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UNIVERSITIES SPACE RESEARCH ASSOCIATION

FINAL REPORT

ANALYTICAL STUDY OF THE ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) EXPERIMENTS

March 5, 1976 to September 5, 1977

By:

Dr. M. H. Davis

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INTRODUCTION

This is the Final Report on the ANALYTICAL STUDY OF THE ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) EXPERIMENTS, NASA Contract NAS8-31901, with the Universities Space Research Association. During the past year the USRA program (Low Gravity Cloud Physics) has been directed by Dr. M. H. Davis and headquartered at 2005 Broadway, Suite 1, Boulder, Colorado.

The concept of low gravity laboratory cloud physics was originated in the late 1960's and the ACPL was pursued under sponsorship by Marshall Space Flight Center (MSFC) as a proposed facility payload for the Space Shuttle. A major feasibility study was carried out by McDonnell Douglas Astronautics Company in 1973-74. MSFC continued planning activities, culminating with preliminary design studies by General Electric Company and TRW, Inc. during 1976. On March 5, 1976, USRA undertook a year-long coordination and liaison effort to bring the best scientific talent to ACPL planning, under Contract NAS8-31901.

The activities of the contract year are summarized in this Final Report. Chapter 1 gives a sketch of the background of the program, together with general conclusions based on the year's experience. Chapter 2 is a list of USRA Cloud Physics Consultants. Chapter 3 gives a description of the ACPL itself. Chapter 4 is a justification of the ACPL as a Shuttle payload and an analysis of experiment classes that appear particularly promising. In Chapter 5 USRA activities during the contract year are detailed, concluding with a list of reports and memoranda.

The Program Director wishes to express sincere appreciation to the members of the USRA Consultant Team; to Dr. Robert E. Smith, Dr. Jeff Anderson, Mr. Charles Ellsworth and Mr. Charlie Johnson, MSFC; and to the GE and TRW ACPL teams, led by Robert Greco and O. W. Clausen.

THE USRA CLOUD PHYSICS PROGRAM - BACKGROUND AND CONCLUSIONS

During the thirteen months, March 5, 1976, to April 5, 1977, the USRA Cloud Physics Program has worked closely with the NASA Marshall Space Flight Center; the two Preliminary Design Contractors, (General Electric Company and TRW, Inc.); and with the scientific community to facilitate the development of the Atmospheric Cloud Physics Laboratory (ACPL) as a useful payload for the Space Shuttle. Our technical efforts were directed toward:

1) the formation of Scientific Functional Requirements for the initial ACPL that would permit a meaningful set of experiments to be carried out and that would have growth capacity.
2) the formulation of plans and priorities for ACPL development.
3) providing the two Phase B Contractors, GE and TRW, with informed scientific advice.

Beyond these specific tasks, the USRA role was seen to be one of broad liaison with the scientific community and NASA to:

a) interpret the ACPL concept of laboratory cloud physics experimentation within an Earth orbiter.
b) to act as advocate for the program.
c) to identify potential Principal Investigators for the program and to involve them early in planning and in related investigative efforts.
d) to publicize the program and act as a source of information about it.

Conclusions to be drawn from the USRA Cloud Physics Program fall into two categories. One concerns the ACPL itself; the proposed functional requirements for the initial laboratory, its potential for research in a number of important areas of cloud microphysics, our

recommendations for developmental growth. The other concerns lessons learned in how best to carry out liaison with the two contractors, with NASA, and with a group of scientists; how to publicize a new space venture such as this; how to involve space-inexperienced researchers; how to "recruit" potential P.I.'s; how to achieve the necessary coordination between different experimenters and different experiment programs.

An important general conclusion of the USRA study is that while the ACPL presents exciting new opportunities for basic research in cloud microphysical processes, the contributions of such research that are foreseen at present are nearly all of a fundamental nature. Applications of ACPL research results will, in time, be made to programs dealing with pollution, weather modification, and long-range forecasting. But so far, at least, ACPL experiments do not appear to deal directly with such applications. These comments should not be interpreted as casting doubt on the utility of ACPL research, however. It is a fundamental principle that solid advances in applied science can only come about through reliable understanding of the basic underlying physical processes. It is here that ACPL research will make a unique contribution.

The design of the initial ACPL, described in Chapter 3, is the outcome of close interactions of USRA consultants, with NASA, and the two contractors. It presents our best effort at providing a facility that can perform significant research, has growth potential, and is technologically feasible.

In our role of providing liaison with the university community and acting as interpreter and advocate for the ACPL Project, we initially identified a group of over 600 atmospheric scientists who through affiliation, from our own or NASA's experience, or through

publications, appeared to be potentially interested in the project. On the basis of responses to an initial mailing, this list was narrowed down to about 400, of whom about 150 are highly interested.

The original group of scientists with whom NASA had been previously dealing in the ACPL Program, through the Phase A Feasibility Study of McDonnell Douglas Corporation and the initial proposed set of functional requirements put together at Marshall Space Flight Center, was expanded to include a number of new people to form the USRA Consulting Team. This enlarged group has contributed very actively to the program through meeting attendance and through production of written materials. Subgroups were formed in the areas of warm cloud forming experiments (headed by Patrick Squires), ice processes (headed by Gabor Vali), scavenging (headed by K. V. Beard), electrification (headed by John Latham). The direct payoff of group meetings and reports has been the formulation of experiments and the specification of functional requirements. A very important indirect payoff is the committed involvement of outstanding experts who will undoubtedly become P.I's in the program.

Besides the sort of activities just described, a very effective way to involve scientists in the program is through award of small research grants to investigate either promising experiment areas or technical problem areas for the ACPL. The results of such support are, again, the specific research results, together with commitment of scientists to the program.

Our general conclusion, based upon experience with the Cloud Physics Program, is that potential PI's are best identified and brought into a NASA program through personal contacts. There is no substitute for the personal scientist-to-scientist approach to liaison and coordination.

This is, we believe, an area where USRA has demonstrated ability and can add significantly, not only to the ACPL Program, but to other NASA programs as well.

Chapter 2

USRA CLOUD PHYSICS CONSULTANTS

	Affiliation
+Kenneth V. K. Beard	University of Illinois
William L. Briggs	USRA, Boulder (no longer employed)
Horace R. Byers	Retired
+Milford H. Davis	USRA, Boulder
June S. Ewing	USRA, Boulder (no longer employed)
Neville Fletcher	University of New England, Australia
Norihiko Fukuta	Denver Research Institute
Donald E. Hagen	University of Missouri, Rolla
George M. Hidy	ERT, Inc., Westlake Village, California
+James L. Kassner, Jr.	University of Missouri, Rolla
Joseph L. Katz	Clarkson College, Potsdam, NY
Ulrich Katz	Calspan Corporation, Buffalo
*Charles A. Knight	National Center for Atmospheric Research, Boulder
Robert C. Knollenberg	PMS, Inc., Boulder
+Warren C. Kocmond	Calspan Corp., now DRI/Reno
John Hallett	Desert Research Institute, Reno
Peter Hobbs	University of Washington
John Latham	University of Manchester, England
Zev Levin	National Center for Atmospheric Research, Boulder
Hendricus G. Loos	Laguna Research Labs, Laguna Beach, CA
Volker A. Mohnen	State University of New York, Albany
Rosa G. de Pena	Penn State University
Myron N. Plooster	Denver Research Institute
Hans Pruppacher	University of California, Los Angeles

