(968)<br>686 | 433 | 108 | SIZE $M^3$<br>WEIGHT<br>POWER | ($FT^3$)<br>KG (LB)<br>WATTS |
| STATIC DIFFUSION LIQUID | 0.06(0.2)<br>4.54(10) | 0.13(4.5)<br>54(119)<br>614 | | | 0.03(1)<br>6.80(15) | | 1.58(55.7)<br>442.26(975)<br>924 | 580 | 132 | SIZE $M^3$<br>WEIGHT<br>POWER | ($FT^3$)<br>KG (LB)<br>WATTS |
| CONTINUOUS FLOW DIFFUSION | 0.01(0.4)<br>13.61(30) | 0.13(4.5)<br>54(119)<br>614 | | | 0.03(1)<br>13.15(29) | | 1.58(55.9)<br>469.88(1008)<br>924 | 580 | 132 | SIZE $M^3$<br>WEIGHT<br>POWER | ($FT^3$)<br>KG (LB)<br>WATTS |
| STATIC DIFFUSION ICE | 0.03(1.2)<br>27.22(60) | 0.11(3.8)<br>28.12(62)<br>384 | | | 0.03(1)<br>6.8(15) | | 1.57(56)<br>439.08(968)<br>694 | 433 | 108 | SIZE $M^3$<br>WEIGHT<br>POWER | ($FT^3$)<br>KG (LB)<br>WATTS |
| EXPANSION | 0.04(1.5)<br>22.68(50) | 0.14(4.8)<br>55.34(122)<br>616 | | | 0.03(1)<br>13.15(29) | | 1.62(57.3)<br>468.11(1032)<br>926 | 580 | 132 | SIZE $M^3$<br>WEIGHT<br>POWER | ($FT^3$)<br>KG (LB)<br>WATTS |

*CONTROL CONSOLE SHAPE (SHOWN IN FIGURES 11 AND 17) IS 1.2 METERS (4 FT) IN DEPTH, 3.3 METERS (10 FT) HIGH AND 2.5 METERS (8 FT) LONG. THE CONSOLE ENCLOSES A VOLUME OF ≈5.95 $M^3$ (≈210 $FT^3$) AND PROVIDES A WORKING VOLUME OF ≈2.83 $M^3$ (100 $FT^3$) FOR A TOTAL VOLUME OF ≈8.78 $M^3$ (310 $FT^3$).

assuming worst-case experiment operation. As shown in Table 14, the power drivers are the aerosol particle counter and the imaging devices. Ground-type power requirements were specified for this equipment and they can be reduced considerably by design improvement (to be undertaken only in the event of a power shortage in the Shuttle-Sortie laboratory).

A 1/12th scale model of the laboratory conceptual design was fabricated and delivered to the Manned Space Flight Center. The front view of the model is shown in Figure 17. Access to the electronics for maintenance is provided by hinged display and control panels. Similarly, hinged access to the equipment installed above and below the laboratory work surface is provided. The major equipment located in the rear of the model is shown in Figure 19. The earth atmosphere sample and sump tankage required large volume, so they were placed at the top of the laboratory. For convenience, sample gas tankage was placed in the same area. As shown, significant growth volume

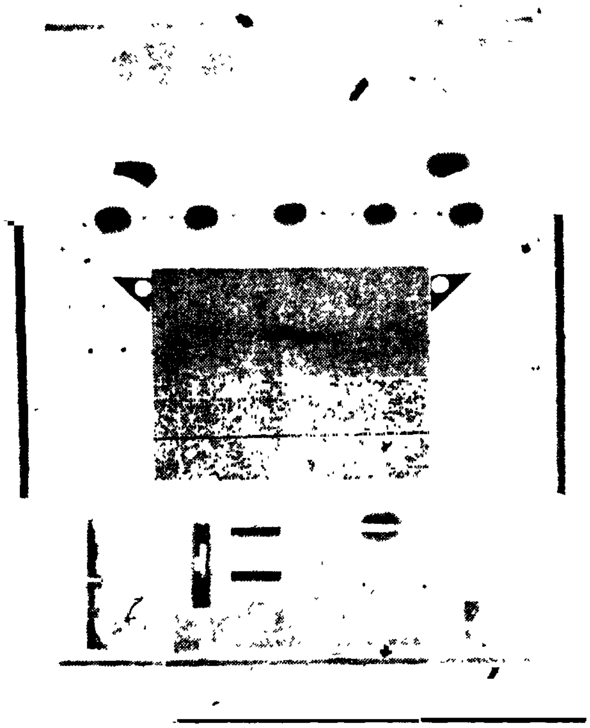


Figure 19. Laboratory Conceptual Design – Rear View

exists for stowage of other gas samples. The conditioning chamber requires a location as close as possible to the cloud chamber; it was therefore mounted immediately below the laboratory work surface. The related pressure, temperature, and dew-point subsystems were located in the volume below the work surface due to the cloud chamber interface requirements. In general, all the electronic subsystems are located immediately behind their control and display panels.

The conceptual design of the cloud physics laboratory and its envisioned usage as a Shuttle-Sortie laboratory payload are described in Appendix A. This appendix provides the payload planning data required to categorize and assess the cloud physics laboratory. Specific data provided include (1) programmatics, (2) payload equipment description, (3) operational cycle, (4) operational constraints, (5) resources utilization, and (6) ground support and logistics.

Cloud Physics Laboratory Programmatics

A schedule to provide a cloud physics laboratory in 1980 when the Shuttle becomes operational was established after formulation of the conceptual design and an assessment of technical risk. The risk assessment was directed to an evaluation of subsystems to establish equipment requiring an advance in the state of the art or long-lead-time for procurement or development which could jeopardize the specific technical project.

In assessment of technical risk, the equipment in terrestrial cloud physics laboratories was evaluated. It was found that all equipment specified for the zero-gravity cloud physics laboratory existed in terrestrial laboratories. (Terrestrial laboratories are, however, specialized and no single laboratory was equipped as fully as the laboratory described in this report.) The evaluation further showed that much of the equipment, although performing the required functions, was not suitable for use in the zero-gravity laboratory based on current standards for space flight operations. The terrestrial laboratories were developed for specific research objectives and were not subjected to the constraints that may be imposed by the Shuttle-Sortie laboratory. Equipment arrangement and packaging is suited to terrestrial gravity and manual operation. Hence, the terrestrial equipment identified as ancillary subsystems include water and ice baths, laboratory-type data-recording instruments, and other large, heavy, and high-power components. The terrestrial laboratory equipment identified for cloud chambers and cloud chamber subsystems, however, provide design concepts suitable for zero-gravity laboratory usage. But in all instances, the equipment requires some redesign for zero-gravity laboratory usage. Astronaut safety alone necessitates many equipment modifications. Modifications to provide compatibility with Shuttle-Sortie laboratory power, heat rejection, and data management would also be required.

As a result of the evaluation of terrestrial laboratories, it was determined that the cloud physics laboratory would require advanced technology efforts for cloud chambers, limited-motion controllers, and generators. For this equipment, however, many terrestrial laboratory equipment design concepts would be utilized. The integrated environmental control system (pressure, thermal and dew-point subsystems) was assessed as requiring a long-lead time for development due to control of tolerance and response time requirements. The rest of the laboratory subsystem equipment uses state-of-the-art technology, although it is not identical to equipment used in terrestrial cloud physics laboratories.

The cloud physics project schedule is shown in Figure 20. The schedule was spread to encompass the available time to anticipate launch. As shown, the feasibility and preliminary design and definition studies will continue to September 1974. A 12-month, in-depth laboratory design and definition study is envisioned to be accomplished from September 1974 to September 1975. The final design, development, testing, and production was defined to produce two flight laboratories on a schedule permitting launch on the Shuttle-Sortie laboratory in late 1980. The schedules are given for associated project systems engineering, ground support equipment, and operations support. Throughout the engineering efforts on the laboratory, a close association will be maintained with the scientific community to ensure a meaningful development program.

A preliminary work breakdown structure (WBS) for the cloud physics laboratory is shown in Figure 21. This WBS reflects the level of depth of evaluation and identification for the laboratory. The items identified are presently being evaluated to provide an estimate of the resources required for the cloud physics laboratory project and their costs.

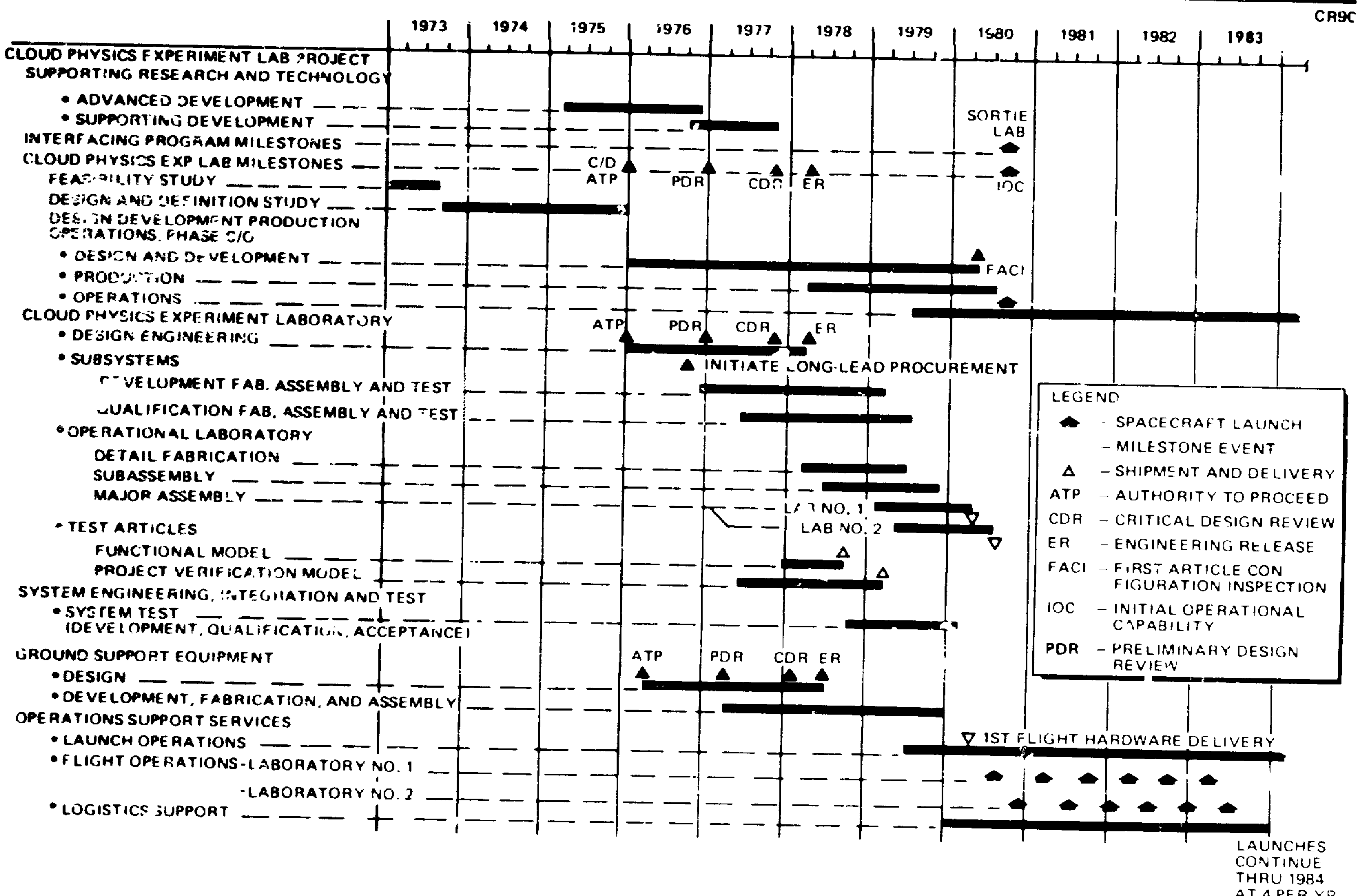



Figure 20. Cloud Physics Laboratory Project Schedule

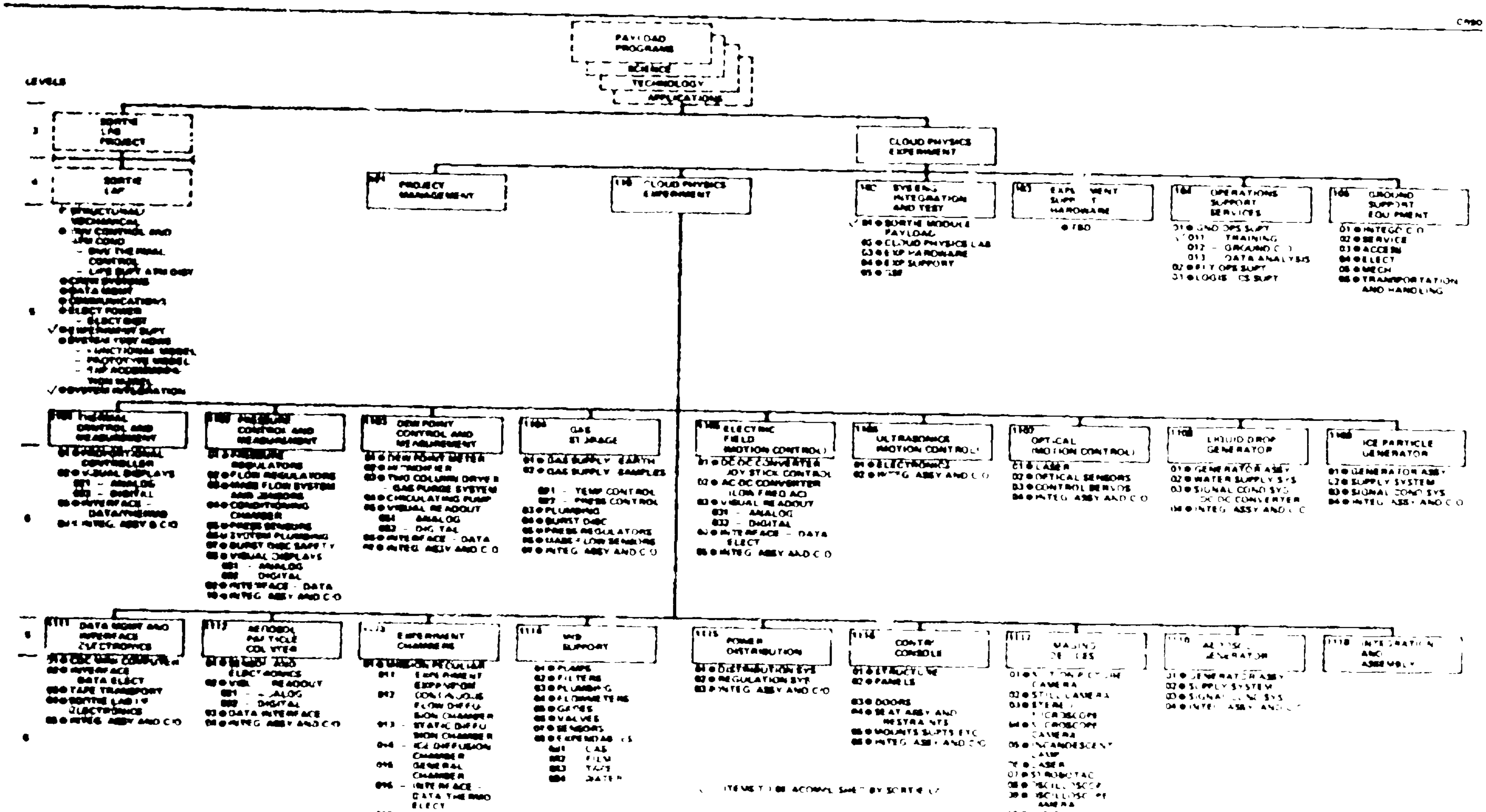



Figure 21 Work Breakdown Structure Cloud Physics Laboratory

V. SPECIAL SUPPORTING STUDIES

During the feasibility study, several long-lead technology items were identified and subcontracts were issued to initiate studies in these areas. The chamber subsystems are the primary focal point for the entire laboratory and two chambers subcontracts were issued: (1) a study of potential zero-gravity cloud physics chambers with emphasis on expansion chambers to the University of Missouri at Rolla (UMR); and (2) a study of potential zero-gravity cloud physics chambers with emphasis on diffusion chambers to the Desert Research Institute (DRI), University of Nevada at Reno. A study of heat pipes as a means of achieving the important thermal controls necessary for zero-gravity cloud microphysics was completed by the Donald W. Douglas Laboratories at Richland, Washington. McDonnell Douglass Electronics Company (MDEC) of St. Charles, Missouri, performed a small study concerning holography as an observational tool in zero-gravity cloud physics. Various aspects of thermal control were studied in the MDAC Space Science Atmospheric Physics Laboratory and this laboratory group also studied alternate means of achieving low- or zero-gravity conditions for test and experiment purposes. Summaries of these studies are given in this section.

Expansion Chamber Studies, University of Missouri, Rolla

The study team at the UMR was headed by Dr. James L. Kassner, Director of the Graduate Center for Cloud Physics Research. This study included (1) a review of the literature on cloud simulation chambers, (2) an evaluation of different types of chambers, (3) a detailed description of the expansion cloud chamber, (4) an evaluation of thermal diffusion chambers, (5) an evaluation of the UMR cloud simulation cloud chamber concept, and (6) a description of a potential zero-gravity cloud simulation chamber.

UMR Review of Literature on Cloud Simulation Chambers

The literature review indicated that two different approaches to the simulation of cloud formation in expansion chambers were evident; other types of chambers are not very suitable for the simulation of cloud updrafts. The first group is characterized by very large chambers in which the designers attempted to extend the time period of quasiadiabatic expansion of the air by making the volume of the chamber exceedingly large. This suppresses the heat flow from the walls by making the surface-to-volume ratio as small as possible.

The second method of simulating cloud formation is to precisely control all physical processes in relatively small chambers. Work along these lines during the past three decades belonged mostly to this group. Only a few scientists have introduced innovations leading to more efficient simulation experiments in smaller chambers in which the expansion rate, temperature, and humidity fields were reliably controlled.

