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FINAL REPORT: NAS8-33131

RESEARCH STUDY: WARM/COLD CLOUD PROCESSES

Since August 1, 1978, USRA has provided support to cloud physics research and related activities at Marshall Space Flight Center through Contract NAS8-33131. The primary activity has been support for a USRA Visiting Scientist, Mr. David C. Bowdle, who has been carrying out laboratory and field research in conjunction with research programs managed by Dr. B. Jeffrey Anderson. Research activities were fully documented in quarterly reports, which are appended to this Final Report. Since the date of the last quarterly report, October 31, 1980, Mr. Bowdle has continued to carry out research along the lines already reported. In addition, Dr. Kenneth V. K. Beard of the University of Illinois conferred with Dr. Anderson and others at MSFC on cloud physics programs.

Distribution: (FINAL)

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Respectfully submitted,

M. H. Davis, Ph.D.

Principal Investigator,
Program Director for
Atmospheric Processes

USRA

PROGRESS REPORT

JULY 1, 1980 -- OCTOBER 31, 1980

CONTRACT NAS8-33131

RESEARCH STUDY: WARM/COLD CLOUD PROCESSES

DECEMBER 15, 1980

PREPARED FOR GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER,
ALABAMA 35812

BY: USRA/BOULDER
P.O. BOX 3006
BOULDER, CO 80307

PROGRESS REPORT: Contract NAS8-33131

Research Study: Warm/Cold Cloud Processes

Period: July 1, 1980 -- October 31, 1980

During the reporting period, USRA Visiting Scientist David A. Bowdle continued to perform research on cloud physics, ice processes, and related problems within the group headed by Dr. B. Jeffrey Anderson. Mr. Bowdle also attended the VIIth International Conference on Cloud Physics July 15-19 in Clermont-Ferrand, France. A small fraction of Mr. Bowdle's effort has been devoted to activities relating to atmospheric aerosols. His narrative report for June 1 to August 31 is attached. Since the end of August, Mr. Bowdle has continued study of the Hallett-Mossop ice multiplication process, and has been working on a final report on the saturator calibration study. These activities were carried out in collaboration with Dr. James Carter, another USRA Visiting Scientist.

The Contract, NAS8-33131 terminated on November 14, 1980. Therefore, this is the last periodic report that will be submitted. A final report on the Contract will be submitted covering the entire contract effort. A Budget Summary through the end of October, 1980 is attached.

Respectfully submitted,

M.H. Davis, Ph.D.
Principal Investigator,
Program Director for
Atmospheric Processes

Distribution: MSFC

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SEVENTH QUARTERLY REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: June 1 - August 31, 1980

BY: David A. Bowdle, USRA Visiting Scientist at
Marshall Space Flight Center (MSFC)

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three months, work has been accomplished under this contract in four principal areas:

- Attendance at the NASA/MSFC FY-80 Atmospheric Processes Research Review, June 3-5, 1980, in Huntsville, Alabama. A brief presentation was given at this review on the gravimetric test for the performance evaluation of a precision saturator. The current status of the test program, some significant technical challenges in the test hardware, and some preliminary results were described in this presentation.

- Attendance at the VIIth International Conference on Cloud Physics, July 15-19, 1980, in Clermont-Ferrand, France.

- Four calibration runs, using the gravimetric test system, followed by numerous small modifications to the test equipment and test procedures. The saturator performance has been verified to $\pm$ 2% in these runs.

- Limited technical assistance to the MSFC Airborne Laser Doppler Program.

II. Results

A. International Cloud Physics Conference

About two hundred papers were presented during the conference, covering studies in cloud microphysical phenomena; the evolution of the cloud particle spectrum; interactions among the microphysical-, cloud-, and meso-scales of phenomena; and advances in cloud physics instrumentation. Results of major importance to the understanding of fundamental cloud physics processes were presented by several workers in two general areas: (1) the initiation and propogation of the ice phase, and (2) the potential of inhomogeneous turbulent entrainment for accelerating the broadening of cloud droplet spectra.

