NASA CONTRACTOR REPORT

NASA CR-129013

ZERO-GRAVITY CLOUD PHYSICS LABORATORY-EXPERIMENT PROGRAM DEFINITION AND PRELIMINARY LABORATORY CONCEPT STUDIES

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FOREWORD

The work reported herein encompasses study efforts during the period April 1973 through September 1973. This report is a sequel to NASA CR-128998 "Feasibility Study of a Zero-Gravity (Orbital) Atmospheric Cloud Physics Experiments Laboratory," November 1972 and to NASA CR-129002 "Zero-Gravity Cloud Physics Laboratory—Candidate Experiments Definition and Preliminary Concept Studies," June 1973. The primary goal of this effort is to provide an orbital multiple experiment laboratory for the members of the cloud physics scientific community to utilize in their research of cloud microphysical processes.

The scope of the effort, performed by the Space Sciences Department of the McDonnell Douglas Astronautics Company under contract to NASA Marshall Space Flight Center, involved the following tasks:

Task I: Maintain communication, where appropriate, with members of atmospheric cloud physics community relative to experiments and ideas they suggested for consideration in the feasibility and experiment definition study.

Task II: Maintain the Senior Scientific Board in order to review and evaluate experiment ideas and concepts for the Zero-G Cloud Physics Laboratory Program. The board may be convened for one meeting during contract extension, and they will also be available for individual consultation on special problems. Changes in membership will be made only by mutual agreement between the NASA and contractor.

Task III: Define in detail the rationale for the program and proposed mission objectives, listed in order of priority.

Task IV: Establish laboratory engineering and performance requirements, with candidate experiments, consistent with mission objectives.

Task V: Accomplish a preliminary system design of a feasible, but not necessarily optimum cloud physics laboratory, and conceptual design of alternate approaches. The laboratory shall be designed to encompass the maximum number of candidate experiments, consistent with the expected scientific potential for the laboratory utilization and effective employment of anticipated resources.

Task VI: Accomplish an assessment of technical risk, including identification of technical problems and the criticality of their solution to follow-on efforts, identification of those problems currently being addressed, and a judgment of effort, time, and cost likely to be necessary to find a practical solution. Provide inputs for the refinement of the project development plan.

Task VII: Define the operational constraints, data acquisition, and ground support equipment consideration for the laboratory based on Task V.

Task VIII: Provide an estimate of schedule and costs to completion, including all associated analyses of experimental results, for one typical flight, assuming a 1981 flight opportunity in the Sortie Laboratory of the Space Shuttle.

This program is being conducted on behalf of NASA's Office of Application and Office of Manned Space Flight. The status of this Space Shuttle payload definition effort has been enhanced by the enthusiastic response and support provided by the members of the cloud physics scientific community and their recognition of the significant potential that a Cloud Physics Laboratory payload will provide to research and applications experimentation of cloud microphysical processes.

Comments on the contents of this report will be welcomed.

Copy of this report is available from the following:

Aerospace Environment Division
Aero-Astrodynamics Laboratory
NASA-Marshall Space Flight Center, Alabama 35812

National Technical Information Service
Springfield, Virginia 22151

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Section 1
SUMMARY

This study summarizes work accomplished from April 1973 to September 1973 on the Zero-Gravity Atmospheric Cloud Physics Laboratory. This program involves the definition and development of an atmospheric cloud physics laboratory and the selection and delineations of 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, aerodynamic, electrical, or other techniques to support the object under study. Terrestrial restrictions such as using supports 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. The laboratory will be made available to the entire cloud physics community so that a wide variety of important experiments can be performed. 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 and served throughout the program. The board members were Drs. C. L. Hosler, L. J. Battan, P. Squires, and H. Weickmann.

In Section 2 of this report, the first two phases of the feasibility study (reported in NASA CR 128998 and NASA CR 129002) are reviewed. The first phase of the study accomplished the following:

A. Developed scientific community support interface.
B. Solicited experiment definitions.
C. Selected high-priority experiments.
D. Determined program feasibility.
E. Identified a concept for multiple experiment cloud physics laboratory including subsystems and components.

The second phase of the study accomplished the following:

A. Experiments suggested by the scientific community were defined and classified.
B. Twenty classes of such experiments that require zero or low gravity were identified.
C. Laboratory requirements were determined, based on the experiment class definitions.
D. A multiple experiment laboratory concept was established to accommodate nearly all the experiments.

The remainder of this report presents the results of the study from April 1973 to date. The results of this study phase are:

A. Experiment program revisions based on scientific community and Senior Scientific Board evaluation and critique.

B. Establishment of three experiment mission timelines.

C. Formulation of the laboratory concept and major subsystems based on experiment class requirements.

D. Assessment of project technical risk including identification of required supporting research and technology (SRT) items.

E. Formulation of key programmatic aspects of the project.

Section 3 describes the five different cloud chambers proposed for Cloud Physics Laboratory usage. An experiment program assessment is presented with identification of the experiment classes and their objectives. The results of the evaluation to establish program mission requirements is described. The contributions to the study of both the scientific community and the Senior Scientific Board are enumerated. Experiment mission timelines for three experiment classes using three different cloud chambers are presented and provide the required subsystem and operational parameters utilized in establishment of cloud physics laboratory requirements.

Section 4 describes the analysis and design efforts related to the formulation of the Cloud Physics Laboratory concept. The criteria for concept formulation including laboratory design features and level 1 guidelines and constraints are presented. A generalized laboratory mission and laboratory description are included. Additional data are provided for laboratory subsystems including equipment description, usage, and primary characteristics. The rationale for baseline laboratory concept selection, based on parametric evaluation, is described. The required supporting research and technology (SRT) items for the laboratory are delineated. Programmatic data regarding project schedule and work breakdown structure (WBS) are included.

Section 5 describes the major subcontractor efforts performed. Two parallel cloud chamber development plans were formulated. Dr. P. Squires of the Desert Research Institute prepared the plan for the continuous flow diffusion chamber. Dr. J. Kassner of the University of Missouri-Rolla prepared the plan for the expansion chamber.

Appendix describes the revised experiment program in detail. Each experiment class includes identification of objectives, primary and alternate cloud chambers, parameter variations and a description of a typical experiment.

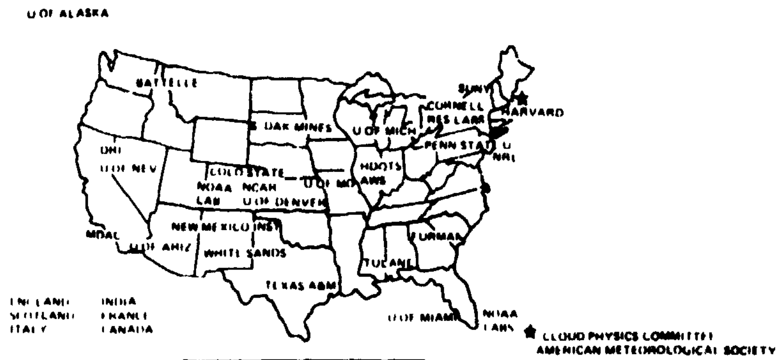
Section 2
FEASIBILITY STUDY STATUS

2.1 FIRST PHASE (SEPTEMBER 1971 TO JULY 1972)

A primary objective of the September 1971 to July 1972 phase of the feasibility and concept 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 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 soliciation was gratifying (Figure 2-1) 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



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

Figure 2-1. Solicitation

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.

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) development of scientific community support, (2) solicitation of experiment definitions, (3) selection of high-priority experiments, (4) determination of program feasibility, and (5) identification of a concept for the multiexperiment cloud physics laboratory, including subsystems and components of the laboratory, with particular emphasis on those items requiring long-lead-time research and development.

2.2 SECOND PHASE (JULY 1972 TO APRIL 1973)

The primary objective of the July 1972 to April 1973 phase of the feasibility and concept study was to define the experiment program. A parallel objective was to define the cloud physics laboratory concept. Scientific community support was used in the attainment of the above objectives by formulation of specific experiment class and/or experiment definitions and by participation in definition of specific cloud physics research equipment and instruments. Additionally, precursor experiments for droplet dynamics and NaCl particle breakup were defined.

The cloud physics laboratory experiment program formulation was based on establishment of 20 experiment classes representing different cloud microphysical processes. Expanded definitions of the objectives, the benefits to man and the experiment method for each experiment class were prepared. A discussion section for each class showed, in detail, the significance of the problems being studied, the current difficulties in terrestrial laboratory experiments and the advantages of low-gravity experimentation.

Each experiment class description included, as an example for simplicity and clarity, a definition of a specific experiment. Each class actually includes many experiments that would require variations in method, procedure, and data requirements.

Each experiment class was further evaluated to establish the experiment groups, experiment parameter variations, experiment iterations, and discrete experiment events. As a result, each experiment class was assigned to a specific cloud chamber and mission hours were established for each experiment class.

The experiment program formulation provided the cloud chamber and the preliminary requirements used to formulate the conceptual design of the cloud physics laboratory. The laboratory conceptual design established preliminary characteristics of weight, power, and volume and identification of the subsystems comprising the laboratory.

The Senior Scientific Board was convened for its second meeting in February 1973 to review study progress, giving particular attention to the experiment in-depth definitions and the laboratory conceptual design. 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 concept in terms of cloud chamber configurations and laboratory subsystems, including their primary performance ranges and tolerance.

As a result of the Senior Scientific Board meeting, the experiment program was finalized with definition of experiment class and cloud chamber assignment. Priority factor, achievement ability factors, and applicability to low-gravity factors were assessed and categorized. Approval of the laboratory concept was obtained from the board, including approval of subsystem equipment.

During the course of this study phase, two precursor carry-on type experiments were defined for pre-Shuttle flight opportunities. A definition study was conducted for a Droplet Dynamics Experiment. The results of this effort were reported in MDAC report MDC G3787, "Preliminary Definition Study - Droplet Dynamics and Breakdup Engineering Demonstration" (July 1972). The major objectives of this experiment are observation of the mechanisms of drop impact, drop stability and drop motion and evaluation of techniques for drop manipulation. Portions of the defined experiment were performed on Apollo 16, Apollo 17, and Skylab II with additional efforts to be performed on Skylab III and IV.

A definition study was also conducted for an NaCl breakup experiment. The results of this effort were reported in MDAC report MDC G3779, "Preliminary Definition Study - NaCl Particle Breakup Carry-On Experiment for the Apollo-Soyuz Test Program" (July 1972). The major objectives of this experiment are observation of particle breakup, cloud characteristics and spacecraft motion, and verification of droplet injection and humidification techniques. Subsequent to this study MSFC initiated and sustained a development effort for this experiment.

During this study phase, several long-lead-time 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 chamber 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 Douglas Electronics Company (MDEC) of St. Charles, Missouri, performed a small study evaluating 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.

Several papers and reports on cloud physics research and applications were given during this study phase. The substance of the material covered is included in Summary Report (NASA CR 129002).

Thus, the significant accomplishments of this study phase included (1) definition of an experiment program consisting of 20 experiment classes; (2) formulation of laboratory requirements based on experiment program definition; and (3) formulation of a laboratory concept accommodating nearly all experiments.

Section 3
EXPERIMENT PROGRAM

The scientific aspect of this segment of the Zero-Gravity Atmospheric Cloud Physics Program involved the evaluation and refinement of the experiment program descriptions which were contained in the NASA Contract Report CR 129002 of June 1973. This information was then utilized in the engineering analysis as appears in Section 4.

Experiment class evaluation criteria concerning experiment priority, applicability, scope, and chamber assignments were formulated. These criteria and the experiment program descriptions were distributed to 58 scientists who had actively participated during the original experiment solicitation phase of the program. Seventeen responses (Table 2-1) were received from the sc· ntific community. These responses were consolidated and sent to the Senior Scientific Board (SSB) for their assessment. The resulting inputs were then used to revise the experiment program descriptions which are contained in the Appendix of this report.

The significant evaluation results are as follows:

A. Earth simulation experiment class definition.
B. Primary and secondary chamber approach to experiment class.
C. Unique cloud chamber approach for specific experiments.
D. Revised expansion cloud chamber geometry.
E. Expanded experiment class parameter variations.

Each of these items will be discussed. The remaining parts of this section contains a general description of the five basic chambers, an assessment of the experiment program, a revised mission assessment, a summary of scientific community participation, and finally representative timelines for Experiment Classes 1, 4, and 12.

Table 3-1

EXPERIMENT PROGRAM EVALUATION SOLICITATION

- Solicitations Submitted 58
- Replies Received 17

Experiment Evaluators	Affiliation	Experiment Classes Reviewed
Appleman, H. S.	USAF - AWS	3, 8, 18
Blanchard, D. C.	SUNY	17
Byers, H. R.	Texas A&M	General
Carstens, J. C.	Univ. of Mo.	1
Davis, B. L.	So. Dak. S.M.T.	1, 12
Fukuta, N.	Denver Univ.	3, 7, 8, 9, 11, 16
Hallett, J. R.	DRI	1-20
Hoffer, T. E.	DRI	5, 11, 20
Holroyd, E. W.	CSIRO	2-11
Jayaweera, K.O.L.F.	Univ. of Alaska	3, 7, 9
Jiusto, J. E.	SUNY	3, 7, 10, 16
Kassner, J./White, D.	Univ. of Mo.	1, 12, 14, 15, 19
Kyle, T. G.	NCAR	2, 4, 9
Langer, G.	NCAR	1, 2, 3, 6, 8, 10
Sogin, H. H.	Tulane	20
Spengler, J. D.	Harvard	1, 2
Weickmann, H.	NOAA	General

Senior Scientific Board

- C. J. Hosler
- L. J. Battan
- P. Squires
- H. K. Weickmann

3.1 CHAMBERS

Five cloud chambers have been identified as being required for the experiment programs. The need for specific chambers may change as the multi-experiment Zero-Gravity Cloud Physics Laboratory evolves. Figure 3-1 provides some facts associated with each chamber. The basic chambers are described in succeeding paragraphs.

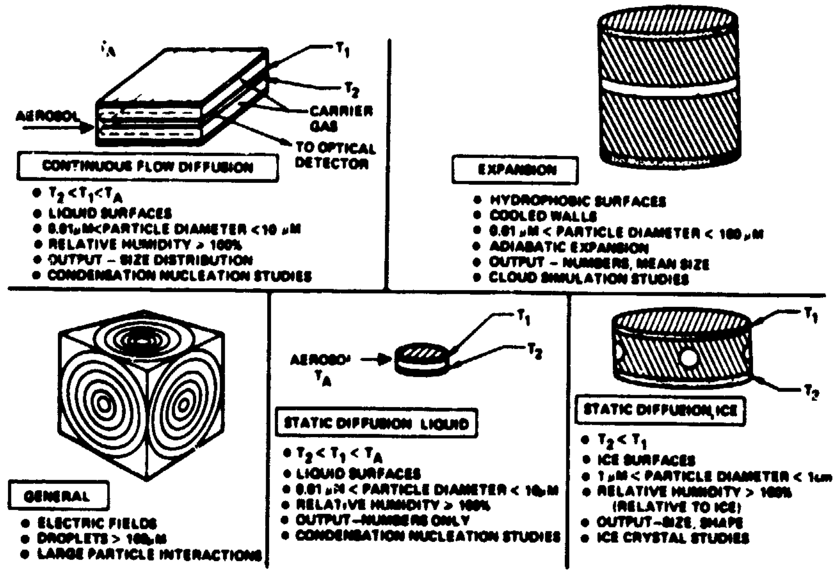


Figure 3-1. Atmospheric Cloud Physics Chambers

3.1.1 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.

3.1.2 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.

3.1.3 Static Diffusion Ice (SDI)

This is a Nakaya type of chamber which utilizes ice surfaces to provide controlled supersaturation relative to ice. Its dimensions are 10 cm deep by 40 cm in diameter.

3.1.4 Continuous-Flow Diffusion (CFD)

The chamber active 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.

3.1.5 Expansion Chamber (E)

This chamber will be a 30-cm-diameter, 45-cm-long cylinder. The cooling of the walls will be synchronized with the expansion cooling of the gas, thus providing for long-term, natural cloud, adiabatic simulation. The shape of the expansion chamber has been revised from a sphere to a cylinder due to the requirement for terrestrial compatibility. At least for initial experiments, comparisons must be made between 1-g and zero-g data. The active time of the 1-g chamber can be extended to a certain extent by stacking cylindrical sections, thus facilitating the desired comparisons. Future experiments may require the spherical symmetry to minimize inaccessible corners and to provide radial symmetry for expansion, thermal transport, and vapor transport.

Block diagrams for each of the five chambers are given in Figures 3-2 through 3-6. These diagrams give a rough view of the concept of common subsystems into which a chamber can be "plugged". The items to the left of the dotted line are primarily the same for all chambers while the items to the right are experiment and chamber dependent. This concept is being further developed and refined. Section 4 discusses the engineering aspects of this laboratory concept.

3.2 EXPERIMENT PROGRAM ASSESSMENT

This segment of the report covers class changes, chamber class assignments, class priority changes, and class requirement modifications. The results include the addition of an experiment class and the considerations for need of alternate and unique chambers.

3.2.1 Experiment Classes

The basic experiment classes remain the same as defined in the NASA CR 129002. The experiment class numbers, titles, and objectives are given in Table 3-2. As indicated, a Class 21-Earth Simulation has been added

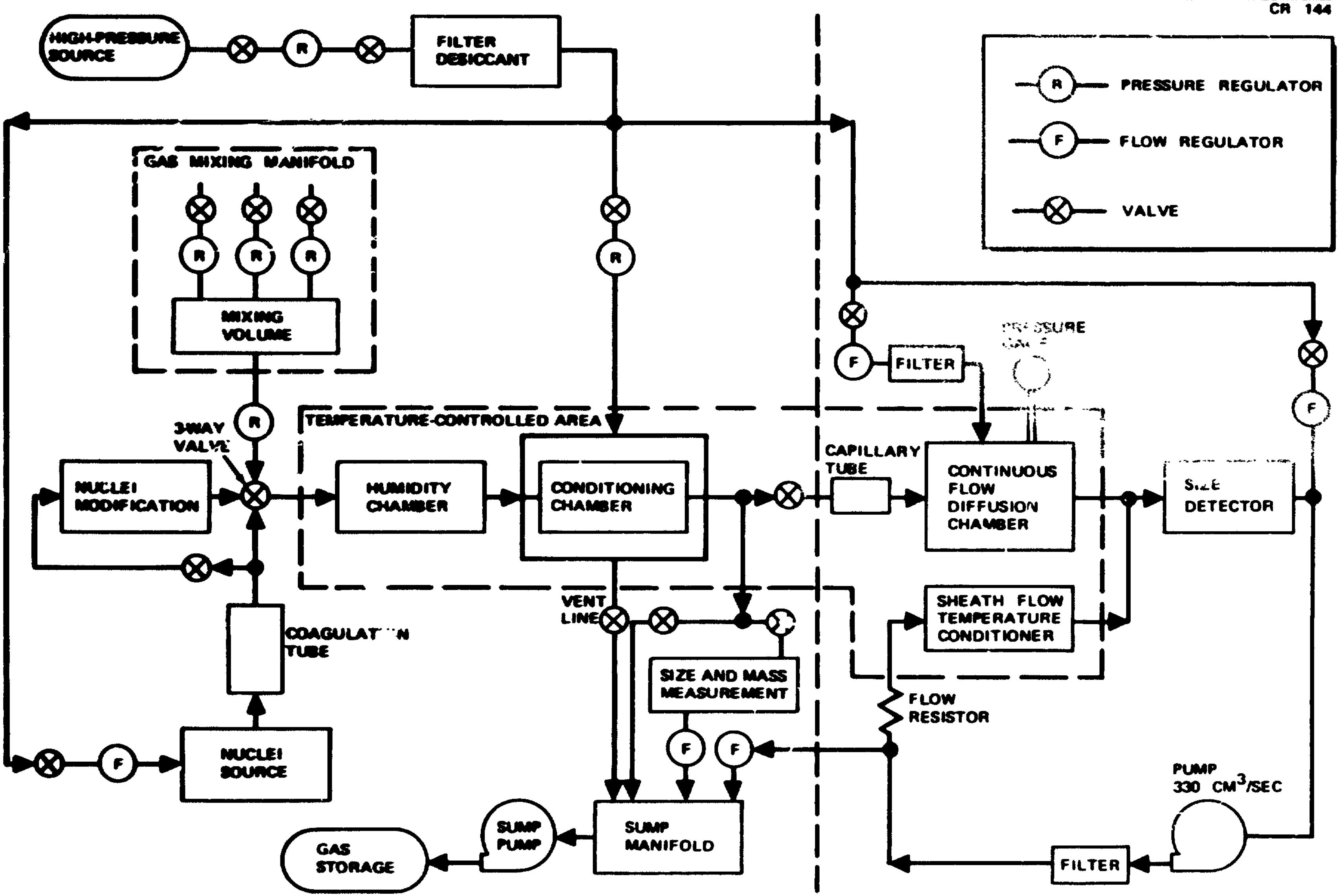


Figure 3-2. Block Diagram For Continuous Flow Diffusion Chamber

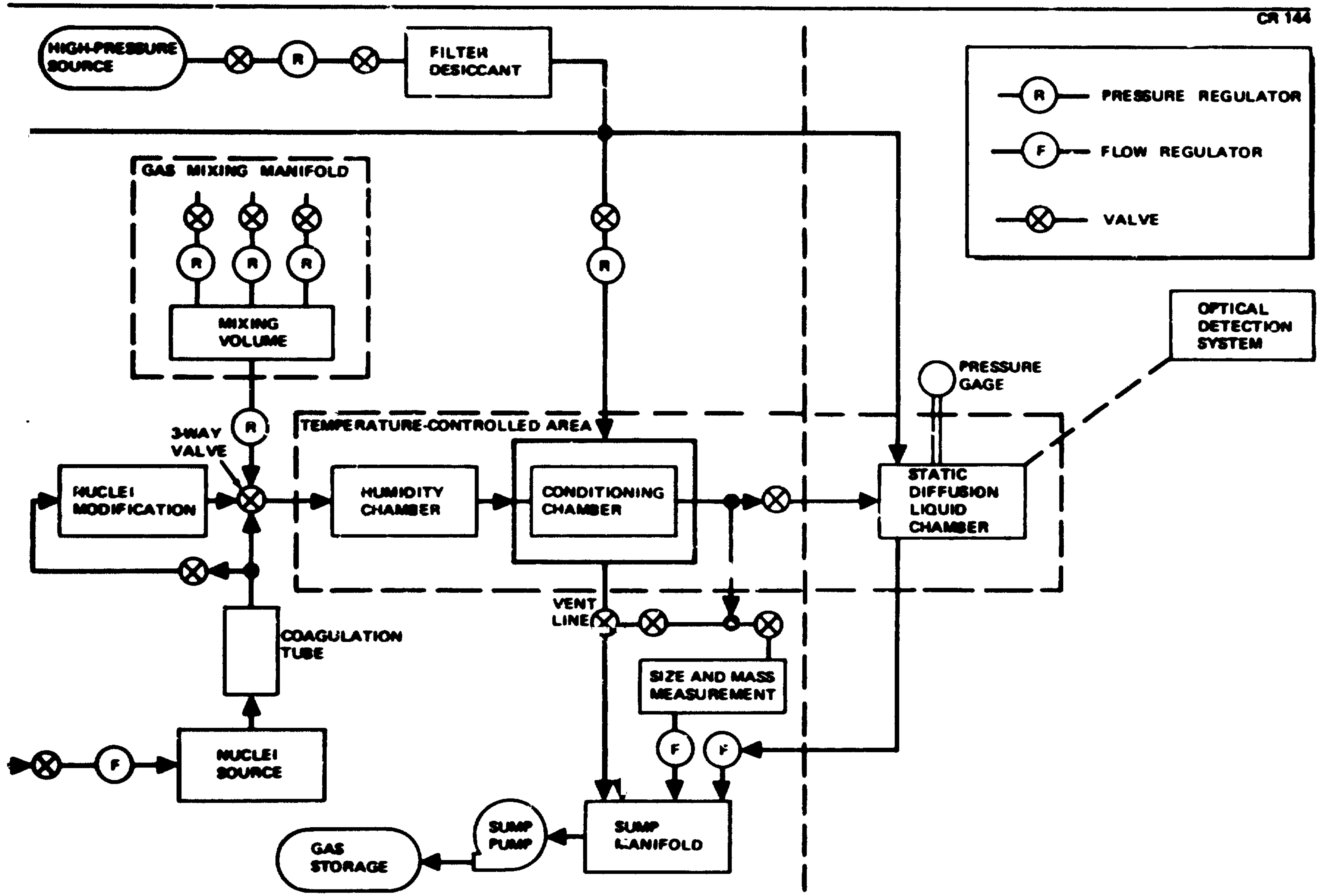


Figure 3-3. Block Diagram for Static Diffusion Liquid Chamber

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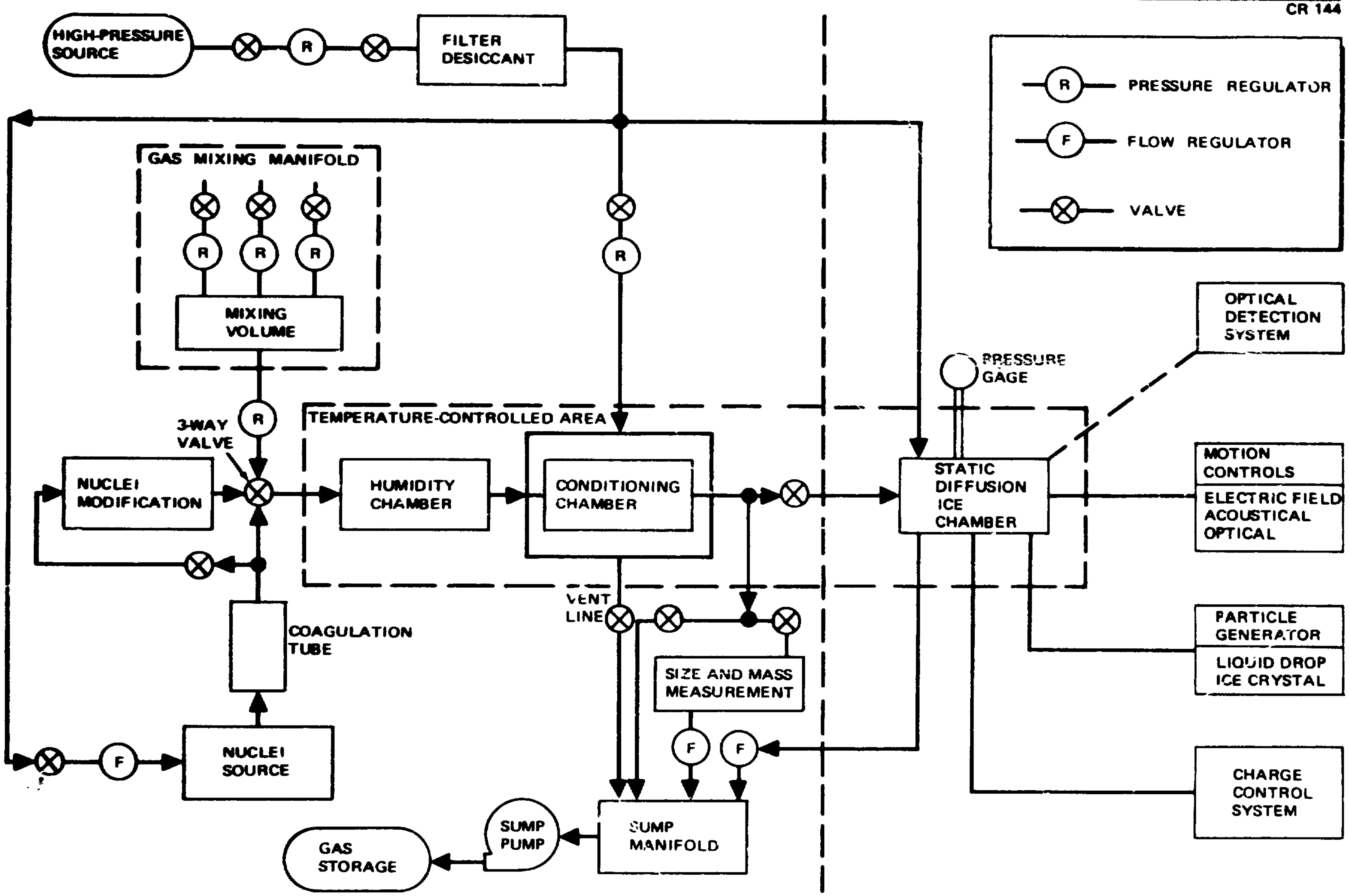

Figure 3-4. Block Diagram for Static Diffusion Ice Chamber

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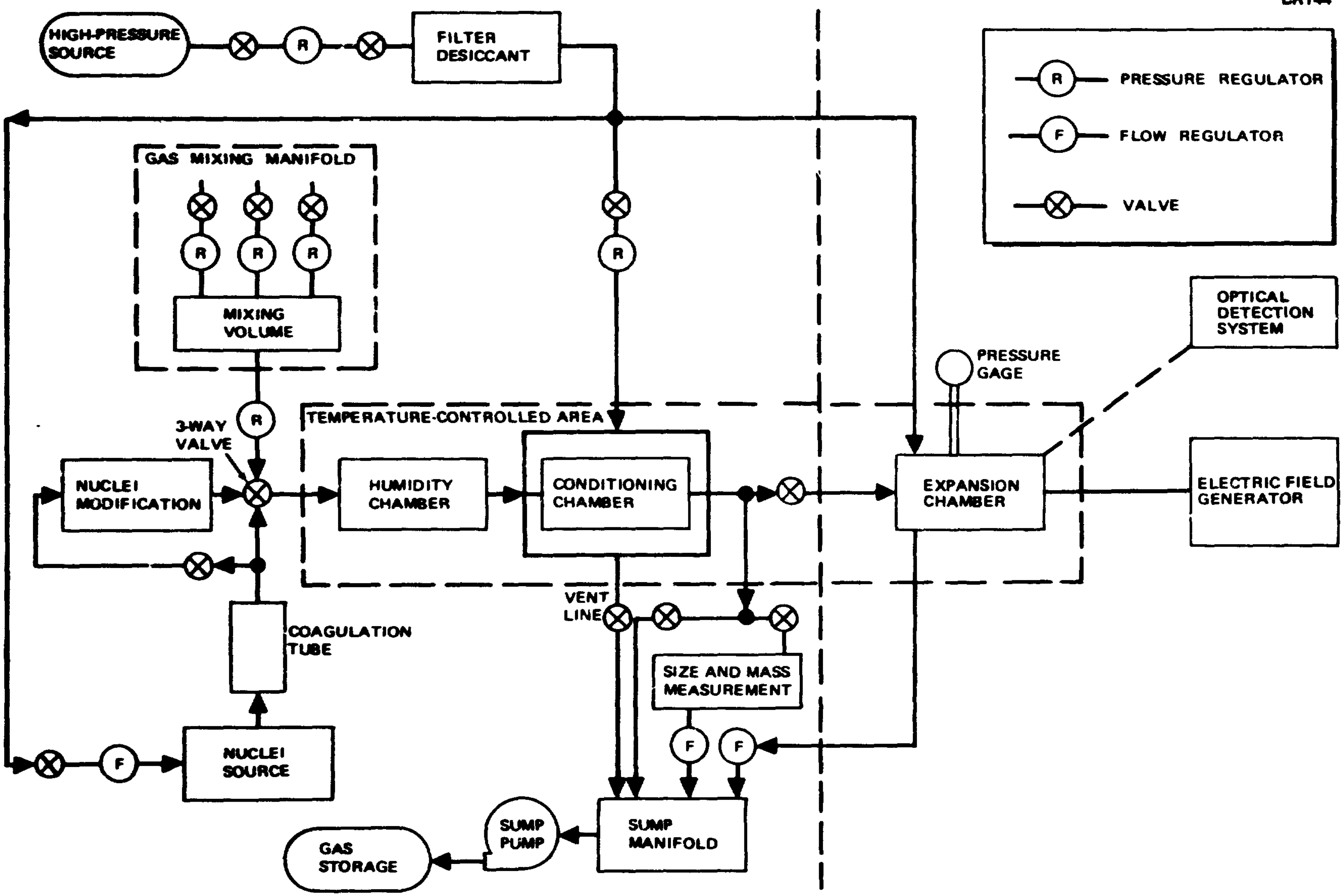

Figure 3-5. Block Diagram for Expansion Chamber

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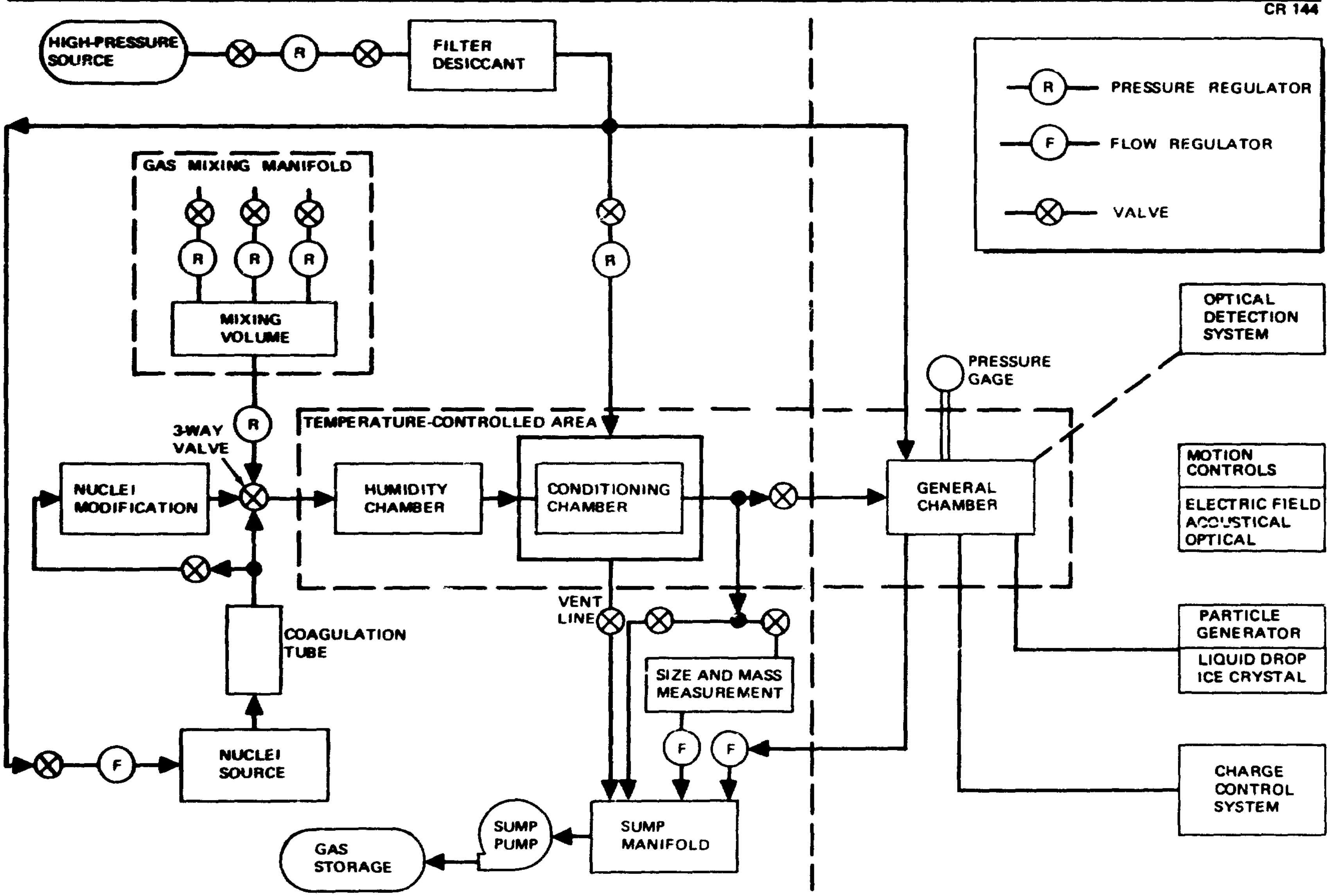

Figure 3-6. Block Diagram for General Chamber

Table 3-2 (Page 1 of 3)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
1	Condensation Nucleation	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.
2	Ice Nucleation	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 sizes.
3	Ice Multiplication	Determine the conditions under which ice fragments are generated during atmospheric precipitation processes and the extent to which they are generated.
4	Charge Separation (Electrification)	Determine quantitative values for charge transfer occurring during several important atmospheric processes.
5	Ice Crystal Growth Habit	Determine the temperature, pressure, and relative humidity conditions which dictate ice crystal geometry and growth rate under pure diffusion (non-convective) conditions.
6	Scavenging	Determine the relative and quantitative importance of thermal (thermophoresis), diffusional (diffusiophoresis), and Brownian forces in the collection of submicrometer aerosol particles by cloud droplets.
7	Riming and Aggregation	Determine interaction between a supercooled water droplet and an ice surface during events associated with riming and graupel formation.