The ideal cloud simulation chamber should be able to accurately produce clouds from a saturated atmosphere containing an aerosol fully characterized by a critical-activation-supersaturation spectrum and the variations of the latter with time. Once nonentraining clouds are simulated, experiments which include mixing of unsaturated air at the cloud boundaries can realistically be considered.

UMR Evaluation of Chambers

It appears that there are experimental situations which suggest that both thermal diffusion and expansion cloud chamber capabilities should be planned for the zero-gravity cloud physics experiments. If one employs the UMR-developed expansion-type cloud chamber which utilizes thermoelectric modules to cool the walls at the same rate that the gas is cooled by adiabatic expansion, the same cloud chamber components can be utilized to fabricate both types of cloud chambers (i. e., a thermal diffusion chamber and an expansion cloud chamber). This is readily feasible from the standpoints of scientific and engineering design.

A study of droplet or ice-crystal growth can best be carried out in an expansion-type cloud chamber utilizing synchronized wall cooling. In the expansion chamber, conditions will be spherically symmetric around individual growing droplets, and droplets will not be subjected to diffusiophoretic and thermophoretic forces such as would exist as a result of the gradients of the thermal diffusion chamber.

Studies of the vapor pressure over supercooled droplets would easily fall in the category of a slight modification of the droplet-growth experiment, as would be measurement of accommodation coefficients. In this category, one would include studies of memory effects of both condensation nuclei and ice nuclei. These experiments can be efficiently carried out only in an expansion-type cloud chamber which is capable of retracing its steps in a compressive mode of operation.

Scavenging-type experiments are ideally suited to the expansion cloud chamber. In addition to providing for growth of the particles, the larger volume of the chamber and the uniform conditions (with the possible exception of boundary layers close to the walls from which fine particles would be preferentially scavenged due to the close proximity of the larger surface area) would mean that the nuclei content of the gas could be sampled as a function of the time available for scavenging by cloud droplets or ice crystals.

The expansion chamber probably provides the most convenient means of assessing the effect of giant nuclei on the evolution of the large droplet tail on the cloud droplet size distribution.

The Expansion Cloud Chamber

The high state of development of the Wilson cloud chamber makes it ideally suited for studies of various condensation problems. However, most of this development has been directed toward building instruments for studying the trajectories of ionizing particles, where the principal interest was good repeatability and perfect uniformity of conditions throughout the chamber. Until UMR began work on the problem in 1960, little effort had been devoted to developing a cloud chamber specifically suited for nucleation measurements where an absolute knowledge of the thermodynamic parameters is required. The problems encountered in nucleation and condensation measurements are somewhat different. During the past 12 years, UMR has undertaken a systematic effort to identify and solve these problems.

A brief review of conventional cloud-chamber processes leads to a clear understanding of the technique employed. Cloud chambers for cosmic ray studies are most frequently designed for precise, fast expansions from a well-defined initial volume to a well-defined final volume. Peak supersaturation is calculated from the volume ratio. Such instruments possess a relatively short sensitive time of about 0.5 sec, which is a property of the surface-to-volume ratio of the chamber.

Expansion establishes the desired degree of supersaturation. The gas is cooled by the expansion while the walls remain at ambient temperature. The walls conduct heat to the layer of gas adjacent to them. However, it would seem that the gas in the center of a large chamber would not experience an appreciable temperature rise for a second or more after the expansion, owing to the relatively slow nature of the heat conduction process. Nevertheless, there is a mechanism which begins to increase the temperature at the center of the chamber immediately after a fast expansion. The heated gas layer adjacent to the walls expands and compresses the entire chamber, resulting in a general increase in temperature throughout the chamber. Thus, the volume as a whole experiences a general increase in pressure and temperature very quickly, and the usual procedure of employing expansion ratios to calculate the final temperature turns out to be exceedingly poor. The slower the expansion, the more nonadiabatic is the volume as a whole. In addition, this compressive mechanism rapidly relieves the degree of supersaturation established by the initial expansion.

Although the temperature throughout the chamber is not homogeneous and the entire volume cannot be treated as a unit, another procedure is possible. As long as actual heat conduction and vapor diffusion have not affected the central portion of the chamber, the mechanism by which the chamber is expanded or compressed is irrelevant; the expansion still remains adiabatic.

Evaluation of Thermal Diffusion Chambers

Thermal-gradient or thermal diffusion chambers have received wide attention because of their simplicity of operation and ease of fabrication. The thermal diffusion chamber has become an important tool in cloud physics and has been used to investigate a variety of interesting problems, including measurement of the critical supersaturation of different vapors in investigating the phenomenon of homogeneous nucleation at large supersaturations and determinations of the activity spectrum of cloud nuclei. Measurements made of the activation supersaturation of the nonhydroscopic nuclei have partially tested the Volmer theory of nucleation on insoluble particles. The volatility of cloud nuclei was studied in the chamber and it was also used to produce appropriate conditions for the processing of millipore filters in order to measure ice nuclei concentrations.

It is no secret that any success in weather modification and air pollution control basically depends upon available information on cloud condensation nuclei (CCN). The three properties of a cloud nucleus are its size, chemical composition, and the surface-active material present on the nucleus. These, in turn, determine the critical supersaturation (sometimes referred to as critical activation supersaturation) at which the nucleus initiates the condensation of water vapor. Therefore, this is evidently the parameter which plays a vital role in weather modification experiments, and why the measurement of the supersaturation spectrum of CCN is so important.

For CCN counting, a very portable chamber of a fairly small size is needed to determine CCN concentration using a small volume of the test sample. The operating supersaturations required are comparable to those encountered in natural cloud formation. For this application, the operating conditions must be carefully controlled – especially sample introduction – to make sure that the highest supersaturation to which the sample is subjected is the steady-state operating supersaturation, which is considered as the critical activation supersaturation for the sample. The test sample should be subjected to this operating supersaturation for a sufficiently long time to allow the activated nuclei to grow to observable sizes as dictated by the optical detection system employed. In addition, the peak supersaturation produced should be estimated precisely. This is a rather stringent condition because the supersaturation is a rare physical quantity which escapes direct measurement because of the ease with which condensation forms on the surfaces of the measuring instrument. It turns out that these requirements impose rather heavy restrictions on the design and operation of the thermal diffusion chamber.

The operation of the thermal diffusion chamber depends upon vapor saturation being accurately established at the two parallel plates. Since porous plates are used as a liquid reservoir at these surfaces, the liquid surface can be contaminated by surface active materials. This is another objection to the thermal diffusion chamber.

The distance between the parallel plates of the chamber determines the time constant for the transient which follows the introduction of samples. This separation is also somewhat limited by convection currents — the smaller the separation, the less susceptible is the chamber to convection currents. In a zero-gravity environment, convection cells would not be a problem and wider plate separations might be feasible for some experiments.

The UMR Cloud Simulation Cloud Chamber Concept

In order to avoid the problems associated with enormous cloud chambers such as have been built in the USSR, UMR decided to employ a design in which the walls were cooled in synchronization with the adiabatic expansion cooling of the gas. After two years of effort with freon refrigeration design concepts, UMR turned to a design concept employing thermoelectric modules. Thermoelectric modules possessed the unique capability of providing for complete electrical control of the system.

The chamber is planned with two or three optical ports for observing the cloud. These ports are designed to accommodate special laser windows in anticipation of using laser scattering techniques. Ports for changing the atmosphere are located at the top and bottom of the chamber, which is designed to withstand about 1-atm pressure or vacuum.

The simulation chamber is designed for computer control. Synchronization of the rate of cooling of the gas by dry adiabatic expansion with the cooling rate of the walls is accomplished as follows. The analog signal from the pressure sensor passes through an analog transfer function generator, which converts the pressure signal into a signal proportional to the temperature change.

A full-size cloud simulation chamber based on the same design concepts would be about 30 feet high and would possess much more elaborate control. (The full-scale chamber will be proposed later to some Federal agency after UMR has had adequate experience with the small simulation chamber.) The small UMR facility possesses adequate capability for studying many microphysical processes of great importance to cloud physics.

Zero-Gravity Cloud Simulation Chamber

The basic concept of the UMR cloud simulation chamber is well suited for zero-gravity applications. An added advantage is that, while it was designed to operate as an expansion chamber, it can also be quickly converted to a noncontinuous thermal diffusion chamber. The primary unsolved problem encountered during operation in this mode is prevention of condensation on the side walls.

While the basic concept is valid, most of the hardware must be redesigned to meet the space, weight, and power limitations. Aluminum has been assumed as the basic construction material due to its low density and high thermal conductivity; however, the possible use of other material in the final design should not be ignored. Descriptions of some requirements of the system follow.

The first requirement of the system is that the initial carrier gas be dry and free of particulate matter; therefore, the initial stage of the system serves as a filter drier unit. The unit will consist of several stages starting with the blower, which provides the slight positive pressure required to drive the gas through the remainder of the system. The blower is followed by a freeze drier, a silica-gel desiccant, a liquid nitrogen vapor trap, and finally a particle filter. The freeze drier removes most of the water vapor, thereby extending the useful life of the silica gel in the next stage. The liquid nitrogen vapor trap removes both the remaining water vapor and other vapors before the gas is reheated prior to its passage through the particle filter. As the carrier gas leaves the filter drier it is divided into two parts: the first for humidification, and the second for aerosol production.

Disregarding any other considerations, the zero-gravity environment of the cloud chamber precludes the presence of liquid water in the chamber itself, as is the normal practice with expansion chambers. Therefore, the gas must be brought to the desired vapor content in external humidifiers before it is put into the chamber.

First, an absolute measurement of the temperature is made to determine the vapor pressure at this point and is then used as a base to calculate the vapor pressure at all points throughout the rest of the system. Second, this is the reference temperature for measuring other temperatures used in calculating the supersaturation of the chamber.

Many of the experiments require that the aerosol be kept in a subsaturated condition until after the experiment has started; therefore, after the saturated gas leaves the final humidifier its temperature must be raised to the desired initial temperature of the cloud chamber.

The second portion of gas leaving the filter drier is used as the input gas for the aerosol generator. The basic technique used for aerosol production is to pass the carrier gas into a furnace containing the aerosol material in vapor form. Then as the gas leaves the furnace and is rapidly cooled, the aerosol is formed by homogeneous nucleation. At this point the size distribution of the aerosol will be very polydispersed and require further treatment to make it more monodispersed.

Once the aerosol has been generated and characterized it must be brought to the same temperature as the gas-vapor mixture. At this point they must be mixed to give the desired relative humidity and aerosol concentration before being placed in the cloud chamber. The mixing chamber is merely a thermostated volume in which the aerosol and vapor can intermix to provide a homogeneous result.

The gas-vapor/aerosol mixture is now ready to be introduced into the cloud chamber. The simplest purging procedure is to introduce the desired sample into one end of the cloud chamber while opening an outlet port at the opposite end. A continuous flow is established throughout the entire system and maintained until the entire system reaches equilibrium. The ports are then closed and the chamber permitted to reach final equilibrium before generation of the supersaturated state.

The ideal arrangement for the control system would be to program the desired expansion and have the wall temperature track the gas temperature; however, due to the inherent time lag associated with any thermal response by the walls, the reverse procedure must be followed in practice. The desired cooling rate as a function of time is set into the programmer controlling the power supply for the thermoelectric modules. Once the experiment is started, both the wall and gas temperatures are measured continuously and the difference is used as an error signal to control the expansion rate. Once the desired supersaturation is achieved, the expansion and thermoelectric cooling will be decreased until the final temperature and pressure are maintained as steady-state conditions.

At present, it is planned to use gas flow to maintain all major components at their required temperatures. It is felt that the small quantities of heat flow being encountered in the zero-gravity system permits the use of gas flow instead of liquid flow as used in the UMR system.

Chamber Studies at Desert Research Institute, University of Nevada

The study team at the Desert Research Institute (DRI) was headed by Dr. Patrick Squires, Director of the Laboratory of Atmoepheric Physics. Their study included (1) the implications of cloud physics research in zero-gravity, (2) a discussion of expansion chambers, (3) a discussion of diffusion chambers, (4) research opportunities in zero-gravity, and (5) a brief discussion of some problem areas.

Research Implications

As compared with the familiar situation of 1-g, a cloud chamber operating in near zero-gravity would be different in two major respects:

A. Density differences caused by differences in temperature or composition (e.g. water vapor mixing ratio) will not result in convective movements.
B. Particles in the chamber will not fall relative to the chamber walls.

The absence of convection. The implication of the absence of convection is that, whereas in 1-g convective stirring brings parcels of gas with different properties into close juxtaposition so that molecular diffusion can then rapidly average out their properties, such motions are absent in zero-gravity. The only mechanisms for heat transfer are molecular diffusion over distances of the same order as the chamber dimension (L cm) and, of course, radiation. The only process tending to cause local changes of composition are molecular diffusion over distances of order L.

Unless an extremely dense cloud is present, radiative transfer from the walls to the interior is relatively slow and probably may be neglected on the time scale (T sec) of cloud chamber experiments.

The diffusive transfer of heat or a gaseous component is not a simple exponential process, but may be roughly described as occurring on a time scale of $\tau_d$ of about $(L^2/\pi^2 D)$ sec, where D is the relevant diffusivity. Approximate values of D for heat and water vapor transfer are given in Table 16.

Table 16

DIFFUSIVITIES IN AIR AT A PRESSURE OF 1,000 MB

| TEMPERATURE °C | HEAT ($CM^2$ $SEC^{-1}$) | WATER VAPOR ($CM^2$ $SEC^{-1}$) |
|---|---|---|
| -20 | 0.17 | 0.20 |
| 0 | 0.19 | 0.23 |
| 20 | 0.22 | 0.26 |

(BOTH DIFFUSIVITIES ARE INVERSELY PROPORTIONAL TO PRESSURE.)

It is clear that the characteristic time scale $\tau_d$ is about $(L^2/2)$ sec for both properties.

Any experiment which is completed in a time T will be effectively adiabatic and unaffected by the walls, provided that $\tau_d \gg T$, and that the experimental arrangements are such that the chamber pressure is held constant so that heating of the parts of the gas lying near the walls does not cause compression of the central parts.

The absence of fallout: Under 1-g conditions, the Stokesian terminal velocity of particles immersed in a gas is given by $V_t = 2g\rho_p r^2/9\eta$, where $\rho_p$ is the particle density, r their radius, and $\eta$ is the (dynamic) viscosity of the gas. At values of r comparable with the mean free path of the gas molecules, this formula overestimates $V_t$, but at such sizes $V_t$ is extremely small. When the Reynolds number approaches unity, the flow about the droplet departs from

Stokesian, and again $V_t$ is overestimated. In cloud chamber experiments in which the chamber gas is air at a pressure of the order of 1 atm and r rarely exceeds 10 μm, the Stokes formula is applicable. For water droplets in air $V_t = 1.2 \times 10^6 r^2$ cm $sec^{-1}$ (virtually independent of pressure).

Depending on the detailed nature of the experiment being conducted, it would appear that if $T \ll L/V_t$, an experiment in 1-g would be unaffected by fallout as such. Experiments in which the contrary is the case are a priori suitable for consideration in a zero-gravity environment.

Plan of discussion: A cloud chamber's purposes are to create an environment characterized by known conditions or supersaturation, and observe the course of following events (i.e., the nucleation and growth of droplets or ice crystals).

The known supersaturation may be created either by adiabatic expansion or by setting up a steady-state diffusion regime. The duration of the known supersaturation conditions depends partly on the course of events. For example, in an Aitken counter where a dense cloud of droplets is nucleated, the supersaturation is depleted by droplet growth in a period which is short compared with 1 sec, whether in 1-g or zero-gravity.

**The discussion given above makes it clear that the advantage offered by a zero-gravity environment is that with suitable design, it may be possible to maintain known conditions for much longer periods of time, and to retain the growing particles in the body of the gas. A zero-gravity environment offers no significant advantage in the case of an Aitken counter, since the supersaturation cannot in any case be maintained in the presence of a large concentration of growing particles; furthermore, these particles are typically so small that even in 1-g their fallout is slow. This indicates that the experiments of particular interest in zero-gravity are those where it is possible and useful to maintain the known supersaturation conditions for longer periods (of about 10 sec) and to retain the particles in the gas for a similar period. Thus, it is important to identify the experiments in which it is useful and possible to maintain known conditions for a period longer than is possible under 1-g.**

In order to approach the problem of determining the characteristics of apparatus which would be useful in a zero-gravity environment, it seems appropriate to discuss the limitations of existing chambers in some detail, distinguishing between those which are related to the presence of 1-g and those which would be present also at zero-gravity.

Expansion Chambers

Expansion chambers are used in meteorology for measuring the concentration of Aitken nuclei: that is, the particles activated at supersaturations exceeding 100 percent, and also in attempts to measure ice-forming nuclei, where the expansion is utilized to briefly generate a low temperature in order to cause the nucleation of ice particles. In the latter use, a large unwanted supersaturation is generated, and it is generally agreed that this technique leaves something to be desired.

One major reason why expansion chambers have not been used at low supersaturations is the difficulty of establishing the initial conditions with sufficient precision. In the measurement of cloud nuclei, it is desirable to know the supersaturation (or relative humidity) to about 0.02 percent, and while an expansion can be used to cause a very accurately known change in the relative humidity, this is of value only if the initial value is known to 0.02 percent or better. The measurement of humidity to this accuracy is quite difficult.

The inflow of heat from the walls of an expansion chamber can produce three effects:

- A. Compression of the central parts, unless the pressure is held constant after the expansion (for example, when expansion to ambient pressure is employed)
- B. Convective stirring (in 1-g) as a result of the buoyancy of the gas near the wall
- C. Eventual heating (and moistening) of the whole gas volume.

The first effect is easily removed, as indicated above. In 1-g, the second effect is for most purposes by far the most serious, and has led to the development of chambers in which the attempt is made to cool the walls in synchronism with the gas. If this is not done in 1-g, convective stirring limits the experimental time available so stringently that the third effect is of no importance.

In zero-gravity, the convective circulation problem is absent, and the third effect could eventually become significant. The presence of a wet, warm surface adjacent to the gas would increase the supersaturation, since the diffusivity of water vapor exceeds that of heat.