Ice Nuclei Apparent concentrations of ice nuclei, determined by the filter sample technique, decay rapidly after the sample is acquired. This decay is particularly evident at temperatures above about -12°C. This troublesome result, combined with the well-known "volume effect," increases the general skepticism in the validity of ice nucleus concentrations from filter samples. Moreover, simultaneous measurements of ice nucleus concentrations by the filter technique and by a continuous flow diffusion chamber suggest that the filter technique can underestimate ice nucleus concentrations by an order of magnitude or more. These latter results call into question the validity of many reported instances of ice multiplication.

Ice Multiplication A review of the Hallett-Mossop ice multiplication process was presented in which certain types of geographical regions were classified according to their climatic potential for supporting precipitation production through this multiplication process. Recent laboratory studies strongly suggest that the Hallett-Mossop process is associated with the shattering of ice spicules ejected from freezing droplets. However, airborne measurements suggest the possibility of another ice multiplication process, possibly outside the Hallett-Mossop range of -3 to -8°C, by the breakup of fragile rime structures.

Entrainment Theoretical and experimental work was presented to support the hypothesis that inhomogeneous turbulent entrainment accelerates the broadening of cloud droplet spectra. The lively discussion following these reports emphasized that this process is likely to be quite important in some clouds, such as long lived stratus, and considerably less important in large clouds or storm systems.

B. Gravimetric Test

Four calibration runs have been made so far. The gravimetric test equipment has remained largely intact throughout these runs, except for numerous small modifications in the connections from the air sample line to the cold traps and in other attachments to the traps. A schematic of the current system is shown in Figure 1. The test system has evolved into a form considerably more complex than was originally envisioned. For this reason, a significant portion of the work on the gravimetric test has been devoted to evaluating modifications of the test procedures.

Much progress has been made since the last report in alleviating trap inlet icing. Early test runs were usually aborted within five to ten minutes because the inlets were completely iced over. Direct heating of the inlets at the locations most susceptible to icing has drastically retarded inlet icing in the calibration runs. It is now possible to complete a twenty minute run without total blockage. It was also possible, in the most recent run, to delay significant inlet icing until well into the run and later in that run, to remove much of the ice that had been deposited in the inlet. Even though the inlet icing is no longer severe enough to abort a run, it does partially restrict the sample airflow. This restriction creates an erratic, but generally rising, pressure in the saturator and reduces the sample flow rate through the saturator. As a result, it has not been possible thus far to acheive both a constant flow rate and a constant saturator pressure throughout a run. Therefore, determination of an average saturator pressure, for input to calculations of the theoretical mixing ratio, has proved to be rather cumbersome. Icing of the trap inlets also requires special procedures to ensure that the collected water is driven into the traps before they are sealed, warmed, dried, and weighed.

The ejection of ice pellets from the trap outlets, which was noted in the early runs, is still present. Ice pellets have been observed in the outlet of the first trap from time to time during several of the calibration runs. Careful experimental procedures are expected to minimize the effects of pellet ejection on the accuracy of the gravimetric test. First, the moist sample air passes through three sequential cold traps, each operated at a lower temperature and experiencing a lower water load than the previous trap. Hence, ice pellets ejected from the first trap are likely to be retained by the second and third traps. Second, ice pellets caught in the plumbing between traps should be driven out during the first stage of shutdown, in which the traps are maintained at a very cold temperature, the interconnecting plumbing is warmed, and the trap system is flushed very slowly by very dry air.

The final significant problems in the gravimetric test have occured during the weighing procedure. On several of the runs, a steady mass loss was observed in one or more of the traps on the Mettler Balance. Recent tests suggest that this drift, which can easily produce errors of up to 0.5% in the test results, can be prevented with more reliable stoppers. However, these same tests also show that the equilibrium mass of the trap appears to depend on the manner in which it was treated after the run. This result suggests that the trap body exterior may be retaining a significant quantity of the water that condensed on it during the cold-temperature stage of a run. It is expected that improvements will be required in the procedure for drying the trap exterior after each run.

Except for the problems noted above in determining the mass of water collected in the cold traps, the basic measurements required for the gravimetric evaluation of the saturator appear to be fairly well established. Hence the most likely sources of error in the experiment can probably be narrowed down now to three general categories: Saturator error, low trap efficiency, and improper procedures (such as undetected leaks, improper drying of the traps, flushing the cold traps with moist gas instead of dry, and various other errors of like nature). The remaining effort on the saturator verification will consist of a thorough error analysis (including these procedural errors), a few more runs to determine the relative performance levels of the saturator and the gravimetric systems, and then a final report on the entire saturator calibration project.