USRA CLOUD PHYSICS CONSULTANTS (continued)

John Ross	Massachusetts Institute of Technology
Georg Rupprecht	Rupprecht and Patashnick, Denver, CO
+Robert E. Ruskin	Naval Research Laboratory, Washington D.C.
*J. Doyne Sarter	National Center for Atmospheric Research, Boulder
Clive P. R. Saunders	University of Wyoming (visiting professor, now returned to UMIST, England)
+Patrick Squires	Desert Research Institute (now NCAR, Boulder)
Sean Twomey	University of Arizona
+Gábor Vali	University of Wyoming
*Helmut Weickmann	NOAA, Boulder
Allen Williams	Independent Consultant

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* Not paid a consulting fee by USRA

+ Core group

Chapter 3

INITIAL ACPL SPECIFICATIONS

THE SPACE SHUTTLE AND SPACELAB

Starting in mid-1980 and every few months thereafter, the Space Shuttle will be launched into orbital flight carrying the Spacelab in its payload bay. Spacelab is a large tank-like structure that will provide a human technician ("payload specialist") with an enclosed "shirt-sleeve" environment in which he can carry out experimental procedures using the scientific equipment provided. After a few days in orbit, the Shuttle will return to Earth with personnel and equipment.

THE ACPL

The ACPL (Atmospheric Cloud Physics Laboratory) occupies two racks within the Spacelab. The initial ACPL is now scheduled to fly aboard Spacelab 3, to be launched in mid-1980. The illustration (from TRW promotional literature) shows the ACPL - Spacelab - Space Shuttle system, together with a suggested arrangement of component elements within the ACPL.

EXPERIMENTAL CHAMBERS

As presently conceived the ACPL has three experimental chambers: a Continuous Flow Diffusion Chamber patterned after the instrument under development by Squires and Hudson at Desert Research Institute, Reno; an Expansion Chamber with precisely controlled wall temperature and very accurate thermal uniformity, based in part on the chamber development of Kassner and co-workers at University of Missouri/Rolla; a Static Diffusion Chamber for above-freezing temperature operation, based on the well-developed design used by Ruskin, Twomey, Rocmond, and others. A major part of the ACPL consists of thermal and fluid control subsystems for the experimental chambers.

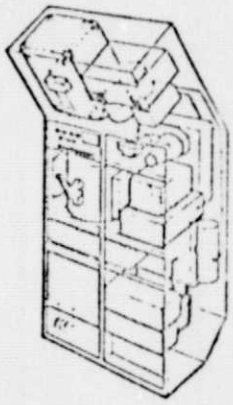
AIR CLEANING, HUMIDIFYING, AEROSOL GENERATION

Subsystems are provided for careful preparation of cabin air before it is used in the ACPL. In addition there are aerosol generators and mixing and dilution systems, together with a precision saturator designed to provide air to the expansion chamber under conditions of precisely known relative humidity and temperature. In conjunction with the aerosol generation subsystems there will be several aerosol characteristizers designed to give information about the size distribution of the aerosol particles. The Continuous Flow Diffusion Chamber provides the cumulative spectrum of critical supersaturation for the aerosol.

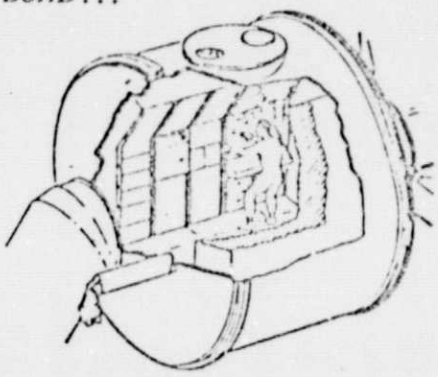
DETECTION AND REAL-OUT

On the first ACPL flights detection and read-out of information will be through camera systems, with film developed upon return to earth after the mission. However, several systems are currently under development for direct real time read-out of particle number density and size spectrum and such a system will likely be included in later ACPL flights.

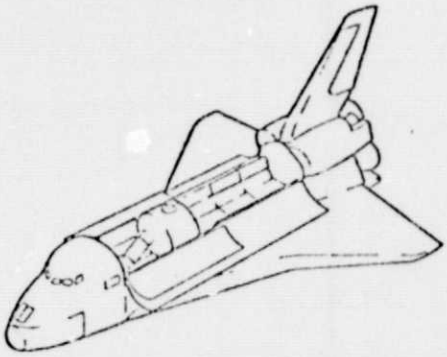
THE ATMOSPHERIC CLOUD PHYSICS LABORATORY . . .

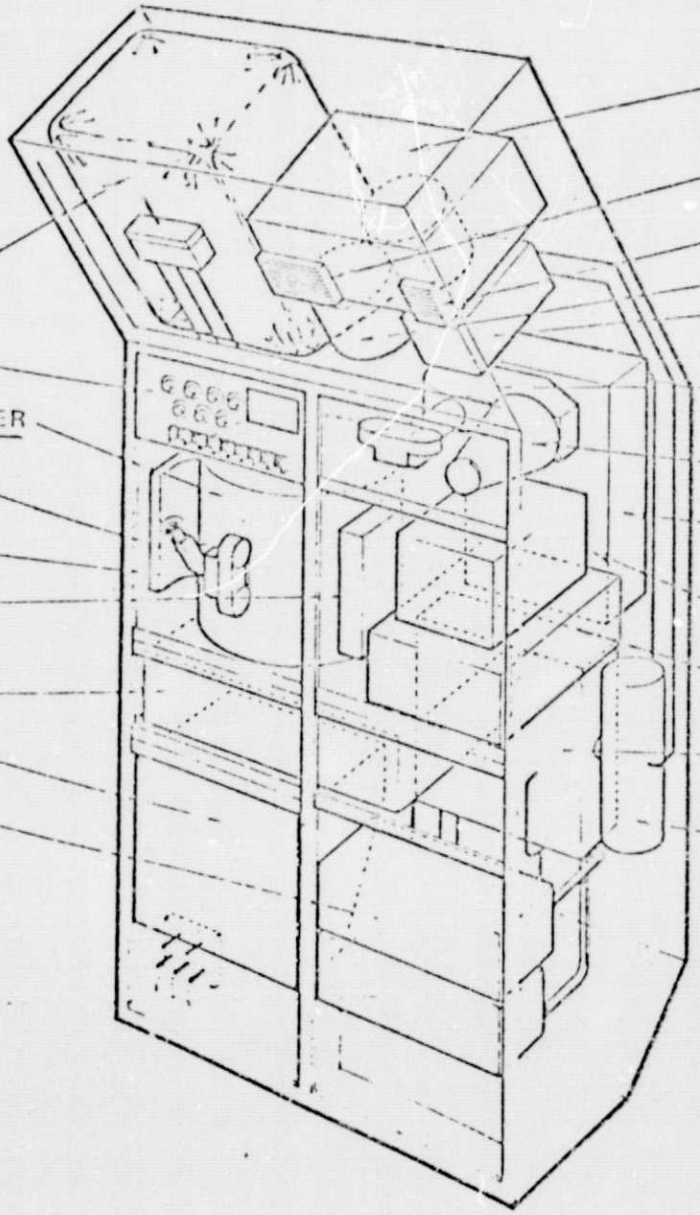


. . . A SPACELAB PAYLOAD . . .