Table 3-2 (Page 2 of 3)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
8	Droplet-Ice Cloud Interactions	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 super-cooled droplets under varying conditions of temperature, pressure, and droplet/crystal concentrations.
9	Homogeneous Nucleation (Ice)	Determine the homogeneous freezing distribution of droplets as a function of time, degree of supercooling, and droplet diameter under conditions of no physical supports.
10	Collision-Induced Freezing	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.
11	Supercooled-Water Saturation Vapor Pressure	Determine the saturation vapor pressure of supercooled water.
12	Adiabatic Cloud Expansion Simulation	Duplicate in time and conditions the early portion of the life cycle of a parcel of air involved in an atmospheric precipitation process.
13	Ice Nuclei Memory	Determine the effect of an ice nuclei's history on its ability to initiate (nucleate) the ice phase.
14	Terrestrial Expansion Chamber Evaluation	Measure condensation and ice nuclei activation efficiencies under operating conditions similar to those utilized in terrestrial laboratories, but without gravity-induced convection.

Table 3-2 (Page 3 of 3)

EXPERIMENT CLASSES AND OBJECTIVES

Experiment ID No.	Experiment Class Title	Objective
15	Condensation Nuclei Memory	Determine the effect of a condensation nuclei's history on its ability to initiate (nucleate) the liquid phase.
16	Nuclei Multiplication	Determine the processes and extent of nuclei material breakup.
17	Droplet Collision Breakup	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).
18	Coalescence Efficiencies	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.
19	Static Diffusion Chamber Evaluation	Determine the absolute nucleation efficiencies of standardized nuclei sources utilizing zero fallout conditions.
20	Unventilated Droplet Diffusion Coefficient	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.
21	Earth Simulation*	Determine the circulation and instability dynamics of the atmosphere and of the oceans by scaled and simulated experiments.

*Candidate Experiment Class requiring in-depth evaluation prior to inclusion in Cloud Physics Laboratory Experiment Program.

based on suggestions received from several members of the scientific community. The basic idea is to extend the "dishpan" type of experiment to a more realistic three-dimensional model as illustrated in Figure 3-7. One concept is to utilize a magnetic-fluid-covered sphere. Local density (thermal) anomalies could be introduced by small electromagnets within the sphere. Thus perturbations could be initiated and the resulting propagations studied. These experiments are important in relation to understanding atmospheric circulation instabilities as well as for an understanding of ocean circulation patterns. This experiment requires much extensive development and thus would be considered as a growth item that could be incorporated into an expanded, comprehensive, zero-gravity laboratory facility. An in-depth definition study would be required before further evaluation can be made.

A look at the class titles will show that the various classes of experiments are not independent of each other. For example, observations for charge separation would be considered during ice multiplication and drop collision breakup experiments. The classes were assigned because certain aspects of one experiment may not permit the observation of other variables or, for a

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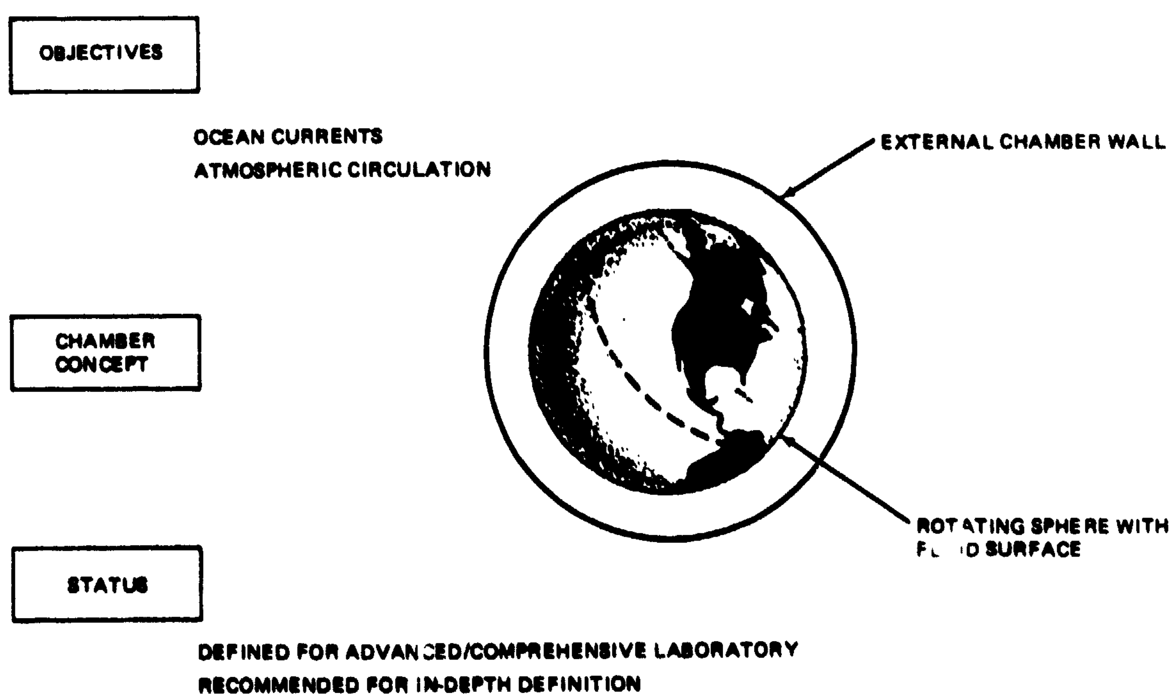

Figure 3-7. Earth Simulation Experiment Class

given experiment in a class, the alternate phenomenum may not be important. Although in practice, aspects of certain experiment classes will be combined, the definition of experiment requirements can be better facilitated by separation of the various phenomena whenever possible.

A very important consideration to keep in mind when considering the total program is that the primary purpose is to develop a facility which will be useful in the 1980's. Thus, it is the tools and techniques that are of prime consideration. Those items which have been used for 20 years will very likely be valid tools for the study of problems pertinent to the 1980's. With this in mind, it is the techniques and experiment requirements needed to solve today's pressing problems that need to be integrated into the zero-gravity laboratory design.

3.2.2 Chamber Assignments

The chamber assignments for each experiment class were reviewed by the scientific community with the result of alternate chambers being suggested for a number of the experiments. The potential of alternate chambers has existed from the start of the program. It now becomes relevant to delineate these potentials.

As a clarification, the procedure for the original chamber assignments will be reviewed and then some alternate assignments will be discussed. Figure 3-8 is a flow diagram for the experiment requirement analysis that has been used. The driving factor for the indicated assignments was the optimum throughput of information per mission hour. The static diffusion (liquid) chamber utilizes photographic data which provide only numbers and require moderate data processing time. Thus the compatible experiments were assigned to the continuous flow diffusion chamber which has high throughput and real-time numbers. The expansion chamber also primarily relies on photographic data recording but is handicapped by the lack of techniques to monitor the relative humidity and/or liquid water content. Those experiments which require well-defined supersaturation values were therefore assigned to the other three diffusion type chambers. This approach was used to assign the primary chamber for each class of experiments.

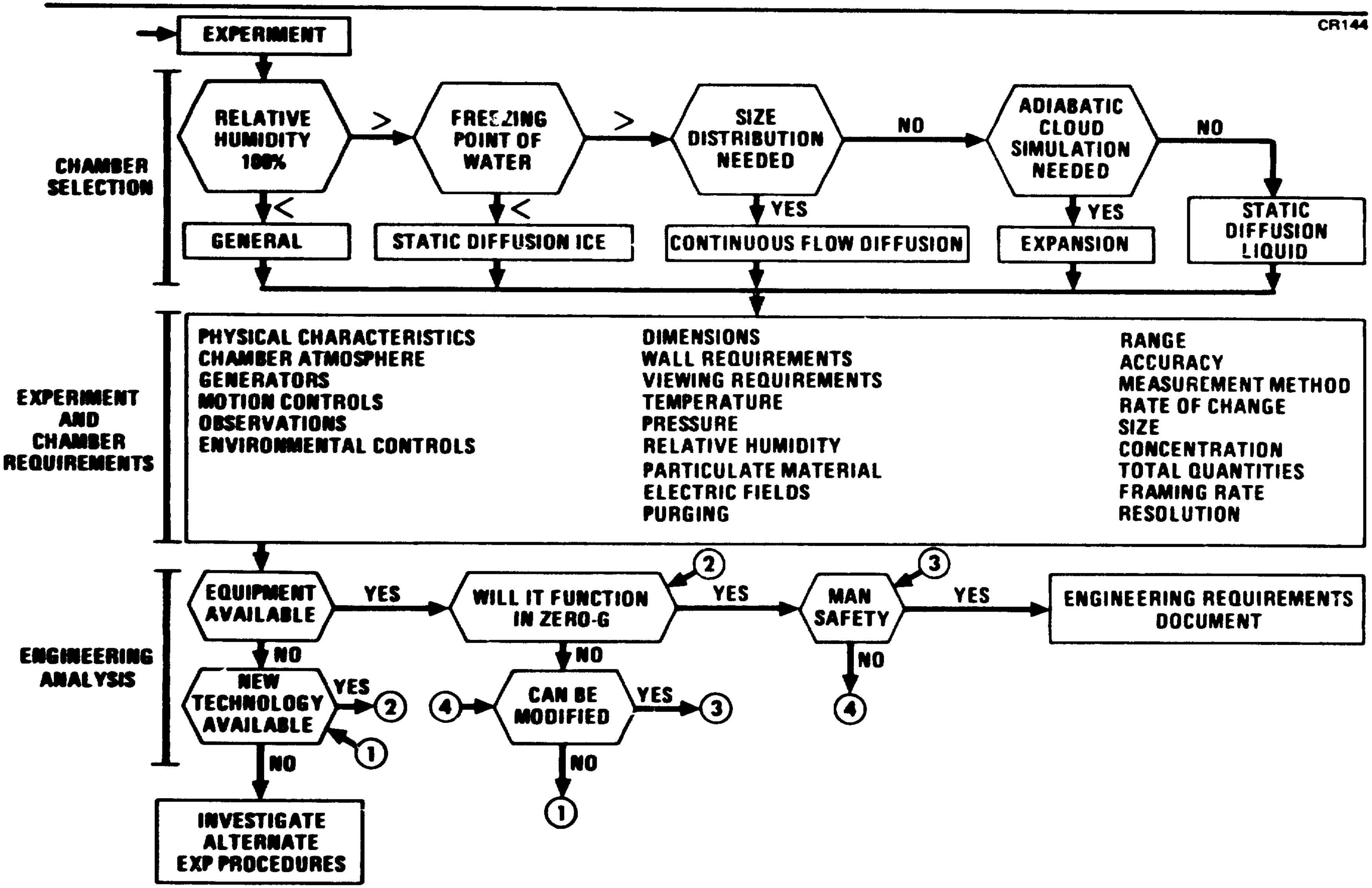

Figure 3-8. Experiment Requirements Analysis

Secondary chambers have now been assigned as given in Table 3-3 along with the primary chamber assignments. Some of the experiments within a given class have special requirements such as special geometry or wall surface coatings (c.f. Appendix, Classes 9, 11, and 15). Examples of the tradeoffs for primary versus alternate or unique chambers are illustrated in Figures 3-9 and 3-10. For Class 1 (Figure 3-9), the primary CFD chamber has well-defined supersaturation and high throughput while the primary chamber (expansion) for Class 15 (Figure 3-10) provides unlimited recycling and a realistic expansion growth environment. Although the initial laboratory has been defined with five specific chamber geometries, the previous section on chambers has shown that the basic console controls are common to all chambers. This capability permits an experimenter to build a special chamber and use it within the framework of the zero-gravity cloud physics laboratory.

3.2.3 Priority Achievability and Applicability Assessment

The Senior Scientific Board reconsidered the experiment priority, zero-g achievement ability, and applicability to zero-g gravity for each experiment class. After consideration of the recommended changes, the class 10 and 17 priorities were changed from B's to A's; achievement class 8 from B to C, class 10 from B to A; and applicability of class 9 from A to B. The current assessments are given in Table 3-3. These priorities and chamber assignments are included with the corresponding experiment description in the Appendix. Further definition of the assessments can be found in the Summary Report, NASA CR 129002.

The scientific priority factor A designates those experiments that were most important, of greater interest, and/or requiring early accomplishment. The B priority classes are also important, but less so than the A classes. The C priority classes are those experiments that would provide useful and interesting information, but their accomplishment is not as pressing as the other classes.

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.

Table 3-3

EXPERIMENT CLASS ASSESSMENT

Class of Experiments	Priority Factor	Primary Chambers	Alternate Chambers	Achievement Ability	Applicability to zero-g
1. Condensation Nucleation	A	CFD	SDL, E	B	A
2. Ice Nucleation	A	SDI	E	B	A
3. Freeze Splintering	A	SDI	E	A	A
4. Charge Separations	A	SDI	E, G	C	A
5. Ice Crystal Growth Habits	A	SDI	E	A	A
6. Scavenging	A	SDI	CFD, E, G	B	B
7. Riming and Aggregation	A	SDI	G	B	B
8. Droplet-Ice Cloud Interaction	A	SDI	E	C	B
9. Homogeneous Nucleation	B	SDI	E	B	B
10. Collision-Induced Freezing	A	SDI	G	A	A
11. Saturation Vapor Pressures	B	SDI	E	C	B
12. Adiabatic Cloud Expansion	A	E	--	B	A
13. Ice Nuclei Memory	A	E	SDI	B	A
14. Terrestrial Expansion Chamber Evaluation	A	E	--	B	A
15. Condensation Nuclei Memory	C	E	CFD, SDL, SDI	B	C
16. Nuclei Multiplication (NaCl Breakup)	B	G	E, CFD	A	A
17. Droplet Collision Breakup (>0.5 mm)	A	G	SDI	C	C
18. Coalescence Efficiencies (<100 μm)	A	G	SDI	C	B
19. Terrestrial Static Diffusion Chamber Evaluation	A	SDL	--	B	A
20. Unventilated Droplet Diffusion Coefficients	B	SDL	E, G, SDI, CFD	B	A

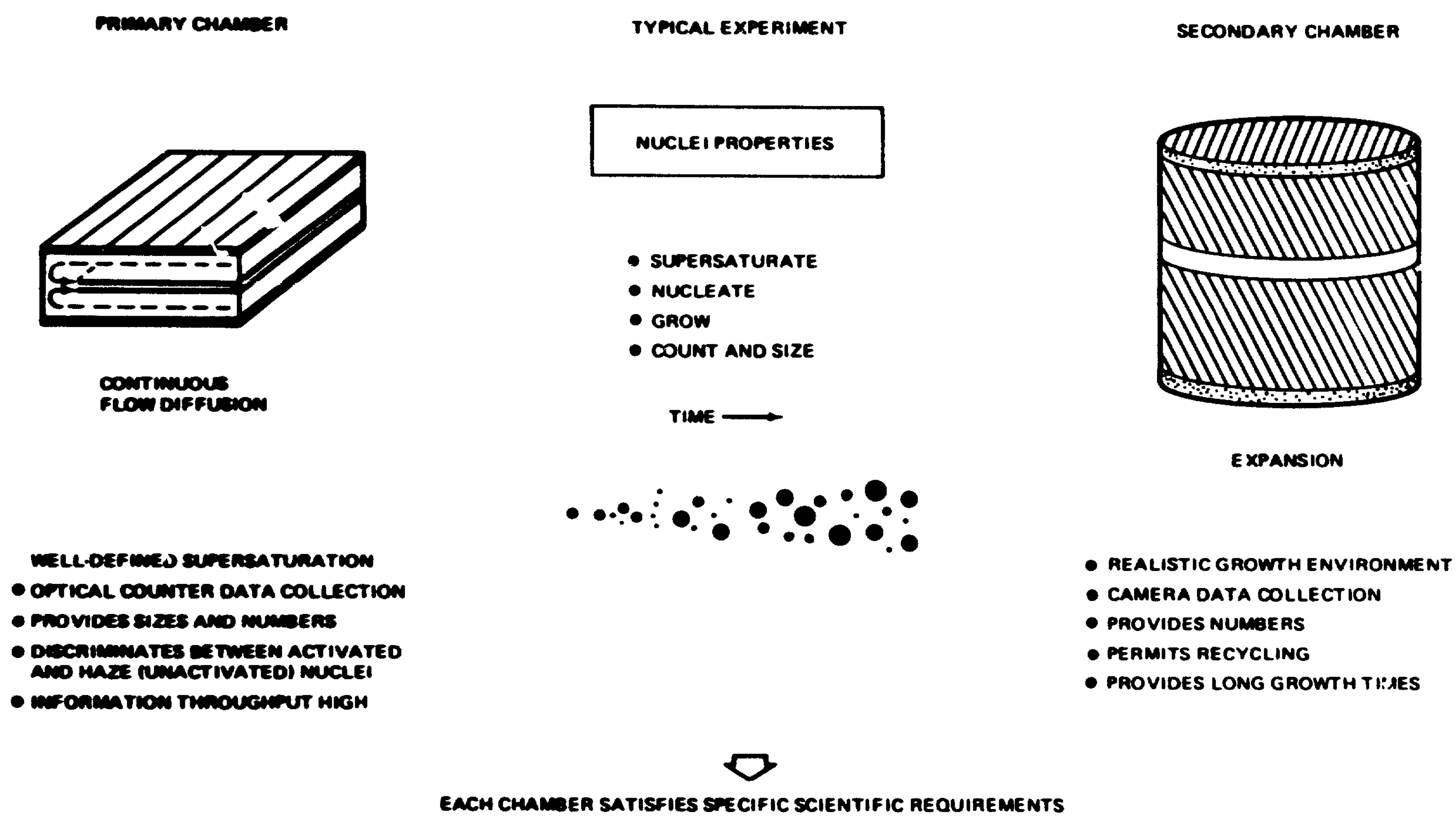

Figure 3-9. Chamber Comparisons – Experiment Class 1

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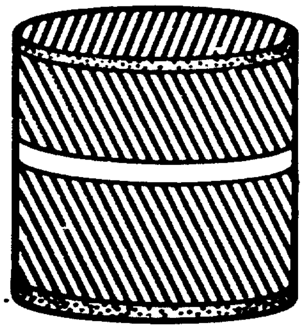
PRIMARY CHAMBER



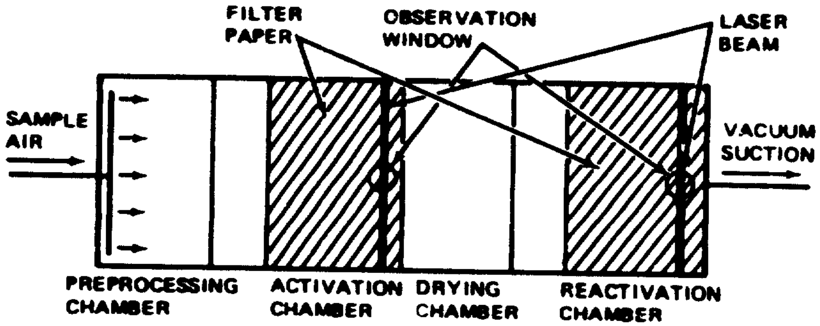
EXPANSION

- CAMERA OR OPTICAL ATTENUATION
- RECYCLES UNLIMITED
- REALISTIC GROWTH ENVIRONMENT

EXPERIMENT CYCLE

- DRY
- SUPERSATURATE
- COUNT
- ANALYZE NUMBERS VERSUS CYCLES

UNIQUE CHAMBER



MODIFIED STATIC DIFFUSION LIQUID

- CAMERA OR OPTICAL ATTENUATION
- RAPID DATA THROUGHPUT
- WELL-ESTABLISHED SUPERSATURATION

EXPANDED SCIENTIFIC COMMUNITY PARTICIPATION
EFFECTIVE USAGE OF LABORATORY CAPABILITY
INCORPORATES TERRESTRIAL RESEARCH ADVANCEMENTS

Figure 3-10. Chamber Comparisons – Experiment Class 15

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 terrestial 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.

3.2.4 Class Requirements

Each experiment class contains one or more groups of experiments. Within each of these experiments, there are a number of variables which must be controlled.

Figure 3-11 illustrates the structure for an experiment. The nucleation properties of soluble nuclei are to be studied, e.g., NaCl. The parameter to be varied is temperature. For this experiment, a CFD chamber will provide many counts per minute so that three or four 5-minute readings (iterations) would provide the desired statistical validity. Other experiments (e.g., rain

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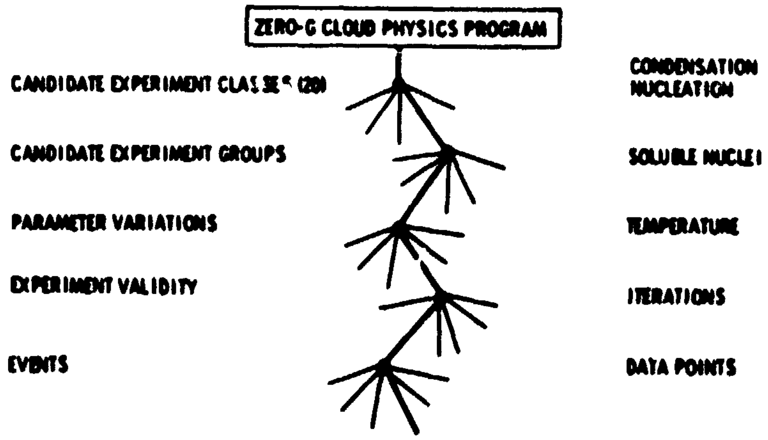

Figure 3-11. Experiment Program Tree

drop breakup) is limited to one event per iteration thus requiring 20 or more iterations for statistical validity. A representative set of parameters is given in Table 3-4 with a nominal assignment discrete variation values for each (e.g., four discrete droplet sizes, six types of material or nuclei). The assignment of these parameter variations was accomplished to estimate the total experiment time required for each class.

The assignment of these parameters to each experiment class is given in Table 3-5. This table also indicates primary and secondary parameters where the secondary parameters may be varied if experiment time and design permit. It is important to remember that this is a broad brush assignment of parameters each of which has a scientific priority. In practice, one, two, or three main parameters will be selected for the initial experiments. The results of these will indicate a need for further study of the same parameters or that certain other parameters must be investigated. In any event, there exists a significant requirement of time to perform these important experiments, the extent of the experimentation dictates the utilization of a manned orbital platform.

3.3 MISSION ASSESSMENT

The scientific community responses, Senior Scientific Board analysis, and timeline considerations were used to update the mission time requirements as given in Table 3-6. The observation hours are those hours that an experiment is actually in progress. Three representative timelines for Classes 1, 4, and 12 were used to define event times as a fraction of an 8-hour day. These numbers were then utilized to determine class-by-class event duration requirements. The resulting observation times, class by class, have changed from the previous determinations but the total hours remain roughly the same at 100 plus missions. As was previously indicated, these considerations provide an indication of the potential of such an experiment program. Significant benefits to man can be obtained from a few to many missions with the potential benefits increasing as the mission hours increase.

3.4 SCIENTIFIC COMMUNITY PARTICIPATION

Throughout the study, special emphasis has been placed on maintaining participation by the cloud physics community and keeping the community informed. Their continued interest and participation are vital to the success of this zero-g laboratory concept. The laboratory is being developed for

Table 3-4

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
Adsorp(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
Age (Aerosol)	3
History (of nuclei)	3
Ion Lev(el)	3
Initial Cond(itions) (exp. chamb.)	4
K(inetic) E(nergy)	5
Gases (ambient)	3

Table 3-5
EXPERIMENT PARAMETER VARIATION ASSIGNMENTS

Classes	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
1. Condensation Nucleation	X	X	X	X	X	X			X	O			X	O		X			X				X	X				X
2. Ice Nucleation	X	X	O	O	X	X	O		X	X	X	X	X	X	O				O				O	O	X			O
3. Ice Multiplication	X	X	X	X	X	X	X	X		X	X		O	O	X								O					X
4. Charge Separation		X		X	X	X	X			X	X		O	O						X					O		X	O
5. Ice Crystal Growth Habits	X	X	X	X	X	X	X			X	X		O	O	X	X	X	X	X	O					O			X
6. Scavenging	X	X	X	X	X	X	X		X	X	X		X	X	O		X		X	O					O			
7. Riming and Aggregation	X	X		X	X	X	X				X		O	O			X	O	X	X							X	O
8. Droplet - Ice Cloud Interaction		X		X	X		X		X	X	X			X		X			X		O							
9. Homogeneous Nucleation	X				X	X	X	X	X	X				O														
10. Collision-Induced Freezing	X	X	X	X	X	X	X			X	X									X							X	
11. Saturation Vapor Pressure	X	X			X		O		X																			
12. Adiabatic Cloud Expansion	X	X	X					X	X	O	X		O	X		X			X		X			X				X
13. Ice Nuclei Memory	X	X	X	X	X	X			X														X	X				
14. Terrestrial Expansion Chamber Evaluation	X	X					X	X																	X	X		
15. Condensation Nuclei Memory	X	X		X	X	X			X															X				
16. Nuclei Multiplication	X	X	O	X	X	X	X			O	X			O										X				O
17. Drop Collision Breakup (>0.5 mm)	X			X	X	X	X				X									X		X					X	O
18. Coalescence Efficiency (< 50 μm)	X		X	X	X	X	X				X									X		O					X	X
19. Static Diffusion Chamber Evaluation	X	X		X	X	X																						
20. Unventilated Droplet Diffusion Coefficients	X	X	X	X	X	X	O				X				X													O

X Primary   O Secondary

Table 3-6

REVISED MISSION ASSESSMENT

	Classes	Primary Chambers	Alternate Chambers	Application Priority	Observ. Hours	Missions (40 Expt. Hr Type.)	
1.	Condensation Nucleation	CFD	SDL, E	A	50		
2.	Ice Nucleation	SDI	E	A	330		
3.	Freeze Splintering	SDI	E	A	520		
4.	Charge Separation	SDI	E, G	A	60		
5.	Ice Crystal Growth Habits	SDI	E	A	330		
6.	Scavenging	SDI	CFD, E, G	A	465		
7.	Riming and Aggregation	SDI	G	A	92		
8.	Droplet-Ice Cloud Interaction	SDI	E	A	410		
9.	Homogeneous Nucleation	SDI	E	B	175		
10.	Collision-Induced Freezing	SDI	G	A	480	A	87
11.	Saturation Vapor Pressure	SDI	E	B	58		
12.	Adiabatic Cloud Expansion	E	--	A	128	B	13
13.	Ice Nuclei Memory	E	SDI	A	180		
14.	Terrestrial Expansion Chamber Evaluation	E	--	A	125		
15.	Condensation Nuclei Memory	E	CFD, SDL, SDI	C	75	C	2
16.	Nuclei Multiplication	G	E, CFD	B	210	Total	102
17.	Droplet Collision Breakup (>0.5 mm)	G	SDI	A	60		
18.	Coalescence Efficiencies	G	SDI	A	185		
19.	Terrestrial Static Diffusion Chamber Evaluation	SDL	--	A	52		
20.	Unventilated Droplet Diffusion Coefficients	SDL	E, G, SDI, CFD	B	60		

their use and therefore requires active interplay between the scientific community's needs and the potential program capabilities.

The Cloud Physics Feasibility Study Summary Report (NASA CR-128998, September 1972) and the Zero-Gravity Cloud Physics Laboratory—Candidate Experiments, Definition and Preliminary Concept Studies (NASA CR-129002, June 1973) were given extensive distribution. Significant events involving the community are shown in Table 3-7.

A list of the scientists who contributed to the initial experiment program is given in Table A-2 of the Appendix with the Experiment Program Descriptions. Contributors to the experiment program critique during June of this phase are given in Table 3-1.

The zero-g Senior Scientific Board continued their program guidance through the critique evaluations. Subcontract efforts were also accomplished by the University of Nevada at Reno and the University of Missouri at Rolla concerning development plans for the Continuous Flow Diffusion Chamber and the Expansion Chamber, respectively. The results of all the above contributions have been incorporated into the various sections of this report.

Considerable development work for a NaCl nuclei breakup experiment has been accomplished by NASA/MSFC, Huntsville, Alabama. This experiment is being developed as an Apollo-spacecraft-compatible experiment and therefore provides the potential for a pre-Shuttle or early Shuttle experiment. This experiment would provide both scientific information and engineering information important to the development of a zero-gravity cloud physics facility.

Some information relevant to cloud microphysics has begun to accumulate. Astronaut interest in cloud physics was initiated during the Apollo 16 and 17 missions. This interest has been cultivated among the Skylab crews with the results that a few minutes of transcripts from the Skylab II 30-day mission (spring of 1973) have been distributed to the scientific community principal investigator team for droplet dynamics experiments (Blanchard, Hoffer, Latham, and Spengler). The present Skylab III team are also performing some interesting droplet dynamic observations.

Table 3-7

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 (NASA CR 128998)
Dec 1972	Apollo 17 droplet dynamics demonstration
Feb 1973	Second scientific board meeting
Mar/Apr 1973	Management briefing-HDQTRS NASA (OA and OMSF)
June 1973	Article - Bulletin of the AMS
June 1973	Scientific community critique of experiment program
June 1973	Paper - AAS/International Congress of Space Benefits
June 1973	Cloud physics candidate experiments and laboratory concepts summary report distributed (NASA CR 129002)
July 1973	Senior Scientific Board evaluation of program critiques
July 1973	Transcript of droplet dynamics observations from Skylab II
Aug 1973	Program summary review NASA/MSFC

Although these observations are limited and were performed under uncontrolled conditions, valuable information is still provided toward the design and implementation of zero-g cloud physics experiments. As the scientific community interest grows and the awareness of the zero-g potential develops, more productive and unique experiments will evolve which will utilize the advantages of a low-gravity environment for the benefit of mankind.

3.5 EXPERIMENT TIMELINES

This section delineates three representative timelines incorporating subsystems associated with three different chambers; the continuous flow diffusion chamber (CFD), the static diffusion ice chamber (SDI), and the expansion chamber (E). These timelines cover a representative range of power and gas requirements. The output of these timelines provided the basis for the engineering analysis presented in Section 4.

The specific purposes of these timelines were to

A. Provide nominal event times.

B. Delineate discrete experiment operations.

C. Provide basis for resources requirements of power, gas, film, and water.

D. Formulate basis for operational constraints involving g-level and duration, spacecraft stabilization periods and communications.

The timeline assumptions are given in Table 3-8. An 8-hour/day experiment period plus 2 hours for maintenance, etc., was used along with a 5-day experiment mission.

As can be observed - that extending the working hours beyond 8 hours will contribute to the experiment observation time in the following ways.

A. Extension of periods before breaks will minimize startup and shutdown procedures and thus contribute directly to experiment observation time.

B. Multiple crew operation as well as multiple shift will also increase the efficiency of data output per unit available time.

Table 3-8
TIMELINE ASSUMPTIONS

Work Day	
Sleep period	8 hours/man
Hygiene and food	2.25 hours/man
Briefing	0.3 to 0.5 hours/man
Experiment period	3 hours/man
Work period	10 hours/man
Flight	
1 man - Single shift	
Five experiment days - 40 hours/mission	
Scheduled maintenance and rest and recreation periods included	

Each timeline consists of three basic sections. The first is the bar graphs of Figures 3-12, 3-13, and 3-14; second the consumable Tables 3-9, 3-11, and 3-13, and the third the equipment list Tables 3-10, 3-12, and 3-14. The items in each bar graph figure corresponds item for item, line for line to their respective consumable table counterpart.

3.5.1 Timeline Charts

The upper half of the timeline charts (Figures 3-12 through 3-14) is a 24-hour breakdown of the major functional mission items. The lower half of each timeline is a minute-by-minute breakdown in terms of time, power, gas consumption, and acceleration constraints for each major item of the experiment operations cycle.

3.5.2 Timeline Consumable Tables

Each item of the timeline chart is again called out in the timeline table (Tables 3-9, 3-11, and 3-13). These numbers are provided for both the major functional items and for the minute-by-minute breakdown of the operations cycle. The first column gives the duration per each discrete event such as a single chamber purge or calibration cycle.