C. Doppler LIDAR

Participation in the Doppler LIDAR program during the past quarter has been restricted to attendance at a recent scientific working group meeting for the 1981 LIDAR field program and oversight of a literature search on measurements of atmospheric aerosol concentrations. Among the various experiments proposed for the airborne LIDAR system by working group members were several which take advantage of the Doppler LIDAR's unique capabilities for cloud physics studies.

III. Planned Effort

During the next three months of the contract year, work is expected to be accomplished in the following principal areas:

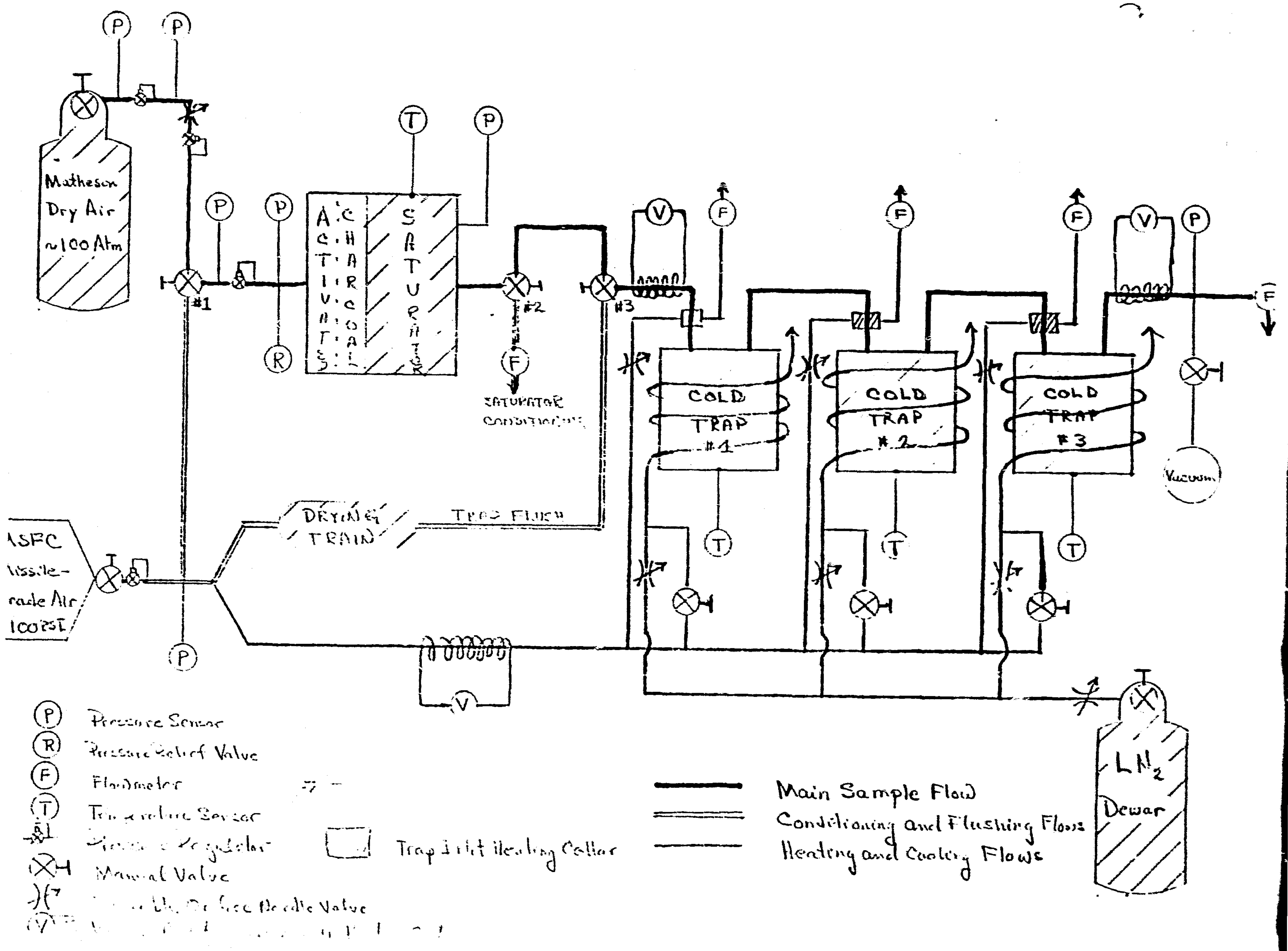
1. Completion of the saturator calibration study and preparation of a final report on the calibration project.