In the Aitken counter, a single fast expansion is carried out either by moving a piston or by a critically damped expansion to ambient pressure; in the absence of a continuing slower expansion, the supersaturation in the chamber is depleted by the removal of water vapor and the addition of heat.

A slower continuing expansion can be used to mitigate this situation, but since this requires foreknowledge of the rate of condensation, its use might well require a procedure of successive approximations to the desired result.

The difficulties with initial conditions and with supersaturation depletion indicate that expansion chambers have limitations in the study of condensation at constant small supersaturation values, such as are used in the study of cloud nuclei. In zero-gravity, however, they seem ideally suited for the direct study of the adiabatic cloud-forming process as it occurs in nature. The time scale of such an event in nature is of the order of 10 sec, which is a period during which the central parts of an expansion chamber of modest design in zero-gravity can remain totally unaffected by the walls, even if these are at a temperature quite different from the gas. In such an experiment, the initial conditions do not present a crucial problem, and the depletion of supersaturation by the growing drops is of the essence of the problem to be studied.

The observation of particles in an expansion chamber is usually made by photographing the cloud. With working distances of the order of several centimeters, it is impossible to resolve the droplet in order to determine its dimensions, and normally all that is recorded is the existence of the droplet as a point scatterer. Holography offers possibilities but the state of the art leaves much to be desired. It is possible that a method could be developed to determine droplet size by measuring the flux of light scattered from a laser beam, but this method might well be limited to droplets of diameter several microns and above.

Thus, there would appear to be serious problems to overcome if expansion chambers are to be used for droplet growth studies, unless a method of measuring droplet sizes in situ can be developed — for example, by observing the reaction of the droplets to an acoustic disturbance.

Diffusion Chambers

The employment of diffusion chambers in meteorological problems began in relation to the measurement of cloud nuclei. At the low supersaturations which occur in clouds ($\simeq 1\%$), the time required for an activated nucleus to form an easily observable droplet is several seconds, which is much longer than the available experimental time in an expansion chamber at 1-g. Moreover, the diffusion chamber is free from the initial condition problem which becomes serious in expansion chambers operating at low supersaturations; however, a complementary problem — the chamber time constant — makes its appearance.

The growth of particles in a diffusion chamber introduces a sink of water vapor and a source of heat — both of which tend to perturb the diffusion field and deplete the available supersaturations. The depletion of the local supersaturations is in this case opposed by the diffusive fluxes on which the operation of the chamber depends. For example, in a chamber 1-cm deep, $10^3$ droplets of 1-μm radius cause a fractional depletion of the supersaturation of about 10 percent.

Fallout at 1-g. In the case of droplets, growth occurs at a supersaturation of supersaturation (S)% according to $dr^2/dt \simeq 2 \times 10^{-8}$ S (cgs) approximately; and a 1-g, fallout occurs according to $ds/dt - 10^6 r^2$. From these equations it follows that the distance fallen, namely z, is related to r according to:

$$z = 10^{14} r^4/4S \text{ (cgs)}$$

and to time according to:

$$z = 10^{-2} St^2.$$

The first relation shows that, if the conditions of the experiment are such that droplets must be grown to radius r in order to be detected reliably, the fall distance involved is greater at small S.

In a diffusion chamber, the full dimension of the apparatus is not always available for experimental use, since the supersaturation is a function of position, approaching zero at each plate. In some applications, it is not essential that each growing particle experience the same value of S throughout its life. For example, in the continuous cloud nucleus counter, it is important only that S nowhere exceed the design supersaturation which occurs close to the center.

Due to the fact that S is a maximum in the center (and therefore stationary with height), only slight errors are incurred if the experiment is carried out in a height interval which is a small part of the chamber depth. If attention is restricted to a central layer with a depth equal to one quarter of the chamber depth, the resulting error in the count is only a few percent.

The "chamber time constant" (T) is defined as the time scale involved in the establishment of the designed supersaturation, or an acceptable approximation of the designed supersaturation, or an acceptable approximation to it. A small value of $\tau_c$ is of value in experiments where it is desired to accurately relate the nucleation and growth of particles to the elapsed time. $\tau_c$ can be extremely small in expansion chambers; the ultimate lower limit is related to the need to minimize mechanically generated turbulence and to the design of fast moving pistons, or, alternatively to the need to critically damp an expansion which occurs directly to the environment. In a diffusion chamber, the value of $\tau_c$ is much larger, since the desired conditions are created by diffusional processes. Thus, if L represents the distance between the plates of such a chamber, the time constant with which S asymptotes to its final value is

$$\frac{L^2}{\pi^2 D} \simeq \frac{L^2}{2} \text{ (cgs)}$$

for both heat and water vapor. If L = 1 cm, several seconds must elapse before a fair approximation to the steady-state is achieved.

It is possible that with careful design the time constant problem could be eliminated in a continuous cloud nucleus counter. The supersaturation is set up in a stream of particle-free air into the center of which the aerosol to be studied is introduced. If the sample were introduced after the design supersaturation had been established in the mainstream of particle-free air, the time constant problem would be eliminated. This process, however, introduces its own problems. The small probe through which the sample is introduced itself can perturb the temperature and vapor density fields at the very point where it is most important that they be accurately known, unless the probe is hydrophobic enough to resist condensation at the ambient supersaturation, and very precisely at the ambient temperature.

Because of the difficulties in achieving these two objectives, the sample is introduced upstream of the supersaturated region. This procedure avoids the probe perturbation problem, but does not eliminate the chamber time constant problem, since in the downstream section, the supersaturation does not appear instantaneously, but asymptotes to its design value with a time constant of $L^2/\pi^2D$.

A diffusion chamber must be shallow in order to keep $\tau_c$ small, control depletion of S, and limit the disturbing influence of side walls.

This results in problems in observing the cloud of small droplets formed in the chamber, as discussed previously. The problem is not entirely unmanageable, as indicated by the use of static diffusion chambers of conventional design. It is more radically and satisfactorily solved in the continuous cloud nucleus counter in which the droplets are carried out of the chamber into a separate optical particle counter, where they can be measured as well as detected. This separation of the functions of growing the droplets and observing them is a significant advantage of the continuous counter, especially in zero-gravity, where in the absence of fallout it would be attractive to grow the droplets to radii of several microns in order to investigate growth processes.

## Research Opportunities in Zero Gravity

<u>General</u>. A zero-gravity environment will provide important opportunities for the study of basic cloud-physical processes, especially in experiments

where sedimentation under 1-g is a critical limitation; and relative motion between particle and air is not of the essence of the problem being studied. Thus, cloud or fog nucleus measurements at low supersaturation (s) could very suitably be explored under zero-gravity. On the other hand, zero-gravity offers no advantage for the study of the diffusional growth of particles in free fall at Reynolds numbers of unity or more (i.e., in the region where, in nature, ventilation significantly affects the transfer of heat and water vapor). Under 1-g conditions, certain measurements such as those of cloud nuclei at $S < 0.3\%$ are inaccurate or questionable as a result of disturbances caused by convective motions and fall-out. Hence, a quite separate area of interest would be to check and calibrate in zero-gravity certain devices designed for environmental studies under 1-g conditions. Under zero-gravity, their performance would be more clearly predictable and trustworthy. This would of course require a highly reproducible aerosol source, to be used both in zero-gravity and 1-g.

A tabulation of the characteristics of expansion and diffusion chambers discussed above is given in Table 17.

Table 17

CHARACTERISTICS OF EXPANSION AND DIFFUSION CHAMBERS

| CHARACTERISTIC OR PROBLEM AREA | EXPANSION | DIFFUSION |
|---|---|---|
| INITIAL CONDITIONS | LIMITS USE TO HIGHER S | NO PROBLEM |
| CHAMBER TIME CONSTANT | NO PROBLEM | MODERATE PROBLEM |
| WALL AFFECTS | NO PROBLEM | NO PROBLEM |
| DEPLETION OF S | SEVERELY LIMITS TIME AND CONCENTRATION | LIMITS CONCENTRATION |
| PARTICLE OBSERVATION | NO PROBLEM | READILY SOLUBLE PROBLEM |
| PARTICLE MEASUREMENT | IMPOSSIBLE AT PRESENT | NO PROBLEM IN A CONTINUOUS FLOW CHAMBER |

Expansion Chambers. The summary given indicates that in zero-gravity expansion chambers are probably most suitable for experiments employing moderately high supersaturations, and at concentrations which are not too high if S is to be maintained constant and known. For meteorological purposes, undoubtedly an attractive opportunity for the use of an expansion chamber would be to reproduce directly the adiabatic cloud-forming process, as it occurs in nature. The characteristic times required for this experiment are of the order of 10 sec, which is available in a modest-sized expansion chamber, even if no attempt were made to cool the walls in synchronism with the gas cooling due to expansion. Unless a substantial effort is mounted to develop methods of measuring drop size, the observation of the cloud could, however, determine only the resulting droplet concentration.

Continuous-Flow Diffusion Chambers at Positive Temperatures. The theoretical treatment of the interaction of small hygroscopic particles with water vapor given by Kohler (1926) has been applied with some success to explain the behavior of atmospheric clouds. Thus, it is known that the ease and rapidity with which rain forms by coalescence is related to cloud microstructure, and that this in turn is largely controlled by the spectrum cloud nuclei.

In some respects, however, the theory does not appear to agree very well with observation. Numerical calculations of the cloud-forming process predict more monodisperse cloud droplet spectra than are commonly observed. One possible explanation of this difference relates to the fact that the accommodation coefficient for condensing water vapor molecules (typically assumed to be 100 percent is not known.

A small value of this coefficient could explain heterogeneity in the droplet sizes resulting from adiabatic expansion. Even if this is not so, since the particles which make up the aerosol are often of mixed constitution, and may be subjected to the influence of various trace gases, the condensation coefficient may not be the same for all of them. Thus, "poisoning" of cloud nuclei may occur in nature; moreover, it may prove eventually to be technologically feasible by such means to produce desired changes in cloud microstructure and behavior.

Experimentation in these areas is most suitably carried out in a diffusion chamber, at constant S. However, these chambers must be shallow, and at 1-g are necessarily arranged with the plates horizontal, so that fallout of particles are a severe limitation, especially at low supersaturations. The utilization of a continuous flow diffusion chamber offers attractive opportunities especially for $S < 0.1$ percent, which represents the lower end of the cloud range and the upper end of the fog range.

Static Diffusion Chambers at Positive Temperatures. Static diffusion chambers in 1-g are not usable below $S = 0.1$ percent, basically because of fallout. Particularly in relation to fog studies, there is a need to develop a method which can be used in the $S = 0.01$ percent to 0.1 percent (fog nuclei) range. In zero-gravity, static diffusion chambers could no doubt be used quite effectively in this range. If, therefore, a reliable and reproducible aerosol source were available, it would be possible to measure the resulting fog nucleus spectrum in zero-gravity and then use this as a standard aerosol source on earth for the calibration and checking of diffusion chambers intended for the measurement of fog nuclei in 1-g for environmental studies.

In the lower end of the cloud nucleus range ($S = 0.1$ to 0.3 percent), the static diffusion chambers normally used are probably inaccurate, and the same kind of checking and calibrating procedure would also be valuable here.

Diffusion Chambers at Negative Temperatures. Two types of studies are being considered. One is the influence of convection on the habit of ice growing from vapor.

The zero-gravity situation will be advantageous for two reasons in this study:

(1) The operation of static thermal diffusion will be simpler as there will be no wall convection currents. This means that large supersaturation can be produced and numerical values computed more realistically.

(2) It will enable the growth habit of ice to be studied entirely in the absence of natural convection.

The problem of the variation of ice crystal habit with temperature and supersaturation has been attacked by many investigators, but as yet no satisfactory explanation has been forthcoming.

The second study considers ice-water drop interactions. Graupel and rime form by the accretion and freezing of supercooled water drops by a falling ice crystal or by a fixed obstacle in the wind. The nature of this interaction is important for a number of atmospheric processes — including crystal multiplication and any associated electrification phenomena. The interaction involves the approach of a drop in a meta-stable state to the ice surface and its subsequent freezing. There are reports that small supercooled drops move around on an ice surface without freezing. This process can be studied in detail in the static thermal diffusion chamber.

Continuous-Flow Diffusion Chamber at Positive Temperatures

This type of chamber is especially suited for the investigation of the nucleation and growth of droplets at small S (condensation coefficient, nucleus constitution, nucleus poisoning, etc.). These chambers are relatively free of the initial conditions problem, and so are suitable for small S; depletion of S is controlled; the droplet sizes can be measured down to about 0.5 μ, since they are carried out of the chamber in a linear stream into an optical particle counter where stray scattered light is well controlled. Thus in studies of droplet growth, there is a clear advantage in using a continuous counter.

Problem Areas

The previous discussions indicate a number of areas in which decisions need to be made in which preliminary research appears to be required. For expansion chambers these are the (1) measurement of droplet sizes in a polydisperse population, (2) the avoidance of mechanical stirring due to the expansion itself, and (3) the value of residual g. For the continuous flow diffusion chamber these are, (1) the introduction of the sample, (2) the termination of the growth region, and (3) pressure constancy in the zero-gravity laboratory.

For the investigation discussed above (using static diffusion chambers at positive temperatures), it will be essential to have available a highly reliable and reproducible aerosol source for use at 1-g or zero-gravity. Extensive work has been carried out by a number of investigators aimed at the reproducible generation of aerosols. Available methods should be evaluated with special reference to their ability to generate identical aerosols, whether under zero-gravity of 1-g.

Pulsed Laser Holography in Cloud Physics, McDonnell Douglas Electronics Company (MDEC), St. Charles, Missouri

This study at MDEC was accomplished by R. M. Rhinehart and associates. This study included a general discussion of holographic systems, experimental results, and recommendations for future study.

General Discussion

Two types of holograms should be considered for recording images of small water droplets or ice crystals. Both have strong and weak points but, fortunately, it is possible to make a universal holographic setup so that one can choose the type best suited for each individual experiment.

First, there is the Fraunhofer or "on-axis" type, which is made with a single beam and requires the object to be small or semi-transparent.

Each illuminated droplet has its own diffusion pattern that reaches the plate and interferes with the non-diffracted light at the plate to form the hologram. The ratio of diffracted to non-diffracted light is determined by the particle's size, composition, distribution, and distance from the plate. The brightness and S/N ratio of the hologram is a function of this ratio. This type of hologram has the following desirable characteristics:

(1) It is easy to set up and requires a minimum amount of external optics.
(2) It doesn't require a great deal of laser power or coherence length.
(3) It defines the outline or shadow of a droplet pretty well.
(4) The reconstruction geometry is less critical.
(5) It probably wouldn't require relay optics.

It also has the following limitations:

(1) The depth of field is limited by the relationship

$$D = 49\frac{d^2}{\lambda}$$

where

$d$ = droplet diameter

$\lambda$ = recording wavelength

As the droplet size becomes small, the depth of field decreases rapidly.

(2) The hologram is inherently noisy because the image of the particles appear on axis or in line with the illumination beam. Due to noise in this beam the particles are harder to see.

(3) The ratio of reference-to-particle illumination energy is fixed.

The second type of hologram is the Fresnel or "off-axis" type where the reference beam does not pass through the object space. This type has the following favorable characteristics as applied to holography of small water droplets.

(1) Depth of field for droplets is greater due to the specular reflection component. The depth of field would be limited by the power, particle distribution, and coherence length.

(2) The S/N ratio is better than for the Fraunhofer type because the image is not reconstructed in the viewing beam.

(3) The ratio of reference to illumination beam can be varied to optimize the hologram.

The disadvantages are:

(1) It requires a more complicated setup with more steering optics.

(2) More windows would be required in the chamber.

(3) Less shape definition since the shadow is not recorded, just the specular points.

(4) Size would have to be determined by brightness measurements or by Mie scattering techniques.

(5) Relay lens would probably be required to maintain a low f number because of the reference beam geometry.

Experimental Results

Holograms of three different-size ranges of droplets were made. Vapor from hot water, aerosol (window-cleaner spray), and three suspended water droplets which range from about 1 mm to 2 mm in diameter. Both "on-axis" and "off-axis" holograms were made of each size range. The vapor in the "on-axis" hologram is very hard to view; therefore, for particles smaller than about 10 μ, "off-axis" holograms would be preferable.

The aerosol droplets show up quite well in both types and more shape definition can be seen in the "on-axis" hologram. The large water droplets appear best in the "off-axis" setup. By illuminating these drops from both sides, a strong specular spot can be seen on each side which will give size information.

Holograms were made to show a double pulse or interference type where the pulses were separated by about 1 min. During this time the drop has changed size or position and interference fringes appear on the drop. This can be observed by letting the projected real image fall on a white card a few inches from the hologram as the card is moved back and forth through the focus position; the fringes appear and disappear. Since our setup was not specifically stabilized for this type of hologram, we cannot be certain that the movement indicated is due to evaporation; however, it does appear to be.

Recommendations

It is recommended that more investigation and tests be performed in the following areas:

(1) Determine an optimum chamber design compatible with the two hologram types. Various techniques for multiangular illumination of the droplets, which would require various window positions and internal or external mirrors.

(2) Make holograms of a mixture of ice crystals and water droplets to determine exactly how well they can be distinguished.

(3) Further investigate the techniques for size determination from droplet specular reflections as obtained in Fresnel or "off-axis" holograms.

(4) Look at techniques for increasing the S/N ratio of Fraunhofer-type "on-axis" holograms by spatial filtering and other signal processing techniques.

(5) Evaluate the chamber design windows to determine if multi-reflections or light scattering will be a limiting factor.

## Application of Heat Pipes to Zero-Gravity Cloud Physics Equipment at Donald W. Douglas Laboratories

The study at Donald W. Douglas Laboratories (DWDC) was accomplished by A. W. Barsell and J. S. Holmgren.

The feasibility of utilizing heat pipes to provide thermal control of the Zero-Gravity Cloud Physics Experiment was evaluated. The preliminary analysis indicates that the approach is feasible, and that excellent performance is attainable with state-of-the-art heat pipe techniques which are simple and very reliable. In addressing the problem, the overall heat transfer was considered first to establish thermal fluxes, followed by an analysis of the performance of heat pipes under representative conditions. No attempt was made to optimize the design since determining feasibility was the principal requirement and funding was limited.