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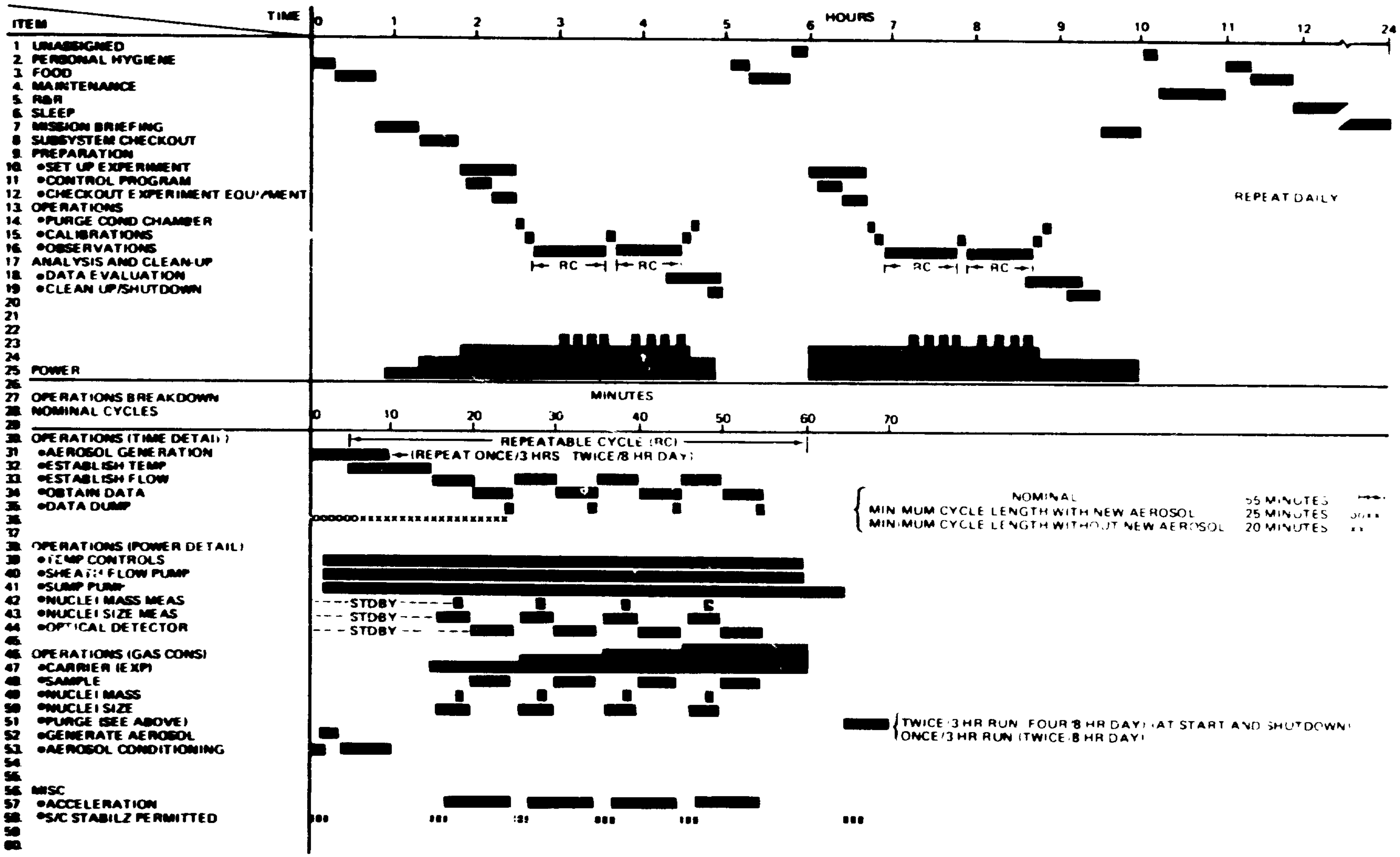


Figure 3-12. Activity Timeline (One Day) – Experiment Class 1

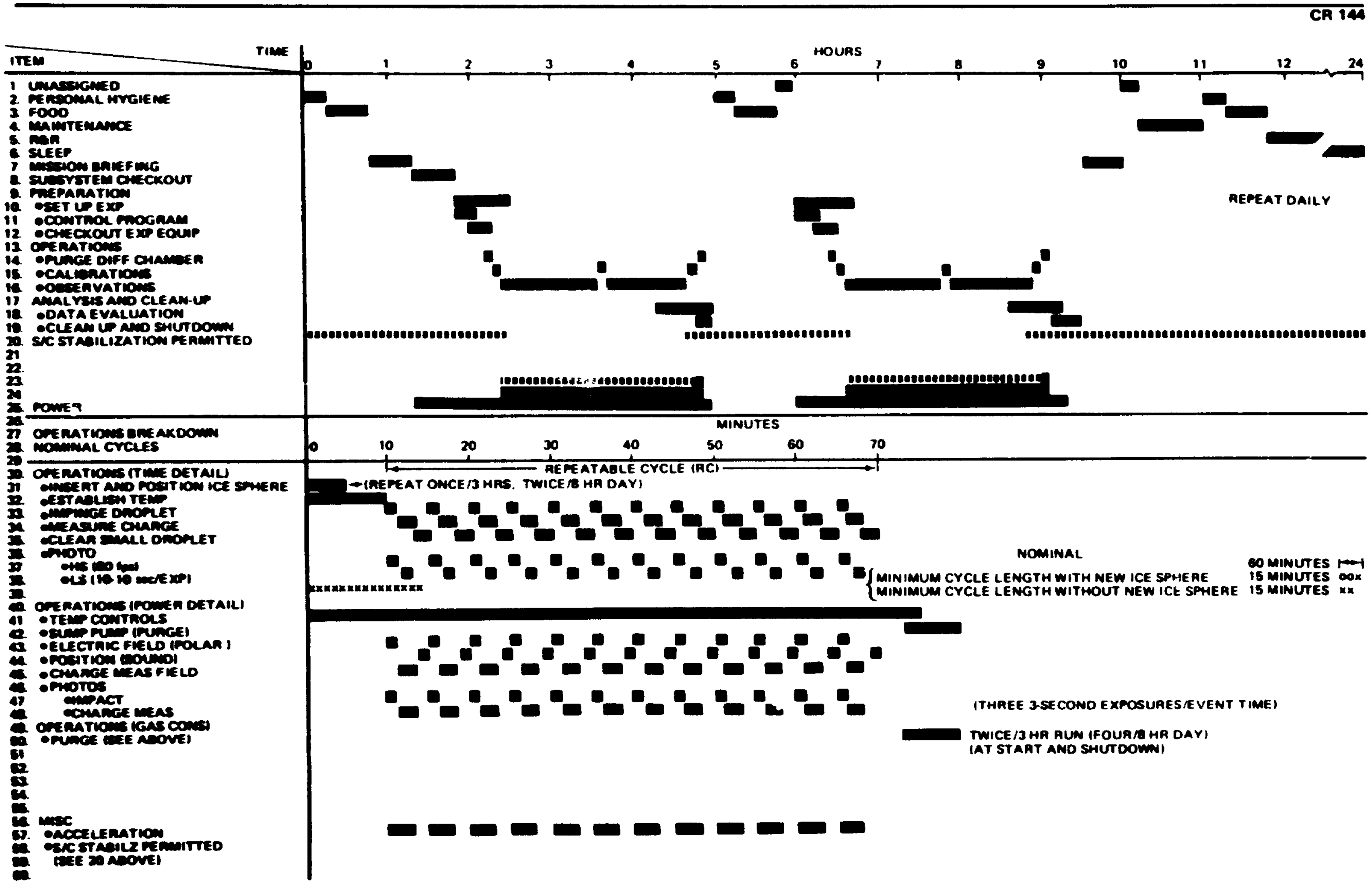


Figure 3-13. Activity Timeline (One Day) – Experiment Class 4

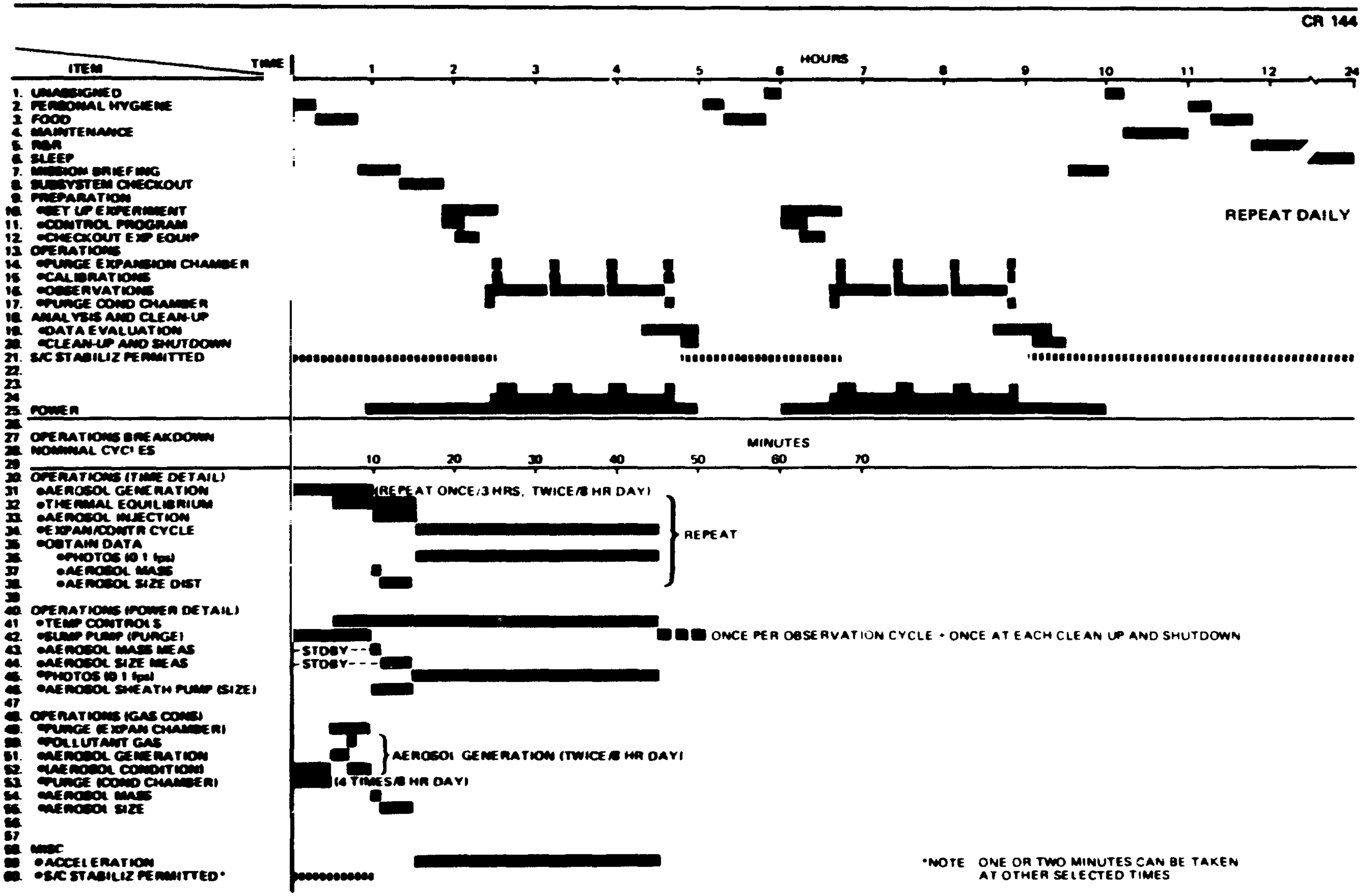


Figure 3-14. Activity Timeline (One Day) – Experiment Class 12

Table 3-9. CONSUMABLES – EXPERIMENT CLASS 1

	ITEM \ QUANTITY	DURATION EVENT (HRS) MIN	NOM	MAX	FRACTIONAL TIME (HR/HR)* (NOMINAL) STDBY	OP	QUANTITY UNIT STDBY	OPERATE MIN	NOM	MAX	UNITS	QUANTITY PER 8 HR WORK PERIOD STDBY	NOM	UNITS	COMMENTS *(FRACTION OF 8 HR WORK PERIOD)
1	UNASSIGNED		(0.2)												
2	PERSONAL HYGIENE		(0.3)			(0.11)									
3	FOOD		(0.5)			(0.19)									
4	MAINTENANCE		(0.8)			(0.10)									
5	R&R		(0.8)			(0.10)									
6	SLEEP		(8.0)			1.00									
7	MISSION BRIEFING		0.5			0.13									
8	SUBSYSTEM CHECKOUT		0.5			0.06									
9	PREPARATION														
10	● SET UP EXPERIMENT	0.17	0.7			0.18									
11	● CONTROL PROGRAM		0.3			0.08									
12	● CHECKOUT EXP EQUIPMENT	0.08?	0.3	1.0		0.08									
13	OPERATIONS														
14	● PURGE CONC CHMBR		0.1			0.05									
15	● CALIBRATION	0.034	0.?	0.34		0.08									
16	● OBSERVATIONS		0.9 0.8			0.4?									
17	ANALYSIS AND CLEAN UP														
18	● DATA EVALUATION		0.7			0.18									
19	● CLEAN UP SHUTDOWN		0.2 0.4			0.08									
20															
21															
22	800		0.1			0.18									
23	600		2.8			0.70									
24	400		3.6 4.0			0.95									
25	POWER WATTS 200		4.0			1.00									
26															
27	OPERATIONS BREAKDOWN														
28	NOMINAL CYCLES														
29															
30	OPERATIONS TIME DETAIL														
31	● AEROSOL GENERATION	0.08?	0.17	0.8?		0.04?									
32	● ESTABLISH TEMP	0.08	0.17	0.34		0.085									
33	● ESTABLISH FLOW	0.050	0.08?	0.1?		0.166									
34	● OBTAIN DATA	0.034	0.08?	0.34		0.166									
35	● DATA DUMP		0.017			0.034									20 CHANNEL × 10^{3} PTS/CHANNEL
36															
37															
38	OPERATIONS POWER DETAIL														
39	● TEMP CONTROLS		0.9?			0.49			0.?00		KWATTS		?.4	KWHRS	
40	● SHEATH FLOW PUMP		0.97			0.49			0.150		KWATTS		[illegible]	KWHRS	
41	● SUMP PUMP		1.05			0.5?			0.150		KWATTS		0.64	KWHRS	
42	● NUCLEI MASS MEAS		0.017		0.38	0.034			0.030		KWATTS		0.008	KWHRS	
43	● NUCLEI SIZE MEAS		0.06		0.38	0.130	0.001		0.030		KWATTS	0.003	0.03	KWHRS	
44	● OPTICAL DETECTOR	0.034	0.08?	0.34	0.25	0.17	0.015		0.200		KWATTS	0.032	0.28	KWHRS	
45															
46	OPERATIONS (GAS CONS)														
47	● CARRIER (EXP)		0.75		0	0.39		?	25	50	cc/sec		300	LITERS	
48	● SAMPLE	0.034	0.083	0.34		0.17		0.1	1	5	cc/sec		5.1	LITERS	
49	● NUCLEI MASS	0.007	0.017	0.083		0.034		5	15	25	cc/sec		15.3	LITERS	
50	● NUCLEI SIZE	0.009	0.067	0.170		0.130			100		cc/sec		390.0	LITERS	**
51	● PURGE (SEE ABOVE)		0.083			0.04			400		LITERS PURGE		1,600.0	LITERS	***
52	● GENERATE AEROSOL	0.002	0.034	0.083		0.009		1	10	230	LITERS GEN		20.0	LITERS	
53															
54															
55															
56	MISC														THESE ARE A FUNCTION OF THE NATURE MAGNITUDE AND DURATION OF THE REQUIRED MOTION
57	● ACCELERATION		0.13			0.26			$<10^{3}$		g				
58	● S/C STABILZ PERMITTED		0.034						$<10^{2}$		g				
59															
60															

NOTE
** SHEATH FLOW OF 1,000 ... REQ ... RECIRCULATED USE OF CHAMBER SHEATH PUMP
*** ... MES A 8.2 LITERS ... TED SIZE ... VOLUME ... SIZE OF 230 LITERS

Table 3-10

MAJOR EQUIPMENT AND COMPONENT LIST – EXPERIMENT CLASS 1

CFD Chamber
Temperature Controls
a. Humidity Chamber
b. Conditioning Chamber
c. Top Plate of CFD
d. Bottom Plate of CFD
e. Sheath Flow of CFD
Conditioning Chamber
R. H. Control
Sump Pump
Sheath Flow Pump (for CFD and Aerosol size)
Nuclei Mass Measurement
Nuclei Size Measurement
Optical Detection
Pulse Analyzer (PHA)
Magnetic Tape (for PHA)
Aerosol Generator
Pollution Gas
Source Gas

The fractional time is based on a single 8-man-hour experiment. These numbers are calculated from duration/event multiplied by number of events (in 8 hours) divided by 8 hours. This gives a fractional expended time tabulation which is then used to determine operation efficiency, total consumables etc., for any specified mission duration. The nominal values for duration/event were used for further calculations.

Table 3-11. CONSUMABLES – EXPERIMENT CLASS 4

ITEM \ QUANTITY	DURATION EVENT (HRS)			FRACTIONAL TIME (HR HR)* (NOMINAL)		QUANTITY UNIT		OPERATE			QUANTITY PER 8 HR WORK PERIOD			COMMENTS *(FRACTION OF 8 HR WORK PERIOD)
	MIN	NOM	MAX	STDBY	OP	STDBY	MIN	NOM	MAX	UNITS	STDBY	NOM	UNITS	
1 UNASSIGNED		(0.2)												
2 PERSONAL HYGIENE		(0.3)			(0.[illegible])									
3 FOOD		(0.5)			(0.19)									
4 MAINTENANCE		(0.8)			(0.10)									
5 R&R		(0.8)			(0.10)									
6 SLEEP		(0.8)			(1.00)									
7 MISSION BRIEFING		0.5			0.13									
8 SUBSYSTEM CHECKOUT		0.5			0.06									
9 PREPARATION														
10 ●SET UP EXP	0.17	0.7			0.18									
11 ●CONTROL PROGRAM		0.3			0.08									
12 ●CHECKOUT EXP EQUIP	0.083	0.3	1.02		0.08									
13 OPERATIONS														
14 ●PURGE DIFF CHMBR		0.1			0.05									
15 ●CALIBRATIONS	0.034	0.1	0.34		0.08									
16 ●OBSERVATIONS		1.2 1.0			0.55									
17 ANALYSIS AND CLEAN UP														
18 ●DATA EVALUATION		0.7			0.18									
19 ●CLEAN UP AND SHUTDOWN		0.2 0.4			0.08									
20 S/C STABILIZATION PERMITTED														
21														
22														
23 500	0.001	0.003	0.010		0.15									
24 400		2.5			0.63									
25 POWER 200		3.7 3.1			0.85									
26														
27 OPERATIONS BREAKDOWN														
28 NOMINAL CYCLES														
29														
30 OPERATIONS (TIME DETAIL)														
31 ●INSERT AND POSITION ICE SPHERE	0.034	0.083	0.34		0.021									
32 ●ESTABLISH TEMP	0.083	0.17	0.34		0.004									
33 ●IMPINGE DROPLET		0.017			0.10									
34 ●MEASURE CHARGE		0.034			0.20									
35 ●CLEAR SMALL DROPLET		0.034			0.20									
36 ●PHOTO														
37 ●HS (80 fps)	0.001	0.003	0.010		0.018									
38 ●LS (1/10 sec EXP)	0.0003	0.001	0.003		0.018									[illegible]
39														
40 OPERATIONS (POWER DETAIL)														
41 ●TEMP CONTROLS		1.25			0.6			0.100		KWATTS		[illegible]	KWHRS	
42 ●SUMP PUMP (PUMGE)		0.12			0.[illegible]			0.15		KWATTS		0.072	KWHRS	
43 ●ELECTRIC FIELD (POLAR)		0.017			0.10			0.006		KWATTS		0.004	KWHRS	
44 ●POSITION (SOUND)		0.017			0.10			0.015		KWATTS		0.012	KWHRS	
45 ●CHARGE MEAS FIELD		0.034			0.20			0.010		KWATTS		0.016	KWHRS	
46 ●PHOTOS														
47 ●IMPACT		0.003			0.018			0.224		KWATTS		0.032	KWHRS	
48 ●CHARGE MEAS		0.001			0.018			0.005		KWATTS		0.007	KWHRS	
49 OPERATIONS (GAS CONS)														
50 ●PURGE (SEE ABOVE)		0.100			0.050			250		LITERS		1.00	LITERS	[illegible]
51														
52														
53														
54														
55														
56 MISC														
57 ●ACCELERATION		0.05			0.30			10^{5}		[illegible]				[illegible]
58 ●S/C STABILZ PERMITTED								$<10^{2}$		[illegible]				
59 (SEE 20 ABOVE)														
60														

Table 3-12

MAJOR EQUIPMENT AND COMPONENT LIST – EXPERIMENT CLASS 4

Static Diffusion Ice Chamber (SDI)

Thermal Controls

a. Humidity Chamber

b. Conditioning Chamber

c. (1) Top Plate of SDI

(2) Bottom Plate of SDI

Sump Pump

Nuclei Mass Measurement

Nuclei Size Measurement

Nuclei Generator

Source Gas

Pollution Gas

Electric Field (Particle Polarization)

Position Control (Acoustical)

AC (DC) Electric Field (Charge Measurement)

Photos - Motion

a. Impact (80 fps)

b. Charge Measurement (1 to 10 sec exposure)

Sheath Flow Pump (Nuclei Size)

Camera and Optics

The next columns are a tabulation of the power and gas consumable rates and the acceleration level requirements. The water requirements are small and the film requirements are delineated in other sections of this report.

The final set of columns is a tabulation of total consumables for each 8-hour experiment period. These charts formed the basis for the analysis of power

Table 3-13. CONSUMABLES – EXPERIMENT CLASS 12

ITEM \ QUANTITY	DURATION/EVENT (HRS) MIN	DURATION/EVENT (HRS) NOM	DURATION/EVENT (HRS) MAX	FRACTIONAL TIME (HR/HR)* (NOMINAL) STDBY	FRACTIONAL TIME (HR/HR)* (NOMINAL) OP	QUANTITY UNIT STDBY	QUANTITY UNIT OPERATE MIN	QUANTITY UNIT OPERATE NOM	QUANTITY UNIT OPERATE MAX	QUANTITY UNIT UNITS	QUANTITY PER 8 HR WORK PERIOD STDBY	QUANTITY PER 8 HR WORK PERIOD NOM	QUANTITY PER 8 HR WORK PERIOD UNITS	COMMENTS *(FRACTION OF 8 HR WORK PERIOD)
1 UNASSIGNED		(0.2)												
2 PERSONAL HYGIENE		(0 3)			(0 11)									
3 FOOD		(0 5)			(0 19)									
4 MAINTENANCE		(0 8)			(0 10)									
5 R&R		(0 8)			(0 10)									
6 SLEEP		(8 0)			(1 0)									
7 MISSION BRIEFING		0 5			0 13									
8 SUBSYSTEM CHECKOUT		0 5			0 06									
9 PREPARATION														
10 • SET UP EXPERIMENT		0 7			0 180									
11 • CONTROL PROGRAM		0 3			0 080									
12 • CHECKOUT EXP EQUIP		0 3			0 080									
13 OPERATIONS														
14 • PURGE EXPANSION CHAMBER		0 1			0 100									
15 • CALIBRATIONS		0 1			0 100									
16 • OBSERVATIONS	0 25	0 75 0 67	1 20		0 520									
17 • PURGE COND CHAMBER		0 1			0 05									
18 ANALYSIS AND CLEAN UP														
19 • DATA EVALUATION		0 7			0 180									
20 • CLEAN UP AND SHUTDOWN		0 2 0 4			0 083									
21 S/C STABILIZ PERMITTED														
22														
23 600		0 2			0 175									
24 400		2 3			0 58									
25 POWER 200		4 1, 4 0			1 01									
26														
27 OPERATIONS BREAKDOWN														
28 NOMINAL CYCLES														
29														
30 OPERATIONS (TIME DETAIL)														
31 • AEROSOL GENERATION		0 17			0 043									
32 • THERMAL EQUILIBRIUM		0 17			0 130									
33 • AEROSOL INJECTION		0 083			0 062									
34 • EXPAN CONTR CYCLE		0 50			0 360									
35 • OBTAIN DATA														
36 • PHOTOS (0 1 fps)		0 50			0 360									
37 • AEROSOL MASS		0 017			0 013									
38 • AEROSOL SIZE DIST		0 067			0 067									
39														
40 OPERATIONS (POWER DETAIL)														
41 • TEMP CONTROLS		0 67			0 500			0 200		KWATTS		0 08	KWHRS	
42 • SUMP PUMP (PURGE)		0 17 0 1			0 120			0 150		KWATTS		0 15	KWHRS	
43 • AEROSOL MASS MEAS		0 017			0 012			0 030		KWATTS		0 003	KWHRS	
44 • AEROSOL SIZE MEAS		0 067			0 050	1		0 030		KWATTS		0 012	KWHRS	
45 • PHOTOS (0 1 fps)		0 50			0 380			0 005		KWATTS		0 015	KWHRS	
46 • AEROSOL SHEATH PUMP (SIZE)		0 083			0 062			0 150		KWATTS		0 075	KWHRS	
47														
48 OPERATIONS (GAS CONS)														
49 • PURGE (EXPAN CHAMBER)		0 083			0 083			636		LITERS		5 088	LITERS	636 LITERS
50 • POLLUTANT GAS		0 017			0 005		2×10^{-4}	2×10^{-2}	2×10^{-1}	LITERS		4×10^{-4}	LITERS	**
51 • AEROSOL GENERATION		0 034			0 009		1	10	230	LITERS		20		
52 • (AEROSOL CONDITION)		0 050			0 125									***
53 • PURGE (COND CHAMBER)		0 083			0 038			400		LITERS		1 600 0	LITERS	
54 • AEROSOL MASS		0 017			0 012			15		[illegible]		4 4	LITERS	
55 • AEROSOL SIZE		0 067			0 050			100		[illegible]		150	LITERS	
56														
57												? 100	?m^3	
58 MISC														THESE ARE A FUNCTION OF THE NATURE MAGNITUDE AND DURATION OF THE REQUIRED MOTION
59 • ACCELERATION		0 50			0 38			10^{-5}		g_o				
60 • S C STABILIZ PERMITTED								$< 10^{-2}$		g_o				

NOTE
** 1 100 1000 PPM OF COND CHAMBER RESPECTIVELY (USED IN EXPAN CHMBR ALSO) TWICE DAY IN COND CHMBR 6 TIMES DAY IF IN EXPAN CHMBR
*** USED FOR ULTRAVIOLET AEROSOL CONDITIONING 20 VOLUMES AT 8 2 LITERS CONTRACTED SIZE = 1 VOLUME AT FULL SIZE OF 230 LITERS

Table 3-14

MAJOR EQUIPMENT AND COMPONENT LIST – EXPERIMENT CLASS 12

Expansion Chamber (E)
Thermal Control
a. Humidity
b. Conditioning Chamber
c. E Chamber
R. H. Control
Sump Pump
Nuclei Size
Nuclei Mass
Sheath Flow Pump (Nuclei Size)
Nuclei Generator
Pollution Gas
Source Gas
Photos (Slow Speed, One per 10 Seconds)

and consumable volume requirements given in Section 4. Major equipment in Tables 3-10, 3-12, and 3-14 was also utilized in the determination of the overall facility weight, power, and volume.

3.5.3 Significant Timeline Features

Table 3-15 is a summary of some of the significant timeline features. The operation time includes chamber purge, calibration, and observation. Observation time is defined as the period of time the chamber is actually capable of providing experimental data. This time includes the periods between actual data collection which may involve inserting a new ice crystal, changing temperature etc., but does not include calibration or conditioning chamber purge times. The data collection time is that time which actual data are taken, e.g. the period a photograph is taken. Visual observations can also

Table 3-15

SIGNIFICANT TIMELINE FEATURES

Feature \ Class No. / Chamber	1 CFD	4 SDI	12 E	Comments
Effective Experiment Time	56	56	77	Percent of 8-hour experiment day
Effective Observation Time	43	43	52	
Data Collection Time	17	4	38	
Low-G Required	36 ($40^{-3}G_0$)	30 ($<10^{-5}G_0$)	38 ($<10^{-5}G_0$)	
S/C Stabilization	10 ($<10^{-2}G_0$)	5 ($<10^{-2}G_0$)	40 ($<10^{-2}G_0$)*	At minute intervals of

*One or two minutes can be taken at other selected times.

provide valuable information at other non-data times within the experiment observation period. The experiment efficiency can be raised by having longer work periods by possibly utilizing more than one astronaut and alternating to keep the experiment operating.

The experiments involving particles below a few micrometers in diameter require only a nominal low-g level of 10^{-3}, as in the case of Experiment Class 1, which can be broken at 10-minute intervals for spacecraft stabilization. For larger particles, such as ice crystals studied in Class 4, a g-level below 10^{-5} is desired. In the case of Class 4, this level can be broken at 5 minute intervals. Class 12 requires low-g levels due to the long event duration even though the particles will probably be only a few tens of micrometers in diameter. Depending on the actual experiment and timeline, the 40-minute interval can be broken for 1 or 2 minutes as specific prearranged times without invalidating the experiment. Acoustical positioning techniques could be periodically utilized for large particle positioning to allow f r spacecraft stabilization with minimal consequence to certain experiment objectives.

These timelines will be refined and other timelines will be generated as the Zero-g Cloud Physics Program develops.

Section 4
CLOUD PHYSICS LABORATORY

4.1 GUIDELINES

The Zero-Gravity Multi-Experiment Cloud Physics Laboratory has been defined based on the concept/philosophy that it serve as a general-purpose facility for the performance of basic research and beneficial applications experimentation. A laboratory of this nature is designed so that it will have the capability to efficiently accommodate a broad spectrum of atmospheric cloud microphysical experimentation, including those identified in the proposed experiment program and supplementary experiments to be defined as a result of increased knowledge or in response to specific application areas. This approach is particularly necessary in light of the dynamic nature of the research and applications activities related to the project objectives.

The general objective of the laboratory is to complement and supplement the cloud physics research performed in terrestrial laboratories. The major capability of the laboratory is the elimination of gravity-induced motion between particles/droplets and the cloud chambers, thus providing longer observation time to study important forces and processes that occur in nature without using artificial measures to prevent gravity effects (increase observation time). The specific scientific objectives relate to increasing the understanding of microphysical processes to enable man to improve weather prediction and to ultimately provide weather modification and control.

Knowledge accumulated during previous study phases has indicated that the requirements exerting greatest influence over the selection and definition of a cloud physics laboratory and its associated experiment program are the project value, cost, and flexibility.

The presently planned cloud physics laboratory project has an operating life in excess of a decade and therefore attention must be directed to both near- and long-term values to be demonstrated. The achievement of project scientific objectives (near-term value - understanding microphysical processes) will advance the scientific knowledge of microphysical processes and will advance man's understanding of his environment and his impact upon it. The achievement of project application objectives (long-term value - weather prediction, modification, and control) will enable man to constrain, contain, and prevent the uncounted losses of life and property presently attributed to weather phenomena.

The project cost, when compared to value, must be minimized. To this end, extensive definition of the experiment program and priority within the program was accomplished. Based on the experiment program definition, alternate terrestrial and space experiment techniques (laminar wind tunnels, KC-135 flights, rockets and satellites) were evaluated and assessed as either inadequate to achieve project objectives and/or as more costly. Effort was initiated and is continuing to further lower the project total cost (cost to initial capability plus experiment operations) by utilization of the capability inherent to the Shuttle/Sortie Laboratory module, design approaches compatible with multiple reuse and ground refurbishment, commonality of equipment and the interrelated aspects of flexibility.

Flexibility is interrelated to low cost and is presently incorporated into the laboratory concept by virtue of the laboratory capability to:

A. Accommodate all envisioned cloud chamber concepts.
B. Provide resources for nearly all experiment classes.
C. Provide resource reserves to accommodate technological advances and changing experiment requirements.

The value, cost, and flexibility requirements were utilized to establish the guidelines for the project and hence the laboratory features. Further considerations incorporated into the defined guidelines and design features resulted from consultation with NASA/MSFC, the scientific community, the Senior Scientific Board, and evaluation of the requirements/resources of the Space Shuttle/Sortie Laboratory module.

4.2 DESIGN FEATURES

The design features for the cloud physics laboratory were identified to provide the key requirements of value, cost, and flexibility and to satisfy the Level 1 guidelines and constraints. These features are as follows:

A. Includes subsystems required for all experiment classes
B. Common subsystems
C. Interchangeable cloud chambers
D. Automated control with manual override
E. Ground refurbishment
F. Capability to accommodate advanced subsystems
G. Capability to accommodate specialized equipment
H. Simplified laboratory to Sortie Laboratory Module interface
I. Maximum utilization of Sortie Laboratory module resources
J. Operation by one astronaut/experimenter with accommodation for two
K. Real-time data transmission (via Orbiter)
L. Sensitive equipment storage
M. Safety features to eliminate all credible hazards

4.3 LEVEL 1 GUIDELINES AND CONSTRAINTS

4.3.1 Programmatics

4.3.1.1 Definitions

Cloud Physics Laboratory Project

This project includes the definition, design, development, and operations of the atmospheric cloud physics payload and the interface equipment required to interconnect and maintain the payload and the Sortie Laboratory module The project also includes ground operations involving experiment mission preparation, astronaut training for experiment conduct, experiment mission data evaluation, and experiment refurbishment and checkout.

Cloud Physics Laboratory

A general-purpose facility for the performance of basic research and beneficial applications experimentation in atmospherics cloud physics. The cloud physics laboratory will be installed within a Sortie Laboratory module and be transported to and from orbit by the Shuttle. The cloud physics laboratory will provide the scientific community a flexible, low-cost facility capable of accommodating a broad spectrum of cloud physics experiments, with rapid user access and minimum interference with other payloads, the Sortie Laboratory module, and Shuttle orbiter activities.

Baseline

The baseline is defined as a fundamental point of reference with regard to project plan, configuration, operations, and experiment program and will serve as a basis for comparison of alternatives.

4.3.1.2 Project Planning

The baseline plan will include two flight units of the cloud physics laboratory, including the associated experiment mission preparation conduct, data evaluation and documentation in accordance for an assumed 1981 Shuttle flight opportunity in a Sortie Laboratory module.

The baseline plan will include provisions for payload ground support equipment and experiment mission support hardware and software to assure orderly and timely checkout, flight readiness verification, and installation into the Sortie Laboratory module.

4.3.1.3 Environment

The environments experienced by the cloud physics laboratory associated with ground operations and all mission phases of flight operations are contained in the following documents:

A. NASA/MSC - Space Shuttle Baseline Accommodation for Payloads MSC-67900, June 1972.

B. NASA/MSFC - Sortie Lab Users Guide (Interim Issue based on US Option)

C. NASA/MSFC - Sortie Laboratory Design Requirements, December 1972.

The descriptive data itemized in the above documents represent the current Sortie Laboratory module payload environment and are presented as reference data only as these requirements are subject to change as design requirements of the Shuttle Orbiter and Sortie Laboratory module evolve from trade studies and design definition maturity.

Natural environment data as specified in NASA TMX 64668* will be used for design and operational analyses.

4.3.2 Systems

4.3.2.1 Design Missions

The cloud physics laboratory will be designed to support the envisioned range of atmospheric cloud research experimentation. The baseline capability of the laboratory includes support of single and multiple experiment classes utilizing single or multiple cloud chambers. The baseline duration of Laboratory missions is 7 days. Extended duration of laboratory missions will be up to 30 days. The laboratory will be designed for operation as a portion of the total payload for the Sortie Laboratory module. Expanded operational capability is to be achieved by multiple laboratory (up to four) installation within a Sortie Laboratory module (dedicated atmospheric cloud physics payload).

4.3.2.2 Design Life

The cloud physics laboratory will be designed for an operational life of at least 20 missions of 7-day duration, with ground refurbishment.

4.3.2.3 Mission Success

The cloud physics laboratory will be designed for a high probability (TBD) of mission success. Mission success will be determined by proper functioning of the laboratory and its subsystems. This probability of mission success will be established based on a cost effectiveness tradeoff. This level of mission success will be assured by component and subsystem reliability, redundancy, etc.. Mission success does not require successful completion of each individual experiment of an experiment mission.

The cloud physics laboratory subsystem designs will be based on a safe life concept for all subsystems where failure could cause hazards to the personnel, other payloads, the Sortie Laboratory module, or Shuttle Orbiter. All other subsystems will be based on a fail-safe concept with redundancy used only to achieve mission success goals or to reduce cost.

*Applicability of this document to be verified.

4.3.2.4 Crew Size

The design of the cloud physics laboratory is predicated on Sortie Laboratory module personnel as defined in Table 4-1.

4.3.2.5 Weight

The total weight of the cloud physics laboratory and expendables, all with suitable weight margins, will be minimized consistent with good engineering design practice and achieving required safety at low cost. Where applicable, safety factors and design margins will be sufficiently large to minimize costly verification and qualification efforts.

4.3.2.6 Power

The total peak and average power of the cloud physics laboratory, with suitable power margins, will be minimized consistent with good engineering design practice. Where appropriate, equipments and subsystems directly compatible with the Sortie Laboratory module will be utilized. The laboratory power control subsystem will incorporate safety features to eliminate hazards to personnel and to prevent laboratory power control subsystem failure from disrupting operation of other payloads or the Sortie Laboratory module. Where applicable, safety devices and design margins will be provided to minimize costly verification and qualification efforts.

Table 4-1

CREW SIZE

	Total Personnel in Orbit	Sortie Laboratory Module Payload Dedicated Personnel*	Cloud Physics Laboratory Personnel
Baseline	**6**	**4**	**1**
Maximum	**8**	**6**	**2**
Minimum	**4**	**2**	**1 (partial)**

***Personnel who devote most of their work time to payload operation and to payload and Sortie Laboratory subsystems.**

4.3.2.7 Volume

The volume of cloud physics laboratory will be able to accommodate equipment and subsystems defined for the baseline, including expendables and to provide sufficient free volume to permit efficient and effective ground refurbishment. Sufficient volume, where appropriate, will be allocated for growth to the extended duration mission and incorporation of advanced equipment and subsystems (including provision for their storage and ground refurbishment).

4.3.2.8 Autonomy (Level of Sortie Laboratory Module Support)

The cloud physics laboratory will make efficient use of Sortie Laboratory Module provided support (i.e., power, communications, environmental control, etc.) consistent with simple laboratory to Sortie Laboratory module interface and with minimum interference during payload integration activities.

4.3.2.9 Subsystems

All elements of the cloud physics laboratory will be selected based on cost, effectiveness evaluation involving consideration of design, development, manufacture, qualification, operation, spares allocation, and replacement project factors. Where cost effective, available subsystems, assemblies, and components will be used. These items are to include standard commercial equipment and equipment developed for other programs/projects.

4.3.2.10 Growth

The baseline cloud physics laboratory will include design provisions, if cost effective, for accommodation of advanced equipments and subsystems and for growth in mission duration up to 30 days. This growth can be provided by addition of an equipment rack assembly and/or tankage.

4.3.3 Operations

4.3.3.1 Mission Operations

The baseline assumption for mission operations for the cloud physics laboratory is that communications and mission control will be through the Mission Control Center at Johnson Space Center (JSC).

4.3.3.2 Communications Network

The characteristics of the communications systems with the earth, as a function of operational date, are described in: "Characteristics of Future Ground Network and Synchronous Satellite Communications System for Support of NASA Orbital Missions (for Planning Purposes Only)," OTDA, September 1972 issue.

4.3.3.3 Data Management

The baseline assumption for the definition and management of data acquisition, processing and handling is that they will be the responsibility of cloud physics laboratory mission integrator.

4.3.3.4 Experiment Payload Integration

The baseline assumption for cloud physics laboratory integration is that it will be the responsibility of cloud physics laboratory mission integrator, but will be carried out in many cases at locations including KSC and various facilities (other NASA centers, other Government laboratories, universities, industrial concerns, foreign users, etc.). This integration will be at the complete laboratory level.

4.3.3.5 Mission Preparation

The baseline assumption for prelaunch mission preparation, including cloud physics laboratory refurbishment, final experiment mission definition, prelaunch crew training, hardware and software experiment mission compatibility, verification and checkout, is that it will be carried out at the location or facility that is most cost effective.

4.3.4 <u>Interface</u>

4.3.4.1 Sortie Laboratory Module Interface

The baseline Sortie Laboratory module to cloud physics laboratory will be defined by the following documents:

A. NASA/MSFC - Sortie Laboratory Users Guide (Interim Issue based on US Option)
B. NASA/MSFC - Sortie Laboratory Design Requirements, December 1972

The descriptive data in the above itemized documents represent the current Sortie Laboratory module interface and are presented as reference data only as requirements are subject to change as design requirements of the Shuttle Orbiter and Sortie Laboratory module evolve from trade studies and design definition maturity.

4.3.4.2 User Provisions

Laboratory utility to the users will be a major consideration in all design and operational features decisions.

The laboratory will provide capability to accommodate all experiment classes, all cloud chamber concepts, and the maximum possible individual experiments associated with the scientific and beneficial applications research areas of atmospheric cloud physics.

The laboratory will provide all support subsystems and defined cloud physics research subsystems and equipments consistent with capability defined above.

The laboratory will provide features to accommodate specialized user's research and applications experiment equipment.

Capability for voice communication will be available between the ground and the onboard experimenter. Capability for wideband data and spacecraft to ground TV will be provided.

4.3.5 <u>Experiment Missions</u>

4.3.5.1 Experiment Mission/Principal Investigator Selection

Criteria for experiment mission selection will be established during workshop activities involving the NASA, representatives of the atmospheric cloud physics community and the cloud physics laboratory mission integrator.