. . . TO FLY IN SHUTTLE





Courtesy of TRW, Inc.

DISCUSSION

The following paragraphs give more specific details on design specifications for the ACPL as planned for the first mission, together with a limited indication of future developmental directions. In its initial configuration the Laboratory is designed primarily for warm cloud-forming experiments, although the ability to operate the expansion chamber down to -25°C will be provided. In addition, an entry port in the Expansion Chamber will permit limited use as a general environmental chamber. Studies contemplated include cloud formation with precisely determined vapor content and on fully characterized soluble aerosols; droplet growth studies; droplet freezing and nucleation of freezing; ice crystal growth habit; studies of Brownian and phoretic scavenging, etc.

MORE DETAILED SPECIFICATIONS

AIR CLEANING

Spacelab cabin air will be drawn into the ACPL and passed through the air cleaning subsystems to remove impurities, both gaseous and particulate. Specifications call for removal of organic compounds (exclusive of methane) to 0.1 ppm-carbon; together with removal of all particles with radii greater than 0.001 micron to $0.1/cm^3$ or better.

AEROSOL GENERATION

Specifications call for NaCl and H_2SO_4 generators: 0.01 to 0.1 micron radius; number density 100 to $1000/cm^3$. Range of critical supersaturation: 0.05% to 3%. Aerosol is to be of highest attainable purity. Ability to produce narrow size distributions is provided. Aerosols are to be brought into charge equilibrium. Similar volumes of aerosol-laden air are to be provided over a 45 minute period to allow repeated experiments. A growth capacity of adding a third aerosol generator provided by a Principal Investigator (e.g. AgI) is called for.

AEROSOL COUNTER SUBSYSTEM

Total aerosol count; multi-channel sizing over the range 0.01 to 0.1 micron radius (4 channels, factor of 2 accuracy). Collection for electron microscopy after the flight.

THE SATURATOR

This provides saturated air for the xpansion hamber at precisely known temperature and pressure so that the water vapor mixing ratio is determined to better than 1%. No condensation is permitted between the Saturator and the Expansion Chamber.

CONTINUOUS FLOW DIFFUSION CHAMBER (CFD)

The Squires-type CFD chamber will accommodate supersaturations in the range of 0.05% to 3%, with primary operating range 0.1% to 1%. The overall accuracy of the instrument is to be of the order 1 - 3%. The primary function of the CFD will be to characterize the aerosol according to its

spectrum of critical supersaturation. On later flights, it may be used in droplet growth studies.

EXPANSION CHAMBER

The chamber will have an internal volume of at least 25 liters. It will be provided with viewing and photography ports, as well as a port (2 cm min dimension) to permit insertion of a probe. Walls will be treated so as to stand off condensation up to 3% supersaturation. In operation the temperature of the chamber walls will be controlled very precisely so that nearly adiabatic conditions are maintained in the central region during expansions. Cooling rates of 0.5°C for up to 60 min (range 20°C to -25°C); 6°C/min for 1 min at temperatures above freezing. Pressure control to match for adiabatic expansions, with pressure measurement to 0.1 mb (static) and 0.5 mb during changes. The basic temperature accuracy is to be 0.1°C with subsequent improvement in later missions. (The problem of maintaining minimal wall influence after the onset of cloud formation is under intensive study.) Follow-on capabilities will include controlled limited re-compression, operation at lower temperatures, equipment for electric field and charging experiments.

STATIC DIFFUSION CHAMBER(SDL)

This is designed to permit the supersaturation in the central region to be known to about 1% of its value (which will be between 0.05% and 3%) for above-freezing operation. In configuration the chamber will be essentially like terrestrial chambers of conventional design. Later ACPL's may include a static diffusion chamber for ice growth experiments.

OPTICAL DETECTION AND COUNTING

This will be accomplished by means of camera systems. Counting data are to be to 3% accuracy for droplets with radii greater than 2 microns within a central region of the expansion chamber and the SDL. Frame rates are to be 3/sec for short times; 1/sec for up to 4 minutes. Sample volume of 1000cm^3 in the Expansion Chamber for ice studies with relaxed detection requirement. Real time droplet sizing and counting by electronic means may come as a later development.

JUSTIFICATION AND ANALYSIS OF THE ACPL

A. Justification

The Atmospheric Cloud Physics Laboratory (ACPL) is planned as a facility payload for Spacelab. In common with many other experimental facilities, it is designed to exploit the very low gravity that will exist in the Shuttle during orbital flight. In the case of the ACPL, this means that clouds and cloud particles, droplets and ice crystals, can be studied without the problems of convective air currents and particle settling. The properties of clouds formed under very carefully controlled conditions can be measured with unprecedented precision over long periods of time. Droplet growth can be monitored, a cloud can be cooled down to subfreezing temperatures and freezing of individual droplets observed. Single particles or small collections of particles can be isolated and studied as they float in a chamber without support.

The ACPL is a new research tool. It will permit observations that can never be possible on the Earth where convection and particle settling invariably occur. But it must be noted that the ACPL is fundamentally a basic research facility. Clouds and other processes that naturally occur in the atmosphere are generally not going to be duplicated or even closely modeled. The reason: gravity, effectively absent in the orbiting laboratory, is the driver for many of the most important atmospheric processes. Buoyant convection drives severe storms; differential particle settling leads to coalescence growth. But in the ACPL, where these conditions do not apply, the cloud physicist can study diffusion and other gravity-independent phenomena in isolation. Moreover, by permitting clouds formed under carefully controlled conditions to be studied for many minutes, slow processes such as the absorption of gases and the tendency of droplets to pick up small particles can be investigated.

It is reasonable to expect that experiments in the orbiting ACPL will lead to significant advances in cloud microphysics which will then impact on such national goals as weather modification and improved weather and climate prediction. The connections are sometimes through a rather long chain of reasoning, as might be expected for basic research. But the impact is nonetheless real. Enhanced understanding of the cloud forming process will lead to improvements in our knowledge of the rate of droplet growth and evaporation, the effect of pollutants on cloud growth, the effect of the nature of the tiny aerosol particles always present in the atmosphere on the clouds that form out of water vapor that condenses on them. We may then be able to answer the question: why do some clouds produce rain while other similar clouds fail to grow? Thus new concepts for weather modification may emerge.

Since ice particles grow rapidly and influence much of the development of severe storms, ACPL experiments that lead to increases in knowledge of how cloud droplets freeze and how the resulting ice particles grow will directly enhance our ability to predict the development of severe storms and may lead to improved methods for modifying them.

Besides experiments relating to cloud formation, freezing and scavenging, the ACPL will provide a new potential for study of electrical phenomena. At the present time it is still not known which mechanisms that have been proposed are most important in producing the very strong electric fields observed in thunderstorms, nor is it known how electrification influences cloud development. The unique ability to employ very large drops will permit new critical experiments to be performed in the ACPL.