The analysis that follows was based on a system proposed by MDAC scientists. The inner surface of the box is to be thermally controlled in terms of absolute temperature and temperature gradients. For most experiments the chamber interior will be below cabin temperature with a worst case condition of 60°C temperature differential. Heat is removed from the package by a temperature controlled pump loop. Thermal distribution within the experimental package is accomplished with a network of heat pipes. (The interface between these two systems is still to be defined.) Little heat is generated within the experiment package; thermal fluxes are primarily the result of the temperature differential between the interior and exterior. Heat transfer is minimized with high performance insulation, but significant heat leaks at the view ports and any required access ports must be accommodated.

### Insulator Types

The range of temperatures for the cloud chamber falls into the upper end of the cryogenic region. Many of the developments in the cryogenic field in the past few years would not have been possible without the development of high-efficiency insulations that are 10 to 10,000 times better than ordinary refrigeration insulations. There are four general types of insulation being used for cryogenic applications. These are (1) high vacuum, (2) multiple layer, (3) powder, and (4) rigid foam.

The powder-type insulation appears to be clearly best for the cloud chamber for the following reasons:

(1) Sufficiently low heat fluxes through the walls can be maintained compatible with a heat-pipe rejection system. Multifoil can yield thermal conductivities that are an order-of-magnitude lower through the walls; considering edge losses; however, the overall insulating characteristics are not as different.

(2) The powder insulation is significantly stronger mechanically than multifoil and can result in a rugged cloud chamber design.

(3) The cost of powder insulation is significantly lower than for multifoil.

(4) Powder insulation does not require a high vacuum and retains reasonable insulative characteristics in event of vacuum failure.

The recommended insulation consists of a hermetically sealed (stainless steel, titanium alloy, or aluminum) lined cavity of required thickness filled with a dielectric powder such as Santocel. The inner walls should be good reflecting surfaces achieved by application of aluminum foil, chemical deposition of silver, or electro-deposition of silver or gold. For aluminum walls, only a cleaning or polishing is required. Surface contaminants such as oxides or films of oil or grease should be removed without work-hardening the metal.

For the recommended insulation system, the heat leaking in may be computed as a function of insulation thickness. The total heat flow is the sum of heat through the walls and windows, and around the window and heat pipe exit openings.

The insulating powder provides mechanical support for the double wall system around the chamber, with closure and metallic support provided around the windows or access ports.

Around each access port or window, the closure was assumed to be 0.04-inch thick 304SS. Heat conduction through this support ring is inversely proportional to the insulator thickness. Thus, heat flow around a single such window exceeds that of all six walls combined. This magnitude can be reduced up to a factor of 8 using titanium-vanadium-aluminum alloys since these titanium alloys have significantly lower thermal conductivity than the SS304. Additional reductions are possible by decreasing access port sleeve thickness to 0.03 or 0.0_ inch.

For the window opening itself, the radiation heat transfer is calculated (assuming a black box) to be only 3/4 watts per 2 in. diameter opening. No attenuation by the window glass was accounted for in this calculation. Conduction losses other than those associated with the support sleeve are negligible if a vacuum space between two windows is utilized.

Using the above values, the total heat flowing into the cloud chamber is calculated for the following representative case:

<u>Design</u>: 1-in.-thick insulation with Santocel-20 w/o Al powder, and two 2-in.-diameter view port with SS-304 liners.

<u>Heat Flows</u>:
- 1.5 watts through walls
- 10.8 watts around (2) windows
- 1.5 watts radiation through windows
- 13.8 watts total.

The analysis indicates that the thermal fluxes can be kept low. Fluxes 3 or 4 times as high, however, could easily be accommodated. Design of the access ports appears to be the most important element in minimizing the flux into the experimental package.

### Heat Pipe Location and Design

A typical heat pipe network which could be used for this application would provide a principal thermal path through the access port support structures with some additional leakage through the insulation. Heat pipes are placed adjacent to access support structure, as indicated, to transport heat away from this region. Additional heat pipes are spaced along the walls to accommodate heat leaks and isothermalize the system. Ten heat pipes per foot are indicated in the reference design, and gradients due to heat leaks through the insulation should be negligible. This close spacing will also provide for very small gradients as the system cools.

Heat transfer down access support structures is more difficult to handle, but can be accommodated by placing heat pipes adjacent to the support structure. Gradients above the desired value can occur (assuming the worst case where the desired internal temperature is -40°C) if the heat pipes are located even only a short distance from support. The recommended approach would be to have the heat pipe in direct thermal contact with the support. In this manner, the gradient would be essentially eliminated.

This approach appears to be attractive and is relatively simple. Heat pipes of the type required are available at DWDL and the designs have been through extensive compatibility, shock and vibration, and thermal performance tests. An aluminum extrusion with SS wick material and either freon or ammonia could be used. Ammonia gives better performance but may not be acceptable due to toxicity problems.

## MDAC Space Sciences Laboratory Efforts

Several important subsystem areas were identified early in the present program that required long-lead-time development. The additional items within these developmental areas were selected for very limited in-house study and hardware breadboarding. Most of these investigations involve technology transfer.

### Heat Pipe Thermal Transport

In many of the cloud physics experiments there is the requirement of having a surface or all surfaces of a chamber accurately temperature controlled. Often the temperature uniformity must be better than the required absolute temperature. The method of large thermal mass to provide this uniformity is often in conflict with the requirement of a short time constants. In addition, large fluid baths pumped at high volumetric rates are bulky and inefficient.

The heat pipe principle has been used (e.g., to passively control the surface temperature of a satellite). The thermal transfer properties of a heat pipe ideally provide both a uniform temperature surface and provide an efficient transfer of heat from one location to another. The heat pipe will not control temperature itself but is an efficient, passive heat transfer mechanism.

As part of this contract effort, several heat pipe configurations were evaluated relative to the cloud physics experiment requirements. These analyses indicated that temperature uniformities over a 30-cm by 30-cm area could be controlled within 0.1°C. An expansion chamber 30 liters in volume with appropriate insulation could be controlled within 0.2°C down to -40°C in an ambient environment of +25°C.

For an evaluation of these concepts, a thermal control shell 5 cm in diameter by 30 cm in length for a Raman cell was constructed. The operating range was to be between 0 and 100°C. Preliminary tests indicated the desired ±0.1°C temperature uniformity was obtained. This unit will be used to control a glass Raman cell for the studies of temperature and molecular concentration measurements by Raman spectroscopy.

As an application to cloud physics chambers, two flat heat pipe plates were constructed to be incorporated into a continuous-flow diffusion chamber subsystem. Preliminary tests have indicated better than ±0.12°C temperature uniformity over a 30-cm surface, uninsulated at 10°C below ambient. Slight design changes would provide extended operational range but this 10°C was the design specification for the present analysis. This chamber will be complete and its operation compared with a presently operating continuous-flow diffusion chamber.

In most cases, heat pipes work more efficiently under low-gravity conditions. Thus, this is a very promising technology area for use in our low-gravity facility development.

Thermal Control

Several of the chambers have modest temperature-range requirements (e.g., the continuous-flow diffusion chamber). Thermoelectric modules promise to provide the desired thermal control under these conditions. As compared with fluid baths, thermoelectric modules provide much lower volume and weight. Fluid leak problems are also reduced with the elimination of the requirement for fluid circulation. Thermoelectric modules are also ideally suited for use with heat pipes.

For these reasons, thermoelectric control was briefly tested on the Raman cell and then on one of the continuous-flow-diffusion-chamber heat pipe plates mentioned in the previous paragraphs. Eight units, 2-cm square, with a fan and finned heat exchange were used to maintain the plate at 10°C below ambient. This arrangement met the desired requirements and will be considered for testing with the operational version of this diffusion chamber.

## Zero-Gravity Techniques

### Terrestrial Techniques

This program has identified a need for a low-gravity environment. A number of attempts have been made in the past to nullify gravity's effects so that large-particles processes can be studied in detail. Table 18 summarizes potential zero-gravity techniques. The electrical and acoustical terrestrial techniques introduce surface forces and conditions that often obscure the desired phenomena being studied.

Vertical laminar-flow wind tunnels have been used for many years in atmospheric physics for the study of water droplets and ice crystals under natural aerodynamic conditions. Discussions with Dr. T. S. Kledanoss (NBS-Washington) indicated that the state of low-Reynolds-number flow tunnels is much the same now as it was in 1964. A good reference is the paper, "Design of Low Speed Wind Tunnels," by P. Bradshaw and R. C. Prankhurst in Progress in Aeronautical Sciences, Vol. 5, 1964, published by Pergamon Press. The NBS is constructing a low-Reynolds-number wind tunnel for calibration work, using information such as given in the above reference.

**Table 18**

**ZERO-GRAVITY TECHNIQUES**

| TERRESTRIAL | POTENTIAL CARRIERS | |
| --- | --- | --- |
| ELECTRICAL | DROP TOWER | APOLLO |
| ACOUSTICAL | KC-135 | SKYLAB |
| LAMINAR FLOW | ROCKETS | SHUTTLE |
| | SATS | |

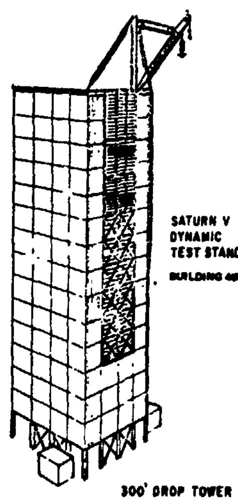
Most of the present technology is concerned with maintaining laminar flow at high Reynolds numbers which is a completely different area of aerodynamics. NBS is attempting to extend the technology to the lower-Reynolds-number region below 100 that is of major concern to cloud physics. The University of California at Los Angeles (UCLA) presently has a state-of-the-art vertical wind tunnel being used for cloud physics work. They utilize sonic nozzle, flow straighteners, etc., to provide a laminar flow with less than 2-percent residual turbulence level. This turbulence is not noticeable for present experiments with droplets under 30 μm in diameter but the level can be reduced if necessary. The National Center for Atmospheric Research (NCAR) has built a larger version of the UCLA wind tunnel which is now operational. Present wind tunnels use state-of-the-art technology and are giving answers to wind-tunnel compatible problems. Some experiments involving multiple particles with greatly different diameters are sometimes difficult to handle with a wind tunnel system. Other areas such as diffusional growth must be studied with diffusion chambers.

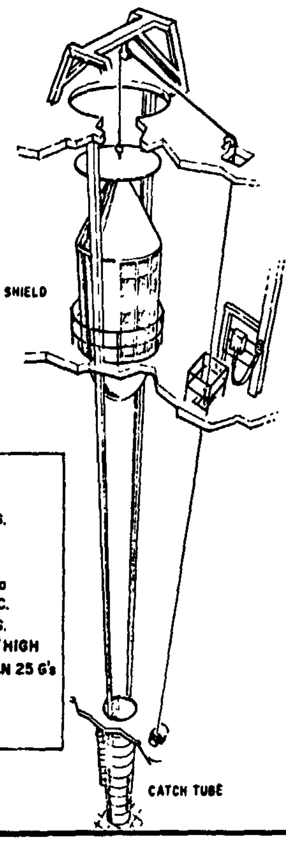
Potential Testing and Development Facilities

The second group of potential carriers which can provide various levels of low gravity are limited in volume or experiment time. They are useful for the development and testing of subsystems that are to be used in zero-gravity cloud physics.

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. The Marshall Space Flight Center (MSFC) drop tower's 4-sec low-gravity duration can potentially be used to test such concepts as drop injection, charging, and positioning (Figure 22). The rapid turn-around time and low cost is attractive. A droplet injection technique is now being developed and tested in this tower by MSFC for the proposed ASTP-NaCl breakup experiment.

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 23 gives the characteristics of the parabolic zero-gravity KC-135 trajectory as well as the required acceleration pattern before




**CAPABILITIES**

| | |
|---|---|
| PAYLOAD | |
| PRESENT | 450 LBS. |
| FUTURE | 1000 LBS. |
| LOW GRAVITY TEST RANGE | |
| MINIMUM | $10^{-5}$ Go |
| MAXIMUM | $4 \times 10^{-2}$ Go |
| DROP TIME (294') | 4.135 SEC. |
| TOTAL DROP WEIGHT | 4000 LBS. |
| MAXIMUM TEST PACKAGE | 3'DIA. X 3'HIGH |
| DECELERATION | LESS THAN 25 G's |
| INSTRUMENTATION CHANNELS | 6 |
| NON-DESTRUCTIVE TESTING | |
| ZERO TURN-AROUND TIME | |

Figure 22. The MSFC 300-Foot Drop Tower



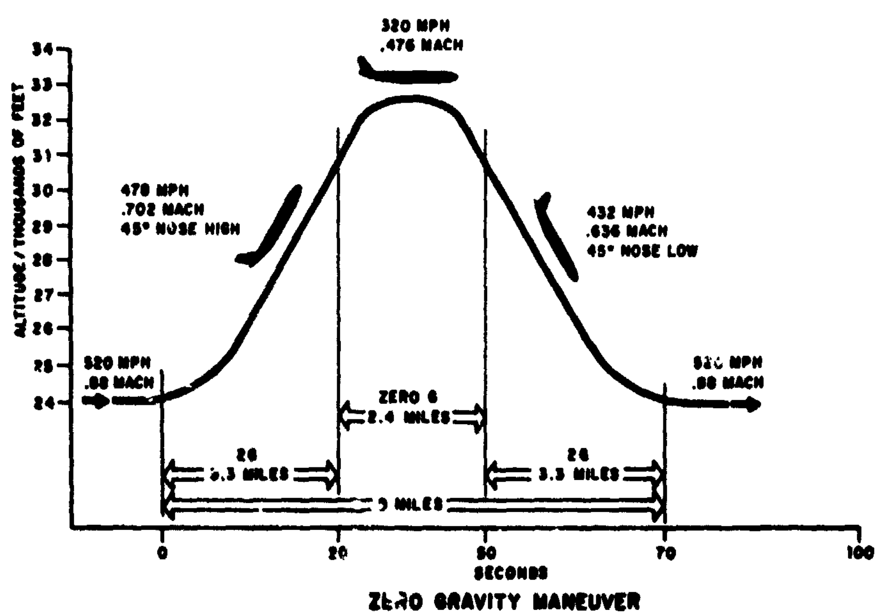



Figure 23. KC-135 Research Aircraft Trajectory

and after the low-gravity segment. Around 40 low-acceleration trajectories can be flown in a 2- to 3-hr flying session. Experience has shown that the level of gravity for the aircraft fluctuates considerably during any given maneuver, thus limiting actual uniform periods with very low acceleration to something less than 14 to 20 sec.

The sounding and suborbital rockets indicate that significant time periods of near zero-gravity are available. In the case of rockets, spin about their long axis is normally used for stabilization. The required spin will then limit the lower total acceleration level attainable. Figure 24 is a typical trajectory for an Aerobee sounding rocket.

Telephonic discussions were held with Messrs. I. C. Yates and J. H. Yost of MSFC with reference to NASA TM X-64665 concerning their use of the Black Brant and Aerobee rockets. Further discussions with Mr. J. N. Brown of Space General revealed that despinning to 20 deg/sec and a 90-deg coning angle would provide a 0.005-g level; to reduce the acceleration below this level, an active ATS attitude control would be required. A Mark II rocket

CR90

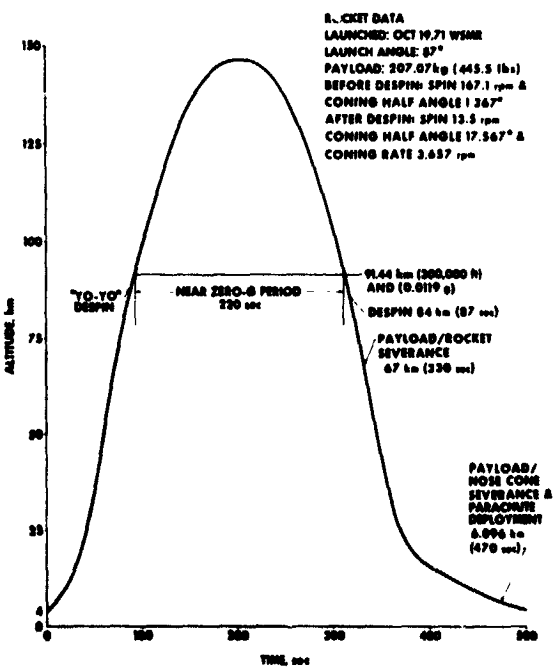



**Figure 24. Altitude Versus Time for Aerobee 170A**

with ATS would hold the orientation to ±1/4 deg (no spin). The initial cost of the ATS unit is around $100, 000, with refurbishment of the gyros costing $40, 000 per flight. These costs are in addition to the rocket cost. From these discussions, rockets with ATS altitude control would provide around 4 min of low-gravity environment that would be useful for testing and development of certain experimental equipment and techniques. The volume available is around 40 cm in diameter and 100-cm long. The cost is considerable more than for a drop-tower test but the potential useful time is 50 times longer.

Potential Experiment Carriers

The third group of carriers is more compatible with the experiment requirements of visual interaction, weight, volume, and experiment duration. Minimal demonstrations of droplet dynamics have been accomplished on Apollo 16 and 17. Skylab shows much potential as a useful experiment and testing facility. More tasks may be completed on the ASTP NaCl breakup experiment, if accepted, in 1975. The main thrust of the program is toward the Shuttle-Sortie laboratory type of facility. This larger facility permits the development of a cost-effective multiexperiment support facility where subsystems common to many experiments can be developed and included once for all experiments and not redeveloped for each experiment.

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## VI. EARLY FLIGHT OPPORTUNITIES

Throughout 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 the lack of experience in working with 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. Objectives of these portable experimentation and testing modules (PETM) are to provide a significant contribution to a relevant scientific objective, and to test one or more subsystem components being developed for the zero-gravity laboratory. To this end, the Skylab, Apollo, and early Shuttle test flights have been examined and have b en 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.