2. Preparation of professional papers on the size distribution of cloud condensation nuclei and on airborne measurements of atmospheric aerosols, as well as final write-ups of other ACPL-related studies.

3. Limited development of the charged-droplet levitation chamber, including proof-of-concept experiments and a literature survey of charged-drop phenomena.

4. Continued limited technical assistance to the MSFC Airborne Laser Doppler Program. This assistance will include preparation of a consultant's report on global measurements of background aerosol concentrations and attendance at subsequent scientific planning or program review meetings.

GRAVIMETRIC TEST FLOW DIAGRAM



USRA

PROGRESS REPORT

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

APRIL 1, 1980 -- JULY 1, 1980

SUBMITTED AUGUST 5, 1980
TO NASA/MSFC

USRA/BOULDER
P.O.Box 3006
BOULDER, CO 80307

PROGRESS REPORT: APRIL 1, 1980 -- JULY 1, 1980

RESEARCH STUDY: WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

During the reporting period, Mr. David A. Bowdle continued as USRA Visiting Scientist, performing research on cloud processes under the direction of Dr. B. Jeffrey Anderson of the MSFC staff.

Mr. Bowdle's narrative report is included as a part of this report.

No problems have developed that would impede progress on this Contract.

Respectfully submitted,

M. H. Davis, Ph.D.
USRA/Boulder
Program Director

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SIXTH QUARTERLY REPORT

CONTRACT:	NAS8-33131, Warm and Cold Cloud Processes
FOR:	The National Aeronautics and Space Administration (NASA)
WITH:	The Universities Space Research Association (USRA)
PERIOD COVERED:	March 1 - May 31, 1980
BY:	David A. Bowdle, USRA Visiting Scientist at Marshall Space Flight Center (MSFC)
TO:	M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three months, work has been accomplished under this contract in three principal areas:

- Final development of the gravimetric test for performance evaluation of a precision saturator
- Design and development of a prototype droplet levitation chamber
- Technical assistance to the MSFC Airborne Laser Doppler Program

II. Results

A. Gravimetric Test

The gravimetric test system for evaluating the performance of the low-gravity prototype saturator is now ready for full-scale operation. A new pressure sensor has been acquired and tested, and the thermistor temperature sensor system has been prepared. Preliminary tests of the thermistor system show that the plate temperature across the sensitive region of the saturator (several time constants downstream from the air inlet port and slightly upstream from the air outlet port) is uniform to within a few tens of millidegrees.

The most significant difficulty in the development of the gravimetric test has been the design of the system which connects the cold trap to the sample flow line from the saturator. This system had to be capable of supplying sample air to the trap at a significant air flow rate (about 30 liters per minute) with only a small pressure drop (several tenths of a PSI or less). It had to be designed to pull a vacuum on the traps and sample lines and then to seal off the traps from the sample lines without opening the lines. The connector system itself could not introduce contamination into the trap and the connector seal could not add more than a few grams to the total mass of the trap. Finally, the connector system could not aggravate the tendency of the trap inlet to freeze shut when moist air from the saturator began to enter the trap.

The trap connector system has been redesigned and the heated sheath concept used previously has been discarded. Tests of the most recent connection design have shown that inlet plugging is still a potential problem. However, during these tests, the location of the plugging was identified, and a simple remedy - localized heating of the trap inlet at the susceptible region - was designed. The present connection design with the localized heating is expected to be adequate to prevent trap plugging without seriously degrading the overall trap efficiency.

B. Levitation Chamber

Work on the levitation chamber was temporarily scaled down during this past quarter so that the gravimetric test system could be finished. Most of the work done on the levitation chamber was related to development of concepts for calibrating and testing the chamber, particularly the measurement of chamber plate temperatures. The most significant difficulty to date in the design and development of the levitation system has been the tradeoff between the required temperature sensitivity and accuracy and the electrical insulation required to protect the temperature transducers (thermistors) from high-voltage discharges. This difficulty has not yet been solved and is expected to be attacked in the following quarter.