Criteria will include scientific priority, achievability, and zero-gravity applicability factors, in addition to factors associated with scheduling for payload selection (experiment mission planning and timeline, astronaut training, experiment mission support, etc.). The experiment mission selection will further depend on the proposed principal investigator or principal investigator team. Preeminence in the area of experimentation and availability for experiment mission support activities will be major considerations.

Selection Procedure (Tentative)

The experiment missions and the principal investigator or principal investigator team will be selected by NASA in accordance with procedures established for scientific participation in the Sortie Laboratory module project.

Though the process by which experiments are identified and selected for flight has not been firmly established at the present time, a typical flow is shown in Figure 4-1. The procedure will be initiated by preparation and submittal of an experiment proposal. At a minimum, the proposal would contain the following types of information in sufficient depth to permit a preliminary evaluation by an appropriate NASA experiment review board.

A. Experiment description, objective and rationale.
B. Desired flight date and duration.
C. Resource requirements for operational support (power, work space, crew skills, data transmission, etc.).
D. Potential hazards and contamination sources.
E. Special ground support equipment and facilities.
F. Status of experiment development.
G. Sortie Lab support equipment needed.

An expansion of the principal investigator/NASA interface and responsibilities (tentative) is included in NASA-Sortie Laboratory Users Guide, April 1973.

The cloud physics laboratory is to be available to the cloud physics scientific community. Its multi-experiment capability will provide potential principal investigators with almost all if not the total equipment required for their experiment. The laboratory, therefore, will permit principal investigator participation in an efficient and effective manner. Procedures for principal investigator participation, where existing experiment equipment exists will be developed.

4.3.6 Safety

A laboratory safety plan will be developed in accordance with NASA Safety Program Directive No. 1 (Revision A), dated December 12, 1969, and other

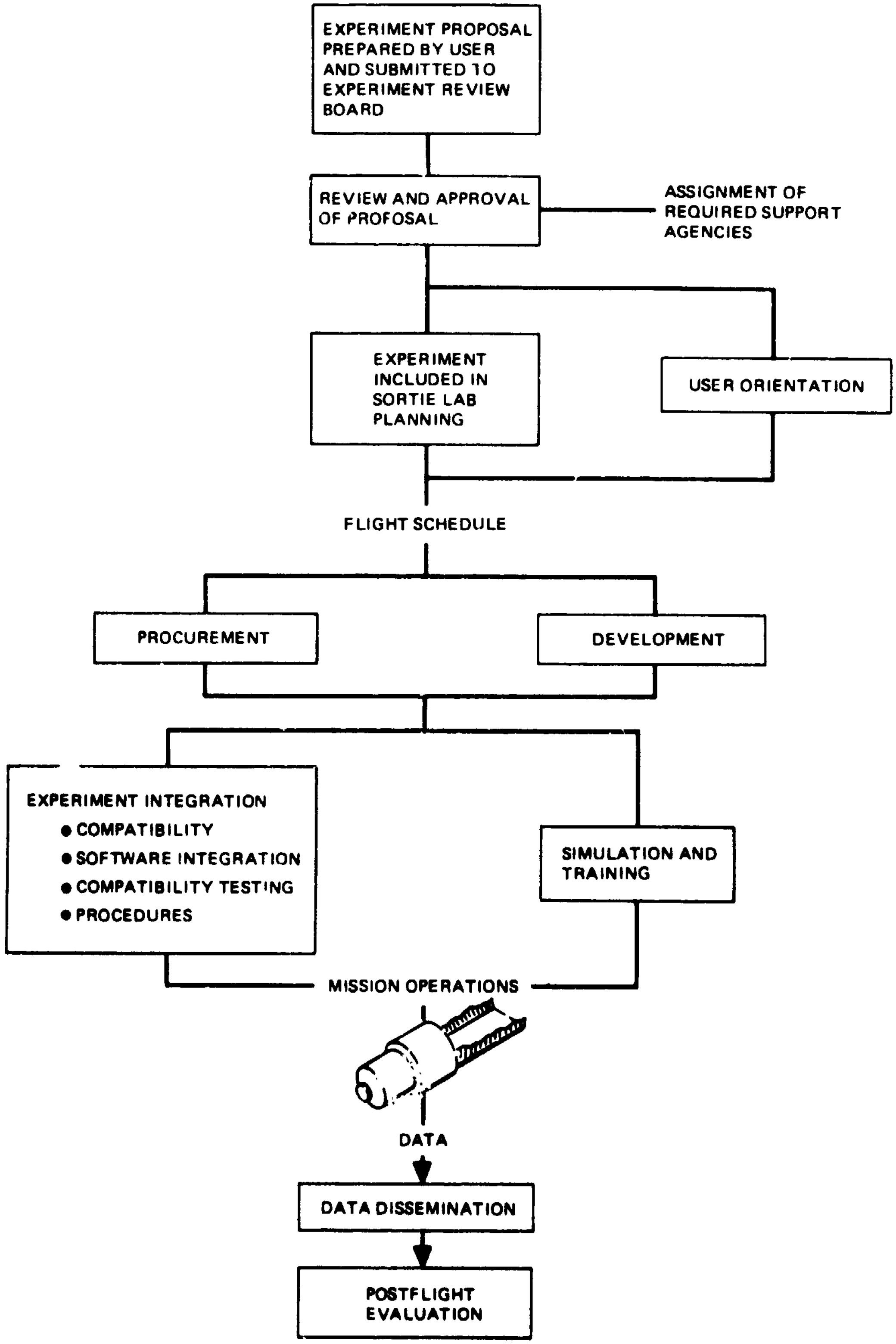


Figure 4-1. Typical Experiment Integration Process

applicable directives (TBD). Compatibility with applicable Shuttle and Sortie Laboratory Module directives is required.

No credible hazard associated with the cloud physics laboratory or its experiment activities will prevent safe termination of a mission.

The cloud physics laboratory will have self-contained protective devices or provisions against all credible hazards generated by its equipment and their operational functions.

The cloud physics laboratory will be designed in accordance with the requirements of the following document: NASA/MSFC, Guidelines for Developing Safety, Reliability and Quality Assurance Requirements for Sortie Lab, March 1973.

4.3.7 Resources

4.3.7.1 Cost

Low initial and total cost is a major objective of the cloud physics laboratory project.

Cost effectiveness will be a major consideration in all design and operational concept decisions.

4.4 LABORATORY MISSION AND DESCRIPTION

4.4.1 Mission Description

The cloud physics laboratory will be a partial payload of the Sortie Laboratory and is to be launched by the Space Shuttle from Kennedy Space Center. The cloud physics laboratory requires an environment of 10^{-2} to 10^{-5} g's (10^{-5} required for critical experiments) and hence, final orbit will be established by the other Sortie Laboratory payloads.* After final orbit has been

*The cloud physics laboratory research can be accomplished on varied Shuttle/Sortie Laboratory missions with many other payloads. The cloud physics laboratory requires only the near zero-gravity environment (>100-nmi near-circular orbits), and limited resources (weight, power, volume, thermal control, and data management). Furthermore, an experiment mi sion can be conducted in any of the various Shuttle/Sortie Laboratory operating modes (bay doors closed or open, Sortie Lab deployed or not deployed.)

achieved and verified, the Sortie Laboratory systems checkout will be accomplished. The scientific crew members, upon occupying the Sortie Laboratory Module will conduct checkout operations of the cloud physics laboratory and the other payloads. The envisioned first experiment mission will encompass experimental operation of the cloud physics laboratory for periods of 2 hours to TBD hours (maximum shift duration) on a daily basis. The predetermined experiment sequences will be performed and periodic real-time contact with the principal investigator will be required. Upon conclusion of the experiment mission, the cloud physics laboratory will be secured for reentry and be returned to earth.

The astronaut-experimenter will observe laboratory operation throughout the experiment mission. His observations and the data from the experiments will be furnished to both the principal investigator team (for the specific experiment mission) and to the experiment program integration contractor. The principal investigator team will review, evaluate, and document the experiment mission data and scientific results. The program integration contractor will disseminate the experiment mission report and will perform the necessary laboratory servicing and refurbishment for the next experiment mission.

In addition to the above-defined mission operations from lift-off through data evaluation and laboratory refurbishment, each experiment mission will involve the selection of the mission experiment objectives and principal investigator team, the formualtion of experiment sequences and operational timeline, the requisite astronaut training, support for installation in the Sortie Laboratory, and other payload coordination. Capability to conduct up to four experiment missions per year, utilizing two cloud physics laboratory flight articles is envisioned.

4.4.2 Laboratory Description

The cloud physics laboratory is intended as a general-purpose facitlity, available to the entire scientific community, and capable of performing complementary and supplementary research in atmospheric microphysics. As shown in Figures 4-2 and 4-3, the laboratory is a self-contained unit approximately 2.44 m (8 ft) long, 3.05 m (10 ft) high, and 1.22 m (4 ft) maximum depth occupying a volume of $\approx 8.8\ m^3$ ($\approx 310\ ft^3$). The laboratory will

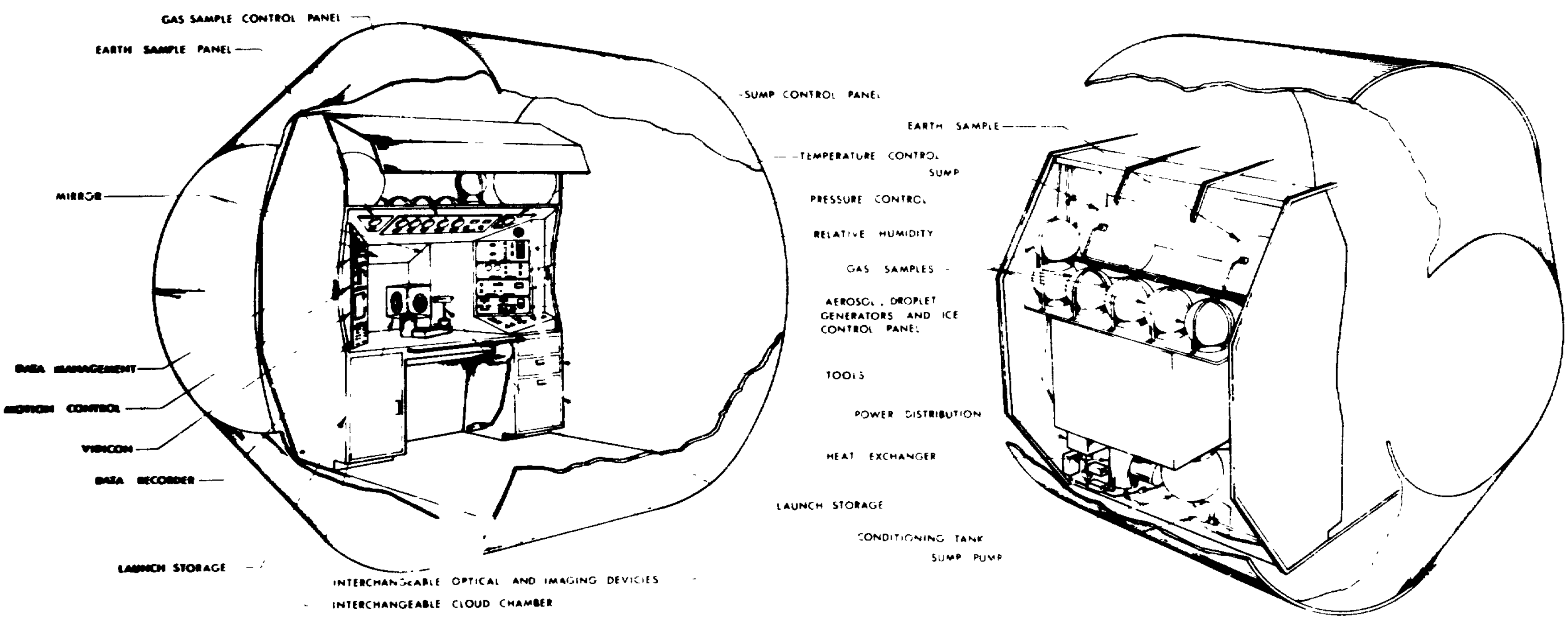


Figure 4-2. Multiple-Experiment Cloud Physics Laboratory (Sheet 1 of 2)

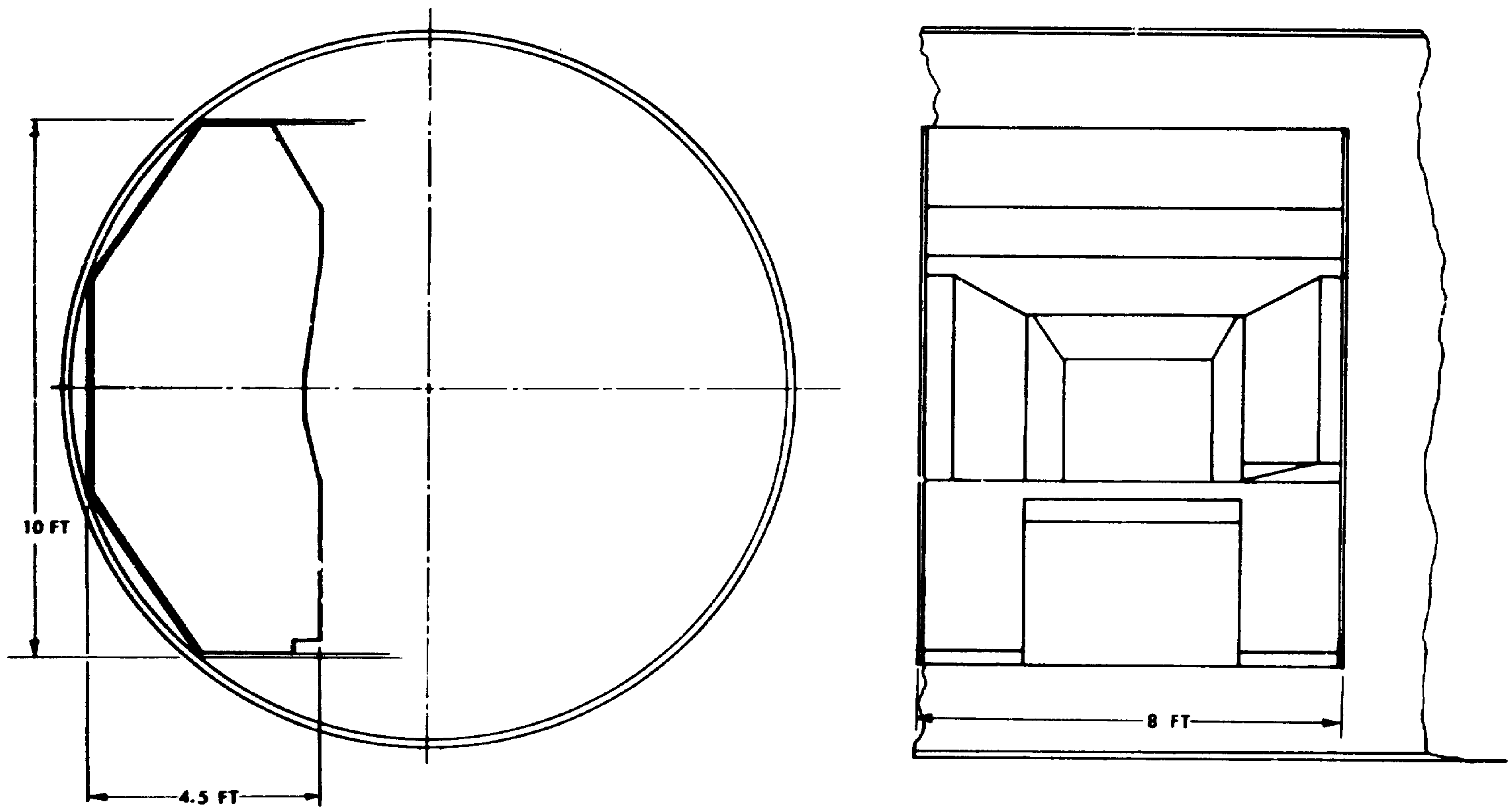
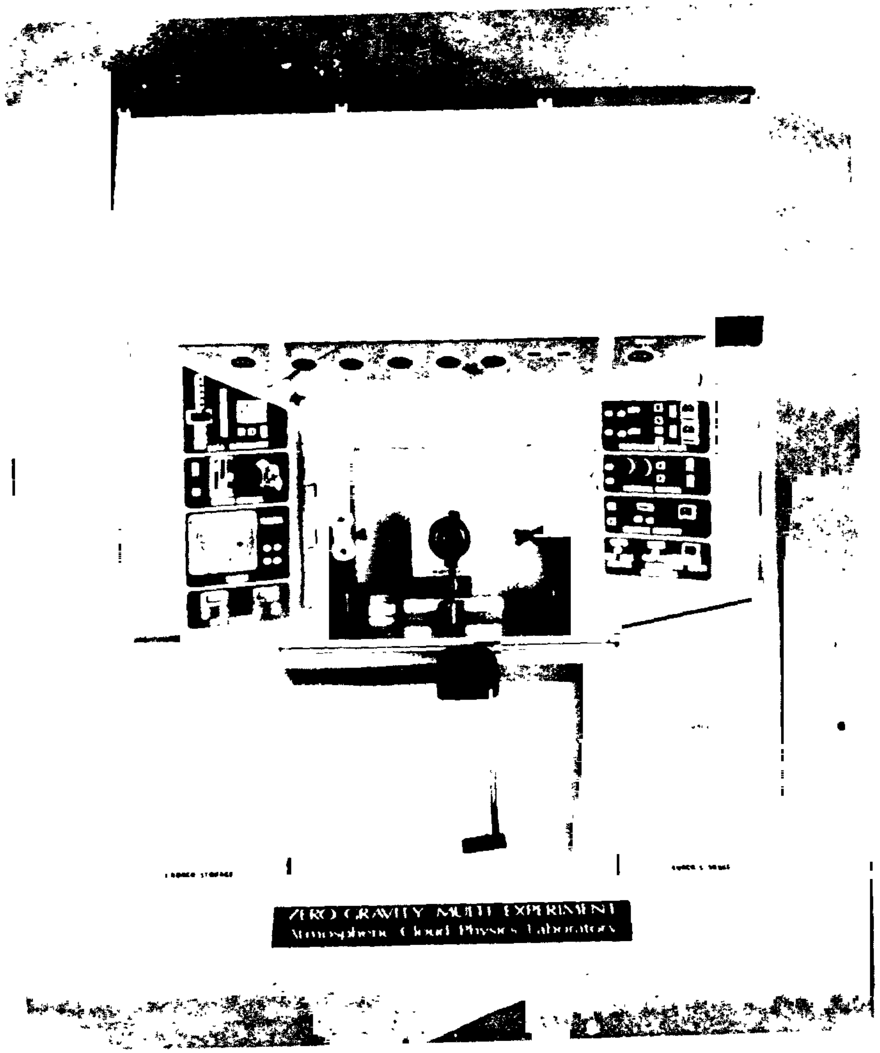
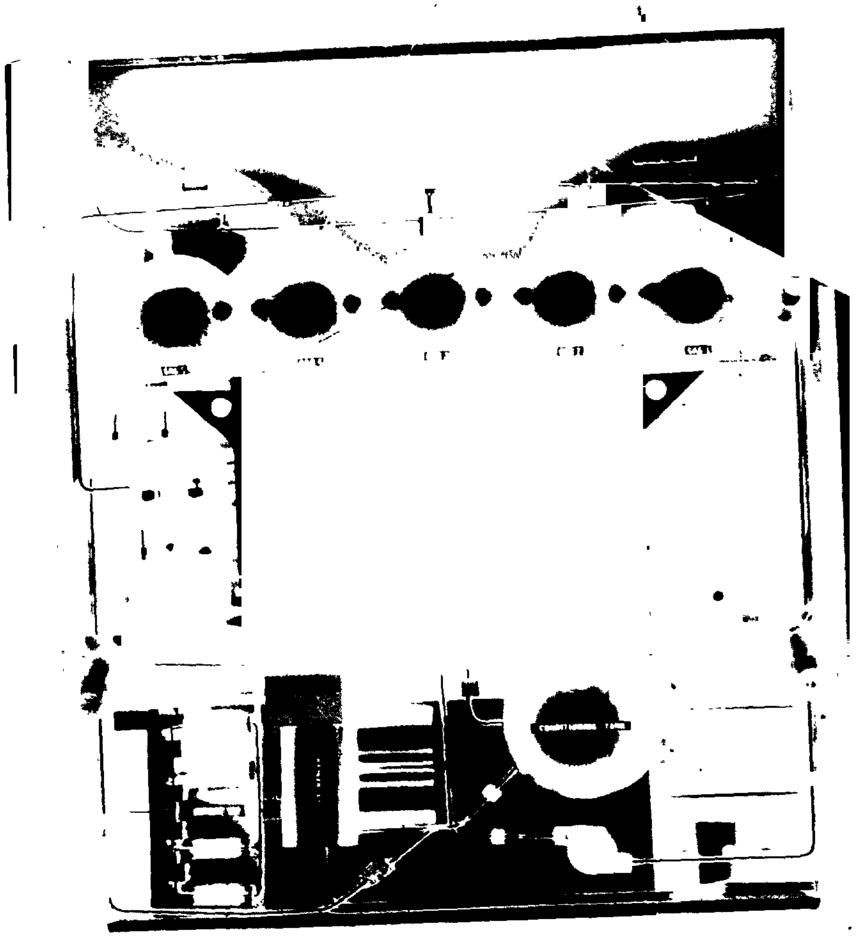


Figure 4-2. Multiple-Experiment Cloud Physics Laboratory (Sheet 2 of 2)



FRONT VIEW



REAR VIEW

Figure 4-3. Conceptual Design of Cloud Physics Laboratory weigh between 625 kg (1,382 lb) and 728 kg (1,607 lb) and will use an average power of 156 to 268 watts. As a partial payload of a Shuttle/Sortie Lab mission the cloud physics laboratory will be dependent on usage of Sortie Laboratory resources for

A. Power
B. Heat rejection
C. Scientific crew member operation (astronaut-experimenter)
D. Limited data management and communications.

The laboratory (Figure 4-2) contains all subsystems required for the conduct of the defined experiment program. Ancillary subsystems (categorized to denote general support requirement for total experiment program) include:

A. Gas Storage and Flow Control
B. Power Control
C. Data Management
D. Displays and Controls
E. Integrated Environmental Control

This equipment is installed within the laboratory console shown in Figure 4-3.

Cloud chamber subsystems (categorized to denote specialized scientific equipment for specific research areas) include:

A. Cloud Chambers
B. Droplet generators
C. Environment controllers
D. Imaging systems

This equipment is installed in the working volume in the center of the laboratory console.

The laboratory flown will be modified for each individual experiment mission. The ancillary subsystems (the major portion of the laboratory equipment) will be used for all missions with specific cloud chamber subsystems. The laboratory, within given limits, can be configured and operated to use available Sortie Laboratory resources for a specific mission (volume is fixed - astronaut time, power, heat rejection and data management support are flexible).

The laboratory subsystems were defined with consideration of ground refurbishment/replacement without major rework. Capability for growth and/or advanced subsystem installation was provided. Sensitive cloud chamber subsystems storage is provided in the laboratory as is space for specialized tools required for experiment conduct.

4.5 CLOUD PHYSICS LABORATORY SUBSYSTEMS

The cloud physics laboratory (CPL) consists of the following subsystems, each of which will be specified in some detail in a section of the following discussion.

A. Thermal control and measurement
B. Pressure control and measurement
C. Dew point and liquid water content control and measurement
D. Gas storage and flow control
E. Electric field environment
F. Acoustical environment
G. Optical environment
H. Liquid drop generator
I. Ice particle generator
J. Aerosol generators
K. Data management and interface electronics
L. Particle counters
M. Experiment chambers
N. Miscellaneous support
O. Power control and distribution
P. Console
Q. Optical and imaging devices

The SRT (supporting research and technology) items are called out in the discussion and are further described in Section 4.9.

4.5.1 Thermal Control and Measurement

The CPL thermal control system will use Sortie Laboratory resources to provide coolant at +7°C and a hot fluid at +38°C. Additionally there will be heat input from the CPL into the Sortie Laboratory cabin atmosphere from electrical/electronic systems and a cryogenic cooler. A cryogenic cooler is required to provide the low temperatures necessary for operation of the general and static diffusion ice chambers. The maximum CPL chamber heat load of 54 thermal watts occurs for the expansion chamber.

The requirements for temperature measurement vary depending on the function and type of experiment. The most stringent specification is ±0.01°C. This accuracy can be obtained using thermistors that have been individually calibrated.

4.5.2 Pressure Control and Measurement

Chamber internal pressures vary between 140 and 760 torr with a maximum measurement accuracy requirement of ±0.05 torr. Pressure control will be by means of pressure regulators using high-pressure storage tanks as the main pressure source. Gas flow pumps will be used for recirculation systems in order to minimize the gas volume requirements. It may also be desirable at certain times to use partial vacuum as a low pressure gas discharge sink.

4.5.3 Dew Point and Liquid Water Content Control and Measurement

The dew point control system will be capable of treating up to 5 ℓ/min of dry air up to a humidity of 100 percent at a maximum temperature of 25°C. The humidity must be measured over a range of 10 to 98 percent with a maximum accuracy of ±1%. For experiment class 15 the humidity measurement accuracy requirement is ±0.05 percent which will necessitate special equipment and procedures. A liquid water content (LWC) meter is required to monitor the LWC within the expansion chamber for the purpose of accurate water budget accounts.

4.5.4 Gas Storage and Flow Control

The CPL contains provisions for an earth gas sample and five sample gases (air or mixtures of air with contaminants or pollutants). The sample gases can be mixed or used separately as required by the individual experiment. Provisions have been made to reduce the number of sample gases and/or increase the quantity of a particular sample gas by installation of additional tankage. The gas storage and flow control subsystem is a closed-loop subsystem in which expended gases are stored in a sump tank and in the earth sample tank (after usage of earth sample).

4.5.5 Electric Field Environment

Three of the CPL cloud chambers require electric fields: static diffusion ice chamber, expansion chamber, and the general chamber. In each case the field will be that of a plane, parallel-plate capacitor (neglecting edge effects). The conductive surfaces across which the potential is applied will be supplied with each chamber. Characteristics of the electric field are as follows.

Frequency: 0 to 100 Hz
Wave Shape: Square
Amplitude: 0 to 3,000 V/m

The voltage and frequency supply will operate from the Shuttle 28-vdc bus. The frequency and amplitude of the field will be controlled and indicated on the display console.

4.5.6 Acoustical Environment

The general chamber and the static diffusion ice chamber will be equipped with audio drivers of variable frequency for the positioning and control of droplets or ice particles in each of three mutually perpendicular axes. Each driver can be controlled independently in frequency and amplitude. The frequency range is from 0 to 10 kHz and the sound amplitude is from 0 to (TBD) db. The frequency of each driver will be indicated on the console and the intensity control on the console control panel will be calibrated in sound intensity level (db). The power supply for each driver will operate from the 28-vdc Shuttle bus.

4.5.7 Optical Environment

This system has been described in an SRT requiring advanced development. The optical devices are used for three purposes:

A. Remote heating of individual particles or groups of particles.
B. Motion control of small particles.
C. Visual and/or photographic observations.

Details of this system will be resolved at a later time.

4.5.8 Liquid Drop Generator

The generator will be required to provide single droplets by manual or system control up to a frequency of 10/sec. The size uniformity of the drops must be sufficient to ensure less than 5 percent variation in droplet diameter.

Droplet diameters vary from 10 to 100 μm, with other techniques giving droplets up to 1-cm diameter. The droplet must be dispensed within the chamber although the driving mechanism is located outside. It must also be possible to generate the droplet at some predetermined initial velocity away from the generator location so that the droplet comes to rest at the required location in the chamber.

4.5.9 Ice Particle Generator

A technique for growing ice particles utilizing terrestial laboratory techniques or a modification of the liquid drop generator will be used for this subsystem. Ice crystals from the micrometer to centimeter size range are required.

4.5.10 Aerosol Generators

These items have been designated as requiring SRT in the advanced development area. Aerosol generators are required to produce the condensation nuclei or droplets which are to be studied in the chambers. Table 4-2 describes the characteristics of each type of generator.

4.5.11 Data Management and Interface Electronics

Figure 4-4 shows the basic operation of the data management and control system. The central digital computer provides the data processing and control functions of the CPL. The particular functions within the dotted boxes are exemplary only and not exclusive. Specific data sources are analog to digital converted in the data interface unit and processed onto data recording devices by the data processing section of the computer. A data

Table 4-2
AEROSOL GENERATOR CHARACTERISTICS

Aerosols	Size Range (cm)	Density (lb/cc)	Production Rate (Hz)	Composition
Cloud Droplet	10^{-4}-10^{-1}	10-10^4	10^4-10^5	H_2O
Large and Giant Nuclei	10^{-5}-10^{-3}	10^{-2}-10^2	10-10^5	NaCl, Dioctylpthalate
Aitken	5 x 10^{-7}-10^{-5}	10-10^5	10^5	Silicone, Sulfates, etc.

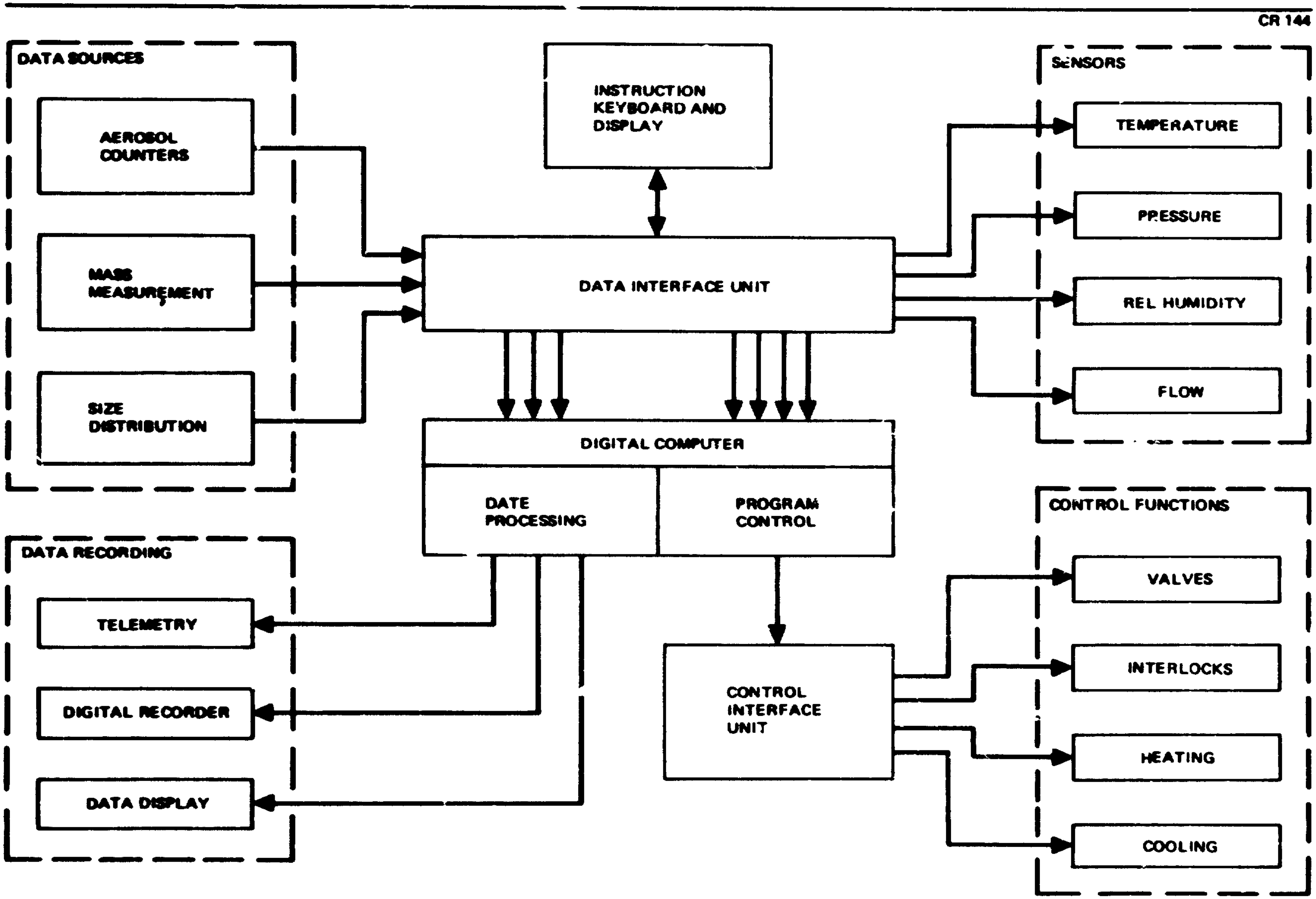


Figure 4-4. Data Management System Selection

display system will be used to provide desired information visually to the operator. Sensor data are tape recorded and are also used for controlling the operation of the chamber within established environmental tolerances. A keyboard and register display unit permit examination of the contents of computer internal registers and also manual inputs to modify computer constants or change program operation at predetermined branch point.

4.5.12 Particle Counters

The CPL will use three types of particle counters:

A. Particle size analyzer

B. Nuclei mass monitor system

C. Nuclei size analyzer

Nuclei are either condensation centers for droplet formation or solidification centers for ice crystal formation. Particles are either water droplets or ice crystals which have grown from nuclei to larger sizes. In order to understand the effects of nuclei in causing condensation, one must know both the characteristics of the nuclei and the resulting particles under known environmental conditions. Thus the nuclei measurement devices will provide information about the initial aerosol distribution while the optical particle counter and cameras will provide information during and after an experiment.

A. Particle Size Analyzer

This optical device will be a size analyzer for particles >0.3 μm diameter. As the air containing the particles flows through an illuminated volume, the intensity of light scattered from individual particles is measured by a photomultiplier. This intensity is proportional to the particle size. The distribution of sizes will be obtained by the measurement of random pulse amplitudes from the photomultiplier amplifier system. This analyzer consists of a sensor head and an electronics unit.

B. Nuclei Mass Monitor System

The mass monitor is a device which measures the total particulate mass per unit volume by electrostatic precipitation of particles in the size range 0.01 to 20 μm diameter onto a crystal oscillator, where the total mass changes the crystal resonant frequency. The rate of change of frequency is thus proportional to the mass per unit volume of sample air. The system consists of a sensor unit and an electronics package.

C. Nuclei Size Analyzer

This analyzer measures the size distribution of particles in the range 0.01 to 1.0 μm. The particles are ionized and their mobility as a function of electric field is measured to give an integral size distribution. The device requires a flow of 50 ℓ/min, most of which is a recirculated sheath flow. Ten voltages are used in sequence giving a ten point integral distribution in 2.5 minutes.

4.5.13 <u>Experiment Chambers</u>

The CPL will be capable of using five different interchangeable cloud chambers. The overall CPL systems required for each chamber will be sized to support the maximum chamber requirement. The system interfaces with the chambers will utilize designs that permit a rapid changeover. The five chambers are as follows:

A. Expansion Chamber (E)

The interior of the expansion chamber will be cylindrical, 15 cm in radius and 45 cm long, giving a volume of 31.8 ℓ. The chamber will be thermally isolated and equipped with cooling systems to enable operation from -60 to +40°C. The upper and lower ends of the chamber may be maintained over a differential temperature of 0 to 10°C which can be controlled to ±0.05°C. The internal pressure will be controlled between 140 and 760 torr and the chamber expansion system will be capable of a pressure rate of change up to 10^3 torr/sec with a tolerance of ±1 percent, and a maximum volume expansion, $\Delta V/V$, of 0.5 ±0.1 percent. The circular ends of the chamber will be equipped with electrically conductive plates which serve as equipotential surfaces for the electric field motion control system.

B. Continuous Flow Diffusion Chamber (CDF)

The interior of this chamber has a square base 30 cm on each side with a 5 cm height. The internal volume is 4.5 ℓ. Inside the chamber are two plates, 30 by 25 cm, spaced 1.3 cm apart and each maintained isothermal to ±0.05°C. The inner surface of each plate is covered with a fine mesh screen which can be saturated with water. The structure of the chamber provides a water feed system which keeps these surfaces wet. Air flow through the chamber provides thermal contact with the two plates so that the air is preconditioned to the temperature of each plate before it enters the region between them. As the air enters this region, the sample gas is introduced into the conditioned flow and enters the region of vapor supersaturation. The air and sample flow leave the chamber and enter the particle size distribution analyzer. The temperature difference between the upper and lower plate is 0 to 10°C and is controlled and measured to ±0.05°C. The chamber operates at a slightly negative pressure of 740 to 760 torr. This pressure will be measured to ±0.2 percent and will not vary in time any faster than 0.4 torr/sec.

C. Static Diffusion Ice Chamber (SDI)

The SDI chamber is cylindrical with a 20-cm radius and a length of 10 cm giving a volume of 12.5 ℓ. The chamber will be thermally controlled from -40 to +25°C with a temperature measurement accuracy of ±1°C. The upper and lower circular ends of the chamber will be separately controlled to provide temperature differences up to 20°C controlled and measured to ±0.05°C. The internal chamber pressure will be controlled between 100 and 760 torr and measured to ±10 torr. The circular ends will be conductive and serve as equipotential surfaces for the electric field polarizing and charge measurement systems.