Another promising area of experimentation is the turbulent mixing of cloudy and dry air. At present the basic physical processes of inhomogeneous turbulent mixing are very poorly understood, and experiments on the Earth are made very difficult

by the presence of convective air movements. Such experiments, if successful in the ACPL, may lead to new appreciation of the factors that determine how cumuli develop and organize into storms, as well as contributing to knowledge of turbulence aloft -- an important factor in aircraft safety.

One cannot promise that successes in basic research will necessarily lead to chosen practical results. However, it is safe to state categorically that goals such as effective weather modification and improved prediction will only come about as a result of improved understanding of the underlying physical processes of meteorology. Since the ACPL promises significant advances in the field of cloud microphysics and certain related areas, results that come from it will be significant in all parts of meteorology where the details of microphysical processes influence the behavior of larger scales in an important way.

B. Analysis of Experiment Classes

I. Warm Cloud-Forming Experiment

The basic cloud-forming process in the atmosphere is this: moist air containing many tiny airborne particles ("aerosols") cools to the point where water condensation can occur. The aerosol particles act as nuclei, centers upon which water vapor condenses to form small droplets a few microns in radius. For a particular cooling rate and water vapor content, whether a particular embryo droplet will continue to grow or not depends upon a delicate balance involving the factors mentioned and the properties of the condensation nucleus. The chemical and physical characteristics of the aerosol particles influence profoundly the nature of the clouds that form, their likelihood of producing rain or other precipitation, and even whether they will collect together to form a major storm system or dissipate. (Here and elsewhere in this report emphasis is on convective clouds,

although ACPL results will contribute to understanding non-convective clouds as well.)

At the present time it is believed that the basic cloud-forming process is understood fairly well, "to maybe a factor of 2." This is in contrast to uncertainties about some of the ice processes in clouds as large as factors of 1000 between "similar" experiments or between experiment and theory. Since the cloud-forming process is fundamental to all of cloud physics, it would be very desirable to verify the theory to high accuracy. This verification cannot be done on the Earth, primarily because gravity-driven convection within laboratory cloud chambers immediately introduces uncertainties. In the ACPL, where convection is effectively suppressed, the cloud-forming process can be studied in detail and with a precision quite impossible on the Earth.

The cloud-forming experiment will be performed by generating aerosol particles (initially of NaCl, later using other substances) which are diluted to the proper concentration, mixed into the air stream, passed through physical characterizers to study their chemical and physical properties, then directed through a Continuous Flow Diffusion Chamber (CFD) which precisely measures their nucleating properties. Specifically, the CFD measures the number of particles that nucleate drops at a specific chosen level of water vapor supersaturation.* The aerosol-laden air, to which a very precisely measured concentration of water vapor has been added in the Saturator, is passed into the Expansion Chamber. There it is cooled adiabatically through expansion with precise wall temperature control and a cloud forms. The basic data is gathered by photographic measurements of the number density of droplets in the cloud. This result is compared with a theoretical

*The Static Diffusion Liquid Chamber (SDL) will also be used for this purpose as a back-up and to gain experience with this popular research instrument in low gravity, although it is inherently less accurate than the CFD. (The SDL also will serve to perform a very sensitive test on the quality of the air used in ACPL experiments.)

prediction based upon the aerosol measurements and knowledge of the adiabatic cooling rate, temperature, and water vapor content. This experiment, devised by Dr. Patrick Squires of the Desert Research Institute, University of Nevada, in collatoration with Dr. James Kassner, Jr., University of Missouri/Rolla, is basic to all cloud physics.

Results will lead to a refining of the underlying theory of warm-cloud formation and to an improved value for the "sticking coefficient," a quantity that enters into a full gas-kinetic treatment of droplet diffusional growth. There is, of course, the chance that something quite unexpected will be discovered, although this appears unlikely. In performing research that contains an unfamiliar element, here the low gravity, there is great advantage in beginning with an experiment whose interpretation should be fairly straightforward and whose theory is believed to be well understood. Although it demands great precision and very delicate controls on temperature, humidity, and pressure, the warm cloud-forming experiment appears to stand a very good chance of producing the desired results. It also has the desirable feature of being an excellent benchmark and check-out for the ACPL as a whole, as well as for the concept of low-gravity laboratory cloud physics.

II. Aerosol Research

The Warm Cloud-Forming Experiment makes use of aerosol generators and associated equipment to produce condensation nuclei, but its primary purpose is to investigate the kinetics of the cloud forming process. Its analysis effectively begins at the point in the procedures where the aerosol is characterized according to critical supersaturation by the Continuous Flow Diffusion (CFD) Chamber.

Another emphasis is to study primarily the nucleating properties of the aerosol itself, along with its behavior in very low gravity. This research

is directed toward relating the chemical and physical properties of the tiny aerosol particles to their ability to nucleate the condensation of water from the vapor (and also their ability to nucleate freezing, although this is a more complex research problem and is usually considered separately.) There is also considerable interest in how aerosols change through coagulation over time as a function of the particle density and particle characteristics. Investigation of this matter in the absence of convection holds promise of permitting the separation of various competing mechanisms that cannot be resolved on Earth.

Aerosol research will be a part of the warm cloud-forming experiment. If the cloud-forming experiments are carefully designed with multiple research goals in mind, and aerosols used as nuclei eventually are generated from a variety of materials (NaCl, H_2SO_4, non-wettable materials, AgI, etc.), results of interest both for cloud formation and for aerosol research will be obtained. Mr. Warren Kocmond, DRI, University of Nevada (Formerly of CALSPAN Corp., Buffalo) had led the USRA effort to plan for investigation of aerosols in the ACPL.

III. Droplet Growth Experiments

Cloud droplets grow initially by condensation of water vapor. After the formation of a cloud, droplets continue to grow and, under certain conditions of the time-behavior of supersaturation within the cloud, the collective behavior of the drops can become rather complicated. Theory indicates that certain drops may grow, while others simultaneously evaporate. This process, known as Ostwald Ripening, is prohibitively difficult to observe in an Earth laboratory because of the interference of convection, although there may be times when it operates in the free atmosphere. An experiment has been suggested by Dr. Donald Hagen, University of Missouri/Rolla, to attempt to observe this

phenomenon in the ACPL. Since it demands extremely close control of temperature and pressure over long periods of time (many minutes), it will be a difficult experiment even in low gravity. The Expansion Chamber would be used.

Other droplet growth experiments have been suggested that involve observation of single drops or small collections of drops within the Static Vapor Diffusion Chamber (SDL). Details have not yet been fully worked out. The importance to atmospheric science is the ability to determine improved values for such quantities as the sticking coefficient, the thermal accommodation coefficient, and the evaporation coefficient which appear in a full gas-kinetic treatment of diffusional growth and have heretofore been extremely difficult to measure.