C. MSFC Laser Doppler Program

During this past quarter, involvement with the MSFC Laser Doppler Program was initiated. This effort has thus far taken the form of technical consultation related to airborne aerosol measurements with the Laser System.

The impetus for this work derives from the operating principle of the Laser Doppler Velocimeter (LDV). A moving particle generates a doppler shifted backscatter signal when it is struck by a pulse of infrared radiation (10.6μm) from the laser. The utility of the LDV in determining atmospheric wind measurements depends on the availability of suitable aerosol particles (roughly 2-5μm diameter) in the air parcel of interest. If expensive flight time is to be used efficiently, program mission planners need to develop insight into the typical concentrations and the spatial and temporal distribution of the appropriate aerosol particles in the region of interest. Negotations are underway with MSFC personnel to determine the scope of the required consultation effort.

III. Planned Effort

During the next three months of the contract year, work is expected to be accomplished in the following principal areas:

1. Attendance at the NASA/MSFC FY-80 Atmospheric Processes Research Review, in Huntsville, Alabama, on June 3-5, 1980. A brief presentation will be given on the gravimetric test of the saturator.

2. Attendance at the VIIIth International Conference on Cloud Physics, in Clermont - Ferrand, France, on 15-19 July 1980.

3. Preparation of papers on cloud condensation nucleus activation theory and field measurements of atmospheric aerosol, as will as final write-ups of the saturator calibration and other ACPL - related studies.

4. Continued development of the droplet levitation chamber, particularly aimed at proving the concept of the levitation chamber.

5. Continued technical assistance as appropriate to the MSFC Laser Doppler Program. At present, this assistance consists of participation in working group meetings for planning deployment of the LDV system and monitoring of a literature review on background aerosol concentrations.

Fifth Quarterly Report

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: November 15, 1979 - February 29, 1980

BY: David A. Bowdle, USRA Visiting Scientist, Marshall Space Flight Ctr. (MSFC)

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three and a half months, work has been accomplished under this contract in two principal areas:

1. Design, development, and assembly of a prototype static diffusion chamber with applied electric field for droplet levitation studies.

2. Final development of the gravimetric test for performance evaluation of a precision prototype saturator.

II. Results

A. The Droplet Levitation Chamber

The static diffusion chamber has been assembled and operated. The results from these preliminary operations suggest that the thermal plates with counter-flowing coolant channels will provide adequate thermal uniformity in the chamber. The sensitive inner surfaces of the chamber end plates have been nickel-coated to improve corrosion resistance. The remaining portions of the end-plate surfaces have been painted with a high-voltage compound to provide electrical isolation between each end plate and its thermal plate. Temperature measurement for the chamber will be provided by coated thermistors embedded in the chamber end plates, subject to the resistance of the thermistor coatings to dielectric breakdown.

Several mesh media have been tested for the diffusion [illegible] surfaces. Several grades of filter papers have been evaluated, [illegible] cellulose membranes, cellulose filter sheets, and filter paper [illegible] activated charcoal. The charcoal-loaded paper displayed [illegible] wicking, and flatness properties when wetted; however, it was somewhat weaker and thicker than desired. Other filter papers were much thinner and stronger, but with somewhat poorer wicking and flatness characteristics, and very poor optical quality. Metal meshes were examined and found to be difficult to adapt for the levitation chamber. Information was also obtained on various kinds of gel systems, but no samples have been tested thus far.

One of the various filter papers, such as the charcoal-loaded paper, will probably make a suitable wicking surface for the diffusion chamber. Filter papers are particularly desirable for one of the less-common modifications of these chambers, in which pure water is replaced by a saturated salt solution on one or both plate surfaces. Since the air near the chamber boundary may be significantly subsaturated in this latter configuration, low supersaturations ($\sim 0.1\%$) may be readily obtained in a portion of the chamber with a relatively large temperature difference ($\sim 5^{\circ}C$) between the plates. By contrast, in the normal pure water configuration, low supersaturations can be obtained only by maintaining very small temperature differences ($\sim 1^{\circ}C$) between the two plates.

The optical system is the main portion of the levitation chamber yet to be designed. Development of this system and related components (such as the sidewalls) will probably be deferred until the rest of the chamber is operational and the levitation concept is shown to work in a laboratory environment. Proof of the levitation concept will also require suitable droplet generation techniques for the various ranges of droplet sizes and droplet charges to be studied. A few such generation systems have been checked thus far and they were found to produce droplet concentrations adequate for study.