D. Static Diffusion Liquid Chamber (SDL)

This chamber is cylindrical, having a radius of 7.5 cm and a length of 1.5 cm giving a volume of 0.27 ℓ. The chamber will be operated between 0 and 30°C. The maximum temperature difference between the two circular ends will be 10°C controlled and measured to ±0.05°C. The internal pressure will vary from 140 to 760 torr, ±5 torr. Flat windows, 90 degrees apart, at two places in the cylindrical walls provide optical viewing ports. The upper and lower ends are maintained moist by means of a capillary or fine screen surface.

E. General Chamber (G)

The interior of this chamber is a cube in shape, 30 cm on each side giving a volume of 27 ℓ. The thermal control system will permit operation in the temperature range of 10 to 30°C. The internal pressure will vary between 140 and 760 torr. Two opposite sides of the cube will serve as electrical field plates for polarizing droplets. Acoustical drivers will be built into three of the mutally perpendicular surfaces to provide sound waves for the positioning drops.

4.5.14 Miscellaneous Support

The CPL will provide locations for storage of equipment which is not mounted during launch of the CPL. Suitable tie-downs will ensure launch compatibility. Expendable CPL items such as film, magentic tape, and special liquids will be stored in the CPL during launch. Special or general tools required for CPL operation, modification, or repair will be provided and stored in appropriate locations.

4.5.15 Power Control and Distribution System

Electrical power for the CPL will be obtained from the Sortie Laboratory via a 28 vdc and a 110 vac (400 Hz) power bus. Each source will be treated separately within the CPL. Each source will have its own circuit breaker/master on-off control on the console. All ac and dc grounds will be kept separate and each separate from chassis ground. A console switch panel with indicating lights will separately control the power to the major electrical systems. Those system which use excessive power but are not used continuously will be designed with standby modes at reduced power levels such that the operator can optimize the level to meet the experiment requirement.

The CPL electronic equipment will be designed to eliminate the duplicity of low-voltabe dc power converters which would occur if one used off-the-shelf laboratory equipment. A standard integrated circuit logic line will be used wherever possible to also reduce the number of bias supply voltages needed. High-frequency switching regulators will be used to maximize power conversion efficiency.

4.5.16 Console

The console of the CPL will be the major work area for the astronaut/scientist to perform the CPL experiment program planned for a particular mission. The console will provide a centralized location to accomplish the following operations:

A. Data Monitoring

This will be accomplished through visual digital displays for temperature, pressure (relative humidity), gas flow, elapsed time, and other pertinent experiment parameters which require observation during the course of the experiment. The proper operation of other subsystems of the CPL will be displayed on the console via indicating lights. These displays and lights will be mounted on the panels of the console and arranged in logical and orderly arrays to indicate visually the actual location and function of the control within the system.

B. Control Device Manipulation

During the operation of a cloud chamber experiment, it may be required of the operator to change the value of one or more of the chamber environmental parameters (e.g. temperature or pressure). Controls will be mounted on the console for these modifications with digital readouts of the parameter values affected. The controls will be mounted in locations such that any effect of the control may be visually observed within the chamber while the change is being made.

C. Visual-Photographic Observation

The console will provide access for the observer to visually or photographically record the progress and/or results of a chamber operation. Suitable hand-holds and camera mounts will allow positioning of the observer or camera so that the chamber and the display area can be viewed conveniently. It will be required that the observer be able to move and observe on all sides of the chamber mounting area since the various chambers require access from different directions depending on the operation underway. The console will also provide the necessary illumination for visual or photographic observation of the chamber interior and the control console itself.

4.5.17 Optical and Imaging Devices

The CPL will include several types of imaging devices to record data, chamber operation, and subsystem operation. These devices include the following:

A. Still Cameras

Certain CPL experiments require the use of a still camera (frame rates up to 2/sec, shutter speeds 1 sec to 1/500 sec, capacity 500 frames) with a variety of lenses of various f-numbers and focal lengths. Both lenses and film packs must be easily interchangeable. For some applications, high resolution (2 μm) and large depth-of-field (1 mm) are required necessitating highspeed film. Both 35-mm and 70-mm film may be utilized for certain operations.

B. Fast Frame Rate Cameras

For CPL experiments on droplet collisions, frame rates of 100/sec are required. Total duration of this rate per collision will be less than 20 sec, requiring at most 2,000 frames per collision. The resolution requirement is not high since the droplets are quite large (> 50 μm). Lens systems must permit large depth-of-field (~1 cm) and wide angle pictures.

C. Microscopes

Some experiments will require a low magnification optical system (10 to 100X) for either visual or photographic observation. A stereo microscope with camera attachment and long working distance (~10 cm) will be necessary. A higher magnification (100 to 1,000X) trinocular (camera attachment) microscope will be required to observe some of the aerosol characteristics as well as characteristics of ice crystal replicas.

D. Oscilloscope and Camera

This device will be limited to recording waveforms from CPL electronic systems on an as-required basis for diagnostic or troubleshooting efforts. The oscilloscope will be used to support the diagnostic efforts required in assessment of subsystem operation and experiment conduct behavior. The scope and camera will also be available for special data aquisition requirements.

E. Video Camera

A video system will be useful in problem situations where interaction between the operator and ground personnel is necessary. The normal Shuttle video downlink will be utilized with the camera being shared with other Sortie Laboratory users.

A dedicated high-resolution low-light-level vidicon may also be utilized to minimize operator fatigue. A video camera would be focused on the chamber event under observation while the operator would observe the TV monitor as the experiment progressed. This approach provides both image magnification and intensification, thus facilitating the performance of an experiment and the collection of experimental data.

F. Image Device Lighting

The various visual and optical recording devices will require suitable lighting for their optimum preformance. Continuous lighting will be used for visual or vidicon observations while higher intensity lights for short periods of time (<1 sec) or laser lighting may be required for some of the high-resolution film recorded data. Stroboscope illumination will provide the high intensity and stop-motion necessary for the fast frame rate camera events.

G. Optical Detector

This solid-state detector will be used to obtain data concerning the scattering properties of ice crystals and possibly extreme droplet size change data. These detectors will be similar to those used to determine the liquid water content within the expansion chamber.

H. Droplet Size Distribution Meter

This unit which has been identified as requiring SRT will be used to determine droplet size distributions within a chamber utilizing optical techniques. Real-time measurement at a distance is vital for several CPL experiments.

I. IR Microscope

The surface temperature of ice crystals and droplets must be known before certain important experiment objectives can be satisfied. The item specified here is an IR imaging device capable of ±0.3°C at -15°C mean temperature.

4.6 CLOUD PHYSICS LABORATORY CHARACTERISTICS

The cloud physics laboratory weight, power, and volume characteristics were calculated for each cloud chamber and are listed in Table 4-3.

The values presented show increases in weight and power from previous contract phase results. These increases are due to the following laboratory design differences.

a. Expanded capability for electric field environment subsystem over previously defined electric field motion control subsystem.
b. Expanded capability for acoustical environment subsystem over previously defined ultrasonic motion control subsystem.
c. Expanded capability for optical environment subsystem over previously defined optical motion control subsystem.

Table 4-3

CPL CHARACTERISTICS

Experiment Class	Chamber	Weight (max) (kg)	Weight (max) (lb)	Weight (avg) (kg)	Weight (avg) (lb)	Volume (m^3)	Volume (ft^3)	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
1	CDF	626	1,382	626	1,382	8.75	310	1,093	465.9	155.6
2 through 11	SDI	728	1,607	682.9	1,507.5	8.75	310	1,404	679.9	225.4
12 through 15	E	766.5	1,692	728.2	1,607.5	8.75	310	1,301	805.7	268.3
16 through 18	G	827.6	1,827	725.9	1,602.5	8.75	310	1,340	647.6	215.8
19 and 20	SDL	[illegible]85.8	1,5[illegible]4	660.2	1,457.5	8.75	310	986	535.1	174.3

d. Improved assessment of sample gas and film expendables.
e. Addition of liquid water content meter.
f. Detailed thermal analysis of cloud chamber.
g. Addition of optical detection and imaging devices.
h. Improved assessment of equipment usage.

The characteristics presented represent conservative values for the experiment classes defined. The laboratory characteristics, as tabulated, are compatible with Sortie Laboratory resources and consistent with laboratory operation as a partial payload.

4.6.1 Laboratory Weight, Volume, and Power

In the establishment of laboratory weight, volume, and power, consideration was given to the various equipment and experiments to be performed. It was determined that laboratory volume, as established by the console, would be fixed at 8.75 m^3 (310 ft^3). The total laboratory equipment provides a volumetric density of 25 percent with ample room for maintenance and refurbishment. The variation in cloud chambers, gas samples, experiments, and optical and imaging systems will provide variations in weight and power (both peak and average) with experiment mission. The following sections describe the technique/rationale used to establish the ranges of these parameters.

4.6.2 Thermal Control and Measurement Subsystem

Subsystem Features (max)
Weight = 61.6 kg (136 lb)
Power = 559 watts
Volume = 0.086 m^3 (3.05 ft^3)

This subsystem will be flown on each experiment mission. Power will vary dependent on cloud chamber, gas sample volume, and experiment temperature range. The values in Table 4-4 were established for a typical experiment mission.

Table 4-4

THERMAL CONTROL AND MEASUREMENT SUBSYSTEM FEATURES

Experiment Class	Cloud Chamber	Weight		P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
		kg	lb			
1	CDF	61.6	136	40	20	6.7
2 through 11	SDI	61.6	136	350	200	67.0
12 through 15	E	61.6	136	550	325	108.0
16 through 18	G	61.6	136	300	175	58.3
19 and 20	SDL	61.6	136	150	80	26.7

4.6.3 Pressure Control and Measurement Subsystem

Subsystem Features (max)

Weight = 31.5 kg (69.5 lb)

Power = 35 watts

Volume = 0.29 m^3 (10.5 ft^3)

This subsystem will be flown on each experiment mission. Power demand is established by the UV aerosol conditioner which will be operated 20 percent of experiment time with minimal difference by experiment class (see Table 4-5).

Table 4-5

PRESSURE CONTROL AND MEASUREMENT SUBSYSTEM FEATURES

Experiment Class	Cloud Chamber	Weight		P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
		kg	lb			
1 through 20	All	31.5	69.5	35	7	2.3

4.6.4 Dew Point and Liquid Water Content Control and Measurement Subsystem

Subsystem Features (max) Weight = 52.2 kg (115 lb)

Power = 125 watts

Volume = 0.079 m^3 (2.8 ft^3)

This subsystem will be flown on each experiment mission. Power will vary with humidity level and sample gas volume (see Table 4-6). Subsystem will be operated up to 15 percent of experiment time.

Table 4-6

DEW POINT AND LIQUID WATER CONTENT CONTROL AND MEASUREMENT SUBSYSTEM FEATURES

Experiment Class	Cloud Chamber	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
1	CDF	52.2	115	125	3	1
2 through 11	SDI	↓	↓	↓	4	1.3
12 through 15	E	↓	↓	↓	14	4.7
16 through 18	G	↓	↓	↓	18	6
19 and 20	SDL	↓	↓	↓	3	1

4.6.5 Gas Storage Supply and Flow Control Subsystem

Subsystem Features (max) Weight = 144 kg (316 lb)

Power = 257 watts

Volume = 0.66 m^3 (23.4 ft^3)

This subsystem will be flown on every experiment mission with varying sample tankage weight based on gas sample requirements (see Table 4-7). Power will vary depending on gas sample volume.

Table 4-7

GAS STORAGE AND FLOW CONTROL
SUBSYSTEM FEATURES

Experiment Class	Weight (max) kg	Weight (max) lb	Weight (avg) kg	Weight (avg) lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
1	91.2	201	91.2	201	257	164	55
2 through 11	100	221	91.2	201		164	55
12 through 15	125	276	100	221		180	60
16 through 18	144	316	82.1	181		147	49
19 and 20	91.2	201	82.1	181		147	49

4.6.6 <u>Electric Field Environment Subsystem</u>

Subsystem Features (max)

Weight = 12.2 kg (27 lb)

Power = 45 watts

Volume = 0.031 m^3 (1.1 ft^3)

This subsystem may be used in conjunction with either the acoustical or optical environment subsystems are used on an experiment mission (see Table 4-8). Power demand is based on approximately 60 percent experiment time usage.

Table 4-8

ELECTRIC FIELD ENVIRONMENT
SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
2 through 12, 14; 16 through 18 and 20	12.2	27	45	27	9

4.6.7 Acoustical Environment Subsystem

Subsystem Features (max) Weight = 32.6 kg (72 lb)

Power = 183 watts

Volume = 0.056 m^3 (2 ft^3)

This subsystem may be used in conjunction with either the electric field or optical environment subsystems are used on an experiment mission (see Table 4-9). Power demand is based on approximately 60 percent experiment time usage.

Table 4-9

ACOUSTICAL ENVIRONMENT SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
2 through 10, 12, 15, 16 and 19	32.6	72	75	45	15

4.6.8 Optical Environment Subsystem

Subsystem Features (max) Weight = 18.1 kg (41 lb)

Power = 85 watts

Volume = 0.022 m^3 (0.8 ft^3)

This subsystem may be used in conjunction with either the electric field or acoustical environment subsystems are used on an experiment mission (see Table 4-10). Power demand is based on approximately 60 percent experiment time usage.

Table 4-10

OPTICAL ENVIRONMENT
SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
5, 8, and 12	18.1	41	85	51	17

4.6.9 Liquid Drop Generator Subsystem

Subsystem Features (max)

Weight = 14.7 kg (32.5 lb)

Power = 58 watts

Volume = 0.020 m^3 (0.7 ft^3)

This subsystem may be flown in conjunction with either the ice particle generator or aerosol generator (see Table 4-11). Power demand is based on 5 percent experiment time usage.

Table 4-11

LIQUID DROP GENERATOR
SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
2, 3, 4, 6 through 11, 16, 17, 18 and 20	14.7	32.5	58	3	1

4.6.10 Ice Particle Generator Subsystem

Subsystem Features (max)

Weight = 17.2 kg (38 lb)

Power = 58 watts

Volume = 0.020 m^3 (0.7 ft^3)

This subsystem may be flown in conjunction with either the liquid drop generator or aerosol generator (see Table 4-12). Power demand is based on 5 percent experiment time usage.

Table 4-12

ICE PARTICLE SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
2 through 7	17.2	38	58	3	1

4.6.1. Aerosol Generator Subsystem

Subsystem Features (max) Weight = 27.8 kg (61 lb)

Power = 76 watts

Volume = 0.062 m^3 (2.2 ft^3)

This subsystem may be flown in conjunction with either the liquid drop or ice particle generators. Either droplet cloud or giant nuclei generator will be flown on a given experiment mission, in conjunction with the Aitken generator. Power demand is based on 5 percent experiment time usage (see Table 4-13).

Table 4-13

AEROSOL GENERATOR SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
1, 2, 3, 5, 6, 8, 12, 16, and 19	16.4	36	46	2.3	0.8

4.6.12 Data Management and Interface Electronics Subsystem

Subsystems Features (max) Weight = 59.8 kg (132 lb)

Power = 237 watts

Volume = 0.067 m^3 (2.4 ft^3)

This subsystem will be flown on each experiment system (see Table 4-14). Subsystem power demand is based on 20 percent experiment time usage

Table 4-14

DATA MANAGEMENT SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
All	59.8	132	237	47.5	15.8

4.6.13 Aerosol Counters Subsystem

Subsystem Features (max)

Weight = 69.4 kg (153 lb)

Power = 293 watts

Volume = 0.109 m^3 (3.9 ft^3)

This subsystem will be flown on all experiment missions. The individual counters in this subsystem are not operated simultaneously. Power demand is based on 20 percent experiment time usage for both the optical and electrical particle counters and 5 percent usage of the particle mass counter (see Table 4-15).

Table 4-15

AEROSOL COUNTERS
SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
1	69.4	153	230	54	18
2 to 20	69.4	153	60	8	2.7

4.6.14 Experiment Chambers Subsystem

Subsystem Features (max)

Weight = 109 kg (240 lb)

Power = 0 watts

Volume = 0.154 m^3 (5.5 ft^3)

On a given experiment mission, one cloud chamber, and possibly one spare chamber will be flown (see Table 4-16).

Table 4-16

EXPERIMENT CHAMBERS
SUBSYSTEM FEATURES

Experiment Class	Chamber	Weight kg	Weight lb	Power (watts)
1	CDF	54.5	120	0
2 through 11	SDI	36.3	80	0
12 through 15	E	54.5	120	0
16 through 18	G	54.5	120	0
19 through 20	SDL	18.1	40	0

4.6.15 Miscellaneous Support Subsystem

Subsystem Features

Weight = 102.2 kg (226 lb)
Power = 0 watts
Volume = 0.148 m^3 (5.3 ft^3)

The subsystem elements are determined by experiment mission, cloud chamber, and expendable requirements (see Table 4-17).

Table 4-17

MISCELLANEOUS SUPPORT SUBSYSTEM FEATURES

Experiment Class	Weight (max) kg	Weight (max) lb	Weight (avg) kg	Weight (avg) lb
1	12.2	27	12.2	27
2 through 11	43.5	100	37.6	83
12 through 15	77.1	170	68	150
16 through 18	87.5	193	54.4	120
19 and 20	43	95	38.5	85

4.6.16 Power Control and Distribution Subsystem

Subsystem Features (max)

Weight = 19.5 kg (43 lb)
Power = 34 watts
Volume = 0.042 m^3 (1.5 ft^3)

This subsystem will be flown on all experiment missions. Power demand will vary dependent on total power load, and is estimated based on 75 percent load factor (see Table 4-18).

Table 4-18

POWER CONTROL AND DISTRIBUTION SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
All	19.5	43	34	26	8.6

4.6.17 Console Subsystem

Subsystem Features

Weight = 120 kg (265 lb)
Power = 75 watts
Volume = 8.75 m^3 (310 ft^3)

This subsystem will fly on every experiment mission. Power demand is based on 100 percent experiment time usage (see Table 4-19).

Table 4-19

CONSOLE SUBSYSTEM FEATURES

Experiment Class	Weight kg	Weight lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
All	120	265	75	75	25

4.6.18 Optical and Imaging Devices Subsystem

Subsystem Features (max)	Weight	109 kg (240 lb)
	Power	= 569 watts
	Volume	- 0.244 m^3 (8.7 ft^3)

Only specific elements of this subsystem will be flown on a given experiment mission. Cameras and microscopes are to be used simultaneously as will TV camera and microscopes. In general, two instrument and lighting will require access to the chamber at a given time. A limit of three instruments and lighting represent the maximum envisioned mission equipment.

The instrument characteristics used in this analysis are summarized in Table 4-20.

The total subsystem characteristics, by experiment class, are tabulated in Table 4-21.

4.7 PARAMETRIC LABORATORY CONCEPTS EVALUATION

In the parametric assessment of laboratory concepts, consideration was given to the various factors to reduce cost and provide an austere concept, and to evaluate growth potential and provide an advanced comprehensive concept. The factors considered in assessment of an austere laboratory concept included:

A. Use commercial equipment
B. Use terrestrial laboratory equipment
C. Reduce tolerance/accuracy of equipment
D. Reduce laboratory automatic controls
E. Delete equipment

Use of any of the above factors resulted in a laboratory that did not meet the needs of the scientific community or satisfy the design guidelines established for the laboratory.

The factors considered in assessment of an advanced comprehensive laboratory included:

A. Growth to longer duration missions
B. Advanced and/or improved subsystems

Table 4-20 (Page 1 of 2)
INSTRUMENT SUMMARY

Instrument	Usage: % Experiment Time	Usage: % Experiment Class	Weight: kg	Weight: lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
16-mm camera	4	50	7.3	16	224	4.5	1.5
35-mm camera	2	50	2.3	5	5	0.05	neg
70-mm camera	8	50	2.7	6	5	0.2	neg
Stereo Microscope	40	50	9.0	20	0	0	0
Binocular Microscope and Camera	10	50	16.8	37	10	0.5	0.17
Oscilloscope	20	100	4.5	10	12	2.2	0.73
Oscilloscope Camera	20	100	4.5	10	5	1.0	0.33
TV Camera	40	50	6.8	15	40	8.0	2.66
TV Monitor	40	50	15.9	35	75	15	5
Image Dev Light	40	100	12.5	27.5	158	63.4	21.13

Table 4-20 (Page 2 of 2)

INSTRUMENT SUMMARY

Instrument	Usage		Weight		P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
	% Experiment Time	% Experiment Class	kg	lb			
Optical Detector	10	50	2.3	5	5	0.25	0.08
Droplet Size Distribution Meter	20	50	4.5	10	20	2.0	0.66
IR Microscope	40	50	19.5	43	10	2.0	0.66

Table 4-21

OPTICAL AND IMAGING SUBSYSTEM FEATURES

Experiment Class	Weight (max) kg	Weight (max) lb	Weight (avg) kg	Weight (avg) lb	P_{max} (watts)	Experiment P_{avg} (watts)	Daily P_{avg} (watts)
1	38.2	84.5	38.2	84.5	185	67.1	22.4
2 through 11	66.5	146.5	54.5	120	528	94.4	31.7
12 through 15	47.4	104.5	43.1	95	225	69.9	23.4
16 through 18	80	176.5	72.5	160	524	96.1	32.1
19 and 20	71	156.5	59	130	320	93.6	31.3

Provisions for the above factors did not impact the selected "baseline" design concept significantly, but that incorporation of equipment would provide cost drivers for the total laboratory.

4.7.1 Baseline Laboratory Concept

The baseline laboratory concept contains the subsystems and subsystem equipment described in previous sections. This concept was determined after consideration of the design guidelines, the utilization of the equipment, and the project long-range goals and objectives. Table 4-22 summarizes the equipment utilization evaluations by experiment class. As shown all the ancillary subsystems and several of the experiment-unique chamber subsystems are required by all experiment classes. The other equipment have high utilization rates. Furthermore all subsystem and subsystem equipment identified is aerospace state of the art, commercial state of the art or presently designed devices utilized in terrestrial research laboratories. The latter two categories require SRT advanced development for use with the baseline laboratory. These SRT efforts were assessed and deemed as appropriate and of nominal cost and risk to the program. Any subsystem component which required advanced technology SRT or was of high cost was deleted from the laboratory baseline concept.

Table 4-22

SUBSYSTEM EQUIPMENT UTILIZATION

Subsystem/Equipment		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Experiment Class																			
Thermal control and measurement		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pressure control and measurement		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dew point and liquid water content control and measurement		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gas storage and flow control		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Electric field environment			X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	
Acoustical environment			X	X	X	X	X	X	X	X	X		X				X	X		X	
Optical environment						X			X				X								
Liquid drop generator			X	X	X		X	X	X	X	X	X					X	X	X		X
Ice particle generator			X	X	X	X	X	X													
Aerosol generator	Droplet cloud		X	X		X	X		X				X				X				
	Aitken	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X
	Giant		X				X		X				X							X	
Data management and interface electronics		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Aerosol counters		X	X	X			X		X				X	X	X	X	X			X	X
Experiment chambers		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Miscellaneous support		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Power control and distribution		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Console		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Optical detection and imaging devices	16-mm camera				X													X	X		
	35-mm camera					X	X	X	X	X	X		X		X					X	X
	70-mm camera		X	X								X		X		X	X				
	Stereo microscope				X	X		X			X							X	X		
	Binocular microscope	X											X	X		X	X				
	Oscilloscope	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Oscilloscope camera	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	TV camera		X	X	X	X		X	X	X	X	X					X	X	X	X	X
	TV monitor		X	X	X	X		X	X	X	X	X					X	X	X	X	X
	Image device light	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Optical detector					X		X	X				X								
	Droplet size distribution meter		X	X		X		X	X				X	X	X	X				X	X
	IR microscope		X	X	X	X	X	X		X	X							X	X		X

It should be noted that the subsystem equipment identified for the baseline laboratory concept is not presently provided in a single terrestrial research laboratory. Terrestrial researchers tend to specialize in micro-physical research associated with specific phenomena and hence utilize a specific cloud chamber and specific optical and imaging devices. It is therefore an advancement to provide a facility capable of performing the majority of cloud microphysics research. Furthermore, the defined baseline laboratory is to be constructed in accordance with proven aerospace development techniques, with relaxation of reliability and quality assurance requirements deemed appropriate for multiple-use payloads.

4.7.2 Austere Laboratory Concept Evaluations

The following sections summarize the rationale used in the assessment of factors considered for the austere laboratory concept.

A. Commercial Equipment

Commercial equipment available that approaches the desired performance required for the baseline laboratory has been identified. It was found that these items were not suitable for inclusion in the baseline concept for one or more of the following reasons:

1. Insufficient performance range
2. Inappropriate techniques
3. Incompatible geometric arrangement
4. High weight, power, and volume
5. Design features incompatible with zero gravity.

Furthermore, these items were found to contain materials not approved for manned space usage and had deficiencies associated with design based on terrestrial laboratory usage. Specifically all designs would require modification to withstand launch and reentry loads and to satisfy astronaut safety requirements.

Commercial equipment, therefore, was not found suitable in an off-the-shelf state for usage in either the baseline concept or in an austere laboratory concept.

B. Terrestrial Laboratory Equipment

Specific subsystem equipment, such as the cloud chambers, droplet generators, and the liquid water content meter are presently used in terrestrial laboratories and are unsuitable for either baseline or austere laboratory concepts for essentially the same reasons as those identified for commercial equipment. In addition, specific items are unique and therefore represent a "laboratory-tuned device" which would require development effort to reproduce.

C. Equipment Tolerance/Accuracy Reduction

Assessment of this factor showed that tolerance and/or accuracy cannot be reduced because to do so would compromise the value of the research conducted. To understand the cloud microphysical processes, a high degree of accuracy is required in all instrumentation sensors and by the optical and imaging devices. Reduction of accuracy and tolerances for these items would tend to mask the data and provide conflicting results hampering the attainment of project goals.

D. Reduce Laboratory Automatic Controls

This factor can be incorporated into an austere laboratory concept. Its main effect would be to reduce laboratory cost to initial operational capability (IOC). Cursory assessment of this cost savings has shown it to be a minor cost factor. Deletion of the envisioned baseline laboratory automatic control features would raise experiment program operational cost by requiring additional on-orbit time for accomplishment. Furthermore, astronaut training and principal investigator familiarization would become more complex and costly.

E. Delete Equipment

The deletion of equipment was studied in the earlier contract phase and reevaluated during this phase. Project cost to IOC can be reduced as can experiment program operational cost (reduction in the number of experiment missions). The cost savings are significant but are not proportional to deletion/elimination of experiment program and are hence not cost effective. This cost ineffectiveness is due to the commonality existing between specific subsystems. For example, the continuous flow diffusion, the static diffusion ice, and the static diffusion liquid cloud chambers have common development aspects. Deletion of one of these chambers would not produce a proportional reduction in cost to the project because a fraction of the common feature development aspect would be added to the remaining cloud chambers. Similar rationale applies to the expansion and general cloud chambers; the liquid drop, ice particle and aerosol generators and other items. Furthermore, as can be seen from Table 4-4, all ancillary sub.ystems and many of the experiment unique subsystems would still be required by the austere laboratory concept.

The above assessments show that the only way to effect significant cost savings and achieve an austere laboratory is by removal of equipment. It was further shown that this approach is not cost effective, that it significantly reduces the experiment program and compromises project objectives, and that it is not responsive to the scientific community desires. A minor cost savings to IOC can result from reduction of laboratory automation, but would increase mission timeline for experiments and therefore raise operating costs. In conclusion, an austere laboratory concept could obtain as much as 7 to 10 percent (estimated) cost reduction to IOC but would accomplish only about 25 percent of the defined experiment program.

4.7.3 Advanced/Comprehensive Laboratory Evaluation

The following sections summarize the rationale used in the assessment of factors for the advanced/comprehensive laboratory concept.

4.7.3.1 Longer-Duration Mission Growth

The growth of laboratory mission duration from 7 to 30 days is a design guideline for the baseline laboratory. Such duration growth involves incorporation for provisions of increased expendables (gas samples, film, water, tape, and possibly spare parts) to accommodate the longer duration. The baseline laboratory has sufficient volume to accommodate all expendables except for sample gases. Since the sample gases need not be incorporated integrally to the laboratory (i.e., proximity to cloud chamber is not required), a design decision was made to provide for sample gas growth in a separate module. Hence, the baseline laboratory has the required growth capability and such capability does not impact baseline laboratory development and cost.

4.7.3.2 Advanced/Improved Subsystems

Since the baseline laboratory has multiple-mission reuse over an extended duration (at least 5 years and possibly 10 years), capability to incorporate advanced or improved subsystems was evaluated. This evaluation resulted in the identification of the equipment desired for cloud physics research, but not included in the baseline laboratory because of state-of-the-art technology status, development cost, and development risk. Specifically these items are:

A. Improved tolerance pressure, temperature, dew point, and liquid water content subsystems (integrated environmental control)
B. Holography
C. Advanced IR imaging
D. Raman spectroscopy
E. UV water vapor profile detector
F. Earth simulation cloud chamber
G. Improved tolerance expansion cloud chamber

Assessment of laboratory growth to accommodate such equipment showed that the baseline laboratory concept was adequate with the possible exception of insufficient cloud chamber access and volume. Since it is not possible to predict the shape and volume of the advanced equipment, the baseline laboratory concept was not modified to incorporate greater cloud chamber access and volume. Provision for such contingency could be achieved by length increase of the laboratory in subsequent study phases or by retrofit during mission operations phase without major cost impact.

The above assessments show that the baseline laboratory concept incorporates features for growth to the advanced/comprehensive laboratory without baseline concept cost impact.

4.8 SUPPORTING RESEARCH AND TECHNOLOGY (SRT)

4.8.1 Analysis Method

The analysis of the SRT items required for the CPL has been performed using the SRT definitions and methods described in the following sections.

4.8.2 Supporting Research and Technology Categories

4.8.2.1 Research

Research (R) is the activity directed toward an increase in scientific and engineering knowledge. When this SRT category has a programmatic implication, it is applied rather than basic research and addresses only the conceptual phase (A) of phased project planning.

This category of activities indicates the need for new scientific knowledge to provide high confidence in proposed problem solutions. To minimize project cost and risk, these items normally should have been completed by the initiation of the Phase B study.

4.8.2.2 Advanced Technology

Advanced technology (AT) is the activity of advancing the state of the art in the field of methods and techniques through the application of science and engineering. Any associated hardware effort does not go beyond that required to demonstrate the validity of the advanced method or technique. The AT category of SRT is primarily concerned with the conceptual phase and only has a secondary concern with the definition phase (B).

This category of activities requires the initiation of scientific and engineering analysis and/or testing to advance the state of the art in methods and techniques. These activities should be completed before the start of Phase C, if program risk is to be minimized. The hardware activities associated with advanced technology objectives should not extend beyond those required to demonstrate validity.

4.8.2.3 Advanced Development

Advanced development (AD) is the activity of developing systems, subsystem, or components which are recognized as having long development times. before Phase D approval of the project in which they will be utilized.

The product of the activity will be a set of specifications within the then-current state of the art, which describes the hardware which was the subject of the advanced development activity. The AD category of SRT is concerned with both the definition phase (B) and the design phase (C).

Subsystems and/or components listed in this category are those which are felt to require long development lead times. These activities normally start during the definition phase (Phase B) but in some selected cases may start some months prior to this time and extend into the design phase (Phase C). The prime reason for performing this type of SR&T is to firm up the performance requirement portion of the particular specification associated with the subject hardware.

For the problem areas discussed in this category, the technology is present and the broad feasibility has been shown, but there remains the long-term task of integrating the elements into a workable subsystem and demonstrating operational capability in the space environment.

4.8.2.4 Supporting Development

Supporting development (SD) is the activity of developing (1) backup or alternate systems, subsystems, and components; and (2) fabrication, cost, and evaluation techniques. Advances in the state of the art may or may not be incorporated as appropriate. The product of this activity is hardware or techniques suitable for replacing their primary counterparts in the major development effort being supported. The SD category of SRT is primarily concerned with the design phase (C).

This category lists those activities leading to the development of backup or alternate subsystem and/or components which should be concurrent with the major Cloud Physics Laboratory development effort. The initiation of these activities during the design phase (Phase C) should accelerate the baseline development schedule and will reduce the program risk.

4.8.3 SRT Assessment

The SRT plan was defined based on the following three-step procedure. The initial step was to present a compilation of the cloud physics laboratory SRT that was technically weighted to reflect the requirements of the current design concept. Secondly, the SRT was filtered from a programmatic standpoint where schedule and cost factors are evaluated. The third step in the assessment was to rank the recommended SRT items from an overall Laboratory concept viewpoint in order to provide the required perspective of the subsystem SRT items.

4.8.3.1 Technical Assessment

The detailed SRT data sheets were prepared by appropriate subsystem and/or experiment equipment personnel. The definition of each SRT item consists mainly of identifying the problem, discussing the present technology available, and listing the benefits to be derived from successful completion. An estimate of the span of time to complete the item was prepared. The weighting factor for each item was established based on the current laboratory design concept and the following three general categories.

A. Category 1. Mandatory -- These items which must be completed or there will be a significant risk in achieving performance and/or schedule requirements. These items are critical to the success of the project and IOC schedule.

B. Category 2. Desirable -- Those items that could be dispensed with if there were severe budget restrictions. However, each of these items is considered cost effective such that a small investment now would be returned many times over during the 10-year life of the cloud physics laboratory project. These items result in increased reliability, decreased weight, and improved or more efficient operation. These items serve to enhance the capabilities of the baseline laboratory.

C. Category 3. Beneficial -- Those items that also appear promising but do not seem to offer quite the improvements of those in Category 2. However, further research in these items could result in their replacing the present approach taken in the baseline laboratory.

The schedule is the estimated time required to perform the SRT described on the detail data sheet.

The risk factor was determined by assessing the SRT item schedule against the postulated constraints. Risk factor was defined as Low (L), Nominal (N), or High (H). Any item in Research was automatically designated as a high risk. For the other SRT categories risk assessment is in conformance with the following guidelines:

A. Low Risk - Item schedule span of less than 9 months.

B. Nominal Risk - Item schedule span between 9 and 18 months.

C. High Risk - Item schedule span between 18 and 24 months.

4.9 SRT AREAS

Cloud physics laboratory SRT items have been identified and are discussed in the following sections. Table 4-23 shows a summary of the assessment of each item using the terminology previously defined.

Table 4-23

SRT ASSESSMENT

Item	AD		AT		Priority Categories			Time (months)	Risk
	B	SD	B	SD	1	2	3		
Environment subsystems									
Electrical	X				X			9	L
Acoustical	X				X			6	L
Optical	X				X			12	N
Generators									
Liquid	X				X			8	L
Ice	X				X			15	N
Aerosols									
Droplet and giant	X				X			6	L
Aitken	X				X			6	L
Experiment chambers									
E, CDF, SDL, SDL, G	X				X			18	N
E (arth) S (imulator)			X			X		24	H
Optical and imaging devices									
IR image	X					X		12	N
Drop size distribution			X			X		24	H
Holography				X			X	24	N
IR imaging (advanced)		X					X	24	H
Raman spectroscopy		X					X	24	N
UV water vapor profile			X				X	18	N
Detection									
X-ray diffraction		X					X	24	N
Dew point and LWC									
Liquid water content			X			X		12	N
Integrated environmental control	X				X			18	N

B = Baseline

SD = Supporting Development

4.9.1 Electrical Environment Subsystem

1. Item: ELECTRICAL ENVIRONMENT SUBSYSTEM
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: ELECTRONIC/ELECTRICAL
4. Descriptive Data:

A. Description

A general ambient (polarizing) electric field within a chamber is required for experiments dealing with the very important processes involved in charge generation, transfer and separation. Electric fields will also provide a very sensitive method of detecting the charge to mass ratios of freely suspended particles. Motion control of particles is a third area which utilizes both direct and alternating electric fields. The ambient polarizing electric field and the charge measurement electric fields are required for a number of the experiments while electrical motion control needs to be evaluated relative to acoustical and optical methods of position control.

B. Technology Available

The various electrical methods have been used to varying degrees within the atmospheric research community. The basic components of the systems are commercially available. The prime development requirement is to reconfigure present subsystems to operate in the appropriate modes for use in zero-gravity and to be compatible with specific experiment objectives. The polarizing field is straight forward with the simple requirements of a parallel dc electric field. Appropriate ac frequency and waveform will have to be determined for the charge/mass ratios to be measured and that are compatible with the observation-experiment objectives in a low-gravity environment. Specifically, longer times are available in zero-g than in a one-g environment thus lower electric fields will be traded against practical observation times. Electric quadripole fields have been used to contain submillimeter size particles in as one-g environment. The appropriate frequency, charge/mass ratio and field strengths must be determined for the specific zero-gravity experiment requirements.