### NaCl Breakup Experiment

Immediately after the announcement that the U. S. Government and the Soviet Union agreed to participate jointly in a space venture, MDAC, NASA, and the Scientific Board selected a candidate experiment for consideration to be performed on this mission. The experiment selected was "NaCl Breakup During Evaporation." A principal-investigator team was formed to advise and assist in the formulation, development, and operation of the experiment and to assist in analyzing the experimental data. Members of this principal-investigator team are:

(1) Dr. C. L. Hosler, Chairman
Dean of College of Earth & Mineral Sciences
Pennsylvania State University
University Park, Pennsylvania

(2) Dr. J. P. Lodge, Jr.
National Center for Atmospheric Research
Boulder, Colorado

(3) Dr. J. L. Kassner
Director, Graduate Center for Cloud Physics Research
Space Sciences Research Center - Rolla
University of Missouri
Rolla, Missouri.

(4) Dr. J. E. Jiusto
State University of New York at Albany
Albany, New York

(5) Dr. L. R. Eaton
Space Sciences Department
McDonnell Douglas Astronautics Company-West
Huntington Beach, California

There was ample scientific justification for the selection of this experiment. The significance of NaCl breakup is important in cloud physics in the formation of precipitation nuclei. Knowledge of NaCl breakup has important terrestrial applications such as the operation of brine cooling towers and the use of salt for highway snow and ice removal. These significant applications are described below.

Precipitation Nuclei

The precipitation processes are a function of available nuclei size and number. Large (0.1 μm to 1 μm) and giant (1 μm to 10 μm) NaCl nuclei in particular play a major role. The oceans are the main source of salt nuclei, which are produced as a result of the formation and subsequent evaporation of droplets formed by the breakup of waves and bubbles at the ocean surface. The giant NaCl particles are known to exist at much lower concentrations over land masses than over the ocean. A number of processes contribute to this decrease: the particle breakup during evaporation is believed to be an important one. Knowledge of these depletion processes causing this loss of large NaCl particles would provide a link to understanding the nuclei size and mass distribution in the atmosphere.

Better understanding of this break-up mechanism could also play an important role in the weather modification technique of dispersing NaCl by spraying salt solutions where precise size and particle numbers are required.

Salt particles are important nucleating agents for oceanic and shoreline haze problems. Better understanding of the break-up process would lead to improved forecasting capabilities and to eventual haze and fog modification and control techniques.

### Brine Cooling Towers

Brine cooling towers are considered a method of avoiding the thermal pollution of lakes and rivers during the generation of electrical power. One aspect of brine towers is the significant loss of the saturated solution to the ambient air. The rate of accumulation of the salt from the brine depends on droplet size and fall velocity. Present theoretical considerations, neglecting particle breakup, indicate that an undesirable salt accumulation could occur in an area around the towers. If salt-particle breakup existed during the rapid evaporation of the brine droplets, the salt would be dispersed over a greater area. The concentration accumulation decreases by as much as the fourth power of the particle diameter. Thus, if the particle diameter decreased by a factor of 2, the concentration would fall by a factor between 4 and 16, depending on particle size. Thus, the ecological impact depends on the dispersion processes and determines the non-use, use, and design of towers versus other cooling methods.

### Highway Salting

There has been concern about the damage done by salt washoff from highways. Another aspect of this problem is the generation of salt mist due to vehicle motion over salt-laden highways. The distance that this salt mist disperses depends on salt size and numbers. Salt particle breakup during the evaporation of the salt droplets would be important in determining the ecological impact of the use of salt on highways.

### NaCl Breakup Experiment Technique and Equipment Testing

In addition to the scientific justification, the experiment would also provide an opportunity to test techniques and equipment under zero-gravity conditions. Of particular interest are droplet motion, injection techniques, and humidification technique. These are discussed as follows:

Droplet Motion – A number of cloud physics areas delineated by the NASA-sponsored Zero-Gravity Atmospheric Cloud Physics Laboratory study would benefit from a zero-gravity experimental environment.

The observation of a cloud of droplets will provide a determination of the constraints of a low- or zero-gravity environment. These constraints include effects caused by residual random accelerations, ambient and particle electrical properties, and air ionization.

These observations would be used to further screen potential cloud physics experiments and also to determine experiment procedures to be followed. This would result in a fuller utilization of the low-gravity environment.

Injection Techniques – A very important aspect of all the proposed experiments is the introduction of the material to be studied into the chamber. Various injection techniques are used in terrestrial laboratories and a low-gravity adaptation of one of these techniques is used in this experiment. The performance of the system in low gravity will assist in the determination of specifications for injection systems and particle and droplet control and positioning subsystems for the Zero-Gravity Atmospheric Cloud Physics Laboratory.

Humidification Techniques – Almost all experiments proposed for the Zero-Gravity Atmospheric Cloud Physics Laboratory involve humidification. This experiment affords an opportunity to test a simple purge subsystem for both humidification and dehumidification capabilities.

NaCl Breakup Experiment Definition and Design

MDAC completed a definition study for the NaCl breakup experiment in July 1972. The results of this study were published in MDAC Report MDC G3779, "Preliminary Definition Study NaCl Particle Breakup Carry-On Experiment for Apollo-Soyuz Test Program." The basic experiment can be described as follows. The experiment chamber utilizes ambient temperature and pressure. The relative humidity is adjusted to a given value using the purge subsystem. A saturated NaCl solution droplet is injected and subsequent evaporation and breakup is observed and photographed. A visual and photographic count is then made of the number of crystal particles. The temperature, pressure, and relative humidity are recorded. This procedure cycle is then repeated for each relative humidity setting. At least three different humidity settings will be used.

The experiment definition involved technical studies regarding drop sizes, evaporation times, acceleration effects, light source requirements, drop stopping distance, and droplet injection techniques. Preliminary design was completed for the chamber subsystem, purge subsystem, droplet injection subsystem and optical subsystem. Electrical requirements and data requirements were established. Experiment procedures including experiment timelines, experiment priorities, and astronaut training requirements were outlined. Development of the experiment is currently underway by the Astronautics Laboratory at MSFC.

Droplet Dynamic Demonstration Experiment

MDAC and NASA recognized the possibilities of using the Apollo missions as a base for pre-Shuttle experimentation. The Zero-G Cloud Physics Program had its inception well after the experiment program for the Apollo was firmly scheduled and it was obvious that it was too late to place an experiment aboard any of the missions. However, it appeared that some scientific demonstrations, involving little or no new equipment, might be accepted for Apollo 17 or Skylab.

A droplet dynamics and break-up engineering demonstration was selected. A principal-investigator team was formed to advise and assist in analyzing the experimental data. Members of this principal-investigator team are:

(1) Dr. D. C. Blanchard, Chairman
State University of New York at Albany
Albany, New York

(2) Dr. T. E. Hoffer
Desert Research Institute
University of Nevada
Reno, Nevada

(3) Dr. J. Latham
University of Manchester
Institute of Science and Technology
Manchester, England

(4) Dr. J. D. Spengler, Jr.
School of Public Health
Harvard University
Boston, Massachusetts

(5) Dr. L. R. Eaton
Space Sciences Department
McDonnell Douglas Astronautics Company-West.
Huntington Beach, California

Selection of droplet dynamics for an engineering demonstration is scientifically justified. The significance of droplet collision and breakup is very important in precipitation formation and in electrification processes. These are discussed below.

Precipitation Formation

The initial phases of precipitation formation involve the diffusional growth of submicron-size nuclei particles to liquid (water) spheres of a few microns in diameter. Although this initial growth by diffusion involves only a few seconds to a few minutes of time under normal atmospheric conditions, diffusional growth from 10 or 20 $\mu$ in diameter to millimeter "precipitation" sizes under non-freezing conditions would take hours, whereas in nature this process is known to take place in 30 to 60 min.

This growth problem has been resolved by considering collision and coalescence of water droplets. Theory indicates that in order for the coalescence processes to occur droplets of different diameters must coexist. One of the possible important sources for this range of droplet sizes is the breakup of millimeter size drops due to collisions.

P. R. Brazier-Smith et al (Proc. R. Soc. London A 326, 393-408 (1972)) summarized the possible modes of interaction when a pair of water drops collide while falling through air: (1) they may bounce apart, contact of the two surfaces being prevented by the intervening air film; (2) they may coalesce and remain permanently united; (3) they may coalesce temporarily and separate, apparently retaining their initial identities; (4) they may coalesce temporarily, with the subsequent separation accompanied by satellite drops; or (5) with very high-energy collisions, spattering may occur, in which numerous tiny droplets are expelled radially from the periphery of the interacting drops. The type of interaction depends upon the sizes of the drops, their velocities, their angular momentum, the existing electrical forces and other parameters.

Item (2) above is droplet growth by collision, while items (4) and (5) provide a spreading of droplet size distribution permitting item (2) to progress more actively. In addition to these two (or more) body interactions, droplets above a few millimeters in diameter can also break up due to aerodynamic forces during their gravity-induced free fall in the earth's atmosphere.

These various break-up mechanisms are very important in the precipitation processes and the understanding of them will contribute toward weather prediction and modification efforts.

Electrification Processes

Droplet breakup can contribute to the electrification and charge separation in clouds. This charging process can, in turn, influence the coalescence processes. Neutral droplets containing impurities, breaking up in an electric field and/or with temperature differences can produce multiple droplets that possess net charges. The understanding of these electrification processes will contribute to the prediction, modification, and prevention of electrical storms that cause forest fires and other electrical damage. Precipitation enhancement may also be possible. Knowledge of the breakup processes will contribute to the understanding of the electrification processes.

Droplet Experiment Technique and Equipment Testing

In addition to the scientific justification, the experiment would also provide an opportunity to test techniques and equipment under zero gravity conditions. Of particular interest are droplet motion control and manipulation and injection techniques. These are described as follows:

Droplet Motion and Manipulation — A number of cloud physics areas delineated by the NASA-sponsored Zero-Gravity Atmospheric Cloud Physics Laboratory study would benefit from a zero-gravity experimental environment.

The observation of drops will provide a determination of the constraints of a low- or zero-gravity environment. These constraints include effects caused by residual random accelerations, ambient and particle electrical properties, and air ionization. Liquid drop manipulation techniques can also be evaluated.

These observations would be used to further screen potential cloud physics experiments and also to determine experiment procedures to be followed. This would result in better utilization of the low-gravity environment.

Injection Techniques — A very important aspect of all the zero-gravity experiments proposed is the introduction of the material to be studied into the chamber. Various injection techniques are used in terrestrial laboratories and a low-gravity adaptation of one of these techniques is used in this experiment. The performance of this system in low gravity will assist in the determination of specifications for injection systems and particle and droplet control and positioning subsystems for the zero-gravity atmospheric cloud physics laboratory.

Droplet Experiment Demonstration and Design

MDAC completed a definition study for a droplet dynamics demonstration in July 1972. The results of this study were published in MDAC report MDC G3787, "Preliminary Definition Study Droplet Dynamics and Breakup Engineering Demonstration." The basic experiment demonstration is described as follows.

Ambient temperature, pressure, and relative humidity are utilized. Liquid and solid spheres are freely suspended inside the spacecraft and subsequent induced and residual motion is observed and photographed. Single spheres are excited by probing, blowing, and by collision with other spheres with special attention given to motion, vibration (amplitude and frequency), and breakup of the spheres. Comparisons of liquids with different surface tensions and viscosities would be desirable if time permits and the materials are available.

The objectives are in four major categories as follows:

(1) Drop Impact: Observation of the break-up modes and characteristics of two colliding droplets as a function of fluid properties and droplet sizes.

(2) Drop Stability: Observation of the oscillation modes, oscillation amplitudes, and breakup of a vibrating liquid sphere as a function of the liquid properties.

(3) Drop Motion: Observation of the effects of spacecraft motion upon conduct of low-gravity dependent experiments.

(4) Drop Manipulation: Evaluate techniques for the generation and manipulation of liquid spheres of various diameters and observe stopping distances and times.

MDAC's definition involved technical studies regarding drop sizes, evaporation effects, Rayleigh oscillation and drop interactions, and breakups. Preliminary design was completed for the air-stream sources, water droplet impeller, sphere impeller, wire probe retractor, and other alternate equipment. Data requirements including photographing, were established, along with experimental procedures including experiment timelines, experiment priorities, and astronaut training requirements. Due to time delays, the demonstration as outlined was not performed aboard Apollo 17. Some droplet manipulations involving the astronaut water gun were attempted but no qualitative data is available. The feasibility of including the demonstration aboard Skylab, either wholly or partially, is currently under consideration.

Shuttle Test Missions

Ten or more test missions are programmed for the Space Shuttle Program. Although these missions have not been delineated, they could possibly serve as a vehicle for PETM's. A number of possible experiments have been identified if flight opportunities become available. Missions would have to have sufficient orbital height and orientation to provide low gravity. However, some PETM's may only require short time periods in low gravity in order to complete their scientific objectives or to test and check out instruments and equipment.

Although there has been no specific solicitation for PETM experiments, a number of experiments have been identified to date. The experiments and the names of the persons suggesting them are listed below:

| | |
|---|---|
| Dr. J. Hallett | DRI - Ice-Water Drop Interactions |
| Dr. K. O. Jayaweera | Univ. of Alaska - Growth Properties of Ice Crystals |
| Dr. W. C. Kocmond | Cornell Laboratory - Nucleation of Prepared Aerosols |
| Dr. J. D. Spengler | Harvard Univ. - Drop Oscillations |
| Dr. J. W. Telford | DRI - Coalescence Process of Liquid Droplets |
| Dr. D. C. Blanchard | SUNY - Coalescence Process of Liquid Droplets |
| Dr. J. Hallett | DRI - Evaporation in a Vacuum |
| Dr. H. R. Byers | Texas A&M - Droplet Splintering |
| Dr. T. E. Hoffer | DRI - Saturation Vapor Pressure Over Supercooled Water |
| Dr. C. L. Hosler | Penn State - Three-Dimensional Simulation of Atmospheric Circulation |

DRI - Desert Research Institute

SUNY - State University of New York at Albany

# Appendix

## ZERO-GRAVITY CLOUD PHYSICS LABORATORY PAYLOAD PLANNING DEFINITION

This appendix presents pertinent payload planning information. The defined Zero-Gravity Cloud Physics Laboratory is to be used with the Shuttle-Sortie Laboratory. It is a multi-experiment laboratory, and the maximum launch configuration parameters (worst-case experiment mission) are presented herein.

LEVEL 1

**ZERO-G CLOUD PHYSICS LABORATORY** CR90

## PLANNING CHARACTERISTICS

**PAYLOAD AREA**

- [■] APPLICATION

**DISCIPLINE**

- SCIENCE
  - [X] ATMOSPHERIC & SPACE PHYSICS
- SPACE TECHNOLOGY
  - [X] ATMOSPHERIC PHYSICS

**MISSION PAYLOAD CENTERS**

- [X] NASA CENTER

**STANDARD PAYLOAD CARRIER USAGE**

- [X] SORTIE LAB

| CY | 79 | 80 | 81 | 82 | 83 | 84 | 85 |
|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 4 | 4 | 4 |

**MAJOR INSTRUMENTS**

| TYPE | OBJECTIVE |
|---|---|
| | |

**SPECIAL COMMENTS**

BASIC LABORATORY WITH SPECIAL CLOUD CHAMBERS AND AEROSOLS TO ACCOMPLISH ATMOSPHERIC MICROPHYSICS EXPERIMENTS TO MODIFY/PREDICT/CONTROL WEATHER'

LABORATORY TO BE FLOWN ON MULTIPLE MISSIONS > 20

## MISSION CHARACTERISTICS (INITIAL FLIGHT ONLY)

- LAUNCH DATA – GENERAL 1980 SPECIFIC TBD

| | | DESIRED | ACCEPTABLE |
|---|---|---|---|
| • INCLINATION RANGE – DEGREES | | ANY | ANY |
| • ALTITUDE • APOGEE | NM | 200 MIN | ANY |
| | KM | ANY | ANY |
| • PERIGEE | KM | ANY | ANY |
| | NM | ANY | ANY |
| • MISSION DURATION – DAYS | | 5 DAY MIN | 2 DAYS MIN |
| • ORIENTATION X-POP Y-POP Z-POP INERTIAL | | ANY | ANY |
| • POINTING | | | |
| • ACCURACY – DEGREES | | ANY | ANY |
| • STABILITY – DEG/SEC | | | ANY |
| • DURATION – HRS/OBSERVATION | SEE COMMENTS | | |
| • FREQUENCY – NO/REVOLUTION | SEE COMMENTS | | |
| • VIEWING OR SUNLIGHT CONSTRAINTS | | NONE | NONE |
| • FREE FLYER | | N/A | N/A |
| • OPERATING LIFE – MONTHS | | N/A | |
| • REVISIT REQUIREMENTS – NUMBER/YEAR | | N/A | |
| • RETRIEVAL REQUIREMENTS – YEAR | | N/A | |

**SPECIAL COMMENTS**

- JUST MAINTAIN $< 10^{-3}$ g's FOR EXPERIMENTAL PERIODS OF 15 MIN TO 2 HOURS; COMPATIBLE WITH ANY MISSION MEETING THESE REQUIREMENTS

## PHYSICAL CHARACTERISTICS OF TOTAL PAYLOAD

(STANDARD PAYLOAD CARRIER PLUS EXPERIMENT PACKAGE)

| | | |
|---|---|---|
| • WEIGHT | 1032 LBS | 468 KG |
| • LENGTH | 8 FT | 2.6 M |
| • DIAMETER | N/A FT | N/A |
| • VOLUME | 310 $FT^3$ | 8.8 $M^3$ |
| • CENTER-OF-GRAVITY | TBD | |
| • MOMENTS-OF-INERTIA (SLUG – $FT^2$) IXX IYY IZZ | TBD | |

## ENVIRONMENTAL REQUIREMENTS

| | GROUND STORAGE | | FLIGHT & CHECKOUT | |
|---|---|---|---|---|
| | DESIRED | ACCEPTABLE | DESIRED | ACCEPTABLE |
| TEMPERATURE °F | | | | |
| • MAX | 90 | 180 | 70 | 90 |
| • MIN | 50 | 40 | 50 | 40 |
| • OPERATION | 68 | 55-85 | 68 | 60-80 |
| HUMIDITY RANGE | 30-50 | 25-80 | — | — |
| CONTAMINATION | | | | |
| • PARTICLES – NO/$M^3$ | N/A | N/A | N/A | N/A |
| • GASSES – TORR | | | N/A | N/A |
| • RADIATION – MILLIRAD/HR | | | N/A | N/A |
| • ELECTRO MAGNETIC INTERFERENCE | | | TBD | TBD |
| ACCELERATION LIMITS – G's | | | $10^{-3}$ | $10^{-3}$ |
| VIBRATION LIMITS | | | TBD | TBD |