IV. Ice Experiments

Ice particles in the atmosphere are known to play a vital role in most severe storm precipitation. Yet the details of how ice forms in clouds, the manner in which ice particles grow, and how ice that forms at one location spreads throughout the clouds are all poorly understood at the present time. In order for a water droplet to freeze when the temperature drops below zero Celsius, it must be nucleated. (Droplet freezing without foreign nuclei occurs at extremely low temperatures and only under very special conditions in the atmosphere.) Freezing nuclei are extremely complex and perverse in behavior. The temperature at which a given nucleus will cause a droplet to freeze is dependent upon its chemical composition, its physical form, its history within the atmosphere (i.e. has it already acted as a freezing nucleus?), and perhaps other conditions. Detection and characterization of freezing nuclei are unreliable. It is known that they act in several ways: by contact, by pre-existing within the drop, and that some nuclei may allow ice to form

directly from the vapor. Separating these mechanisms for study has proved extremely difficult in the terrestrial laboratory. Uncertainties of factors of 10 to 1000 are common.

Once a drop freezes, ice grows by vapor diffusion and also, in Earth gravity, through collisions with other ice particles and supercooled water droplets. The form of this growth depends upon temperature, impurities, and other factors. Because water is a complicated molecule, theoretical understanding of the modes of ice crystalline growth is still very limited. One importance of the growth habit to atmospheric physics lies in the possibility of fragile dendritic forms fracturing to form small crystals which can then act as very efficient nuclei. Energetic electrification mechanisms also result from freezing and other ice growth processes.

Snow, soft-hail, and hail are weather phenomena that have great economic and social importance and so are a challenge to the atmospheric scientist to predict, to modify and control. Moreover, much of the rain that reaches the Earth has gone through a stage in which it was in the ice phase. The most important mechanism by which drops can grow rapidly in the early stages of the development of many clouds arises from the vapor pressure difference over ice and over supercooled water at the same temperature. An ice particle grows rapidly at the expense of nearby water droplets.

The ACPL offers a new opportunity to study many of these mechanisms in isolation and will certainly produce new and important information. The absence of convection will allow ice crystals to be grown in a purely diffusive environment, which is impossible to achieve on the Earth. Another important type of experiment will be to create a cloud of water droplets in the Expansion Chamber, then cool down to sub-freezing temperatures, cause a few drops to freeze, and observe their subsequent growth through vapor diffusion. If splintering occurs in low gravity, fragments will remain in the vicinity of

the source, again a totally new phenomenon. By use of different types of freezing nuclei and different means of mixing them with the cloud, it may be possible to separate the several possible nucleation mechanisms and thus to address one of the most pressing problems in cloud physics. A cloud once formed in the Expansion Chamber can be cooled, warmed, even re-evaporated. Thus memory or hysteresis phenomena will become accessible.

Experiments that deal with the vapor interaction between ice particles and supercooled water drops, or that deal with nucleation of freezing will be carried out in the Expansion Chamber. The Chamber as presently designed will have the limited ability to cool down to -25°C. A lower temperature of -40°C would be desirable and has been requested as a follow-on capability. The planned camera detection and data gathering system will be marginal for ice experiments, and a real-time electronic read-out system is needed. Such a system is currently being developed under USRA sponsorship.

Experiments dealing with the basic mechanisms of ice growth will be best performed using an "SDL" Chamber, a vapor diffusion chamber operated at below freezing temperatures. Such a chamber is planned as a follow-on after the first ACPL missions. It appears to be in some ways a simpler instrument than the other chambers planned.

A USRA Consultant Group under the direction of Dr. Gabor Vali, University of Wyoming, has made preliminary studies of ice experiments for the ACPL. This is a most important research area and one where there should be direct payoff in the form of information that will relate directly to severe storm modeling and to weather modification.

V. Scavenging Experiments

Water droplets and ice crystals in the atmosphere act as scavengers by picking up tiny airborne particles and by absorbing trace gases. Particles

are collected through differential settling and collisions, through electrostatic attraction, through Brownian collection -- brought about by random collisions with air molecules, and through diffusiophoretic and thermophoretic forces that arise from vapor and temperature gradients. Certain gases dissolve and enter into chemical reactions within water droplets, certain large molecules present in pollution form surface layers on drops or crystals. The importance of these phenomena arises not only in the ability of droplets and crystals thus to remove material from the atmosphere, but also because material that is not actually removed is frequently modified significantly. Moreover, the evaporation of drops and the growth characteristics of ice particles can be altered through interaction with trace chemicals.

A full understanding of microphysical scavenging mechanisms is essential if air pollution is to be predicted adequately and eventually brought under control. Moreover, even where the atmosphere is unpolluted by man's activities, removal and modification of naturally occurring particles and trace gases significantly affect both precipitation and atmospheric radiation.

Theoretical analysis of scavenging mechanisms is extremely difficult, particularly for particles in the "intermediate range" of sizes comparable to the free path of air molecules, and this is often the most important size class to consider. Many important chemical reactions are imperfectly understood and little is presently known about interactions involving ice crystals. Advances will come only through very careful experiments and the development of improved theories based upon the results of those experiments. However, Earth gravity causes droplets and ice crystals to settle differentially, and convection currents in the air always occur which make precise long-duration measurements nearly impossible. In the orbiting ACPL, particle settling will be unimportant, and convection is effectively suppressed. It should be pos-

sible to separate the various mechanisms for study and comparison with theory. Of course mechanisms that require ventilation or differential settling cann. be studied directly in the ACPL. Comparison between ACPL and ground-based laboratory results will be essential.

Experiments can be conducted that last for many minutes, making use of a single cloud of water droplets or ice crystals whose properties are known in great detail. Droplets or crystals, motionless within the Expansion Chamber, can be caused slowly to grow or to evaporate in the presence of small particles or trace gases, and subsequently removed for analysis.

The Expansion Chamber is well suited to scavenging experiments. Designed primarily for the cloud-forming experiment, the aerosol generation and characterization equipment, the Continuous Flow Diffusion Chamber, the Saturator, and the Expansion Chamber will be used to create a "well-documented" cloud. Provisions for mixing in another aerosol or trace gases to be scavenged are either provided or are under study. The ability to carry out a slow controlled recompression of a few percent is required for many scavenging studies. This will not be possible on the initial flights, but it has been called for as a laboratory growth requirement. Means must also be provided for removal of cloud particles for analysis.

Preliminary studies by the USRA group led by Dr. Kenneth Beard, University of Illinois, have shown the feasibility of scavenging experiments in the ACPL. Current technical problems do not appear insurmountable, and it appears scavenging experiments will be among the most significant in the ACPL program in terms of usable results that apply directly to environmental problems.

VI. Turbulence Experiment

Professor James Telford of DRI, University of Nevada, has proposed that the ACPL be used to study the details of turbulent mixing of cloudy and clear

air. Although turbulent mixing is known to be a determining factor in the evolution of a cumulus cloud, relatively little is known about its details. The opportunity afforded by the ACPL is to study turbulent mixing in the absence of convection. The droplets in a cloud within the Expansion Chamber would be used as tracers to follow the motions induced in air within the chamber and, in fact, observation of the behavior of the drops themselves will form a key part of the experiment.

Studies to design such an experiment for the ACPL are in the preliminary stage. This research area is vital to cloud physics and to the development of successful cloud models. USRA continues to support preliminary studies by Telford. The Expansion Chamber would be used for this research, together with associated camera systems for data gathering. The question of how best to induce turbulent motions in the air within the chamber is under investigation.