Item: ELECTRICAL ENVIRONMENT SUBSYSTEM (continued)

C. Program/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. The following experiment classes are affected:

		Classes	Chambers
1.	Ambient Electric Fields	2, 3, 4, 6, 7, 8, 10, 18, 20	SDI, G, SDL
2.	Charge Measurement	3, 7, 8, 10, 14, 18	SDI, E, G
3.	Motion Control	3, 5, 7, 10, 17, 18, 20	SDI, G, SDL

Item 1 will be required in the expansion chamber as improved data output devices become available thus making this chamber more attractive for experiments now assigned to other chambers.

D. Benefits

This development effort will provide the necessary ambient electric fields required in about 50 percent of the experiments. Charge measurement "at-a-distance" is critical in the very important areas f charge generation. Motion control by electric fields provides volume control of particles with minimal disturbance to the surrounding air and with minimal heating of the particles. Comparative evaluations must be made between electrical, optical and acoustical motion techniques.

E. Schedule

9 months

4.9.2 Acoustical Environment Subsystem

1. Item: ACOUSTICAL ENVIRONMENT SUBSYSTEM
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: ELECTRO/MECHANICAL
4. Descriptive Data:

A. Description

A number of experiments require positioning over extended periods of time (hours). Even in a low gravity environment, a particle will have to be brought back into position every 10 minutes. The actual effect on the experiment of this positioning will be minimal as the positioning duty cycle can be maintained below 1 percent. This technique will also be very useful to reposition a particle after a particle-particle collision in preparation for another cycle. Acoustical fields will also be required to provide air turbulence and general air motion for some experiments.

B. Technology Available

Acoustical positioning techniques have been used in laboratory experiments in the past. Subsystem components are off the shelf. Development work will involve determining the wave length and intensity of the sound to accomplish the specific goals of positioning, turbulence generation, and general air motion. The acoustical positioning shows the most promise as compared with optical and electrical. Comparative evaluations must be made relative to ambient acoustical disturbances as opposed to optical heating and charge/mass ratio dependency of the electric field. Turbulence and other general air motions will be required.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. The following experiment classes are affected:

		Classes	Chambers
1.	Motion Control	3,5,7,10,17,18,20	SDI, G, SDL
2.	General Air Motion	2,3,4,5,6,7,9,10,13, 17,18,20	SDI, E, G, SDL

Item: ACOUSTICAL ENVIRONMENT SUBSYSTEM (continued)

D. Benefits

The general air motions are required for over 50 percent of the experiment classes and involves four out of five of the chambers. This air motion will permit the extension of pure zero-velocity data to the present one-g available data. The positioning technique using acoustical fields will provide the capability of using a given particle for multiple experiment cycles for certain of the experiments. This procedure would maximize the data throughput rate and thus help optimize the utilization of the zero-gravity facility. This technique will also permit the study of large particles (e.g., ice crystals) over a period of hours even with the restriction of 10^{-4} to 10^{-5}g acceleration levels.

E. Schedule

6 months

4.9.3 Optical Environment Subsystem

1. Item: OPTICAL ENVIRONMENT SUBSYSTEM
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: OPTICAL
4. Descriptive Data:

A. Description

Optical sources will be required for remote heating of particles and possible motion control in addition to the general optical lighting requirements for visual observations, photographing, and measurement of specific properties such as the scattering characteristics of ice crystais.

Several of the experiments require that a particle be maintained at an elevated temperature with reference to the general ambient temperature. This can be accomplished by using standard optical sources which provide radiation that is absorbed by the particle. The mechanism of manipulating the sources and the selection of specific optical qualities must be accomplished. Optical positioning has been demonstrated in a terrestrial laboratory for 20-micrometer-diameter particles. Optical positioning offers the advantage in that it can operate on a single particle or a group of particles while acoustical and electrical positioning influence all particles in a volume. This characteristic must be considered, with the heating caused by radiation absorption and evaluated relative to acoustical and electrical techniques for the specific requirement of motion control.

B. Technology Available

A number of small radiative optical sources are presently available that should satisfy the experiment requirements. Specific selection, determinations of beam requirements and developing beam aiming techniques need to be accomplished. Laboratory work has indicated that heating and positioning by optical means can be accomplished by the judicial selection of wavelength, beam shape and beam power. Only specific refinements need to be made for the proposed low-gravity conditions. Where as a quarter of a watt of optical power is

Item: OPTICAL ENVIRONMENT SUBSYSTEM (continued)

B. Technology Available (continued)

necessary to work against gravity, a few tens of milliwatts should be sufficient for the experiment requirements in a low-gravity, non-convective environment.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. The following experiment classes are affected.

	Classes	Chambers
1. Motion Control	3, 5, 7, 10, 17, 18, 20	SDI, G, SDL
2. Heating, Optical Scattering	5, 8, 6, 12, 20	SDI, E, SDL

A given class of experiments can often be performed in more than one chamber. As improved data collection techniques become available, a number of the experiments will probably shift from other chambers to the expansion chamber.

D. Benefits

The availability of remote heating and motion control will greatly enhance the performance of a number of the specified experiments. The lack of these techniques will negate some of the advantages gained by the use of a low gravity environment.

E. Schedule

12 months

4.9.4 Liquid Droplet Generator

1. Item: LIQUID DROPLET GENERATOR
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: ELECTROMECHANICAL
4. Descriptive Data:

A. Description

Atmospheric microphysics deal with droplet and droplet-droplet interactions. These droplets range in diameter from a few micrometer to millimeters. Experiments require various combinations of single, multiple, stationary, and moving droplets. The droplet generator must provide controls for position, direction, velocity and initial charge.

B. Technology Available

A number of single and multiple droplet generators are available for cloud physics work. Although these items have never had a great enough demand to warrant commercial production, their principle and construction have been fairly well established over the past 15 years. More than one generator may be required to satisfy the droplet generation requirements. Specific modifications will have to be made to present generator subsystems to make them zero-gravity compatible.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. The experiment classes affected are 2, 3, 4, 6, 7, 8, 9, 10, 11, 16, 17, 18, 20 and the experiment chambers involved are SDI, E, G, SDL.

D. Benefits

90 percent of the experiment classes require droplets in one form or another. Droplet generation will be an integral part of the cloud physics facility.

E. Schedule

8 months

4.9.5 Ice Particle Generation

1. Item: ICE PARTICLE GENERATION
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: ELECTROMECHANICAL
4. Descriptive Data:

A. Description

Ice crystals from micrometer to centimeter in dimensions are required for a number of the studies. Often a cloud of ice crystals will be generated from a source of nuclei or small water droplets. Of specific interest in this development area is the production of single or a few ice crystals above 50 micrometers in dimension.

B. Technology Available

Most terrestrial laboratory techniques utilize the growing of ice crystals on a surface. These techniques will be considered along with approaches for growing charge free floating crystals. Millimeter crystals will take tens of minutes to grow and thus may require periodic positioning by appropriate acoustical, optical, or electrical devices.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. The experiment classes affected are 4,5,6,7 and 8 involving the static ice diffusion chamber. Specific needs for ice crystals may occur for the expansion and general chambers as the experiment program develops.

D. Benefits

The study of ice crystals, their characteristics and their interactions is an integral part of atmospheric microphysics studies. The role of ice in charge generation and transfer is a very important area in which the low-gravity environment can make a significant contribution.

E. Schedule

15 months

4.9.6 Aerosol Generators — Clouds of Giant Nuclei or Droplets

1. Item: AEROSOL GENERATORS - CLOUDS OF GIANT NUCLEI OR DROPLETS

2. Category: ADVANCED DEVELOPMENT

3. Technology Area: ELECTROMECHANICAL

4. Descriptive Data:

A. Description

Several cloud microphysics experiments require the study of monodispersed and polydispersed clouds of droplets and/or giant nuclei. The particle concentration ranges from a few to several thousand per cubic centimeter. Observations are made of the growth and interaction characteristics of these clouds of particles as a function of time and varying ambient conditions.

B. Technology Available

Laboratory and commercial aerosol generators are available which will produce polydispersed and monodispersed clouds of droplets and certain types of giant nuclei. The techniques range from dispersion of a fluid from the surface of an ultrasonic probe to the highly uniform production of droplets from a vibrating nozzle or orifice. These techniques must be adapted for operation in a low-gravity condition and functionally optimized for the specific experiment requirements, in relation to droplet size and production rates. Some types of giant nuclei can be generated by generating droplets containing dissolved quantities of the desired material. The droplets are permitted to evaporate leaving behind the desired particles. These basic techniques differ from those of generation of single droplets or ice crystals.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. Experiment classes 1, 2, 3, 6, 8, 12, 13, 14, 16, 16, 19 and 20 are affected by this development work. These experiments will involve all of the chambers to varying degrees.

Item: AEROSOL GENERATORS – CLOUDS OF GIANT NUCLEI OR DROPLETS (continued)

D. Benefits

The cloud physics experiment program requires clouds of particles composed of droplets and/or giant nuclei. Methods for the generation of large numbers of particles in a short time will be necessary to assure the versatility of the cloud physics laboratory facility.

E. Schedule

6 months

4.9.7 Aitken Nuclei Generators

1. Item: AITKEN NUCLEI GENERATORS
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: ELECTRONIC/ELECTRICAL
4. Descriptive Data:

A. Description

Atmospheric processes involve nuclei in the condensation and freezing processes. Submicrometer particles are also of concern in air pollution and in subsequent atmospheric cleansing processes. Weather modification efforts also utilizes these particles. The Aitken nuclei are particles which range in size from roughly 0.005 to 0.1 micrometer in radius.

These particles are so small that they must coagulate, act as condensation nuclei, or be scavenged onto larger particles before they can be removed from the atmosphere. The study of these processes are of prime concern

B. Technology Available

Several techniques are presently used in the laboratory to generate Aitken type nuclei. Some methods as bubbling air through a solution of the desired material are not directly adaptable to zero-gravity. Other techniques such as hot wire aerosol generators are low gravity compatible. This development effort would select and standardize the required aerosol generation techniques so that comparable experimental data from zero-gravity and terrestrial laboratories can be compared.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Laboratory. This development work will be used in the five basic chambers and affect experiments 1,2,6,12,13,14,15,16,19, and 20. The requirements are dependent on the specific experiment within a given class of experiments.

Item: AITKEN NUCLEI GENERATORS (continued)

D. Benefits

Standardized aerosol generators are vital for the experimental work which is being considered if the objective of applying the low gravity results to terrestrial problems is to be accomplished. These generators would permit optimization of the laboratory timeline.

E. Schedule

6 months

4.9.8 Experiment Chambers

1. Item: EXPERIMENT CHAMBERS
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: STRUCTURAL/MECHANICAL
4. Descriptive Data:

A. Description

There are five basic chambers utilized in cloud physics research which are applicable in varying degrees to zero-gravity experiments. The continuous flow diffusion, static diffusion liquid and static diffusion ice chambers operate on a thermal vapor diffusion principle to provide controlled supersaturated conditions. These chambers require thermally controlled surfaces which are water or ice covered. The expansion and general chambers require thermally controlled surfaces. These chambers are used to define the relative humidity, pressure and temperature environment for the experiments.

B. Technology Available

The basic chamber mechanism and configurations have been developed and utilized within terrestrial laboratories. The present development is concerned with making the thermal control, water supply delivery, weight and power requirements compatible with zero-gravity operation. Gravity feed water systems will be replaced with positive displacement or capillary feed methods. Uniform surface temperature may require heat pipe technology rather than high volume fluid flow. The requirement and demand for each chamber varies but the various subsystems and techniques involved concerning surface temperature control, supply of water in zero-g, etc., is to a degree independent of the particular chamber.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. This development affects all experiment classes that have been identified.

Item: EXPERIMENT CHAMBERS (continued)

D. Benefits

These chambers are required for the performance of atmospheric cloud physics experiments. An accurately controlled environment is essential in order to provide meaningful data.

E. Schedule

18 months

4.9.9 Imaging Devices – Infrared (IR)

1. Item: IMAGING DEVICES – INFRARED (IR)
2. Category: ADVANCED DEVELOPMENT
3. Technology Area: OPTICAL/ELECTRICAL
4. Descriptive Data:

A. Description

Several cloud physics experiments require surface temperature measurements of liquid droplets and ice crystals. The thermal mapping of an ice crystal surface temperature when compared with growth sites could shed some light on the growth characteristics of ice crystals under varying ambient conditions. Specifically of interest is to determine whether surface migration of water molecules exist for certain ice crystal shapes. This can be studied by comparing localized "hot" spots (due to the latent heat of condensation) with the actual areas of growth. Differences in the location of these areas will indicate surface migration.

B. Technology Available

Commercially equipment is available which can contribute significantly to the experiment requirements. The present development would be involved in tailoring the present units to the specific experiment requirements. The replacement of liquid cryogenic cooling with available closed-cycle cryogenic coolers would have to be considered.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. The experiment classes 2, 3, 4, 5, 7, 9, 10, 11, 16, 17, 18 and 20 would utilize this IR capability and would involve compatibility considerations with the SDI, G, and SDL chambers.

D. Benefits

This development effort would provide a valuable instrument which is compatible with the objective of zero-gravity research, i. e., of observing freely suspended objects without physical attachments which upsets the experiment goals.

E. Schedule

12 months

4.9.10 Optical Detection and Imaging Devices - In Situ Droplet Size

1. Item: OPTICAL DETECTION AND IMAGING DEVICES - IN SITU DROPLET SIZE DISTRIBUTION

2. Category: ADVANCED TECHNOLOGY

3. Technology Area: ELECTROMECHANICAL, OPTICAL

4. Descriptive Data:

A. Description

A number of experiments require the measurement of cloud droplet size distributions during the growth and decay cycles of the precipitation cycle. This measurement needs to be made without physical contact or disruption of the growth processes. The required data are droplet numbers per unit volume as a function of diameter

B. Technology Available

Laser doppler methods are available to measure droplet size distributions based on the terminal fall velocity of the particles through air. This velocity of fall is a function of the particle size among other things which can be uniquely defined for specific conditions. In the terrestrial laboratory, gravity provides the necessary motion. The development effort in this area would be to determine if the desired motion can be provided by acoustical waves. An alternate approach which has worked for size distributions of fogs, blood cells, etc., is based on the optical Fourier analysis of light scattered by particles. Advanced development would be involved with interfacing this later technique to the specific experiment/chamber requirements. This may involve special optical arrangements all of which would be within the state of the art. The optical approach would not be limited to spherical particles but would also detect various crystal structures.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. This development would apply to all areas of particle sizing including experiment classes 2, 3, 5, 8, 11, 12, 13, 14, 15, 17, 19, and 20. These experiments involve the SDI, E, G, and SDL chambers.

D. Benefits

Presently cameras are used to obtain droplet concentrations for particles above a few micrometer sizes. There is a strong need for

Item: OPTICAL DETECTION AND IMAGING DEVICES – IN SITU DROPLET SIZE DISTRIBUTION (continued)

D. Benefits (continued)

better data collection and size monitoring techniques. For low-gravity conditions where realistic growth times would be available, it is imperative for experiment optimization and data throughput to have a continuous size distribution method

E. Schedule

24 months

4.9.11 Liquid Water Content Measurement

1. **Item:** LIQUID WATER CONTENT MEASUREMENT
2. **Category:** ADVANCED TECHNOLOGY
3. **Technology Area:** OPTICAL
4. **Descriptive Data:**

A. Description

The experimental study of precipitation processes requires a continuous monitoring of the water balance between vapor and liquid. A knowledge of this balance becomes important in experiments containing multiple droplets which deplete the available water vapor within the chamber. This depletion is desirable as it is the natural process in the atmosphere. But for a study and understanding of the physical processes, continuous tabs must be maintained on the available water vapor or the relative humidity. Relative humidity has been a very elusive quantity to measure and to date no method is available for this measurement. The alternate approach that is being used is to place a fixed amount of vapor within a chamber and then monitor the liquid water content (LWC) in the form of growing droplets. The initial water vapor content minus the LWC provides the remaining water vapor content. This value plus temperature and pressure measurements provides the relative prevailing relative humidity.

B. Technology Available

Optical methods to determine LWC are being used in laboratory experiments. Although the complete unit is not commercially available, the component parts are not complex and are available commercially. The development requirements will involve determining the specific geometries which are compatible with the applicable chambers being considered for the zero-gravity laboratory. The present technique is limited to monitoring monodispersed cloud droplets.

C. Programs/Projects Affected

Zero-Gravity Atmospheric Cloud Physics Program. This development affects the SDI and E chambers which are used for experiment classes 6, 8, 11, 12, 13, 14, and 15.

Item: LIQUID WATER CONTENT MEASUREMENT (continued)

D. Benefits

This LWC technique will permit a continuous monitoring of the liquid volume in the form of uniform size droplets. This measurement is important for those experiments which involve clouds of particles which cannot be affectively monitored in real time with the usual camera techniques.

E. Schedule

12 months

4.9.12 Wick Evaporator Humidifier

1. **Item:** WICK EVAPORATOR HUMIDIFIER
2. **Category:** ADVANCED DEVELOPMENT
3. **Technology Area:** STRUCTURAL/MECHANICAL
4. **Descriptive Data:**

A. Description

Cloud physics experiments require gas samples to be humidified with specific amounts of moisture. The most effective method of gas humidification in a null gravity environment is through the utilization of a wick evaporator made of wick pads separated by layers of rigid foam material which provides gas passages. Gas flow rate, velocity, humidity ratio, temperature, and pressure constitute varying experiment parameters. For a fixed geometry wick evaporator, gas humidity will be a function of the other parameters listed. The unit developed should have predictable performance characteristics and high accuracy. Temperature and pressure measurements will be required to determine the relative humidity.

B. Technology Available

Alternate humidification methods, such as water spraying or evaporation of water from wetted surfaces, have been used in laboratory experiments. Wick evaporators have been developed and operated by McDonnell Douglas for the recovery of water from urine. Wick evaporator humidifiers will be essentially similar in construction but will have different operating characteristics as they will operate with pure water rather than contaminated waste water.

C. Programs/Projects Affected

Zero-gravity atmospheric Cloud Physics program. This development affects the G and E chambers which are used for experiment classes 12, 13, 14, 15, 16, 17 and 18.

D. Benefits

The wick evaporator humidifier will provide a reliable and controllable source of gas humidification for the cloud physics experiments. This device is gravity independent equally capable of operation in space and on earth. The wick evaporator is also more

Item: WICK EVAPORATOR HUMIDIFIER (continued)

D. Benefits (continued)

reliable and less costly than alternate devices capable of performing the same function in space.

E. Schedule

12 months

4.9.13 Integrated Environmental Control Subsystem

1. Item: INTEGRATED ENVIRONMENTAL CONTROL SUBSYSTEM

2. Category: ELECTROMECHANICAL

3. Technology Area: ADVANCE DEVELOPMENT (LONG LEAD TIME)

4. Descriptive Data

A. Description

The pressure subsystems involve all laboratory gas sample pressure control, feed, transfer hardware and software among the gas sample supply tanks, cloud chambers and sump tankage. Thermal subsystems control temperatures of electronic equipment, cloud chambers, conditioning chamber and gas samples. Relative humidity (dew point or frost point). Control of the gas samples must be provided for the experiments. Pressure vessels will be used in gas storage of fresh and spent gasses. These subsystems are to be designed to have minimal impact on the Shuttle-Sortie environment. Maximum utilization will be made of the Sortie heat rejection and supply facilities while overboard dumping will be used for emergency dump. This overboard dump will be used in place of a sump tank if Sortie constraints and other Sortie payloads on the same mission permit it.

B. Technology Available

Most of the subsystems are state of the art, but require development due to the need for tolerances and automatic control for the complex and sophisticated interfaces among the various integrated environment control subsystems (i.e., pressure, temperature, relative humidity, and gas storage).

C. Programs/Projects Affected

Zero-G Atmospheric Cloud Physics Program. This development affects all experiment classes within this program.

D. Benefits

This development is necessary for time effective orbit operation which will result in lower cost per experiment hour.

E. Schedule

18 months

4.10 PROGRAMMATICS

4.10.1 Project Schedule

Utilizing the top-level project schedule, the detailed project schedule of Figure 4-5 was developed. This schedule reflects the following changes from that presented in the Summary Report NASA CR 129002.

A. First launch mid-calendar year 1981 (change from mid-calendar year 1980).

B. Start Supporting Research and Technology Advanced Development – in November 1974 (change from February 1975).

C. Complete Supporting Research and Technology Supporting Development in January 1977 (change from October 1976).

D. Independent Definition Study, October 1973 to September 1974.

E. Independent Design Study (Phase B), November 1974 to November 1975.

F. Start Operations Support Services – Launch Operations in April 1980 (change from July 1979).

G. Start Operations Support Services – Logistics Support in January 1981 (change from January 1980).

It should be noted that the design, development, and production (Phase C/D) schedule was not extended due to launch schedule changes. This decision retains cloud physics laboratory availability for earlier launch, should a flight opportunity exist. This schedule also permits a period of familiarization of the scientific community with the cloud physics laboratory capability and thereby enhance both their participation and effective usage of the laboratory.

4.10.2 Work Breakdown Structure

The preliminary work breakdown structure (WBS) of Figure 4-6 was formulated based on the results of the study efforts to date. The WBS has been reviewed and modified to reflect changes resulting from subsystem tradeoffs and laboratory requirements analyses.

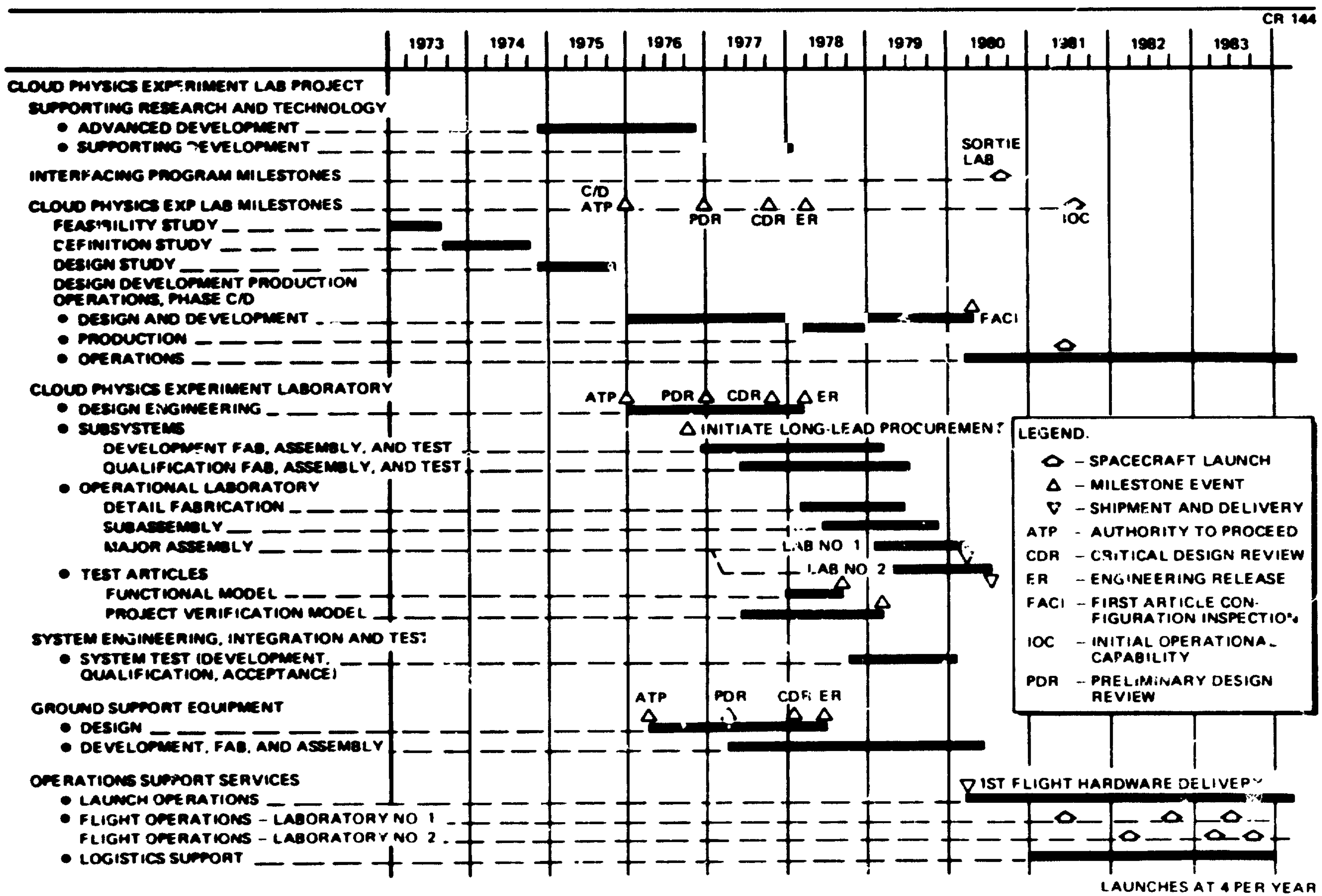


Figure 4-5 Cloud Physics Laboratory Project Schedule

LEVELS

3

SORTIE LAB PROJECT

4

SORTIE LAB

5

- STRUCTURAL/MECHANICAL
- ENV CONGROI AND ATM COND
  - ENV THERMAL CONTROL
  - LIFE SUPT ATM DIST
- CREW SYSTEMS
- DATA MANAGEMENT
- COMMUNICATIONS
- ELECT. POWER
  - ELECT. DIST
- √ EXPERIMENT SUPPORT
- SYSTEM TEST HARDWARE
  - FUNCTIONAL MODEL
  - PROTOTYPE MODEL
  - √ EXP ACCOMMODATION MODEL
- √ SYSTEM INTEGRATION

101 PROJECT MANAGEMEN

6

1101 THERMAL CONTROL AND MEASUREMENT

01 • HEAT EXCHANGER
02 • CIRCULATING COOLANT LOOP
021 RESERVOIR
022 PUMP/FILTER
023 SOLENOID VALVES
024 MODULATING VALVES
03 • TEMPERATURE CONTROLLER
04 • CRYOGENIC COOLER ASSEMBLY
05 • TEMPERATURE SENSORS
06 • VISUAL DISPLAYS
061 ANALOG
062 DIGITAL
07 • INTEGRATION, ASSY AND C/O

1102 PRESSURE CONTROL AND MEASUREMENT

01 • PRESSURE REGULATORS
02 • SOLENOID VALVES
03 • CONDITIONING CHAMBER
031 PRESSURE SHELL
032 POSITIVE EXPULSION REGULATOR
033 UV AEROSOL CONDITIONER
04 • PRESSURE SENSORS
05 • VISUAL DISPLAYS
051 ANALOG
052 DIGITAL
06 • INTEGRATION, ASSY AND C/O

5

6

1110 AEROSOL GENERATORS

01 • AEROSOL GENERATORS
011 DROPLET CLOUD
012 AITKEN
013 GIANT
014 OTHER
02 • ELECTRICAL HARNESS
03 • VISUAL DISPLAY
031 ANALOG (CRT)
032 DIGITAL
04 • INTEGRATION, ASSY AND C/O

1111 DATA MANAGEMENT AND INTERFACE ELECTRONICS

01 • COMPUTER
02 • RECORDER – TAPE
03 • MASTER CONTROLS
04 • TV CAMERA
05 • SIGNAL CONDITIONING ELECTRONICS
06 • DISPLAYS
061 ANALOG
062 DIGITAL
07 • INTEGRATION, ASSY AND C/O

√ ITEMS TO BE ACCOMPLISHED BY SORTIE LABORATORY

FOLDOUT FRAME

PAYLOAD PROGRAMS

SCIENCE

TECHNOLOGY

APPLICATIONS

CLOUD . EXPERIM LABOR.

101 PROJECT MANAGEMENT

102 SYS ENG INTEGRATION AND TEST

√ 01 • SORTIE LAB/PAYLOAD LABORATORY
02 • CLOUD PHYSICS LAB
03 • EXP HARDWARE
04 • EXP SUPPORT
05 • GSE

110 CLOUD PHYSICS EXPERIMENT LABORATORY

103 EX SU HA

• TBD

ESSURE CONTROL D MEASUREMENT

RE REGULATORS
VALVES
IONING CHAMBER
SHELL
EXPULSION REGULATOR
OSOL CONDITIONER
SENSORS
DISPLAYS

TION, ASSY AND C/O

1103 DEW POINT AND LIQUID WATER CONTENT CONTROL AND MEASUREMENT

01 • HUMIDIFIER
011 EVAPORATOR
012 HEATER
013 WATER TRAP
014 METERING PUMP
015 WATER TANK WITH BLADDER
02 • DEW POINT SENSOR
03 • LIQUID WATER CONTENT METER
04 • CONDENSER – WICK TYPE
05 • VISUAL DISPLAYS
051 ANALOG
052 DIGITAL
06 • INTEGRATION, ASSY AND C/O

1104 GAS STORAGE SUPPLY AND FLOW CONTROL

01 • EARTH SAMPLE STORAGE TANK
011 PRESSURE VESSEL
012 POSITIVE EXPULSION REGULATOR
013 BLADDER
02 • GAS SAMPLE STORAGE TANKS
03 • SUMP STORAGE TANK
04 • FLOW CONTROL ASSEMBLY
041 PLUMBING COMPONENTS
042 SOLENOID VALVES
043 FILL ASSEMBLY
044 VENT ASSEMBLY
045 SAFETY COMPONENTS
046 MIXING SUBASSEMBLY
05 • SUMP PUMP
06 • VISUAL DISPLAYS
061 ANALOG
062 DIGITAL
07 • INTEGRATION, ASSY AND C/O

1105 ELECTRIC FI ENVIRONME

01 • DC-DC CONVERTER CONTROLLED DC)
02 • DC-DC CONVERTER FREQUENCY AC)
03 • ELECTRIC FIELD CON
031 DC
032 AC
04 • ELECTRICAL HARNE
05 • VISUAL DISPLAYS
051 ANALOG (CRT)
052 DIGITAL
06 • INTEGRATION, ASSY

MANAGEMENT AND RFACE ELECTRONICS

– TAPE
CONTROLS

CONDITIONING
NICS

ION, ASSY AND C/O

1112 AEROSOL PARTICLE COUNTER

01 • OPTICAL PARTICLE COUNTER
02 • ELECTRICAL PARTICLE COUNTER
03 • PARTICLE MASS MONITOR
04 • MULTICHANNEL ANALYZER (PHA)
05 • ELECTRICAL HARNESS
06 • VISUAL DISPLAY
061 ANALOG
062 DIGITAL
07 • INTEGRATION, ASSY AND C/O

1113 EXPERIMENT CHAMBERS

01 • EXPANSION CHAMBER
02 • CONTINUOUS FLOW DIFFUSION CHAMBER
03 • STATIC DIFFUSION ICE CHAMBER
04 • STATIC DIFFUSION LIQUID CHAMBER
05 • GENERAL CHAMBER
06 • INTEGRATION, ASSY AND C/O

1114 MISCELLANE SUPPORT

01 • STORAGE EQUIPMEN
011 MOUNTS
012 PACKAGES
013 RESTRAINTS
02 • EXPENDABLES
021 EARTH SAMPLE GAS
022 GAS SAMPLES
023 WATER
024 FILM – MOTION PICT
025 FILM – STILL
026 TAPE
03 • TOOLS
04 • INTEGRATION ASSY

FOLDOUT FRAME

2

CLOUD PHYSICS EXPERIMENT LABORATORY PROJECT

103 EXPERIMENT SUPPORT HARDWARE

- TBD

104 OPERATIONS SUPPORT SERVICES

01 • GROUND OPS SUPPORT
011 – TRAINING
012 – GROUND C/O
013 – DATA ANALYSIS
02 • FLT OPS SUPPORT
03 • LOGISTICS SUPPORT

105 GROUND SUPPORT EQUIPMENT

01 • INTEGRATED C/O
02 • SERVICE
03 • ACCESS
04 • ELECT.
05 • MECH
06 • TRANSPORTATION AND HANDLING

ELECTRIC FIELD ENVIRONMENT

DC-DC CONVERTER (VOLTAGE CONTROLLED DC)
DC-DC CONVERTER (LOW FREQUENCY AC)
ELECTRIC FIELD CONTROLLER
DC
AC
ELECTRICAL HARNESS
VISUAL DISPLAYS
ANALOG (CRT)
DIGITAL
INTEGRATION, ASSY AND C/O

1106 ACOUSTICAL ENVIRONMENT

01 • ACOUSTICAL GENERATOR
02 • TRANSDUCER
03 • AMPLIFIER
04 • ELECTRICAL HARNESS
05 • VISUAL DISPLAY
051 ANALOG CRT
052 DIGITAL
06 • INTEGRATION, ASSY AND C/O

1107 OPTICAL ENVIRONMENT

01 • LASER DEVICES
02 • OPTICAL SENSORS
03 • POSITIONING SERVO CONTROL
04 • ELECTRICAL HARNESS
05 • VISUAL DISPLAY
06 • INTEGRATION, ASSY AND C/O

1108 LIQUID DR

01 • DROP GENERAT
02 • ELECTRONIC DI
021 POWER SUPPL
022 POWER SUPPLY
023 DUAL PULSE G
03 • ELECTRICAL HA
04 • VISUAL DISPLA
041 ANALOG (CRT)
042 DIGITAL
05 • INTEGRATION,

MISCELLANEOUS SUPPORT

STORAGE EQUIPMENT
MOUNTS
PACKAGES
RESTRAINTS
EXPENDABLES
EARTH SAMPLE GAS
GAS SAMPLES
WATER
FILM – MOTION PICTURE
FILM – STILL
TAPE
TOOLS
INTEGRATION ASSY AND C/O

1115 POWER CONTROL AND DISTRIBUTION

01 • POWER CONTROLLERS
011 AC
012 DC
02 • PROTECTIVE CIRCUITRY
021 AC
022 DC
03 • ELECTRICAL HARNESS
05 • VISUAL DISPLAYS
051 ANALOG
052 DIGITAL
06 • INTEGRATION ASSY AND C/O

1116 CONSOLE

01 • STRUCTURE
02 • PANELS/DOORS/SHELL
03 • SEAT ASSEMBLY AND RESTRAINTS
04 • FIXTURES
05 • LIGHTING
06 • MIRRORS
07 • STORAGE CABINETS
08 • INTEGRATION ASSY AND C/O

1117 OPTICAL D IMAGING

01 • MOTION PICT
011 16 mm
02 • STILL CAMER
021 35 mm
022 70 mm
03 • STEREO MICR
04 • BINOCULAR M
05 • MICROSCOPE
06 • OSCILLOSCOP
07 • SCOPE CAMER
08 • TV CAMERA
09 • TV MONITOR
10 • IMAGING DE
101 OPTICAL ILL
102 STROBOSCOP
103 LASER
11 • OPTICAL DET
12 • DROPLET SIZ
13 • IR MICROSCO
14 • INTEGRATIO

FOLDOUT FRAME

3

GROUND SUPPORT EQUIPMENT

- INTEGRATED C/O
- SERVICE
- ACCESS
- ELECT.
- MECH
- TRANSPORTATION AND HANDLING

OPTICAL ENVIRONMENT

DEVICES
ıL SENSORS
ONING SERVO CONTROL
RICAL HARNESS
. DISPLAY
RATION, ASSY AND C/O

1108 LIQUID DROP GENERATOR

01 • DROP GENERATOR
02 • ELECTRONIC DRIVER
021 POWER SUPPLY (GENERATOR)
022 POWER SUPPLY (CHARGE)
023 DUAL PULSE GENERATOR
03 • ELECTRICAL HARNESS
04 • VISUAL DISPLAY
041 ANALOG (CRT)
042 DIGITAL
05 • INTEGRATION, ASSY AND C/O

1109 ICE PARTICLE GENERATOR

01 • ICE PARTICLE GENERATOR
02 • ELECTRONIC DRIVER
021 POWER SUPPL (GENERATOR)
022 POWER SUPPLY (CHARGE)
023 DUAL PULSE GENERATOR
03 • ELECTRICAL HARNESS
04 • VISUAL DISPLAY
041 ANALOG (CRT)
042 DIGITAL
05 • INTEGRATION, ASSY AND C/O

CONSOLE

'URE
B/DOORS/SHELL
SSEMBLY AND RESTRAINTS
RES
NG

GE CABINETS
ATION ASSY AND C/O

1117 OPTICAL DETECTION AND IMAGING DEVICES

01 • MOTION PICTURE CAMERA
011 16 mm
02 • STILL CAMERA
021 35 mm
022 70 mm
03 • STEREO MICROSCOPE
04 • BINOCULAR MICROSCOPE
05 • MICROSCOPE CAMERA
06 • OSCILLOSCOPE
07 • SCOPE CAMERA
08 • TV CAMERA
09 • TV MONITOR
10 • IMAGING DEVICE LIGHTING
101 OPTICAL ILLUMINATOR
102 STROBOSCOPE
103 LASER
11 • OPTICAL DETECTOR
12 • DROPLET SIZE DISTRIBUTION METER
13 • IR MICROSCOPE
14 • INTEGRATION, ASSY AND C/O

1118 INTEGRATION AND ASSEMBLY

Figure 4-6 Work Breakdown Structure (Preliminary)

2

Section 5
SUPPORTING STUDIES

5.1 CONTINUOUS FLOW DIFFUSION CLOUD CHAMBER

5.1.1 Summary

A study was made of the continuous flow thermal diffusion cloud chamber and associated equipment by the Laboratory of Atmospheric Physics, Desert Research Institute, University of Nevada at Reno. Based on their laboratory experience in developing and utilizing continuous flow diffusion chambers they have performed an analysis of requirements for a zero-gravity version of a CFD chamber. The following is a condensation of their efforts.
Table 5-1 summarizes the weight, volume, and power requirements as well as the principal types of materials involved in each item which comprises the complete CFD chamber system.