## RESOURCE UTILIZATION

| | | DESIRED | ACCEPTABLE |
|---|---|---|---|
| • CREW – PAYLOAD SPECIALIST ONLY | | | |
| • NUMBER | | 1-2 | 1 |
| • SKILLS CLOUD PHYSICS | | 4-8 | — |
| • UTILIZATION – HR/DAY | SINGLE SHIFT | 4-8 | |
| | DOUBLE SHIFT | 8-16 | |
| • EXTRA VEHICULAR ACTIVITY – NO/MISSION | | NONE | NONE |
| • POWER • TYPE | | 115 VAC, 28 VDC | 28 VDC |
| • POWER LEVEL, AVG – KW | | 0.2 | 0.13 |
| • POWER LEVEL, PEAK – KW | | 0.2 | 0.15 |
| • DURATION – HRS | | 0.750 | 0.650 |
| • ENERGY – KWH | | 0.1 | 0.05 |
| | | 2 MAX | 1.5 MAX |
| • DATA | | | |
| • SHUTTLE COMPUTER SUPPORT NEEDED | | YES ___ | NO X |
| • DIGITAL • RATE – BPS | | TBD | TBD |
| • TOTAL – MO/DAY | | TBD | TBD |
| • DURATION – HR/DAY | | TBD | TBD |
| • TAPES | | TBD | TBD |
| • ANALOG • DURATION – HR/DAY | N/A | — | — |
| • BAND WIDTH | N/A | — | — |
| • TAPES | N/A | — | — |
| • TV – HR/DAY | N/A | — | — |
| • VOICE TO GROUND | YES X NO ___ | | |
| • HEAT REJECTION | | | |
| • PEAK – BTU/HR | | 0.19 | 0.15 |
| • AVG – BTU/HR | | 0.71 | 0.85 |
| • MIN – BTU/HR | | 0.1 | 0.06 |

## LEVEL 2
## SORTIE PAYLOAD DEFINITION AND REQUIREMENTS DATA

3/2/73

PAYLOAD NO. ______ PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY DISCIPLINE APPLICATIONS

| SHEET NO. | TITLE |
|---|---|
| S-1 | PROGRAMMATICS |
| S-2 | OBJECTIVES |
| S-3 | PAYLOAD EXPERIMENT AND SUPPORT EQUIPMENT |
| S-4 | SKETCHES – INTERNAL EQUIPMENT |
| S-5 | SKETCHES – EXTERNAL EQUIPMENT |
| S-6 | POINTING AND STABILITY |
| S-7 | MISSION OPERATIONS |
| S-8 | EXPERIMENT OPERATIONAL CYCLE |
| S-9 | PAYLOAD OPERATIONS DATA |
| S-10 | ELECTRICAL POWER REQUIREMENTS |
| S-11 | DATA AND COMMUNICATIONS REQUIREMENTS |
| S-12 | ENVIRONMENTAL REQUIREMENTS |
| S-13 | CREW AND EVA REQUIREMENTS |
| S-14 | GROUND SUPPORT REQUIREMENTS |
| S-15 | FACILITY REQUIREMENTS |
| S-16 | LOGISTICS REQUIREMENTS |
| S-17 | MISSION EQUIPMENT COST DATA |

CR90

## PROGRAMMATICS

DATA SHEET NO ______ S-1
PAYLOAD NO ______
DATE ______ 3/2/73 ______ REV ______

PAYLOAD NAME ______ ZERO-G CLOUD PHYSICS LABORATORY

1 PROGRAM TITLE ______
2 PROGRAM NUMBER DESIGNATION ______
3 DEVELOPMENT AGENCY ______
4 INITIAL LAUNCH ______ (DATE)

5 PROGRAM LIFETIME, YEARS ______ 5-10
6 NUMBER OF MISSIONS IN PROGRAM ______ 20
7 NOMINAL MISSION DURATION, DAYS ______ 5
8 MEAN PAYLOAD LIFETIME, YEARS ______ 5-10

| LAUNCH SCHEDULE: | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATA ITEM NO: | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17 | 18 | 19 | 20 |
| YEAR: | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 |
| NO. LAUNCHES: | ___ | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

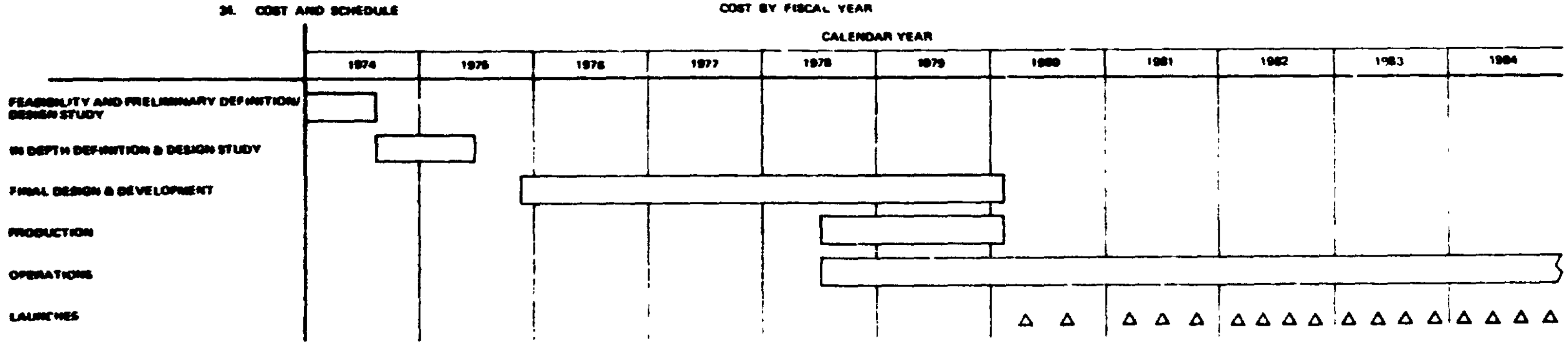
ORBIT PARAMETERS:

21. MAXIMUM PERIGEE, KM (NM) ______ ANY
22. MINIMUM PERIGEE, KM (NM) ______ (100)
23. NOMINAL PERIGEE, KM (NM) ______ ANY
24. MAXIMUM APOGEE, KM (NM) ______ ANY
25. MINIMUM APOGEE, KM (NM) ______ (100) PREFER CIRCULAR ORBIT
26. NOMINAL APOGEE, KM (NM) ______ ANY
27. MAXIMUM INCLINATION, DEG ______ ANY
28. MINIMUM INCLINATION, DEG. ______ ANY
29. NOMINAL INCLINATION, DEG. ______ ANY

30 LAUNCH SITE ______ ETR OR WTR
31 LAUNCH WINDOW CENTER ______ N/A (DATE) (TIME)
33 LAUNCH WINDOW DURATION, HRS ______ N/A

34. COST AND SCHEDULE

COST BY FISCAL YEAR



## OBJECTIVES

DATA SHEET NO 52

PAYLOAD NO

DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

1. SUMMARY A ZERO-G ATMOSPHERIC MICROPHYSICS/CLOUD PHYSICS FACILITY DESIGNED TO ACCOMMODATE A LARGE VARIETY OF EXPERIMENTS PROPOSED BY ATMOSPHERIC PHYSICISTS FROM THROUGHOUT THE INTERNATIONAL SCIENTIFIC COMMUNITY. THIS MULTIPURPOSE FACILITY WILL BE DESIGNED TO BE REUSABLE FOR A MINIMUM OF TWENTY MISSIONS

2. MISSION OBJECTIVES THE OBJECTIVES OF THE PLANNED MISSION ARE TO ACQUIRE DATA CURRENTLY UNACHIEVABLE IN TERRESTRIAL LABORATORIES. THESE DATA WILL BE USED IN WEATHER MODIFICATION AND CONTROL (E.G., WHEN DECISIONS—THE TIMING IN THE CLOUD GROWTH CYCLE WHEN SEEDING IS TO BE APPLIED, WHERE DECISIONS—WHAT LEVEL IN THE CLOUD OR RELATIVE TO THE CLOUD SHOULD THE MODIFICATION AGENTS BE PLACED, WHAT DECISIONS—THE RELATIVE MERITS OF DIFFERENT SEEDING AGENTS, AND HOW MUCH DECISIONS—AMOUNTS OF SEEDING MATERIAL REQUIRED TO PRODUCE DESIRED RESULTS.)

3. RELATIONSHIP TO DISCIPLINE OBJECTIVES THE OBJECTIVES OF THIS PAYLOAD ARE TO CONCENTRATE ON A RANGE OF PARTICLE SIZES THAT ARE AFFECTED BY GRAVITY BUT THE FORCES TO BE STUDIED ARE GRAVITY INDEPENDENT. THESE DATA WILL FILL IMPORTANT DATA GAPS IN THE EXISTING THEORIES OF ATMOSPHERIC MICROPHYSICS ESPECIALLY IN THE AREAS OF WEATHER MODIFICATION AND CONTROL. THEY WILL ALSO BE USEFUL IN WEATHER PREDICTION AND MAY HAVE IMPORTANT APPLICATION IN AIR AND WATER POLLUTION STUDIES

4. EXPERIMENTS

| NO. | TITLE | OBJECTIVES |
|---|---|---|
| 1. | NUCLEATION PROPERTIES OF HYDROPHOBIC, HYGROSCOPIC AND SOLUBLE CLOUD CONDENSATION NUCLEI | DETERMINE THE NUCLEATION CONDITIONS AND INITIAL GROWTH RATES FOR VARIOUS TYPES OF ATMOSPHERIC CLOUD CONDENSATION NUCLEI AT LOW SUPERSATURATIONS UNDER VARIOUS CONDITIONS OF CLEAN AIR, POLLUTED AIR, AND ELECTRIC FIELDS |
| 2 | CONTACT, INTERNAL AND DEPOSITION NUCLEATION PROPERTIES OF ATMOSPHERIC ICE NUCLEI | DETERMINE THE PROPERTIES AND RELATIVE EFFECTIVENESS OF CONTACT, INTERNAL AND DEPOSITION NUCLEATION PROCESSES FOR VARIOUS TYPES OF ATMOSPHERIC NUCLEI AND NUCLEI USED IN WEATHER MODIFICATION |
| 3. | ICE PARTICLE MULTIPLICATION DURING FREEZING OF ATMOSPHERIC CLOUD DROPLETS. | DETERMINE THE ATMOSPHERIC RELATED CONDITIONS AND EXTENT OF DROPLET BREAK-UP DURING FREEZING AS A FUNCTION OF TEMPERATURE, PRESSURE AND RELATIVE HUMIDITY. EFFECTS OF ACOUSTICAL, SONIC AND ELECTRIC FIELDS WILL BE STUDIED AND OBSERVATIONS FOR CHARGE SEPARATION WILL BE MADE |
| 4. | ATMOSPHERIC CLOUD CHARGE SEPARATION MECHANISMS. | QUANTITATIVE EVALUATION WILL BE MADE OF VARIOUS PROPOSED CHARGE SEPARATION MECHANISMS DUE TO THE INTERACTION OF DROPLET AND ICE CRYSTALS UNDER THE INFLUENCE OF TEMPERATURE GRADIENTS AND ELECTRIC FIELDS |

## OBJECTIVES

PAYLOAD NAME: ZERO-G CLOUD PHYSICS LABORATORY

DATA SHEET NO. 5-2

PAYLOAD NO.

DATE 3/2/73 REV.

1. SUMMARY: A ZERO-G ATMOSPHERIC MICROPHYSICS/CLOUD PHYSICS FACILITY DESIGNED TO ACCOMMODATE A LARGE VARIETY OF EXPERIMENTS PROPOSED BY ATMOSPHERIC PHYSICISTS FROM THROUGHOUT THE INTERNATIONAL SCIENTIFIC COMMUNITY. THIS MULTIPURPOSE FACILITY WILL BE DESIGNED TO BE REUSABLE FOR A MINIMUM OF TWENTY MISSIONS.

2. MISSION OBJECTIVES. THE OBJECTIVES OF THE PLANNED MISSION ARE TO ACQUIRE DATA CURRENTLY UNACHIEVABLE IN TERRESTRIAL LABORATORIES. THESE DATA WILL BE USED IN WEATHER MODIFICATION AND CONTROL, (E.G., WHEN DECISIONS—THE TIMING IN THE CLOUD GROWTH CYCLE WHEN SEEDING IS TO BE APPLIED, WHERE DECISIONS—WHAT LEVEL IN THE CLOUD OR RELATIVE TO THE CLOUD SHOULD THE MODIFICATION AGENTS BE PLACED, WHAT DECISIONS—THE RELATIVE MERITS OF DIFFERENT SEEDING AGENTS, AND HOW MUC I DECISIONS—AMOUNTS OF SEEDING MATERIAL REQUIRED TO PRODUCE DESIRED RESULTS.)

3. RELATIONSHIP TO DISCIPLINE OBJECTIVES THE OBJECTIVES OF THIS PAYLOAD ARE TO CONCENTRATE ON A RANGE OF PARTICLE SIZES THAT ARE AFFECTED BY GRAVITY BUT THE FORCES TO BE STUDIED ARE GRAVITY INDEPENDENT. THESE DATA WILL FILL IMPORTANT DATA GAPS IN THE EXISTING THEORIES OF ATMOSPHERIC MICROPHYSICS ESPECIALLY IN THE AREAS OF WEATHER MODIFICATION AND CONTROL. THEY WILL ALSO BE USEFUL IN WEATHER PREDICTION AND MAY HAVE IMPORTANT APPLICATION IN AIR AND WATER POLLUTION STUDIES.

4. EXPERIMENTS

| NO. | TITLE | OBJECTIVES |
|---|---|---|
| 5. | ATMOSPHERIC ICE CRYSTAL DIFFUSION GROWTH HABITS. | DETERMINE THE EFFECTS OF PRESSURE, TEMPERATURE AND RELATIVE HUMIDITY UPON THE CRYSTAL TYPE AND DIFFUSION GROWTH RATES UNDER NONCONVECTIVE CONDITIONS. OBSERVATIONS WILL INCLUDE THE DETERMINATION OF THE ROLE OF WATER MOLECULE SURFACE MIGRATION IN DIFFUSION GROWTH OF ICE CRYSTALS. |
| 6. | SCAVENGING MECHANISMS OF GASES AND PARTICULATES BY ATMOSPHERIC DROPLETS AND ICE CRYSTALS. | EVALUATE , IE RELATIVE IMPORTANCE OF BROWNIAN MOTION, VAPOR GRADIENTS AND TEMPERATURE GRADIENT SCAVENGING MECHANISMS. OBSERVATIONS WILL ALSO BE MADE OF THE RELATIVE COLLECTION EFFICIENCIES OF VARIOUS POINTS ON A COMPLEX ICE CRYSTAL. |
| 7. | RIMING AND SNOWFLAKE AGGREGATION. | A STUDY OF THE TEMPERATURE AND HUMIDITY EFFECTS ON CRYSTAL AGGREGATION AND ON THE MOTION OF SUPERCOOLED WATER DROPS ON AN ICE CRYSTAL SURFACE |
| 8. | DIFFUSIONAL GROWTH INTERACTION OF ICE CRYSTALS AND WATER DROPLETS. | A STUDY OF THE DIFFUSION RANGE AND MAGNITUDE OF THE EFFECT OF ICE CRYSTALS IN A CLOUD OF SUPERCOOLED WATER DROPLETS UNDER NONCONVECTIVE CONDITIONS. |
| 9. | HOMOGENEOUS FREEZING OF SUPERCOOLED CLOUD DROPLETS. | MEASUREMENT OF THE FREEZING RATE OF CLOUD DROPLETS AS A FUNCTION OF RATE OF COOLING RELATIVE HUMIDITY AND DROPLET DIAMETER. EXPERIMENT WOULD BE DESIGNED TO DETERMINE EFFECT ON FREEZING OF SURFACE AREA TO VOLUME RATIO. |

## OBJECTIVES

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATA SHEET NO S-2
PAYLOAD NO
DATE 3/2/73 REV.

1. SUMMARY A ZERO-G ATMOSPHERIC MICROPHYSICS/CLOUD PHYSICS FACILITY DESIGNED TO ACCOMMODATE A LARGE VARIETY OF EXPERIMENTS PROPOSED BY ATMOSPHERIC PHYSICISTS FROM THROUGHOUT THE INTERNATIONAL SCIENTIFIC COMMUNITY. THIS MULTIPURPOSE FACILITY WILL BE DESIGNED TO BE REUSABLE FOR A MINIMUM OF TWENTY MISSIONS.

2. MISSION OBJECTIVES THE OBJECTIVES OF THE PLANNED MISSION ARE TO ACQUIRE DATA CURRENTLY UNACHIEVABLE IN TERRESTRIAL LABORATORIES. THESE DATA WILL BE USED IN WEATHER MODIFICATION AND CONTROL (E.G., WHEN DECISIONS—THE TIMING IN THE CLOUD GROWTH CYCLE WHEN SEEDING IS TO BE APPLIED, WHERE DECISIONS—WHAT LEVEL IN THE CLOUD OR RELATIVE TO THE CLOUD SHOULD THE MODIFICATION AGENTS BE PLACED, WHAT DECISIONS—THE RELATIVE MERITS OF DIFFERENT SEEDING AGENTS AND HOW MUCH DECISIONS—AMOUNTS OF SEEDING MATERIAL REQUIRED TO PRODUCE DESIRED RESULTS.)