VII. Electrification Experiments

Highly charged cloud particles and hydrometeors together with the very strong electric fields in thunderstorms lead to greatly enhanced growth rates by particle collision and aggregation. This precipitation growth mechanism, together with the phenomenon of lightning, make the study of cloud droplet electrification an important branch of cloud microphysics. A large number of electrification mechanisms have been studied theoretically and in the laboratory, yet many questions remain and the ACPL presents a unique opportunity to resolve some of them. The advantage of a low-gravity environment for this particular class of experiments is that much larger drops can be studied than are possible to work with on the Earth. In the orbiting laboratory it will be possible to create and investigate the behavior of stable spherical water drops several centimeters in diameter. These very large drops can be charged to the point of disruption, which occurs when electrical stress exceeds sur-

face tension, and the break-up studied in detail. Phenomena that occur in microseconds for micron-sized droplets have characteristic times of milliseconds. Another great advantage of using large drops is the enhanced ability to photograph complex electrohydrodynamic events. The connection between these experiments and phenomena that occur in the Earth's atmosphere with very much smaller drops can be reliably made using existing theory.

A number of interesting and important experiments dealing with charged drop break-up and the dynamic behavior of charged drops have been suggested by Dr. John Latham, University of Manchester, and other USRA consultants. They are good examples of the use of the ACPL to carry out basic research that does not simulate directly atmospheric processes, but rather contributes to background knowledge of the underlying physics processes.

The electrification experiments proposed by Latham and collaborators will make use of the Expansion Chamber to provide a controlled environment and use of the camera system already planned. Droplet charging and control techniques must be developed, but no serious problems are apparent. The results from these experiments will provide important background information to aid in the understanding of severe storm electrification. The suggested experiments appear to be reasonably simple and seem likely to produce the anticipated research data.

A. Principal Meetings

All important meetings held during the contract year are listed in this section along with the USRA representatives who attended, the purpose of the meeting, and its specific results. Meetings with two individuals are listed only where their role was pivotal in the program development. (Meetings called by Marshall Space Flight Center are identified with an *; other meetings were on USRA initiative.)

March 18, 19, 1976 Preliminary Functional Requirements Meeting
University of Missouri, Rolla, Missouri

Kassner, Squires, Beard, Knight, Loos, Vali, Kocmond, Weickmann, Fletcher, Hidy, Davis, Ewing.
(also attended by Ellsworth and Anderson, NASA-MSFC)

The purpose of the meeting was to discuss and formulate, if possible, scientific functional requirements for the ACPL. An informal meeting report of 45 pages was prepared and distributed to the participants, NASA, and the Phase B contractors.

Specific results:

1) Affirmation of the importance of ice experiments early in the ACPL Program.

2) Discussion of the importance of scavenging studies, definition of many experimental difficulties.

3) Identification of: a) hydrophobic coatings, b) ice crystal detection, c) air quality standards as specific problem areas that need further study.

4) Appreciation on the part of all concerned of the extreme difficulty of specifying functional requirements for the ACPL in the absence of definite experiment plans.

5) Commitment of the participants to the ACPL concept and Program.

*April 14, 15, 1976 Requirements Review Meeting
Huntsville, MSFC, with NASA personnel, GE, and TRW

Davis, Hagen, Squires, Hallett, Vali, Kocmond, Beard, Ruskin.

The purpose was to discuss and refine the original functional requirements developed by MSFC personnel and interpreted by the two Phase B contractors.

Specific results:

1) Further discussion of ice experiments.

2) Detailed interaction between USRA consultant team and Phase B contractors.

May 4, 1976 Discussion of Electronic Drop and Ice Crystal Sensor
USRA Boulder Office

Davis, Vali, Knollenberg

The result was a proposal by Dr. Knollenberg to carry out a detailed investigation of electronic means for monitoring the drops and crystals within the expansion chamber. This study was subsequently funded by USRA.

May 6, 1976 Meeting to Define Condensation Experiments
USRA Boulder Office

Davis, Kassner, Squires.

The purpose of this meeting was to explore the differences in functional requirements for the Squires warm cloud-forming experiment and the Kassner condensation droplet-growth experiments.

The meeting was successful in clarifying the issues, and in making clear the source of the differences between requirements for these two experiment classes.

May 12, 1976 Discussion of Static Diffusion Chambers
USRA Boulder Office

Davis, J. Katz.

This meeting with Katz brought into focus the uses of the Static Diffusion Chamber (SDL-SDI) in the ACPL.

May 25-26 Scavenging Committee Meeting
Calspan Corporation, Buffalo, New York

Beard, U. Katz, Kocmond, Williams, Mohnen.

Preliminary meeting to define scavenging experiments for the ACPL and to take necessary steps toward specifying functional requirements for this experiment class. A draft report was prepared and distributed June 15, 1976; superseded by a final version of the report distributed

July 15, 1976. The report was reviewed critically by three other experts in the scavenging field and will be reissued in 1977.

Specific results:

1) The initial field of likely experiments was narrowed to three for careful consideration:

   a) scavenging of nearly monodisperse Aitken particles by a nearly monodisperse droplet cloud in the expansion chamber with subsequent impactor analysis.

   b) scavenging of nearly monodisperse Aitken particles by an ice cloud of uniform crystal size and habit in the E chamber with analysis by crystal impactor studies.

   c) droplet scavenging of SO_2 and resultant oxidation in the presence of NH_3.

2) Functional requirements were specified.

3) Specific equipment requirements emerged for:

   a) an approximately monodisperse Aitken particle generator
   b) ability to mix aerosols of several types
   c) recompression capability
   d) impactor collection of specimens.

4) Appreciation of both the capability of the ACPL for this experiment class, and of its likely importance to the ACPL program.

5) Involvement of a new group of potential P.I.'s.

* June 30, July 1,1976 Concept Review Meeting
Huntsville, MSFC

Davis, Beard, Kassner, Squires, Vali, Ruskin, Hagen, NASA representatives and GE, TRW representatives.

The purpose of this meeting was to acquaint the USRA team and the NASA representatives with the design concepts developed by the two Phase B contractors. Besides formal sessions, special evening meetings were held between the USRA team and each of the contractors.

The result of the meeting was a closer understanding on the part of the contractors of the science requirements and a better understanding on the part of the USRA team of the technical difficulties encountered by the contractors in meeting requirements. The functional requirements were reviewed and modified as a result of this meeting.

July 28, 1976 Liaison Meeting Regarding Scientific Functional Requirements

Huntsville, MSFC

Davis - consulted with Dr. Robert E. Smith regarding the latest version of the Scientific Functional Requirements.

The result of this meeting was a definitive set of functional requirements for the ACPL based upon detailed inputs from the USRA consultant team.

July 30, 1976 International Cloud Physics Conference - Special Session

University of Colorado Campus, Boulder, Colorado

Davis, Telford, Weickmann, Knollenberg, Squires, Ruskin, Hagen, Hallett, Latham, from the USRA consultant team; also representatives of GE, TRW, and about fifteen other atmospheric scientists, some of whom later became USRA consultants (Fukuta, Plooster, Levin, Saunders).