5.1.2 Block Schematics

Figure 5-1 shows a schematic diagram of continuous counter (chamber and optical detector) which gives the important flow paths of the sample and carrier gasses and the liquid flow paths required if it is determined advantageous to use fluid flow thermostatic control systems. Only some of the required subsystems are shown here and these in schematic fashion only. The gas flow system is partly recirculated but requires both a source and sink of carrier gas as well as a source of sample gas containing the nucleating agents to be tested.

5.1.3 Data Gathering

The body of the CFD chamber is made from optical-grade plexiglass which permits viewing and photographing of the chamber interior from any location transverse to the flow direction and the thermal gradient. This can be for purposes either of direct quantitative data gathering or for gross evaluation of chamber interior conditions. The method of droplet size measurement is

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Table 5-1

CHAMBER CHARACTERISTICS (CFD)

	Item	Size/Dimension	Weight	Volume	Power	Materials
1.	**Cloud chamber box**	**14 x 14 x 11-1/4 in. plus external fixtures. Pressure gauge, etc. Air and water lines.**	80 lb	2,200 cu in.	0	1 in. and 3/4 in. thick plexiglass sheets. Hollow Al plates. Tygon connecting lines.
2.	**Royco optical bench**	21-3/4 x 5-1/2 x 2-3/4 in. and connecting to cloud chamber.	12 lb	332 cu in.	See below included	Plastic glass lens (electronics)
3.	**Royco main frame**	18-1/2 x 17 x 9 in.	42 lb	2,830 cu in.	254W max.	Metal
4.	**Thermoregulators (two identical units) controlled temperature circulator baths**	19 x 15-1/2 x 12 in. and 7 in. extending from top.	60 lb each with water total 120 lb	3,540 cu in.	805W max.	Each stainless steel
5.	**Millivoltmeter**	11 x 11 x 9 in.	8 lb	890 cu in.	25W	Metal (electronics)
6.	**Flowmeters on rack (four meters)**	15-1/2 x 12 x 7 in.	4 lb	1,300 cu in.	0	Aluminum rack. Plastic meters.
7.	**Filter (air)**	49 x 9-1/2 x 8-1/2 in.	15 lb	3,960 cu in.	0	Metal shell. Packed cotton inside.

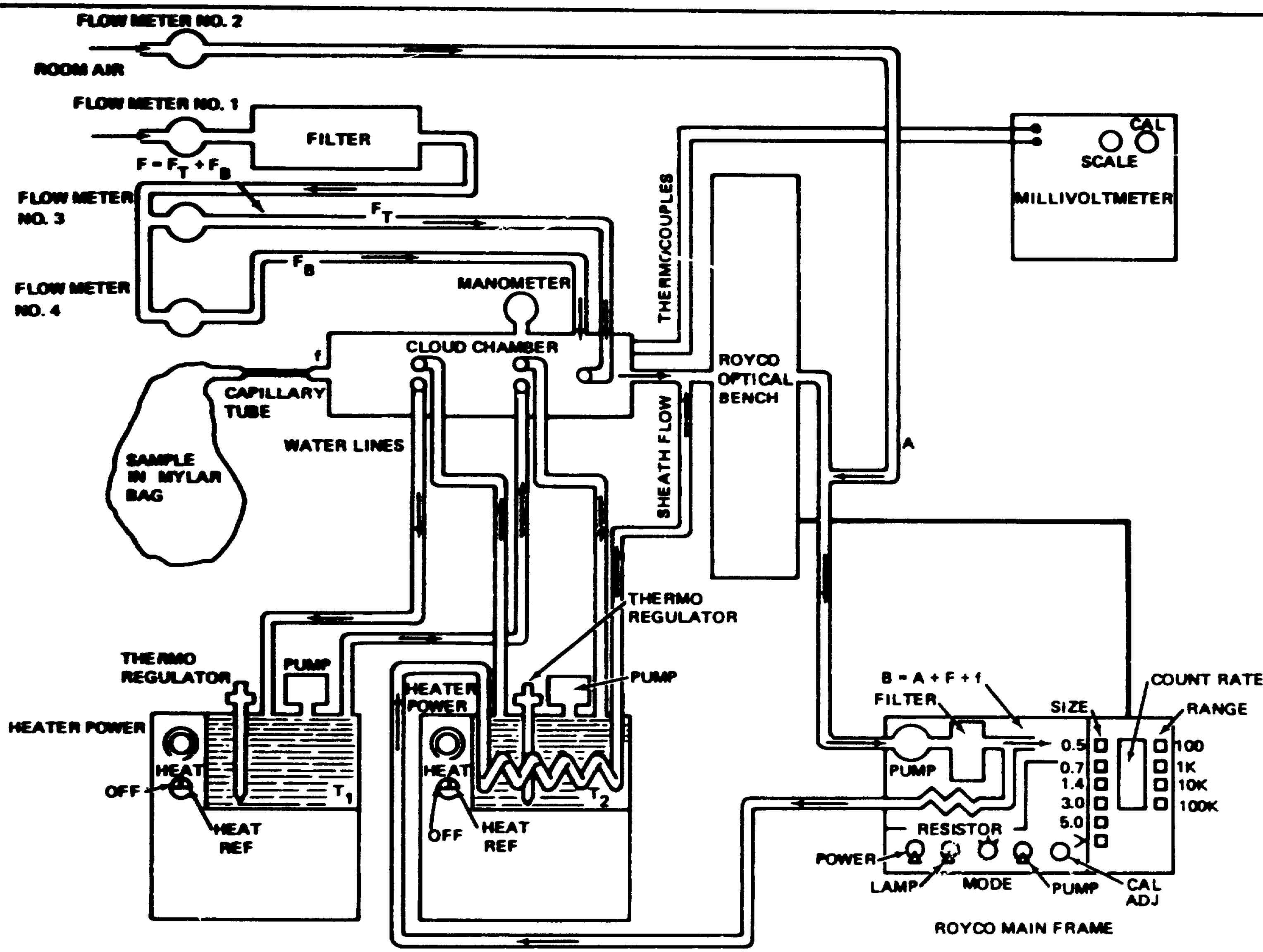

Figure 5-1. Schematic Diagram of Continuous Counter (CFD)

by means of an optical particle size analyzer which measures the quantity of light scattered by individual droplets as these droplets pass from the chamber through the analyzer.

The present CFD utilizes a Royco Model No. 225. This model, which uses near-forward scattering, has the significant disadvantage that the magnitude of the pulses produced is not a monotonic function of drop size below 1 micrometer. For the study of growth rates, it is essential that this be replaced by a sensor with a unique relationship such as that made by CLIMET, or such as the radically different device following the work of C.G. Gravatt, National Bureau of Standards. The latter device senses scattered intensities from two near-forward scattering angles, the integrated signals from which then compose a ratio which has been shown to be a strictly monotonic function of droplet diameter in the submicrometer region. A laser beam would eliminate the illumination nonuniformities such as occur in the incandescent system of the Royco. Furthermore, the ratio of scattered intensities, as well as being a good indicator of droplet diameter, is also nearly insensitive to index of refraction. Thus, commercially available, accurately sized, latex aerosols may be used to calibrate the output signal from the integrated-circuit ratio module, without fear of error due to the difference in index of refraction of latex (1.60) and water (1.33).

The output from a suitable optical sensor will be fed to a pulse height analyzer or equivalent to provide real-time spectra of the sizes of the droplets being produced in the CFD. The data would also be recorded on magnetic tape for later analysis on the ground.

5.1.4 Required Development

The areas where further development and testing will be required for compatibility with zero-g usage are as follows:

A. Flow meters
B. Water supply to chamber surfaces
C. Temperature control of chamber surfaces.

Regarding A, it will be necessary to substitute resistormanometer networks for the ball-type flow meters presently used under 1g and this may call for some other slight modifications in the overall gas-flow network.

Regarding B, one solution would be to substitute a device such as a kymograph-syringe (position displacement) pump for the present gravity and resistor combination in order to supply a slow and steady flow of water to the warmer plate and the upstream section of the colder plate. A similar arrangement acting in reverse could be used to withdraw excess water from the colder plate (which is largely supplied with water by vapor diffusion). The nature of the "well" from which excess water would be withdrawn is somewhat of a problem; indeed, since in 1-g laboratory practice, the most reliable way to maintain a thoroughly wet surface is to supply an excess of water at a high point and withdraw water at the lowest point, using gravity to move the excess water across the wet surface, this problem may be rather general wherever thoroughly wet surfaces are required in a zero-g laboratory.

Regarding C, several possibilities exist: the present thermostatted water supply tanks could be miniaturized and completely enclosed; heat pipes could be used to transport heat to and from the plates instead of the present water flows; a thermoelectric unit could be designed to maintain two heat reservoirs at a constant temperature difference and at a constant mean temperature.

Enviromental aerosols will not be available for study more than a few hours after launch, at best. Hence it will be essential to provide aerosol generators capable of producing aerosols in the size range down to 0.01 μm, and consisting of

A. Soluble salts
B. Insoluble materials
C. Hydrophobic materials

The ideal generator would produce a relatively monodisperse aerosol; for example, by using an ultrasonic small droplet generator with very dilute solutions of soluble salts. However, the difficulties of producing and handling monodisperse aerosols in adequate quantities are well known, and it would seem essential to provide a means of independently determining the spectrum of particle sizes. Many methods are available to give some description of the spectrum, but the Whitby aerosol analyzer is undoubtedly the most powerful tool, and should definitely be included in the design of the zero-g laboratory.

5.1.5 Suitability for Experiment Classes

Experiment Class 1, (Condensation Nucleation), includes types of research which have been primarily carried out in CFD chambers. The important characteristics of the CFD chamber which permit these results to be obtained are the following:

A. Absence of unwanted transient supersaturations.

B. Rapid and predictable rise of the supersaturation to its final design value.

C. Nuclei restricted to the region of maximum supersaturation, so that they all experience the same history.

D. A unique relation between the size of the droplet and the magnitude of the pulse to which it gives rise.

E. High count rates -- up to 10^3 sec^{-1}.

F. Accurately defined sample volume.

G. Essentially real-time data presentation.

H. The sample is drawn into the CFD, simplifying sample handling procedures.

I. Even under 1 g, the CFD is virtually an absolute instrument at supersaturations above 0.2 percent. It has been demonstrated to yield constant results over a range of values of all the chief operating parameters.

These characteristics make the CFD eminently suited to the measurement of the nucleation and early growth of droplets on nuclei of various kinds, and for the study of the effects of various contaminants on their behavior.

Experiment Class 15 (Condensation Nuclei Memory) may also be performed in the C F D chamber. The sample of aerosol after exposure to desired conditions of temperature and humidity for a suitable period of time could be passed into the CFD for determination of its nucleation characteristics. The fact that the sample is drawn into the CFD means that the flow rate can be independently determined; not all of the treated aerosol has to pass through the CFD, resulting in greater flexibility in the conduct of the experiment. The high sampling rate of the CFD is a distinct advantage.

Experiment Class 16 (Nuclei Multiplication) bears a strong resemblance to Class 15 (Nuclei Memory) and could well be designed in a similar fashion, the sample flowing from a preconditioning chamber at low relative humidity to a CFD. By cycling the humidity in the conditioning chamber, any breakup of nuclei could be very readily detected. In zero g, fallout being absent, it would be possible to ensure that no changes in the observed result would be due to changes in the mechanisms active in eliminating particles in the conditioning chamber. The CFD approach provides sizes as well as numbers in real time.

5.2 EXPANSION CLOUD CHAMBER

5.2.1 Weight, Power, and Volume

A second study was made of the expansion cloud chamber and associated equipment by Graduate Center for Cloud Physics Research of the Space Sciences Research Center at the University of Missouri at Rolla (UMR). This center has been very active in the development and usage of expansion cloud chambers of very sophisticated types. The following is a condensation of their study efforts. The interior of their suggested chamber is a right circular cylinder whose walls are temperature controlled by 552 individually controlled thermoelectric modules. The following gives the pertinent factors.

Volume	19.26 ℓ
Diameter	30 cm
Length	27.25 cm
Weight	30 kg
Power	400 w

The chamber is shown in Figure 5-2.

The observation ports can be either a continuous ring extending around the chamber or individual ports located as required. If individual ports are used, it is recommended that they be limited to a size which requires removal of only one thermoelectric module. This will minimize the disturbances created in the wall temperature profile.

Expansion ports should be located along the side wall to produce a radial expansion in the chamber.

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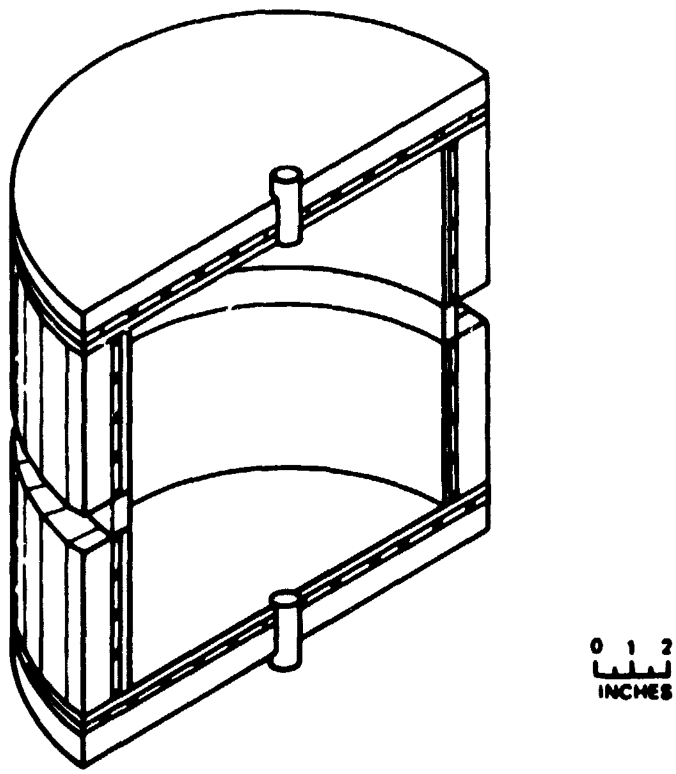

Figure 5-2. Zero-g Expansion Chamber

5.2.2 Block Schematics

Figure 5-3 shows an overall block diagram of an expansion chamber air flow system currently being built at UMR. A chamber for zero gravity would require essentially the same subsystems. The air preparation unit provides a continuous supply of clean dry air for sample preparation. The two-stage humidifier accurately saturates the air with water vapor at the temperature of the humidifier second stage. The aerosol generator supplies the sample aerosol of the required type, size, and concentration. The concentration is controlled by the amount of dilution from the air preparation unit. The sample size and type will be monitored by particle analyzers. Aerosols can be generated by spraying. Moreover, provisions will be made for using natural aerosols stored in an approximately 20 m^3 gasometer equipped with a bellows system for taking samples in and out of the container.

The thermal regulation system brings the humidified air and aerosol to the same temperature as the initial temperature of the control and simulation chambers. The sample mixing unit controls the final mixing of humidified air and aerosol to give the required accuracy for the final sample before

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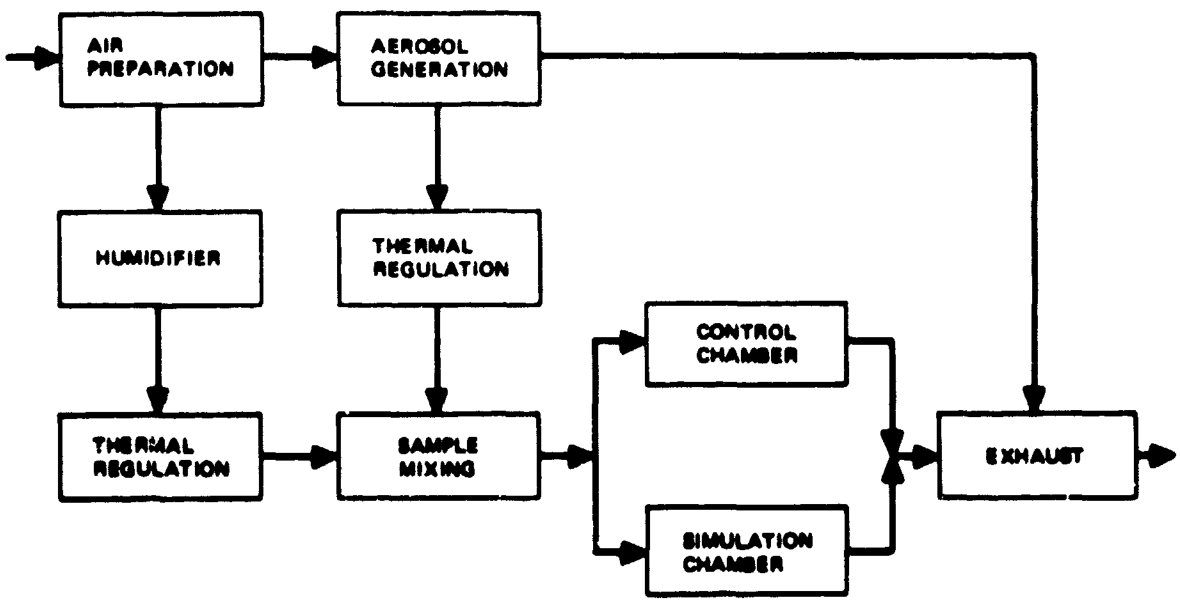

Figure 5-3. Air Flow Through Major Subsystems UMR Cloud Simulation Project

entering the chamber. Part of this sample then goes into the control chamber where its size and composition is analyzed while the rest enters the expansion chamber where the particular experiment is performed.

5.2.3 Data Gathering Instruments

5.2.3.1 Temperature

The use of thermocouples for measuring the pre-expansion gas temperature in expansion cloud chambers has been a standard practice for many years. They are relatively easy to make and have a fast response, provided extremely small-diameter wire is used. The circuitry is relatively simple requiring only a constant reference temperature and a suitable high impedance, high gain dc amplifier and a readout device. A further advantage is their lack of heat dissipation.

The thermistor has far greater mechanical strength than the thermocouple and is also relatively simple to use. The necessity of passing a current through it does cause some heat dissipation which disturbs the system being measured. Unfortunately the smaller the current used the more difficult it is to obtain a usable ouput. When high resolution is required, the detection of small changes in a large resistance becomes extremely difficult if not impossible. The finite size of the thermistor bead makes the response considerably slower than that which can be obtained with thermocouples.

The transistor thermometer developed for use with the UMR cooled wall expansion chamber has a resolution of 0.001°C, good mechanical strength, good short-and long-term stability, and is relatively inexpensive and easily calibrated. Part of the resolution characteristics are due to the fact that the sensor is actually a transistor and the first stage of amplification takes place in the sensor. This greatly reduces the problems of signal noise common in thermocouples. but is comparable with many thermistors. Since it is an active circuit element, there is some self-heating but this can be minimized by the use of very small currents and a usable ouput can still be obtained. Sensor failure, which is rare, is almost always catastrophic, so if the data is consistent; the sensor is probably functioning. The entire unit is physically small and the probes can be made interchangeable to several hundredths of a degree. The use of any of these methods represents the application of existing technology.

5.2.3.2 Pressure

Use of a pressure transducer is the normal method used to measure pressures in modern expansion cloud chambers. In fast expansion cloud chambers the use of a flush diaphragm transducer is virtually mandatory due to the turbulance and local increase in supersaturation caused by the jetting action of the excess gas leaving a recessed port during the expansion. In the case of slow expansions, this does not normally present a problem.

The vast majority of experience at UMR has been with the use of flush diaphragm strain gage type transducers which have proved extremely reliable. Using this type of transducer and a total circuit calibration technique, they are able to measure pressures in excess of one atmosphere with a resolution of 0.1 torr. Variable reluctance type transducers had to be abondoned due to zero-point drift and rather large low-frequency noise levels. The present system using a strain gage transducer has good stability, low noise, and a resolution of 0.005 torr at 1.0 psid.

Use of pressure transducers can give the required accuracy and represents the application of existing techniques.

5.2.3.3 Concentration

The standard method for obtaining droplet concentrations in fast expansion chambers is to photograph a known volume of the chamber at a demagnification of from 5 to 10 and count the resulting images on a screen when the negatives are projected. The method is relatively simple and straightforward due to the rapid growth of droplets in a fast expansion chamber. The droplets are usually photographed at a fairly definite size, somewhere around 8 μm radius. For a slow expansion chamber where knowledge of the concentrations is desired while the droplets are still smaller than 8 μm radius, the use of photography is a more demanding art. With smaller droplets, a more intense light or longer exposure is required. If size distributions are to be obtained photographically, higher magnification must be used; however, increased magnification increases the size of the camera and decreases the depth of field for a given object to image distance. Photography offers a ready means of determining the concentrations for the larger droplet sizes.

The use of a video camera and tape recorder offers several advantages in observing droplet concentrations as well as droplet position as a function of time and interaction events. First, vidicon tubes are available which are sensitive to light levels considerable below that required for film photography. The use of the tape recorder and monitor permits both a permanent record and instant replay of the experiment to determine the quality of the data. Use of the monitor during the experiment allows direct observation of the visual data as they are obtained and comments can be recorded on the audio portion of the tape. The primary difficulty is the resolution limit due to the finite number of lines associated with one complete scan. The resolution cannot equal that obtainable with film photography, but still should be adequate for work with larger droplets. This type of system is currently being installed for use with a fast expansion chamber. Plans are also being made for possible use with the UMR cloud simulation project.

The use of laser scattering to obtain concentrations requires at least two different measurements. This is due to the fact that the amplitude of the scattered light depends not only on the concentration but also on the droplet radius. The second measurement is used to remove the dependence on radius. The primary advantages are that smaller size droplets can be detected than with any photographic method, the output is an electrical signal that is immediately available and the measurement can be continuous with respect to time. Moreover, if laser scattering techniques are being used to determine the liquid water content and the average droplet size, then with only a minimum amount of additional circuitry the average concentration can be obtained. These techniques are quite well known and fairly standard in general procedure. For fairly monodispersed clouds or aerosols the size is determined with great accuracy.

5.2.3.4 Size

The same advantages and disadvantages in using photography for droplet concentrations apply to droplet size with the added factor that at the smaller droplet size with the added factor that at the smaller droplet sizes and large demagnifications the actual image is a diffraction pattern which is difficult to relate to the true droplet size. The image must be magnified to reduce this effect.

Current work directed toward measuring droplet sizes using laser scattering indicates that provided the size distribution is not too broad the mean size as a function of time can be determined from the Mie scattering. The method is fairly standard and requires only adaptations to meet specific requirements. It can detect particle sizes down to 0.5 μm with relative ease. For real-time use, a procedure must be developed to assure that the droplet size is being related to the correct Mie peak. Probably the primary disadvantage of this method is the fact that the Mie peaks used for detection are washed out when the size distribution becomes too broad.

5.2.3.5 Liquid Water Content

The disymmetry ratio method is based on using the ratio of light scattered to two angles symmetric about 90 degrees and the attenuation of the incident beam. It shows promise of yielding a real-time measure of the liquid water content of the chamber for use in correcting for the release of latent heat. The technique is independent of gravity and therefore usable with a zero-g chamber. There still remains some development to prefect the system, primarily in the areas of calibration and reliability testing. The technique uses fairly standard concepts and existing components.

The measurement of the liquid water content by determining the total amount of frequency shifted scattered light resulting from the photon-phonon interaction (Brillouin scattering) in the bulk of the liquid droplets has been suggested as an alternative method of measuring liquid water content. The technique has the desirable feature that the total intensity would yield a direct measurement of the liquid water content and theoretically is the most straightforward procedure. However, the idea has not been developed at this time; only a theoretical feasibility study has been done. The method would be compatible with other laser techniques and would further increase the amount of information gained from a single laser probing of the system. At least a preliminary attempt should be made to explore the applicability of this technique.

5.2.3.6 Relative Humidity

Commercially available continuous or direct-reading relative humidity sensors appear to be too inaccurate to serve any real useful purpose in cloud physics experiments where an accurate knowledge of this crucial variable is needed. For instance the dew point type instruments depend upon the repeated nucleation and evaporation of dew upon a polished surface. The nucleation centers on the plate are subject to the "memory effect" which in turn is due to the buildup of contamination. Such an instrument cannot be used to establish relative humidities to such an accuracy as would be necessary to study similar nucleation processes in great detail. The accuracy of such instruments is specified to be within ±0.25°C, but even this accuracy cannot be reliably maintained because laboratory contaminants (both surface active vapors and aerosols) cannot be controlled; neither can cleaning procedures be depended upon to reproduce themselves under the usual measures to maintain laboratory cleanliness.

The approach at UMR has been to produce the relative humidity in the first place with the kind of Bureau of Standards accuracy required for equation of state work.

The laboratory humidifiers utilize a moving water film which tends to keep surface films broken up so that they do not effect the saturation vapor pressure. Moreover, the time required to bring a slowly moving column of air to the degree of saturation required can be calculated and used as a conservative estimate in determining the flow rate through the saturator. Then in order to establish a lower relative humidity, the temperature of the saturated air is raised. The temperature of the saturator is the single most critical measurement in expansion cloud chamber techniques devoted to cloud physics measurements. The transistor thermometers are capable of the measuring accuracy and stability needed to adequately serve the requirements for measuring temperature in the humidifiers, and they can also serve the purpose of providing temperature control as well. UMR believes that complicated earth-bound laboratory procedures can be evolved to measure absolute relative humidity for the purpose of testing humidifiers but that these are not likely to be suitable for the space laboratory. If the humidifiers are well developed and tested in the earth-bound laboratory, hopefully they will perform similarly in the Space Shuttle laboratory in zero gravity.

5.2.4 Suitability for Experiment Classes

5.2.4.1 Class 1-Condensation and Nucleation

The nucleation efficiencies and early growly properties of nuclei can be studied using a cooled-wall expansion cloud chamber. The procedure consists of introducing the nuclei into the sensitive volume at a predetermined pressure, temperature and relative humidity. During this step the relative humidty can be held at a value which insures that the nuclei do not become activated. After the chamber is sealed and equilibrium has been established, a slow expansion is carried out to increase the supersaturation (relative to the nuclei in question) to the desired level or to simulate the effect of atmospheric updraughts on a small parcel of air. Once the desired value of supersaturation is achieved, it is maintained until all the droplets nucleated have grown to the desired extent and all measurements are completed. The counting and sizing can be accomplished by photographing a known volume within the chamber, defined by expanding and limiting a laser beam. Lasers provide the sharpest beam definition which can be obtained.

If the initial size spectrum of the nuclei is sufficiently narrow, the growth rate of the droplets can be obtained by observing the Mie scattering as a function of time for a fixed scattering angle. Analysis of the peaks in the scattering amplitude permits an extremely accurate determination of droplet size as a function of time.

5.2.4.2 Class 2-Ice Nucleation

Studies of the nucleation of ice can be readily carried out in a cooled-wall expansion cloud chamber using the same techniques as those used in the study of condensation nucleation. The changes consist primarily in the temperature range over which the chamber operates and the nuclei being studied. Thermoelectric units can provide chamber thermal control over a temperature range of 70°C.

Once the nuclei are placed in the chamber a slow adiabatic expansion is carried out and the number of ice crystals formed per unit volume determined by video tape recording of a known volume using a polarizing lens. A cloud of mixed water drops and ice crystals can be formed in the chamber by using a mixed aerosol of both condensation and ice nuclei.

5.2.4.3 Class 3-Ice Multiplication

For studies of the droplet breakup during freezing in a cooled-wall expansion chamber the expansion can be carried out in two steps. First the chamber is expanded to form droplets of the desired size using condensation nuclei, or droplets can be injected via a means similar to that developed for the NaCl break up experiment. When the desired conditions of temperature, pressure, relative humidity and drop size are achieved the expansion is stopped and droplet freezing is initiated by injecting either ice nuclei or ice crystals. After the droplets have been frozen the chamber is further expanded to cause any fragments created during freezing to grow to observable size. Note that ice crystals falling from the walls of chambers has always presented a very difficult problem in earth bound laboratory experiments. In the zero-g chamber ice fragments originating at the walls will remain fairly well localized for long times and should not infect r nucleate the entire chamber. (This assumes that splintering of small droplets is a relatively unimportant process.)

5.2.4.4 Class 4-Charge Separation

In considering the relative advantages of using a cooled-wall expansion chamber to those of a thermal diffusion chamber, two points stand out. First, the range of relative humidities over which it is desired to conduct experiments extends below the saturation level, and while a thermal diffusion chamber can be operated in this region, the cooled wall expansion chamber is designed to include this region as part of its normal operating range for a given experiment. Second, for relative humidities above saturation, the moving droplets are subject to a varying relative humidity unless motion its confined to a plane parallel to the plates of the thermal diffusion chamber and thermophoretic forces are always present. The uniform vapor density within a cooled wall expansion chamber effectively eliminates this difficulty. The remaining conditions of controlled temperature, and pressure are common to both chambers.

5.2.4.5 Class 5-Ice Crystal Growth Habits

The procedure for carrying out experiments in a cooled-wall expansion chamber to determine the growth properties of ice as a function of temperature is basically the same as used for studies of droplet growth, but conducted at lower temperatures and using either ice nuclei or ice crystals as the nucleating agents. Use of an expansion chamber offers two advantages. First, the vapor fields surrounding the growing crystal are spherically symmetric except for those effects caused by the growing crystal itself, and second, the chamber is capable of being recompressed to cause the crystal to evaporate and permit a second growth under the same or different conditions on the same crystal to determine repeatibility of the process or changes in habit.

5.2.4.6 Class 6-Scavenging

These experiments require subjecting droplets to conditions of growth, nongrowth, and evaporation. The cooled-wall expansion chamber's ability to provide all three conditions within a single experimental run make it ideally suited for this work. As the chamber is expanded and a homogeneous supersaturated condition created, the droplets begin to grow. This growth results in the formation of a thermal gradient and a vapor density gradient in the vicinity of the droplet, both of which have spherical symmetry. When the expansion is stopped and the pressure and temperature held constant the droplets will come to equilibrium, growth stops, and the thermal and vapor density gradients decrease to zero. The chamber is then compressed causing a decrease in supersaturation so that the droplets begin to evaporate. During evaporation the spherically symmetric thermal and vapor density gradients again form but in the opposite direction. The effects due to Brownian forces are present in all three cases.

5.2.4.7 Class 8-Droplet-Ice Cloud Interactions

The chamber can be purged and brought to the desired initial conditions and the cloud of water droplets injected or generated on condensation nuclei by an expansion. The chamber is then cooled and expanded to the selected final temperature, pressure, and relative humidity and held at those conditions. The formation of a few ice crystals by injection of some ice nuclei will initiate freezing of some of the supercooled water droplets.

5.2.4.8 Class 9-Homogeneous Nucleation (Ice)

The expansion chamber is already designed to provide for the uniform cooling of the walls required in this experiment. The only changes in operation consist of deactivating the expansion mechanism and insuring that the therm-electric cooling modules are capable of cooling the walls to -40°C from the desired starting temperature. This is easily within the capability of the thermoelectric units proposed. The requirement that the walls be non-nucleating is common to most other experiments to be carried out in the expansion chamber.

5.2.4.9 Class 11-Saturation Vapor Pressure of Supercooled Water

The uniform wall cooling capability of the expansion chamber coupled with the high-pressure measuring resolution capability required in its normal operation make it ideally suited for measurement of the saturation vapor pressure of water at temperatures between +5° and -3°C. The capability of measuring droplet temperatures is highly desirable for use in several other experiments in addition to this one. Also the normal resolution required in measurements of wall temperatures should be equal to or better than the 0.01°C listed for the proposed experiment.

5.2.4.10 Class 16-Nuclei Multiplication

Provided that a suitable solution can be found to reduce the size of the proposed observation ports to a size compatible with other design requirements, the cooled wall expansion chamber would be suitable for carrying out the experiments proposed in this class. The drops to be studied would be injected into the subsaturated chamber (relative humidity less than 80 percent and allowed to evaporate. The evaporation process could be speeded up at this point by a compression to further reduce the relative humidity. After evaporation is complete the chamber would be expanded to create a super-saturated condition resulting in activation and growth on the small nuclei resulting from fragmentation during crystallization.

5.2.4.11 Class 20-Unventilated Droplet Diffuction Coefficient

The use of a cooled wall expansion chamber offers two advantages over the thermal diffusion chamber. First the diffusion profiles around the growing droplets will be superimposed on a homogeneous background instead of on the thermal and vapor density gradients required for operation of a thermal diffusion chamber. This should simplify analysis of the experimental results since the droplet induced gradients will have true spherical symmetry. The second advantage is the ability of the chamber to extend the measurements to include the cases where droplets are evaporating. This could be done by permitting the chamber to come to equalibrium at a saturated condition after the initial expansion used to measure the coefficients during growth. A compression of the chamber would then homogeneously reduce the chamber to a subsaturated state causing the droplets to evaporate. Comparison of the results would determine the existence or absence of any directional dependence of the diffusion coefficient.

Appendix
EXPERIMENT PROGRAM DESCRIPTIONS

This appendix contains a representative experiment description for each experiment class listed in Table A-1.

The first sheet in each experiment description provides a summary of compatible chambers, scientific assessment, and pertinent experiment variables. The chamber incorporated in the experiment description is also indicated. The scentific assessment ratings (A, B, or C) were established in accordance with the procedure described in Section 3.2.3

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 concern 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 4. The procedural section specifies representative event times, but it does not include times for setup, calibration, and shutdown. These items are included in the timeline analysis of Section 3.

Table A-1

EXPERIMENT CLASSES

Class No.*	Title
1.	Condensation Nucleation
2.	Ice Nucleation
3.	Ice Multiplication
4.	Charge Separation
5.	Ice Crystal Growth Habits
6.	Scavenging
7.	Riming and Aggregation
8.	Droplet-Ice Cloud Interactions
9.	Homogeneous Nucleation
10.	Collision Induced Freezing
11.	Saturation Vapor Pressure
12.	Adiabatic Cloud Expansion
13.	Ice Nuclei Memory
14.	Terrestrial Expansion Chamber Evaluation
15.	Condensation Nuclei Memory
16.	Nuclei Multiplication
17.	Drop Collision Breakup
18.	Coalescence Efficiencies
19.	Static Diffusion Chamber Evaluation
20.	Unventiliated Droplet Diffusion Coefficients

*The experiment class numbers were assigned for reference and clarity only. The number designation is not on indication of priority, applicability achieveability, or any other measure of scientific relevance.