3. RELATIONSHIP TO DISCIPLINE OBJECTIVES THE OBJECTIVES OF THIS PAYLOAD ARE TO CONCENTRATE ON A RANGE OF PARTICLE SIZES THAT ARE AFFECTED BY GRAVITY BUT THE FORCES TO BE STUDIED ARE GRAVITY INDEPENDENT. THESE DATA WILL FILL IMPORTANT DATA GAPS IN THE EXISTING THEORIES OF ATMOSPHERIC MICROPHYSICS ESPECIALLY IN THE AREAS OF WEATHER MODIFICATION AND CONTROL. THEY WILL ALSO BE USEFUL IN WEATHER PREDICTION AND MAY HAVE IMPORTANT APPLICATION IN AIR AND WATER POLLUTION STUDIES.

4. EXPERIMENTS

| NO. | TITLE | OBJECTIVES |
|---|---|---|
| 10. | DROPLET FREEZING DURING COLLISION | A STUDY OF DROPLET FREEZING INDUCED BY DROPLET COLLISIONS AS A FUNCTION OF RELATIVE KINETIC ENERGY, TEMPERATURE PRESSURE AND DROPLET DIAMETER |
| 11. | SATURATION VAPOR PRESSURE OVER SUPERCOOLED WATER DROPLET | MEASURE THE VAPOR PRESSURE AROUND AN UNSUPPORTED SUPER COOLED CLOUD WATER DROPLET AS A FUNCTION OF DROPLET DIAMETER AND TEMPERATURE. DETERMINATIONS OF SHORT RANGE MOLECULAR ORDER AS A FUNCTION OF TEMPERATURE WILL ALSO BE OBTAINED |
| 12 | ADIABATIC CLOUD EXPANSION SIMULATION | OBSERVE THE NUCLEATION AND EARLY DIFFUSIONAL GROWTH CYCLE UNDER CONDITIONS OF TEMPERATURE, PRESSURE AND RELATIVE HUMIDITY THAT ARE SIMILAR TO THE TRUE ATMOSPHERIC PROCESSES. GROWTH CYCLES OF UP TO TWENTY MINUTES WILL BE STUDIED WITH ASCENT AND DESCENT PHASES. OBSERVATIONS OF DROPLET DIAMETER DISTRIBUTIONS AS A FUNCTION OF NUCLEI MATERIALS AND RATES OF RISE WOULD BE MADE |
| 13. | ICE NUCLEI MEMORY STUDIES. | MEASUREMENTS ARE TO BE MADE OF CHANGES IN THE NUCLEATION EFFICIENCIES OF ICE NUCLEI CAUSED BY WET DRY CYCLING OF THE NUCLEI |
| 14 | TERRESTRIAL EXPANSION CHAMBER EVALUATION | COMPARISONS OF DATA WITH AND WITHOUT GRAVITY WILL BE MADE TO DETERMINE THE MAGNITUDE OF THE EFFECTS OF PARTICLE FALL OUT AND AIR CONVECTION ON THE EARTH BASED ON EXPANSION CHAMBER NUCLEI COUNT MEASUREMENTS |

## OBJECTIVES

PAYLOAD NAME: ZERO-G CLOUD PHYSICS LABORATORY

DATA SHEET NO: S-2
PAYLOAD NO.:
DATE: 3/2/73 REV.:

1. SUMMARY A ZERO-G ATMOSPHERIC MICROPHYSICS/CLOUD PHYSICS FACILITY DESIGNED TO ACCOMMODATE A LARGE VARIETY OF EXPERIMENTS PROPOSED BY ATMOSPHERIC PHYSICISTS FROM THROUGHOUT THE INTERNATIONAL SCIENTIFIC COMMUNITY. THIS MULTIPURPOSE FACILITY WILL BE DESIGNED TO BE REUSABLE FOR A MINIMUM OF TWENTY MISSIONS.

2. MISSION OBJECTIVES THE OBJECTIVES OF THE PLANNED MISSION ARE TO ACQUIRE DATA CURRENTLY UNACHIEVABLE IN TERRESTRIAL LABORATORIES. THESE DATA WILL BE USED IN WEATHER MODIFICATION AND CONTROL, (E.G., WHEN DECISIONS—THE TIMING IN THE CLOUD GROWTH CYCLE WHEN SEEDING IS TO BE APPLIED, WHERE DECISIONS—WHAT LEVEL IN THE CLOUD OR RELATIVE TO THE CLOUD SHOULD THE MODIFICATION AGENTS BE PLACED, WHAT DECISIONS—THE RELATIVE MERITS OF DIFFERENT SEEDING AGENTS, AND HOW MUCH DECISIONS—AMOUNTS OF SEEDING MATERIAL REQUIRED TO PRODUCE DESIRED RESULTS.)

3. RELATIONSHIP TO DISCIPLINE OBJECTIVES THE OBJECTIVES OF THIS PAYLOAD ARE TO CONCENTRATE ON A RANGE OF PARTICLE SIZES THAT ARE AFFECTED BY GRAVITY BUT THE FORCES TO BE STUDIED ARE GRAVITY INDEPENDENT. THESE DATA WILL FILL IMPORTANT DATA GAPS IN THE EXISTING THEORIES OF ATMOSPHERIC MICROPHYSICS ESPECIALLY IN THE AREAS OF WEATHER MODIFICATION AND CONTROL. THEY WILL ALSO BE USEFUL IN WEATHER PREDICTION AND MAY HAVE IMPORTANT APPLICATION IN AIR AND WATER POLLUTION STUDIES

4. EXPERIMENTS

| NO. | TITLE | OBJECTIVES |
|---|---|---|
| 15. | CLOUD CONDENSATION MEMORY STUDIES. | MEASUREMENTS ARE TO BE MADE ON THE EFFECTS OF WET AND DRY CYCLES ON THE NUCLEATION EFFECTIVENESS OF CLOUD CONDENSATION NUCLEI |
| 16. | NUCLEI MULTIPLICATION. | DETERMINE MECHANISMS THAT SHAPE ATMOSPHERIC NUCLEI SIZE DISTRIBUTION THROUGH BREAK UP OF NUCLEI MATERIAL DURING DROPLET SOLUTION EVAPORATION (E.G. OCEAN GENERATED DROPLETS) |
| 17 | DROPLET BREAK-UP BY COLLISIONS OF DROPLETS ABOVE 0.5 DIAMETER. | DETERMINE THE DEPENDENCE OF INTERACTING ATMOSPHERIC DROPLET BREAK-UP UPON SURFACE ENERGY, RELATIVE DROPLET KINETIC ENERGY, AND INTERNAL VISCOSITY UNDER CONTROLLED RELATIVE KINETIC ENERGY CONDITIONS |
| 18. | COALESCENCE EFFICIENCY OF DROPLETS BELOW 50 $\mu m$ DIAMETER. | MEASUREMENTS WILL BE MADE FOR DROPLET COALESCENCE EFFICIENCIES FOR THE ATMOSPHERIC IMPORTANT TRANSITION REGION BETWEEN DIFFUSION GROWTH ONLY AND THE NECESSARY COALESCENCE GROWTH OF CLOUD DROPLETS |
| 19. | TERRESTRIAL STATIC DIFFUSION CHAMBER EVALUATION. | COMPARISONS OF THE DATA WITH AND WITHOUT GRAVITY WILL BE MADE TO DETERMINE THE MAGNITUDE OF THE EFFECTS OF FALL OUT ON THE EARTH BASED STATIC DIFFUSION CHAMBER CONDENSATION NUCLEI CONCENTRATION MEASUREMENTS |

## OBJECTIVES

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATA SHEET NO 8-2
PAYLOAD NO
DATE 3/2/73 REV

1. SUMMARY A ZERO-G ATMOSPHERIC MICROPHYSICS/CLOUD PHYSICS FACILITY DESIGNED TO ACCOMMODATE A LARGE VARIETY OF EXPERIMENTS PROPOSED BY ATMOSPHERIC PHYSICISTS FROM THROUGHOUT THE INTERNATIONAL SCIENTIFIC COMMUNITY. THIS MULTIPURPOSE FACILITY WILL BE DESIGNED TO BE REUSABLE FOR A MINIMUM OF TWENTY MISSIONS.

2. MISSION OBJECTIVES THE OBJECTIVES OF THE PLANNED MISSION ARE TO ACQUIRE DATA CURRENTLY UNACHIEVABLE IN TERRESTRIAL LABORATORIES. THESE DATA WILL BE USED IN WEATHER MODIFICATION AND CONTROL (E.G. WHEN DECISIONS—THE TIMING IN THE CLOUD GROWTH CYCLE WHEN SEEDING IS TO BE APPLIED, WHERE DECISIONS—WHAT LEVEL IN THE CLOUD OR RELATIVE TO THE CLOUD SHOULD THE MODIFICATION AGENTS BE PLACED, WHAT DECISIONS—THE RELATIVE MERITS OF DIFFERENT SEEDING AGENTS, AND HOW MUCH DECISIONS—AMOUNTS OF SEEDING MATERIAL REQUIRED TO PRODUCE DESIRED RESULTS.)

3. RELATIONSHIP TO DISCIPLINE OBJECTIVES THE OBJECTIVES OF THIS PAYLOAD ARE TO CONCENTRATE ON A RANGE OF PARTICLE SIZES THAT ARE AFFECTED BY GRAVITY BUT THE FORCES TO BE STUDIED ARE GRAVITY INDEPENDENT. THESE DATA WILL FILL IMPORTANT DATA GAPS IN THE EXISTING THEORIES OF ATMOSPHERIC MICROPHYSICS ESPECIALLY IN THE AREAS OF WEATHER MODIFICATION AND CONTROL. THEY WILL ALSO BE USEFUL IN WEATHER PREDICTION AND MAY HAVE IMPORTANT APPLICATION IN AIR AND WATER POLLUTION STUDIES.

4. EXPERIMENTS

| NO | TITLE | OBJECTIVES |
|---|---|---|
| 20. | TEMPERATURE AND VAPOR DIFFUSION COEFFICIENTS FOR UNVENTILATED DROPLETS. | THE EVAPORATION/CONDENSATION RATIO AND DROPLET SURFACE TEMPERATURE WILL BE MEASURED UNDER NONVENTILATED CONDITIONS AS A FUNCTION OF TEMPERATURE, PRESSURE AND RELATIVE HUMIDITY. THESE MEASUREMENTS ARE NECESSARY TO DETERMINE CONSTANTS FOR THE DIFFUSION GROWTH EQUATIONS. |

## PAYLOAD EXPERIMENT AND SUPPORT EQUIPMENT

DATA SHEET NO 9-3

PAYLOAD NO

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATE 3/2/73 REV

| EQUIPMENT | | LOCATION | | SIZE M (FT) | | | | 9. WEIGHT KG (LB) | POWER | | | | DATA | | FIELD OF VIEW RAD (DEG) | | ENVIRONMENT | | 20. REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 REF NO | 2. NAME | 3. ASCENT/ENTRY | 4. ON-ORBIT OPERATION | 5. WIDTH | 6. HEIGHT | 7. LENGTH | 8. DIAM | | 10 STANDBY W | 11 OPERATING W | 12. PEAK W | 13. PEAK DURATION SEC | 14. FORM D, A, FILM | 15 RATE OPS, HZ, FRAMES | 16. INSTANTANEOUS | 17 TOTAL | 18. CONTAM SENSITIVITY | 19 T, °K | |
| | COMPLETE LABORATORY* | INTERNAL | INTERNAL | 1.2 (4) | 3.3 (10) | 2.6 (8) | N/A | 465 (1025) | 25 | 50 TO 500 | 500 | 60 | D FILM | TBD 400/MAX SEC | N/A | N/A | 10,000 CLASS | 280 TO 300 | |

*TOTAL LABORATORY EQUIPMENT DEFINITION CONTAINED IN SECTION 4

## SKETCHES – INTERNAL EQUIPMENT

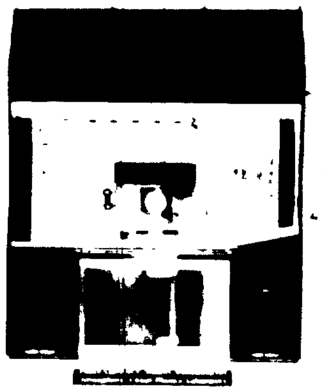
DATA SHEET NO. S-4

PAYLOAD NO.

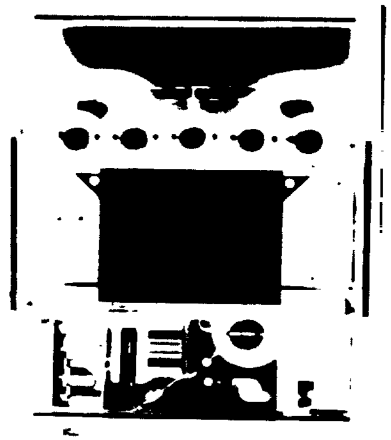
PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

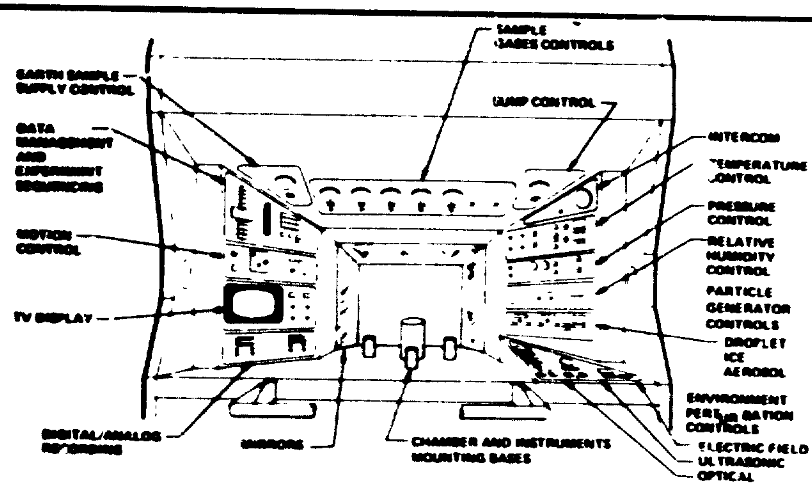
DATE 3/2/73 REV

Laboratory Conceptual Design – Front View

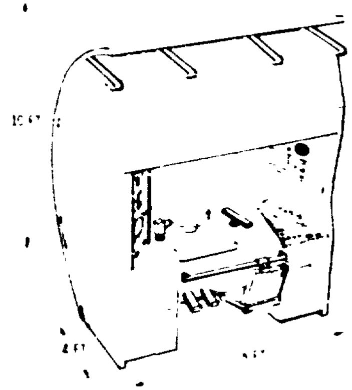


Laboratory Conceptual Design – Rear View (Model)






Zero-G Cloud Physics Laboratory Conceptual Displays and Controls



Conceptual Design of Zero-Gravity Cloud-Physics Laboratory

NOTE: STOWED AND DEPLOYED CONFIGURATIONS SHOWN, WHERE APPLICABLE

## SKETCHES – EXTERNAL EQUIPMENT

DATA SHEET NO. S-5

PAYLOAD NO.

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATE 3/2/73 REV.

NONE

NOTE: STOWED AND DEPLOYED CONFIGURATIONS SHOWN, WHERE APPLICABLE

## POINTING AND STABILITY

DATA SHEET NO. 5.6

PAYLOAD NO.

DATE 3/2/71 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| SENSOR | | | SPACECRAFT POINTING | | | | MOUNT POINTING* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. REF NO | 2. NAME | 3. ORIENTATION OR TARGET(S) | 4. ACCURACY RAD | 5. DURATION SEC | 6. STABILITY RAD | 7. STABILITY RATE RAD/SEC | 8. ACCURACY RAD | 9. DURATION SEC | 10. STABILITY RAD | 11. STABILITY RATE RAD SEC |
| | TOTAL LABORATORY | N/A | N/A | N/A | N/A | TBD* → $10^{3}$ gs REQ'D ALL AXES | N/A | N/A | N/A | N/A |

*ACCURACY REQUIRED AT INNER GIMBAL

## MISSION OPERATIONS

DATA SHEET NO. S-7

PAYLOAD NO. ______

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATE 3/2/73 REV. ______

| | MISSION OPERATION | MISSION TIME |
|---|---|---|
| 1 | INITIAL SETUP | REMOVE INTERNALLY STORED EQUIPMENTS AND MOUNT ON LABORATORY WORK SURFACE -- MAKE REQUIRED ELECTRICAL AND MECHANICAL CONNECTIONS (10 TO 30 MIN). |
| 2 | EXPERIMENT C/O | CONDUCT ESTABLISHED PROCEDURE TO DETERMINE INITIAL LABORATORY CONDITION – VERIFY OPERATIONAL CAPABILITY OF ALL LABORATORY SUBSYSTEMS (2-8 MIN). |
| 3 | CALIBRATION/WARM UP | PERFORM CRITICAL PARAMETER CALIBRATION AND INITIATE WARM-UP OF EXPERIMENT EQUIPMENTS (2-15 MIN). |
| 4 | EXPERIMENT OBSERVATIONS | PERFORM EXPERIMENT SEQUENCE AND RECORD REQUIRED DATA (5-30 MIN). |
| 5 | DATA EVALUATION | VERIFY THAT DATA WAS OBTAINED AND PERFORM CRITICAL ASSESSMENT (5-10 MIN). |
| 6 | CALIBRATION | RECALIBRATE EQUIPMENT (2-15 MIN). (SEE NOTE) |
| 7 | SECURE | SHUT DOWN EQUIPMENT TO NON-OPERATIONAL STATUS (2-10 MIN). |
| 8 | REPEAT OF 2 THRU 6 | CONDUCT REPEAT OF ORIGINAL EXPERIMENT OR GO TO NEW EXPERIMENT (16 TO 78 MIN). |
| 9 | TERMINATION | REMOVE EQUIPMENT FROM LABORATORY WORK SURFACE AND SECURE IN STORAGE AREA. SAFE LABORATORY FOR RE-ENTRY (20-40 MIN). |

NOTES:

AFTER STEP 6 – GO TO STEP 8 IF ADDITIONAL EXPERIMENT TIME AVAILABLE. IF NOT, GO TO STEP 7 AND SECURE LABORATORY FOR PERIOD OF INACTIVITY.