A special informal session was called by Dr. Weickmann, Chairman of the Conference, to air plans and ideas on the ACPL. Even though the Conference had officially ended, this added session was fairly well attended. Several of the USRA consultants delivered prepared statements, and a lively general discussion ensued.

The result was to further publicize the ACPL concept and to answer questions by scientists previously outside the Program.

* September 22,23, 1976 Interim Review Meeting

Huntsville, MSFC, with NASA personnel and GE and TRW

Davis, Latham, Byers, Weickmann, de Pena, Fukuta, Plooster, Squires, Ruskin, Vali, Beard, Kassner, Loos, Kocmond, Knollenberg.

The purpose of the meeting was to acquaint a broad group, including the core USRA consultant team, with the design concepts developed by the Phase B contractors. In addition, the USRA consultant group held detailed discussions on priorities for follow-on capabilities for the ACPL, for possible experiment sets for the initial ACPL, and for plans for a ground based simulation facility.

Results:

1) Input of new ideas into the Program, and possible involvement of new potential P.I.'s.

2) A priority ranking of developmental capabilities for the ACPL. This was documented in a memorandum by Davis.

3) Preliminary in-depth discussions of requirements and possible configurations for a ground based simulation facility. This discussion was also summarized in a memorandum edited by Davis.

*November 2, 3, 1976 "Trade-off Priority" Meeting
Huntsville, MSFC

Davis, Squires, Kassner, Vali, Ruskin

This meeting was called when it became apparent that there were serious cost constraints on the initial ACPL design. The USRA consultant team was called upon to judge the merits of various trade-offs and to assign priorities.

Results:

1) After the recommendation that no significant changes be made, the USRA group proceeded to rank the various ideas for cutting back; i.e., what to eliminate first, what second, etc.

2) Several additional recommendations emerged to permit early ice forming experiments without significant cost impact.

November 29, 30, 1976 Electrification and Drop Interaction Meeting
NCAR, Boulder, Colorado

Davis, Sartor, Latham, Saunders, Levin.

Dr. John Latham chaired this meeting, whose purpose was to refine ideas Latham had developed and documented under USRA sponsorship for electrification and drop interaction experiments to be carried out in the ACPL. Other than Davis, the participants represented a new group of atmospheric physicists.

Results:

1) Committed involvement in the Program of a new group of potential P.I.'s.

2) Definition of an interesting and feasible set of experiments for the ACPL involving study of drop electrification, behavior of charged drops, and drop collisions. Subsequent to the meeting, Latham prepared a second report summarizing its results, which contains specific suggestions for ACPL experiments. This latter report was distributed March, 1977.

* December 7, 8, 1976 Final Review Meeting
Huntsville, MSFC with NASA representatives, GE,TRW

Davis, Squires, Kocmond, Terwilliger, Kassner

The purpose of the Final Review Meeting was to present the completed ideas of the Phase B contractors.

The principal result was an affirmation of the potential utility of the completed disigns, together with some discussions of possible directions for future development.

January 14, 1977 Liaison Meeting with Dr. Morris Tepper
NASA Headquarters, Washington, D.C.

Davis, Squires, Terwilliger

The purpose of this meeting was to acquaint Dr. Tepper with details of the ACPL Program and USRA involvement. .

The result was the establishment of a close working relationship between USRA and the cognizant NASA Headquarters Office.

*March 22, 23, 1977 ACPL Advisory Subcommittee Initial Meeting
Huntsville, MSFC

USRA attendees will be: Davis, Terwilliger, Kocmond, Beard, Twomey, together with members of the newly formed USRA Science Council, James Juisto, Robert Sax, Georg Rupprecht.

B. Specific Small Research Contracts to Scientists (mostly under $5,000)

To James Telford, Desert Research Institute, Reno, Nevada to study possibility for turbulence experiment, turbulent mixing of dry and cloudy air in the ACPL. Report completed July 23, 1976.

To Warren Kocmond, Calspan Corp. to prepare a brief memorandum dealing with H_2SO_4 aerosol generation by photolysis for ACPL: delivered June 17, 1976.

To Donald Hagen, University of Missouri, Rolla, to carry out detailed computer simulation of the expansion chamber operation during cloud formation. Completed July 27, 1976.

To Robert Knollenberg, to carry out a feasibility study of a new drop counting, sizing, and ice particle detection device with direct electronic read-out using an image dissector. Report delivered October 18, 1976.

To Norihiko Fukuta and Myron Plooster, Denver Research Institute to re-examine the potential for ACPL nuclei memory experiments (condensation and ice forming nuclei), Completed November 30, 1976.

To John Latham, University of Manchester, England, to carry out a preliminary study of electrification and drop interaction experiments for the ACPL. Completed November 5, 1976.

To Patrick Squires, Denver Research Institute, Reno, Nevada, for study on the propagation of errors arising from those occuring in the measurement of initial temperature and of the initial and current pressure in the expansion chamber during the ACPL warm cloud forming experiment. Completed May, 1976.

To Georg Rupprecht, Rupprecht and Patashnick, Denver, Colorado, to investigate certain ACPL ice and droplet experiments: ice particle stability in space, droplet radiation balance, evaporation coefficient for ice. Limited distribution.

To Calspan Corporation, Dr. Rodney Anderson, to conduct a literature survey on aerosol generation and characterization methods for the ACPL. ($15,000 contract, study completed February, 1977)

C. Other Short Research Studies

Where needed, other brief investigations were undertaken by USRA consultants and results delivered to NASA and the contractors. These studies included investigation of hydrophobic coatings, temperature diffusion, convective stability, requirements for ice experiments in the ACPL.

D. Response to Direct Requests by NASA

Close liaison was maintained with Dr. Robert Smith and Mr. Charles Ellsworth of MSFC. The formulation of the Scientific Functional Requirements necessitated frequent calls, letters, and meetings, as requested by NASA personnel, or at the initiative of the USRA Program Director. Other tasks undertaken at the direct request of NASA personnel included the formation and maintainance of a large address list of cloud physicists, preparation of "justification material" for the ACPL to be used in Congressional Testimony, and preparation of a draft Announcement of Opportunity for the ACPL.

E. Liaison with Scientists on "General Mailing List"

March 17, 1976. Letter to entire original mailing list of 684 carefully screened atmospheric scientists asking for their support and requesting them to return a card. (Eventually received over 400 returns.)

June 19, 1976. First ACPL "Newsletter" sent to entire mailing list. Gave information on the status of the program.

February 24, 1977. Second ACPL "Newsletter" sent out to entire mailing list, primarily to alert them to the forthcoming AO for the ACPL.

F. Liaison with Special Groups of Scientists

The scientists who had been originally involved in experiment conception for the ACPL were contacted for their up-dated ideas. In addition there were several special mailings to scientists on our list who had expressed particularly keen interest in the ACPL alerting them to specific opportunities, or asking for their reaction to the proposed design. The response to these mailings was gratifying and provided very useful imput to the ACPL development.

G. Liaison with Key Individuals Outside the "Inner ACPL Group"

M. H. Davis and others on the USRA Consultant Team made personal contact with key scientists whose support (or friendly criticism) was judged to

be of particular importance to the ACPL Project.