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

Table A-2

SCIENTIFIC PARTICIPATION

PRINCIPAL EXPERIMENT CONTRIBUTORS

ALKAZWEENY, A. J.	BATTELLE	HOFFER, T. E.	DRI	PODZIMEK, J.	U. OF MO.
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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	RUSKIN, R. E.	ONR
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BYERS, H. R.	TEXAS A&M	KOCMOND, W. C.	CORNELL LABS	SLINN, W. G. N.	BATTELLE
CARSTENS, J. C.	UNIV. OF MO.	KYLE, T. G.	NCAR	SOGIN, H. H.	TULANE
CHENG, R. J.	SUNY	LANGER, G.	NCAR	SOULAGE, R. G.	FRANCE
COTTON, W. R.	NOAA	LATHAM, J.	ENGLAND	SPENGLER, J. D.	HARVARD
CORRIN, M. L.	COLO. STATE	LODGE, JR., J. P.	NCAR	SOLDANO, B. A.	FURMAN
DAVIS, B. L.	SO. DAK. S.M.T.	LOW, R. D. H.	WHITE SANDS	SQUIRES, P.	DRI
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HALLETT, J. R.	DRI	PHILLIPS, B. B.	NOAA	ZUNG, J. T.	U. OF MO.
HALES, J. M.	BATTELLE				

A.1. CONDENSATION NUCLEATION

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CLASS

CONDENSATION NUCLEATION

COMPATIBLE CHAMBERS

Primary CFD (Experiment Description)

Alternate SDL
E

ASSESSMENT

Priority - A **Achievement Ability** - B **Applicability to Zero G** - A

VARIABLES

Primary		Secondary
Size	Absorption	Sound
Type	Optical	Turbulence
Pollution	Concentration	
Pressure	Age	
Temperature	History	
Relative Humidity		
Time		
Gases		

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 contrit te 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 pressures 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 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 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 6 to 7 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 A-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 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 A-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

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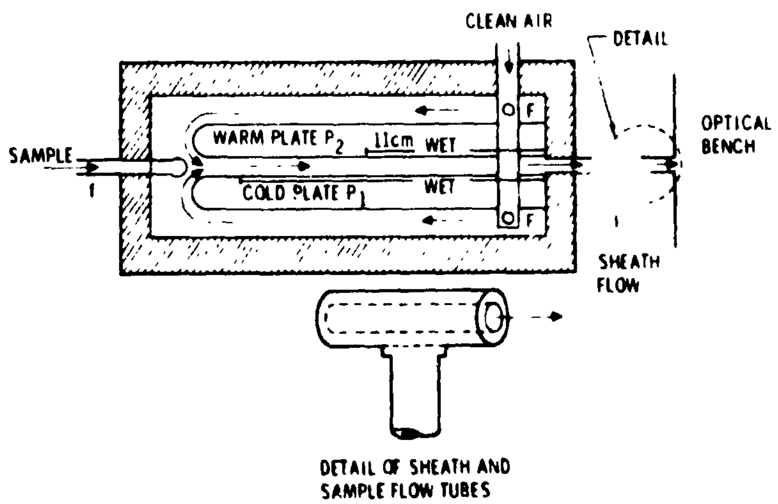

Figure A-1. Continuous-Flow Diffusion Chamber

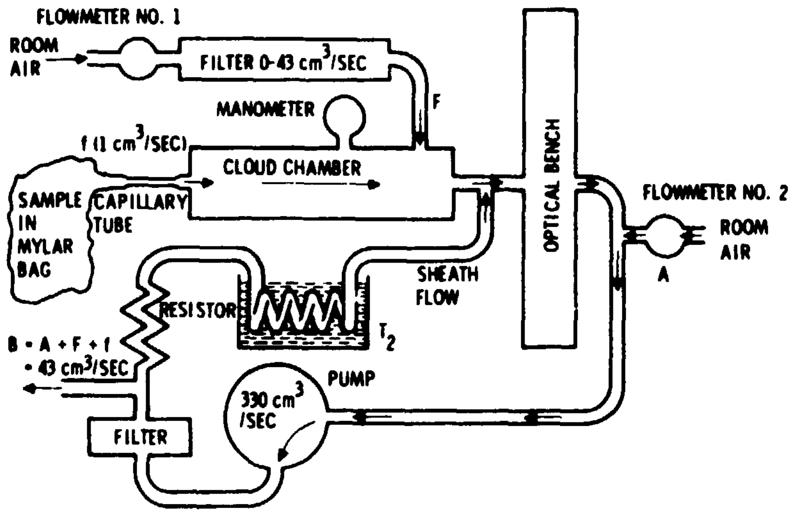

Figure A-2. Continuous-Flow Diffusion Chamber Air Flow

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 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 difference between the two plates is measured to 0.05°C.

The chamber operates at a deficit pressure 1.33×10^3 N/m^2 (10 torr) relative to the air supply pressures. In an experiment where it is desired that the super-saturation be constant to within 0.0? 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 50 N/m^2 sec (0.38 torr/sec) relative to a total pressure of 8×10^4 N/m^2 (610 torr). 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 4 x 10^{-5} m^3/sec (cfh) at one standard 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	2-30
• 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, six settings)	5
• Change plate temperature settings and stabilize (saturation levels, four settings)	10
• 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. Surface active agents are of particular interest as they relate to warm fog modification. These experiments can be conveniently divided into sessions of a few hours duration.

ACKNOWLEDGEMENTS

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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• Briant Davis	South Dakota School of Mines and Technology
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A.2. ICE NUCLEATION

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CLASS

ICE NUCLEATION

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate E
G (cooled)

ASSESSMENT

Priority - A Achievement Ability - B Applicability to Zero-G - A

VARIABLES

	Primary	Secondary
Size	Electric Field	Pollution
Type	Nuclear Radiation (ions)	Pressure
Temperature	Absorption	Ventilation
Relative Humidity	Turbulence	Concentration
Time	Ion Level	Age
Sound		History
		Gases

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).

Zero Gravity

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-gravit, 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 their diameters exceed 10 μm. 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-dihydroxynapthalene 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 a 1.6-mm-diameter 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 sub-freezing 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	10
• Purge diffusion chamber	5
• 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 ΔT (c.f., METHOD) at 0.25°C/min	10
• Recycle for new mean temperature (four 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. Observations should be continued beyond the freezing point to record the crystal types as a function of nuclei and ambient conditions.

ACKNOWLEDGEMENTS

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

	Contributors	Affiliations
•	W. R. Cotton	Experimental Research Laboratory NOAA Miami, Florida
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•	T. Kyle	National Center for Atmospheric Research
•	G. Langer	National Center for Atmospheric Research
•	R. D. H. Low	White Sands Missile Range
•	[illegible] Maybank	Saskatchewan Research Council, Canada
•	[illegible] L. Ogden	Institute of Occupational Medicine Edinburgh, Scotland
•	W. D. Scott	National Hurricane Laboratory NOAA Miami, Florida

A. 3. ICE MULTIPLICATION

CLASS

ICE MULTIPLICATION

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate E

ASSESSMENT

Priority - A Achievement Ability - A Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Size	Charge	Absorption
Type	Rate of Cooling	Turbulence
Pollution	Sound	Age
Pressure	Electric Field	
Temperature	Ventilation	
Relative Humidity	Gases	

ICE MULTIPLICATION EXPERIMENTS

INTRODUCTION

Objective

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

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. Numerical modeling of mixed-phase clouds is now in a rather primative state.

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 crystallization processes (including melting) will be performed in a static ice diffusion chamber utilizing the low-gravity conditions of a space platform to eliminate mechanical support and provide the necessary experiment time. 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. These studies will lead to a better understanding of cold cloud evolution and precipitation efficiency. One consequence would be better snowfall forecasts.

Zero Gravity

In many of these experiments in a terrestrial laboratory, fallout prohibits 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 A-3). Initial sizes of all ice particles over a few micrometers in diameter 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

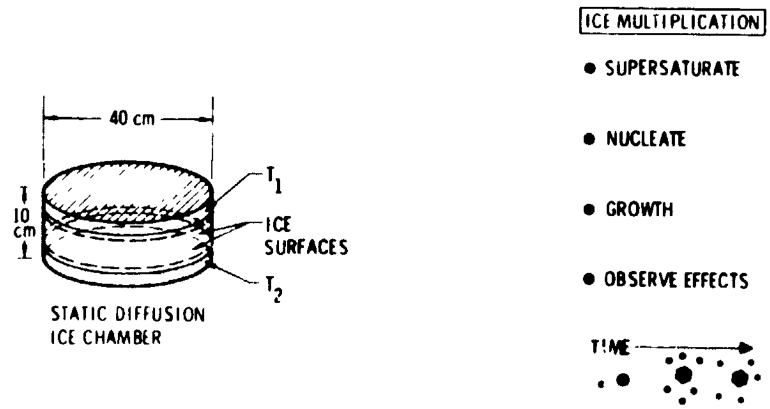

Figure A-3. Typical Experiment – Droplet Breakup

which are conducive to droplet breakup during freezing. Other experiments deal with ice and snow type crystal breakup during conditions of collision or melting. Crossed polarizers can be used to distinguish between water drops and ice crystals. The addition of a telescope arrangement would alleviate some of the camera focusing problems if crystal size and shape are not needed. Other experiments would study collisional breakup of dendrites. Dendritic crystals would be impacted with relative velocities between 10 cm/sec and 2 m/sec with observations of resulting breakup. Also collisions between droplets and ice crystals, 10 μm to 1 mm in diameter, would be studied.

INSTRUMENTATION

A static diffusion ice chamber will be utilized for these experiments. 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.

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 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)	2
• Freeze droplet (e.g., insert nuclei)	3
• Allow submicrometer fragments to grow	5
• Record temperatures and pressure	
• Warm and recycle with same droplets (5 times)	
• Recycle with a given droplet diameter (10 events)	
• Recycle with four other droplet diameters	
• Recycle with other humidity levels (4 levels)	
• Recycle with other temperature levels (4 values)	
• Recycle with other pressure levels (3 levels)	
• Recycle with other gas (e.g., pollutant) composition (3 types)	

ACKNOWLEDGEMENTS

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

Contributors	Affiliations
• H. Appleman	USAF - Air Weather Service
• H. R. Byers	Texas A & M
• A. N. Dingle	University of Michigan

Contributors	Affiliations
• J.. Hallett	Desert Research Institute, University of Nevada
• K. O. L. F. Jayaweera	University of Alaska
• J. E. Jiusto	State University of New York (Albany)
• J. Latham	University of Manchester, England
• J. P. Lodge, Jr.	National Center for Atmospheric Research
• T. Ohtake	University of Alaska
• W. D. Scott	National Hurricane Laboratory NOAA, Miami, Florida.

A. 4. CHARGE SEPARATION (ELECTRIFICATION)

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CLASS

CHARGE SEPARATION
(ELECTRIFICATION)

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate E
G

ASSESSMENT

Priority - A   Achievement Ability - C   Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Type	Sound	Absorption
Pressure	Electric Field	Turbulence
Temperature	Velocity	Ion Level
Relative Humidity		Gases
Charge		
Initial Condition		

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 differential migration of positive and negative ions along a temperature gradient in ice 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 are 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 various angles 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. The ice surface roughness should also be varied. Freezing droplets onto the ice surface could be used to vary surface textures.

INSTRUMENTATION

A static diffusion ice chamber will be utilized for these experiments. 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.

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	2
• Apply appropriate charge measuring electric field (resulting motion being photographed)	3
• Turn off charge measuring fields	
• Recycle with other droplets (50 events) (purge when necessary)	
• Recycle with other droplet diameters (4 sizes)	
• Recycle with other humidity levels (4 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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A. 5. ICE CRYSTAL GROWTH HABIT

CLASS

ICE CRYSTAL GROWTH HABIT

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate E

ASSESSMENT

Priority - A Achievement Ability - A Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Size	Electric Field	Absorption
Type	Ventilation	Turbulence
Pollution	Optical	Velocity
Pressure	Shape	Ion Level
Temperature	Orientation	
Relative Humidity		
Charge		
Sound		
Concentration		
Gases		

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, New York) 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 super-cooled 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 diffusional 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 periods of time for crystal growth without 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 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 A-4), 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, τ_d, is given by approximately

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

Where h (height) = 10 cm and D (thermal diffusivity) = 0.2 $cm^2\ sec^{-1}$, the resulting equilibrium time constant τ_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.

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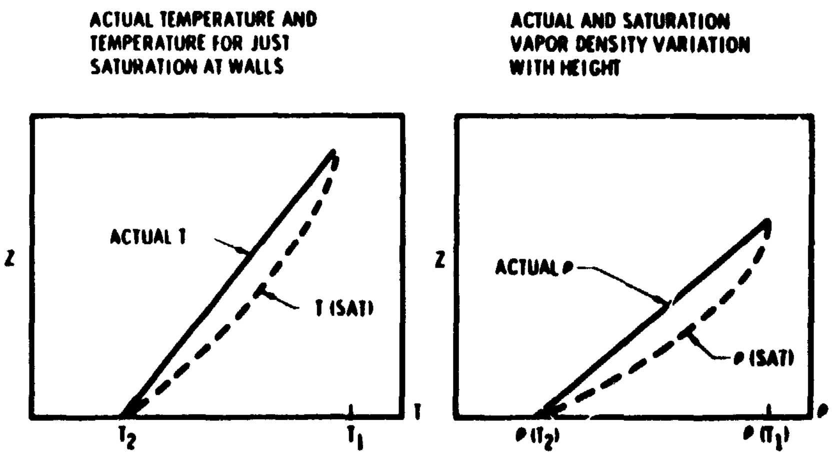

Figure A-4. Saturation Temperature and Density as a Function of Chamber Position

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 percent) over at least a 3-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. 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
• Purge chamber	5
• Establish temperature profile between plates, ΔT	5
• Insert ice or ice nuclei within chamber*	3
• Record plate temperature and time	
• Time lapse photography of crystal growth	10 - 100
• Recycle for various ΔT	

*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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A.6. SCAVENGING

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CLASS

SCAVENGING

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate CFD
E
G

ASSESSMENT

Priority - A   Achievement Ability - B   Applicability to Zero-G - B

VARIABLES

Primary		Secondary
Size	Time	Ventilation
Type	Sound	Velocity
Pollution	Electric Field	Ion Level
Pressure	Absorption	
Temperature	Turbulence	
Relative Humidity	Shape	
Charge	Concentration	

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 cleaning 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 nongrowth 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 submicrometer 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 nongrowth. A comparison of the resulting numbers will give the relative effectiveness of the scavenging forces. The analysis is shown in Figure A-5.

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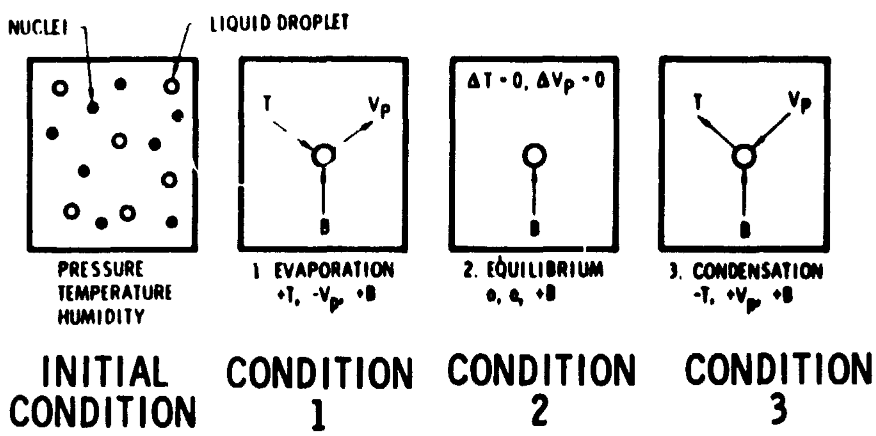

Figure A-5. Configurations for Determining Scavenging Mechanism

Condition 1 is in Figure A-5 indicates that when a droplet is evaporating the thermal gradient force (T) is inward, the vapor gradient force (∇_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.

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	5
• 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.

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A. 7. RIMING AND AGGREGATION

CLASS

RIMING AND AGGREGATION

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate G (cooled)

ASSESSMENT

Priority - A   Achievement Ability - B   Applicability to Zero-G - B

VARIABLES

Primary		Secondary
Size	Electric Field	Absorption
Type	Shape	Ventilation
Pressure	Concentration	Orientation
Temperature	Velocity	Gases
Relative Humidity	Kinetic Energy	
Charge		

RIMING AND AGGREGATION EXPERIMENTS

INTRODUCTION

Objective

Determine interaction between a supercooled water droplet and an ice surface 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 allowing detailed 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 μm) 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.

Undersaturation: 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 have their entry inhibited by the vapor flux away from the evaporating crystal. An infrared thermometer would provide the ice crystal surface temperature.

The following preliminary experiment may be considered for an earlier opportunity: A drop is injected with very low velocity onto an ice surface. The droplet-surface interaction is examined by successive strobe photography using a microscope (Figure A-6). The microscope views the drop interactions edge on. The droplet trajectory will be studied by stroboscope and the interaction by direct photography

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.

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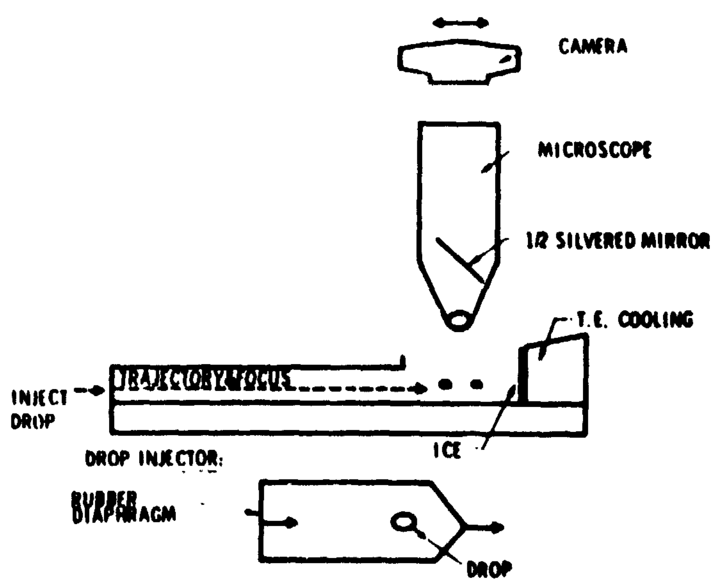

Figure A-6. Low Velocity – Drop Impaction Study

INSTRUMENTATION

Crystals in a diffusion chamber typically grow to a millimeter in diameter 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 requires that the chamber cannot be less than ~2 cm deep. 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 also desirable to prevent significant depletion 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 percent over at least a 3-hr period.

MEASUREMENT AND DATA REQUIREMENTS

Supercooled droplet motion on an ice surface is of specific interest. Strobe photography will record this motion as well as the time interval required for freezing. 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.

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	2
• Reposition crystal	1
• Recycle with another droplet d_1 (20 times)	
• Recycle with droplet d_2	
• Recycle with new thermal profile	

The thermal profile will include supersaturated and undersaturated conditions. Effects of superimposed electric fields will also be studied. Crystal-crystal "aggregation" should be examined as a function of crystal type, temperature, humidity, and electric fields.

ACKNOWLEDGMENTS

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

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A. 8. DROPLET-ICE CLOUD INTERACTIONS

CLASS

DROPLET-ICE CLOUD INTERACTIONS

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate E

ASSESSMENT

Priority - A **Achievement Ability** - C **Applicability to Zero-G** - B

VARIABLES

Primary		Secondary
Type	Sound	Liquid Water Content
Pressure	Electric Field	
Temperature	Turbulence	
Charge	Optical	
Time	Concentration	

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 thermodynamic energy 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 are 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 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). Freezing could be initiated by other means including a cold probe or dry ice in addition to the above-mentioned ice nuclei.

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 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
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A.9. HOMOGENEOUS NUCLEATION (ICE)

CLASS

HOMOGENEOUS NUCLEATION (ICE)

COMPATIBLE CHAMBERS

Primary SDI

Alternate E (cooled, Teflon covered walls) (Experiment Description)
Unique (spherical, cooled)

ASSESSMENT

Priority - B Achievement Ability - B Applicability to Zero-G - B

VARIABLES

Primary		Secondary
Size	Rate of Cooling	Turbulence
Temperature	Time	
Relative Humidity		
Charge		
Sound		

HOMOGENEOUS NUCLEATION (ICE) EXPERIMENTS

INTRODUCTION

Objective

Determine the homogeneous freezing distribution of free-floating droplets as a function of time, degree of supercooling, and droplet diameter.

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., Fairbanks, Alaska) ice fogs occur when temperatures fall below -35°C.

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 the various suspension methods 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 microphysical 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)	5
• 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)	40
• 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

A.10. COLLISION-INDUCED FREEZING

CLASS

COLLISION-INDUCED FREEZING

COMPATIBLE CHAMBERS

Primary SDI (Experiment Description)

Alternate G (cooled)

ASSESSMENT

Priority - A Achievement Ability - A Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Size	Charge	
Type	Sound	
Pollution	Electric Field	
Pressure	Velocity	
Temperature	Kinetic Energy	
Relative Humidity		

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 the 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 on 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 long observation times and eliminate the need for mechanical 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 of 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	5
• Thermal and vapor equilibrium (+5° C)	10
• 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 (20)	
• Recycle with other temperatures (4)	
• Recycle with electric fields (3)	
• Recycle with sound fields (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
• K. O. L. F. Jayaweera	University of Alaska
• J. E. Jiusto	State University of New York (Albany)
• T. Ohtake	University of Alaska
• H. Weickmann	Environmental Research Laboratory, NOAA, Boulder, Colorado

A.11. SUPERCOOLED-WATER SATURATION VAPOR PRESSURE

CLASS

SUPERCOOLED-WATER SATURATION VAPOR PRESSURE

COMPATIBLE CHAMBERS

Primary SDI

Alternate E
Unique (spherical, nonwetting walls) (Experiment Description)

ASSESSMENT

Priority - B Achievement Ability - C Applicability to Zero-G - B

VARIABLES

Primary	Secondary
Size	Charge
Type	
Temperature	
Time	

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 obstacles 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 2.5×10^3 N/m^2 (25 millibars) with water vapor	5
• Establish temperature equilibrium (initial +5°C)	10
• Inject a number of droplets (200 micrometer 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

A.12. ADIABATIC CLOUD EXPANSION SIMULATION

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CLASS

ADIABATIC CLOUD EXPANSION SIMULATION

COMPATIBLE CHAMBERS

Primary E (Experiment Description)

Alternate E (Sperical)

ASSESSMENT

Priority - A Achievement Ability - B Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Size	Turbulence	Sound
Type	Optical	Absorption
Pollution	Concentration	
Rate of Cooling	Liquid Water Content	
Time	History	
Electric Field	Gases	

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 0.15 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 conditions 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. Other items of interest are the study of Ostwald ripening (growth when expansion has stopped), loss of nuclei due to passage through a warm cloud base and effects of fluctuations in supersaturation on nucleation and droplet growth.

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 acoustical, optical, and electrical fields will also be studied as the same parcel of air is taken through several growth cycles. Also of particular interest is the study of a tenuous cloud (< 0.5 g/m^3 liquid water content) over periods of 10 minutes in which ice crystals are grown through artificial nuclei by sublimation or contact nucleation.

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 an expansion chamber. 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 expansions 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 have provisions for expansion in 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
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• J. Kassner	University of Missouri
• P. Squires	Desert Research Institute, University of Nevada
• H. K. Weickmann	Environmental Research Laboratory, NOAA, Boulder, Colorado

A. 13. ICE NUCLEI MEMORY

CLASS

ICE NUCLEI MEMORY

COMPATIBLE CHAMBERS

Primary E (Experiment Description)

Alternate SDI

ASSESSMENT

Priority - A Achievement Ability - B Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Size	Relative Humidity	
Type	Time	
Pollution	Age	
Pressure	History	
Temperature		

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 numbers of ice crystals versus time in conjunction with the cycled ambient conditions will delineate 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. Measurement 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.

Zero Gravity

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 A-7) 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 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),

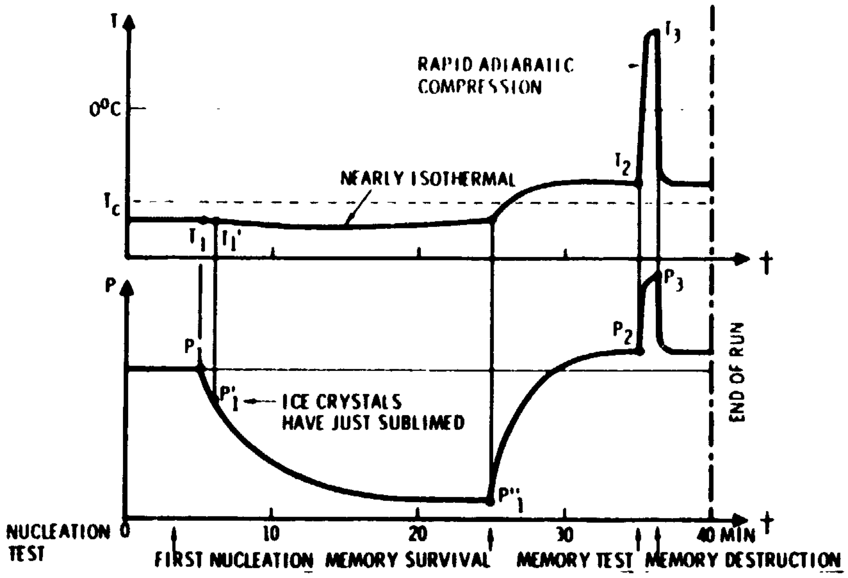

Figure A-7. Process of Adiabatic Expansion Chamber for Memory Study

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 at -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 mechani m, 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 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 (10^5 N/m^2) or slightly less.

MEASUREMENT AND DATA REQUIREMENTS

Chamber pressure, temperature and relative humidity will be measured. Photographs will provide data storage of the quantities of ice crystals 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 A-7)	20
• Establish pressure P_1	
• Generate supercooled fog using steam source	5
• Inject nuclei sample	5
• Photograph nucleated droplets and following events	
• Quasi-isothermal expansion of 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

A.14. TERRESTRIAL EXPANSION CHAMBER EVALUATION

CLASS

TERRESTRIAL EXPANSION CHAMBER EVALUATION

COMPATIBLE CHAMBERS

Primary E (Experiment Description)

Alternate

ASSESSMENT

Priority - A **Achievement Ability** - B **Applicability to Zero-G** - A

VARIABLES

	Primary	Secondary
Size	Rate of Cooling	
Type	Ion Level	
Charge	Initial Conditions	

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 particicpate 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 an 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 due to errors 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 and 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.

A. 15. CONDENSATION NUCLEI MEMORY

CLASS

CONDENSATION NUCLEI MEMORY

COMPATIBLE CHAMBERS

Primary E

Alternate CFD
SDL
SDI
Unique (modified SDL or CFD) (Experiment Described)

ASSESSMENT

Priority - C **Achievement Ability** - B **Applicability to Zero-G** - C

VARIABLES

	Primary	Secondary
Size	Relative Humidity	
Type	Time	
Pressure	Temperature	

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 preconditioning (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 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 A-8.) The temperature of the pre-processing chamber is the same as that of the drying chamber, and it is 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.

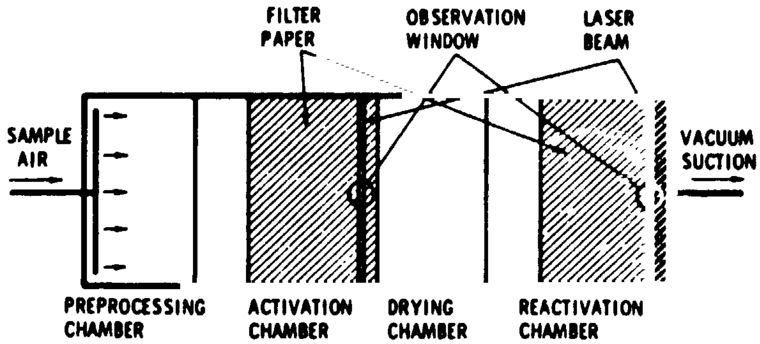

Figure A-8. Apparatus Design for Nuclei Memory Experiment

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 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 before launch. 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 preprocessing 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 preprocessing 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 A-8.

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	5-30
• Purge chambers	5
• 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

A. 16. NUCLEI MULTIPLICATION

CLASS

NUCLEI MULTIPLICATION

COMPATIBLE CHAMBERS

Primary G

Alternate E (Experiment Description)
CFD

ASSESSMENT

Priority B **Achievement Ability** - A **Applicability to Zero-G** - A

VARIABLES

Primary		Secondary
Size	Relative Humidity	Pollution
Type	Charge	Sound
Pressure	Electric Field	Turbulence
Temperature	History	Gases

NUCLEI MULTIPLICATION EXPERIMENTS

INTRODUCTION

Objective

Determine the processes and extent of nuclei material breakup.

Application

The extend 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 breakup 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 diameter by 45 cm high will be sufficient for a duration of several minutes, 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 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 A-9). 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 2.1×10^{-4} gm. Assuming twice this value to include the purge system gives 4.2×10^{-4} gm of water. A desiccant such as molecular sieve can absorb 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.

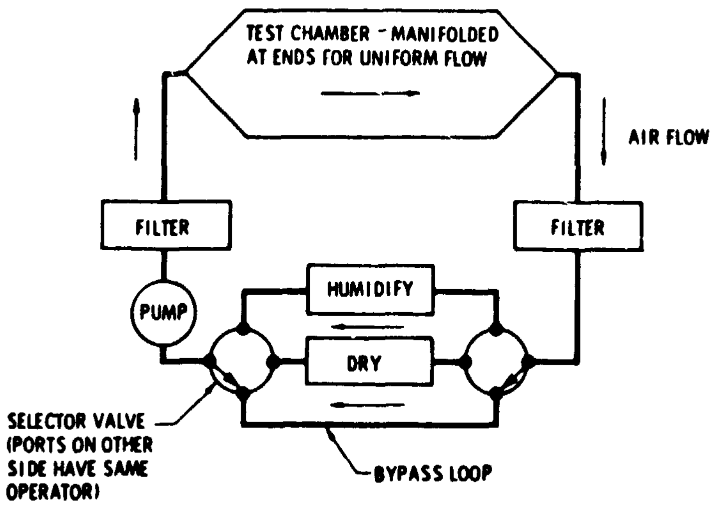

Figure A-9. Purge System Schematic

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 A-10.

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., nuclepore filter) will be used to prevent salt particles from entering the humidity control section and also to prevent particles from entering the chamber.

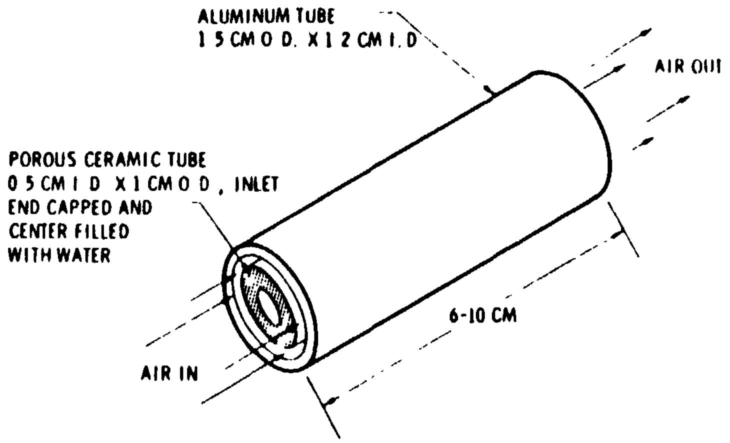

Figure A-10. Humidifier

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	10
• Insert solution droplet(s)	1
• Photograph evaporation rate and motion	2
• Expand to supersaturation	1
• Photograph resulting droplets	
• Recompress-evaporate droplets	2
• Expand photograph droplets	1
• Recycle with more droplets of the same size (15 times)	
• Recycle for other droplet sizes (4 sizes)	
• Recycle for other humidity values (4 values)	
• Recycle for other temperatures (4 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)

A. 17. DROP COLLISION BREAKUP (>0.5 mm)

CLASS

DROP COLLISION BREAKUP (>0. 5 mm)

COMPATIBLE CHAMBERS

Primary G (experiment Description)

Alternate SDI

ASSESSMENT

Priority - A **Achievement Ability** - C **Applicability to Zero-G** - C

VARIABLES

Primary		Secondary
Size	Electric Field	Gases
Pressure	Velocity	
Temperature	Surface Tension	
Relative Humidity	Kinetic Energy	
Charge		

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 impace on shaping the rain drop size distribution. Soil erosion, rain-induced crop damage, and damage to high-speed aircraft are of concern. A better understanding of the role of drop breakup in cloud physics processes would result in increased understanding of the droplet growth mechanisms within clouds, which in turn would contribute 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. Growth beyond a few tens of micrometers involves collision and coalescence processes. In order for these 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.

Much work in cloud physics has started with drop-size distributions to work "backward" to deduce the "starting conditions" within a cloud so that the mechanism that started the rain might be found. However, drop breakup could modify the diffusion and coalescence produced drop-size dsitribution to such an extent that the above extrapolation is not legitimate (c. f. , JAS 27, 101, (1970). This breakup would then explain why the median volume diameter does not change as the rain intensity exceeds 70 to 100 mm per hour. Also, if the breakup exists, soil erosion theory could predict erosion due to rain simply by using the rain intensity.

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 the 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	2
• Recycle with other velocities, diameters and trajectories	
• Recycle with various surface tension and viscosities	
• Recycle with sound and electric fields	

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A. 18. COALESCENCE EFFICIENCIES

CLASS

COALESCENCE EFFICIENCIES (<100 μm)

COMPATIBLE CHAMBERS

Primary G (Experiment Description)

Alternate SDI

ASSESSMENT

Priority - A Achievement Ability - C Applicability to Zero-G - B

VARIABLES

Primary		Secondary
Size	Charge	Surface Tension
Pollution	Electric Field	
Pressure	Velocity	
Temperature	Kinetic Energy	
Relative Humidity		
Gases		

COALESCENCE EFFICIENCIES EXPERIMENTS (< 50 μm)

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, collisions between millimeter diameter droplets representing 10 μm droplets will be studied 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 1,000 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 practica analog which accurately simulates the motion with large drops involves reducing gravity and then scaling the diameter and velocity of the droplets to experimentally appropriate values. Recent work has suggested that mathematical models will then give the correct interaction dynamics thus 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.

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.

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

ν = η/ρ' = kinematic viscosity of air

η = dynamic viscosity of air

ρ' = density of air

ρ = 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 = 1,000 μm to simulate the behavior of 10 μm 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 0.05 cm 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	5
• 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.

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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

A. 19. STATIC DIFFUSION CHAMBER EVALUATION

CLASS

STATIC DIFFUSION CHAMBER EVALUATION

COMPATIBLE CHAMBERS

Primary SDL (Experiment Description)

Alternate CFD

ASSESSMENT

Priority - A **Achievement Ability** - B **Applicability to Zero-G** - A

VARIABLES

Primary		**Secondary**
Size	Temperature	
Type	Relative Humidity	
Pressure		

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 as indicated by the present attempts to dissipate the warm fog-smog combination in the Los Angeles International Airport area which 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 competive, resulting in a narrower droplet size distribution. The resulting size and numbers of cloud droplets have an important role in determining 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 A-11. 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 temperature and the internal pressure of the static diffusion chamber determine the relative humidity distribution within the chamber. A portion of a preconditioned standard nuclei sample 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

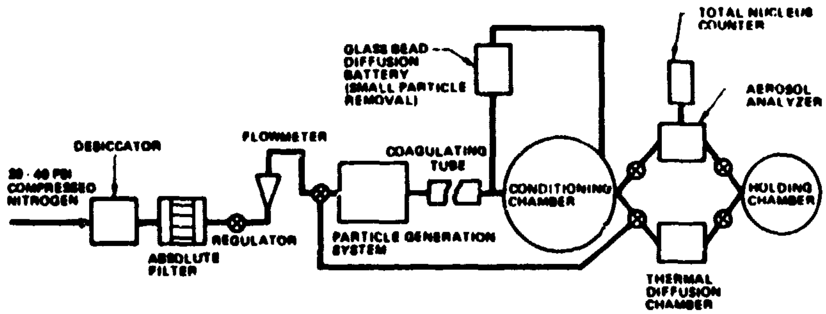

Figure A-11. Thermal Diffusion Flow Diagram

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.

INSTRUMENTATION

A terrestrial static thermal diffusion chamber with representative dimensions as used by the Calspan Laboratories is given in Figure A-12.

The upper and lower plates are wetted. A temperature gradient is applied across the chamber by controlling the upper at T_2 and the lower plate at T_1. This ΔT (1°C to 10°C) and the moist surfaces establish 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

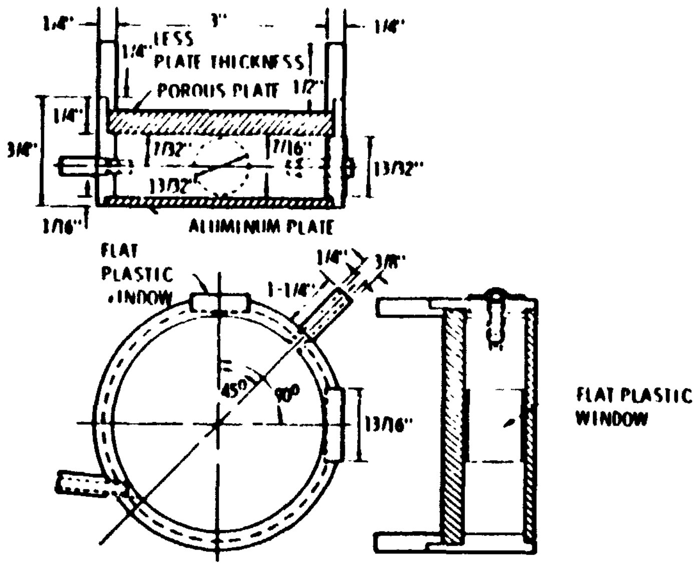

Figure A-12. Cornell Aeronautical Laboratories' Thermal Diffusion Chamber

plates of around 1 cm, which is independent of gravitational considerations. Thus, these dimensions basically apply 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 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.

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 (10 times)	
• Recycle with different relative humidities (4 values)	
• Recycle with different standard nuclei (6 types)	

This chamber will also permit a clearer determination of the effective time limits on such chambers imposed by phoretic forces.

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Contributors	Affiliations
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A.20. UNVENTILATED DROPLET DIFFUSION COEFFICIENT

CLASS

UNVENTILATED DROPLET DIFFUSION COEFFICIENT

COMPATIBLE CHAMBERS

Primary SDL

Alternate E
G
SDI (operating above freezing) (Experiment Described)
CFD

ASSESSMENT

Priority - B   Achievement Ability - B   Applicability to Zero-G - A

VARIABLES

Primary		Secondary
Size	Temperature	Charge
Type	Relative Humidity	Gases
Pollution	Electric Field	
Pressure	Ventilation	

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 "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 condirions. 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
- Temperature
- 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	10
• 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

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