## EXPERIMENTAL OPERATIONAL CYCLE

DATA SHEET NO S-8

PAYLOAD NO

DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| 1. EXPERIMENT | INITIAL SETUP: 2. FUNCTION | INITIAL SETUP: 3. TIME, HRS | REPETITIVE CYCLE: 4. SETUP & DEPLOY TIME, HRS | REPETITIVE CYCLE: 5. EXPT. OR OBSERV. DURATION, HR. | REPETITIVE CYCLE: 6. SHUT-DOWN & RETRIEVE TIME HR | REPETITIVE CYCLE: 7. DATA EVAL TIME, HRS | REPETITIVE CYCLE: 8. TOTAL CYCLE TIME, HRS | REPETITION RATE: 9. CYCLES PER DAY | REPETITION RATE: 10. CYCLES PER MISSION | TERMINATION: 11. FUNCTION | TERMINATION: 12. TIME HRS | 13. CONSTRAINTS | 14. REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LABORATORY MINIMUM EXPERIMENT MISSION | UNPACK AND MOUNT EQUIPMENT | 0.1 | 0.05 | ~1.5 TO 4.5 | 0.1 | 0.1 | 2.5 | 1 | 3 | RESTORE EQUIPMENT AND SAFE LABORATORY | 0.33 | 1 EXPERIMENTER $<10^{-3}$ g | |
| LABORATORY NOMINAL EXPERIMENT MISSION | | 0.25 | 0.2 | ~4 TO 7 | 0.1 | 0.1 | 5.8 | 1 | 5 | | 0.5 | 1 EXPERIMENTER $<10^{-3}$ g | |
| LABORATORY MAXIMUM EXPERIMENT MISSION | | 0.5 | 0.5 | ~7 | 0.1 | 0.2 | 8 | 2 | 10 | | 0.66 | 2 EXPERIMENTERS $<10^{-3}$ g | |

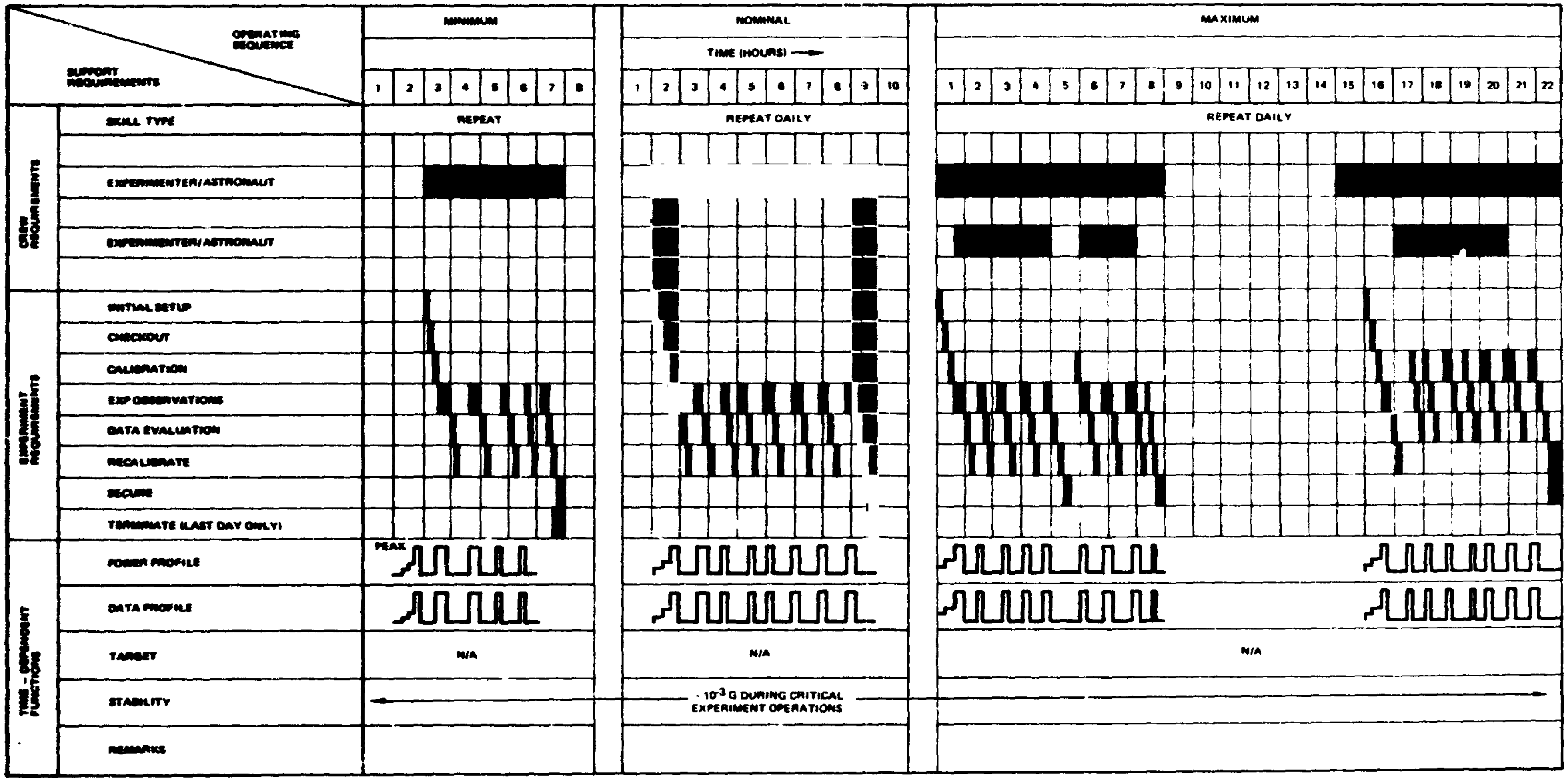
PAYLOAD OPERATIONS DATA
MISSION DAY NO.

DATA SHEET NO S-9

PAYLOAD NO

DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY



## ELECTRICAL POWER REQUIREMENTS

DATA SHEET NO S-16
PAYLOAD NO
DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| REQUIREMENT PARAMETER / MISSION PHASE | 1. POWER FORM | 2. FREQ HZ | AVERAGE POWER 3. LEVEL W | AVERAGE POWER 4. DURATION, HR | PEAK POWER 5. LEVEL W | PEAK POWER 6. DURATION SEC | PEAK POWER 7. REPETITION RATE | 8. 24 HR AVERAGE POWER W | ENERGY 9. PER DAY KW - HR | ENERGY 10. PER MISSION KW - HR | 11. REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRELAUNCH | 28V | | 2 | DURING COUNTDOWN | N/A | N/A | N/A | 2 | – – | – – | |
| ASCENT | NONE REQUIRED → | | | | | | | | | | |
| ON-ORBIT OPERATIONS | 28V 115 VAC 60 CYCLES | | 193 | 8 HRS/ DAY | 580W | 60 SEC | 0.68 HR PER DAY | 130 | 2.8 | 140 → | |
| ENTRY | NONE REQUIRED → | | | | | | | | | | |
| POST LANDING | NONE REQUIRED → | | | | | | | | | | |

## DATA AND COMMUNICATIONS REQUIREMENTS

DATA SHEET NO S-11

PAYLOAD NO

DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| MEASUREMENT PARAMETER / MISSION PHASE | DATA ACQUISITION: 1. MEASUREMENT SOURCE | 2. OUTPUT FORM | 3. OUTPUT RATE | OPERATIONS: 4. DURATION HRS | NUMBER OF OPS.: 5. PER ORBIT | 6. PER DAY | 7 DAILY TOTAL HRS | 8. COMPUTER SUPPORT REQ'D YES, NO | DATA DISPOSITION: 9. USEAGE MONITOR, CONTROL, EXP. OUTPUT | TRANSMIT %: 10 REAL TIME | 11 ON-ORBIT DUMP | TRANSMIT %: 12 RETURN | 13 ON-ORBIT DISPLAY | 14 REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRELAUNCH | N/A | | | | | | | | | | | | | |
| ASCENT | N/A | | | | | | | | | | | | | |
| ON-ORBIT OPERATIONS | EXPERIMENT OPERATION | PHOTO-GRAPHS | TBD | INST | N/A | 10-1000 | 0.15-1.5 | NO | EXP. OUTPUT | | | 100 | | EXPERIMENT WILL HAVE DISPLAY SYSTEM FOR EXPERIMENT PECULIAR PARAMETERS |
| | | FILM | TBD | 2.5 | N/A | 2-8 | 0.5-2 | NO | EXP. OUTPUT | | | 100 | | |
| | | MAG TAPE | TBD | TBD | N/A | TBD | TBD | TBD | EXP. OUTPUT | | | 100 | 50 | |
| | | VIDICON | TBD | 0.25 | N/A | 2 | 0.5 | NO | MONITOR | 10 | 20 | 70 | | |
| ENTRY | N/A | | | | | | | | | | | | | |
| POST LANDING | N/A | | | | | | | | | | | | | |

## ENVIRONMENTAL REQUIREMENTS

DATA SHEET NO S-12

PAYLOAD NO

DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| MISSION PHASE | 1. TEMPER-ATURE °K | 2. RELATIVE HUMIDITY % | 3. ATMOSPHERE GAS TYPE | 4. ALLOW-ABLE PRESSURE N/M² (PSI) | 5. CONTAMINATION SENSITIVITY | 6. EMI CONSTRAINTS | 7. ACOUSTIC OVERALL LEVEL dB | 8. ACCELERATION G | VIBRATION 9. FREQ RANGE Hz | VIBRATION 10. LEVEL g²/Hz | 11. NUCLEAR RADIATION J/KG SEC (MRAD/HR) | 12. REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLIGHT OPERATING | 300 ±10 | 50 ±20 | ANY $N_2$ AND/OR $O_2$ | $10^5$ (15) ±TBD | 10,000 CLEAN | TBD | TBD | $10^{-4}$ | TBD | TBD | TBD | |
| FLIGHT NONOPERATING | 300 ±10 | 50 ±20 | ANY $N_2$ AND/OR $O_2$ | $0\text{-}10^5$ (0-15) | 10,000 CLEAN | N/A | N/A | N A | TBD | TBD | N/A | |
| GROUND | 300 ±10 | 50 ±20 | ANY $N_2$ AND/OR $O_2$ | $10^5$ (15) | 10,000 CLEAN | N/A | N/A | N/A | TBD | TBD | N/A | |

## CREW & EVA REQUIREMENTS

DATA SHEET NO S-13

PAYLOAD NO

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATE 3/3/73 REV

| 1. EXPERIMENT OR SUPPORT OPERATION | 2. FUNCTION | 3. SKILL TYPE | CREW TIME: 4. HOURS PER DAY PER SKILL | CREW TIME: 5. TOTAL HOURS PER MISSION | 6. EVA REQUIREMENTS | 7. REMARKS |
|---|---|---|---|---|---|---|
| LABORATORY EXPERIMENT OPERATION | OPERATE INSTRUMENTS, MAKE DECISIONS, VOICE RECORD DATA, FOCUS MICROSCOPE AND OPERATE CAMERAS | ATMOSPHERIC CLOUD PHYSICS TRAINING OR GENERAL SCIENTIFIC TRAINING WITH SPECIFIC MISSION EXPERIMENT TRAINING | 4-8 | 12-40 | NONE | |
| | | MECHANICAL AND ELECTRICAL SYSTEMS OPERATION, GENERAL LABORATORY PROCEDURES EXPERIENCE | 2-4 | 12-40 | NONE | |

## GROUND SUPPORT REQUIREMENTS

DATA SHEET NO. S-14

PAYLOAD NO.

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

DATE 3/2/73 REV.

| 1. FUNCTIONAL REQUIREMENT | SUPPORT REQUIREMENTS | | | |
|---|---|---|---|---|
| | 2. FACILITIES | 3. SUPPORT EQUIPMENT | 4. PERSONNEL | 5. OTHER |
| ASTRONAUT TRAINING | LABORATORY SIMULATOR | TRAINING AREA | ASTRONAUT | |
| SORTIE MODULE INTEGRATION | INTEGRATION TEST ARTICLE | INTEGRATION AREA | SYSTEMS INTEGRATION | |
| GROUND CHECK OUT | CLEAN ROOM | CHECK OUT AREA | LABORATORY MFGR | |
| POST FLIGHT DEBRIEFING<br>DATA REDUCTION | NO SPECIAL REQUIREMENTS | | ASTRONAUT | |
| GROUND STORAGE | STORAGE EQUIPMENT | STORAGE AREA | LAUNCH SUPPORT | |

## FACILITY REQUIREMENTS

DATA SHEET NO  S 15

PAYLOAD NO

DATE  3/2/73  REV

PAYLOAD  ZERO-G CLOUD PHYSICS LABORATORY

| 1 FACILITY TYPE | SIZE | | ENVIRONMENT | | | UTILITIES | | | 10 SPECIAL HANDLING | 11 REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2. AREA $M^2$ ($FT^2$) | 3. MIN HEIGHT M (FT) | 4. TEMP °K | 5 RELATIVE HUMIDITY % | 6. CONTAMINATION SENSITIVITY | 7 ELEC-TRICAL | 8. LIQUIDS/ GASES | 9 OTHER | | |
| LABORATORY SIMULATION TRAINING AREA | 18.58 (200) | 3.66 (12) | 290 ±10 | 50 ±20 | TBD | 28VDC 115 VAC | N/A | N/A | YES | HANDLE IN ACCORDANCE WITH MAN-RATED FLIGHT ARTICLE REQUIREMENTS |
| SORTIE MODULE INTEGRATION TEST ARTICLE | 27.88 (300) | 3.66 (12) | | | | N/A | N/A | N/A | | |
| CLEAN ROOM | 27.88 (300) | 3.66 (12) | | | | N/A | N/A | N/A | | |
| STORAGE AREA | 18.58 (200) | 3.66 (12) | | | | N/A | N/A | N/A | | |

## LOGISTICS REQUIREMENTS

DATA SHEET NO S 16

PAYLOAD NO

DATE 3/2/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| 1. EXPERIMENT OR SUPPORT OPERATION | OPERATIONAL CONSUMABLES | | | SPARES AND MAINTENANCE CONSUMABLES | | | SERVICE MISSION PAYLOAD | | | 11. REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2. TYPE | 3. WT KG (LB) | 4. VOL $M^3$ ($FT^3$) | 5. TYPE | 6. WT KG (LB) | 7. VOL $M^3$ ($FT^3$) | 8. TYPE | 9. WT KG (LB) | 10. VOL $M^3$ ($FT^3$) | |
| | FILM | 0.06 (1) | 0.01 (0.5) | N/A | N/A | N/A | FILM | 0.06 (2) | 0.01 (0.5) | |
| | MAGNETIC | 0.03 (1) | 0.01 (0.5) | N/A | N/A | N/A | MAGNETIC TAPE | 0.03 (1) | 0.01 (0.5) | |
| | GAS | 11.8 (26) | 0* | N/A | N/A | N/A | GAS | 11.8 (26) | 0* | |

*CONTAINED WITHIN GAS STORAGE SUBSYSTEM

MISSION EQUIPMENT COST DATA

DATA SHEET NO. 8-17

PAYLOAD NO.

DATE 3/9/73 REV

PAYLOAD NAME ZERO-G CLOUD PHYSICS LABORATORY

| 1. ITEM NO. | 2. EQUIPMENT ITEM | 3. PERFORMANCE | 4. SIZE M (FT) | 5. WEIGHT KG (LB) | 6. TYPE OF EQUIPMENT: STRUCTURAL/MECH | ELECTRONIC/ELECT | ELECTRO MECH | OPTICAL | ELECTRO/CHEM | OTHER | 7. STATE OF THE ART: CURRENT | ADVANCED | MANRATED | UNMANNED S/C | AIRCRAFT | COMMERCIAL | 8. DEVELOPMENT STATUS: NEW | REDESIGN EXIST | REMFG EXIST | REPACKAGE EXIST | MINOR CHANGE EXIST | AVAILABLE | COMPLEXITY: LOW | MEDIUM | HIGH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LABORATORY (MAIN) | — | 1.2 x 3.3 x 7.6 (4 x 10 x 25) | [illegible] ([illegible]) | | | | | | | | | | | | | | | | | | | | | |
| | CLOUD CHAMBERS | CONTAINED WITHIN OR ON LABORATORY | | | X | | | | | | | | | | | | X | | | | | | | | X |
| | AEROSOL GENERATOR | | | | | | X | | | | | X | | | | | X | | | | | | | X | |
| | LIQUID DROP GENERATOR | | | | | | X | | | | | X | | | | | X | | | | | | | X | |
| | ICE PARTICLE GENERATOR | | | | | | X | | | | | X | | | | | X | | | | | | | X | |
| | ELECTRICAL CONTROLLER | | | | | X | | | | | | X | | | | | X | | | | | | X | | |
| | ACOUSTICAL CONTROLLER | | | | | | X | | | | | X | | | | | X | | | | | | X | | |
| | OPTICAL CONTROLLER | | | | | | | X | | | | X | | | | | X | | | | | | X | | |
| | AEROSOL PARTICLE CENTER | | | | | | | X | | | X | | | | | | X | | | | | | X | | |
| | IMAGING DEVICES | | | | | | | X | | | X | | | | | | | | | | | X | X | | |
| | PRESSURE CONTROL | | | | X | | | | | | X | | | | | | X | | | | | | | X | |
| | TEMPERATURE CONTROL | | | | | | X | | | | X | | | | | | X | | | | | | | X | |
| | DEW POINT CONTROL | | | | X | | | | | | X | | | | | | X | | | | | | | X | |
| | GAS STORAGE | | | | X | | | | | | X | | | | | | X | | | | | | X | | |
| | DATA MANAGEMENT | | | | | X | | | | | X | | | | | | X | | | | | | X | | |
| | DISPLAYS AND CONTROLS | | | | | X | | | | | X | | | | | | X | | | | | | X | | |
| | MISCELLANEOUS SUPT | | | | | X | | | | | X | | | | | | X | | | | | | X | | |
| | CONTROL CONSOLE | | | | X | | | | | | X | | | | | | X | | | | | | X | | |
| | EXPENDABLES | | | | | | | | | X | X | | | | | | | | | | | X | X | | |
| | MISC EQUIPMENT | | | | X | | | | | | X | | | | | | X | | | | | | X | | |