H. Other contacts with Scientists about Specific Promising Experiment Programs for the ACPL, Initiated by USRA

M. H. Davis contacted a number of scientists to promote interest in experiment areas that had not been previously explored. These included: single particle growth and nucleation studies, the nucleating properties of large soil aerosol particles, the kinetics of the early stages of condensation growth, phoretic forces.

I. Liaison with Phase B Contractors

Very close liaison was maintained with the two contractors, GE and TRW, through phone contacts, personal visits, an informal newsletter, special sessions after meetings at MSFC.

J. Publications (All are informal reports, available upon request unless otherwise noted.)

Progress Reports #1 - #12.

Scientific Objectives and Functional Requirements For the ACPL Meeting Report on March 18-19, 1976 at Rolla, Mo. (Limited Distribution)

Preliminary Report to the 1976 USRA Annual Council Meeting, By M. H. Davis, March 30, 1976.

Zero-G Cloud Physics Project Informal Memoranda Collection #1, May 18, 1976.

Cloud Modeling Computer Program - Typical operating curves
by D. E. Hagen

ACPL particle sizing and counting
by K. Beard

Remarks on bringing ice crystals back to Earth
by C. Knight

Informal draft of requirements for zero-g ice experiments
by G. Vali

Zero-G Cloud Physics Project Informal Memoranda Collection #2, June 11, 1976

A general discussion of scientific functional requirements for the ACPL, by M. H. Davis

Thermal and inertial instabilities in the ACPL Cloud Chambers
by K. Beard

What is the best way to get results from a scientific meeting?
By J. Ewing

H_2SO_4 Aerosol Generation by Photolysis, by Warren C. Kocmond July 17, 1976

On Hydrophobic Coatings, By William Briggs (short memorandum), July 23, 1976.

Consultants Report: Scavenging Experiments for the ACPL
ed. by K. V. Beard, July 15, 1976

Turbulent Mixing of Dry and Cloudy Air, A proposed zero-g Experiment
by J. W. Telford, July 23, 1976

Typical Cloud Chamber Thermodynamic Profiles and Error Analysis
by D. E. Hagen, July 27, 1976

International Cloud Physics Conference
Discussion of Zero-Gravity Cloud Physics - TRANSCRIPT OF THE MEETING
ed. by M. H. Davis, August 4, 1976

Suggestions for Future Development of the ACPL: Priorities and Implications
by M. H. Davis, October 19, 1976

Reevaluation of Ice and Condensation Nuclei Memory Experiments
by N. Fukuta and M. Plooster, November 30, 1976

Preliminary Report on Research Problems in Cloud Electrification and Cloud Particle Microphysics Particularly well suited to Experiments in the ACPL by J. Latham, November 5, 1976

Discussion of Experiments Planned for the Atmospheric Cloud Physics Laboratory (ACPL) by M. H. Davis, February 10, 1977 (reproduced here as Chapter 4.)

The Propagation of Efforts arising from those occuring in the measurement of the initial temperature and of the initial and current pressure - direct and indirect efforts
by P. Squires - (Chapter X of his continuing notes on the ACPL Cloud forming experiment, May, 1976)

Potential Zero Gravity Experiments for the Space Shuttle
by G. Rupprecht. Limited distribution

A Literature Review for Aerosol Generation and Characterization Techniques Suitable for Use Aboard the Atmospheric Cloud Physics Laboratory
by R. J. Anderson, (Calspan Corp.) February, 1977.

Preliminary Analysis and Discussion of the Ground Based Scientific Functional Simulation Facility for the ACPL
by M. H. Davis, November 5, 1976.

ACPL Wall Temperature and Pressure Control for the Expansion Chamber
by D. E. Hagen, June 24, 1976.

Chapter 6

GENERAL CONTRACT INFORMATION

The original USRA contract, NAS8-31901, was signed March 1, 1976. The amount of the contract was $99,000. On October 15, 1976, $16,210 was added specifically to sponsor a study on aerosol generation for the ACPL by the CALSPAN Corporation. A further addition of $26,750.00 took place on December 8, 1976, and on June 15, 1977, a six-month no-cost extension of the contract was obtained. Total contract funds: $141,960; termination date: September 5, 1977.

As of September 5, 1977, subject to final adjustments by the USRA Bookkeeper, all contract funds had been either spent or committed.

In accordance with Section 2 of the Reports Requirements, approval of this Final Report was obtained from Dr. Robert E. Smith on August 29, 1977, prior to final distribution.

Respectfully submitted:

Dr. M. H. Davis
USRA/Boulder Program Director

APPENDIX A

SCOPE OF WORK

Background:

NASA has been studying the feasibility and desirability of doing atmospheric cloud microphysical processes experiments in the low gravity environment at orbital altitudes since 1971. It is now time to initiate the preliminary design (Phase B) portion of the process required to insure that a laboratory facility is ready for flight in the Spacelab on the Shuttle in 1980. The aerospace contractors doing the Phase B studies need to know the scientific functional requirements of the various components of the Atmospheric Cloud Physics Laboratory (ACPL), as well as a preliminary definition of potential experimental areas and operational procedures. These can only be provided by potential users of the ACPL facility -- members of the university science community, cloud physicists in particular, but also possibly fluid dynamicists and physical chemists.

Statement of Work:

The contractor shall provide the personnel and facilities required to:

1. Establish and update/refine, as required, the scientific functional requirements for the components, subsystems and systems of the ACPL.

2. Complete a preliminary definition of nucleation, scavenging, and cloud growth experiments that should be accomplished on the early flights of the ACPL, and if possible and practical, complete a priority ranking based on scientific need for the data.

3. Work through and with the ACPL Project Scientist to insure that the design efforts of the Phase B contractors are directed toward providing the best possible ACPL facility and that the facility capabilities are responsive to the needs of the science community.

It is envisioned that two or possibly three experiment definition teams of 4-6 scientists would be required to encompass the microphysical processes listed in par. 2., above. The chairmen of these individual teams would work closely with the contractor's program coordinator and the ACPL Project Scientist in establishing a single integrated set of scientific functional requirements and a preliminary experiment program. Results of these activities will be subject to review/approval by the ACPL Advisory Subcommittee of the Applications Steering Committee. Team members will be selected jointly by the COR and contractor's coordinator/P.I.

Initial efforts will be directed toward functional requirements and experiments for the early flight version of the ACPL; however, the functional requirements established by this effort should not preclude the accomplishment of more sophisticated experiments as well as experiments on other microphysical processes on later flights with minor modifications to the systems and components. While initial flight activities may be restricted due to a requirements to minimize expenses during the 1975-1980 time period, it is essential that the growth capabilities be retained in the early flight version.

Future plans include the expansion of these experimental activities into the ice, charge separation, and collision-coalescence problem areas unless scientific functional requirements and experiment operational procedures can be established and hardware that can accomplish experiments in those areas on the early flights be made within budgetary limitations.

Future activities of the contractor may include participating in the process of selection of Principal Investigators (P.I.) for the individual missions by providing peer review groups. It may also be desirable to institute a visiting scientist type of activity to either assess or investigate in detail certain technical aspects of the project. This facet of

the program will require detailed coordination between the COR and the contractor's coordinator if such a requirement evolves during the course of the contract.