B. <u>Gravimetric Verification of Saturator Performance</u>

The gravimetric test system now appears to be ready for final operation. Dry bottled air has been acquired from Matheson and the plumbing system for the test is complete. A change was made in the test concept by replacing one cold trap (operating at very low temperatures ($-100^{\circ}C$)) with serial cold traps (operating at progressively lower temperatures (e.g., -40, -80, $-120^{\circ}C$)). This modification is expected to eliminate the problem of ice pellet ejection from the initial cold trap, as well as to provide a simple measurement of trap efficiency.

During the previous quarter, NASA management has been evaluating the Atmospheric Cloud Physics Laboratory (ACPL) program for the Space Shuttle, after a Critical Design Review on the ACPL project in October, 1979. Because of the likelihood of program cancellation, little effort was expended under this contract during this quarter in support of ACPL or of ACPL related objectives, such as the saturator calibration. Now that the ACPL project has been officially terminated by NASA, there no longer appears to be a pressing reason to achieve an accuracy of [illegible] in the saturator calibration. Nevertheless, since the test equipment and procedures were designed to achieve such stringent accuracy, it [illegible] reasonable to hold 0.05% as a goal for the calibration accuracy.

III. Planned Effort

During the next three months of the contract year, work is expected to be accomplished in three principal areas:

1. Assembly and testing of the prototype levitation chamber. Testing is expected to include proof of the levitation concept, evaluation of various wicking surfaces, and droplet-generation/droplet-sensing techniques. Particular attention will be paid to the adequacy of the high voltage isolation for the thermal plate and the thermistor system to ensure that the levitation system can be operated safety.

2. Completion and documentation of the saturator test (under relaxed restrictions) using the gravimetric method and an alternate vapor pressure method.

3. Numerical solution of the cloud condensation nucleus (CCN) activation polynomial derived from the Kohler equation, and preparation of a professional paper on the results. This treatment may also be extended to include a treatment of electrical effects and of surface energy effects in mixed nuclei.

UNIVERSITIES SPACE RESEARCH ASSOCIATION
P.O. Box 3006
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PROGRESS REPORT

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

OCTOBER 1, 1979 -- MARCH 31, 1980
(TWO QUARTERS)

DATE OF REPORT: APRIL 28, 1980

SUBMITTED TO: NASA/MSFC
THE GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

PROGRESS REPORT: October 1, 1979 -- March 31, 1980

<u>RESEARCH STUDY: WARM/COLD CLOUD PROCESSES</u>

CONTRACT: NAS8-33131

This Report covers two quarters. Mr. David A. Bowdle has continued to perform laboratory research on cloud microphysics under the direction of Dr. B. Jeffrey Anderson as a USRA Visiting Scientist. His research activities during the reporting period are fully documented in the two reports attached.

Other activities during the reporting period included sponsorship of travel of Dr. M. H. Davis to Marshall Space Flight Center and to Washington, D. C. to confer with NASA officials on aspects of contract activities and on technical problems related to cloud microphysics. In addition, the following scientists were brought to MSFC to confer with Dr. Anderson and others there on cloud physics and, in particular, its relation to atmospheric electricity:

Dr. Donald R. MacGorman, University of Oklahoma
Dr. Hugh Christian, New Mexico Tech
Dr. C. R. Church, Purdue University
Dr. William Beasley, University of Florida (Gainsville)
Dr. E. Philip Krider, University of Arizona
Dr. William L. Wolfe, University of Arizona

No problems are known to have developed that may impede progress on this Contract.

Mr. Bowdle will continue as USRA Visiting Scientist during the next reporting period.

Respectfully submitted,

M. H. Davis
USRA/Boulder
Program Director

Distribution:

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	ES84	3		

FOURTH QUARTERLY REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: September 1 - November 15, 1979

BY: David A. Bowdle, USRA Visiting Scientist, Marshall Space Flight Center (MSFC)

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the final two and a half months of the contract year, work has been accomplished under this contract in four principal areas:

1. Preparation for and participation in the NASA Severe Storms and Local Weather Review, held in Huntsville, Alabama, on September 12 and 13. A numerical feasibility study on "The Stable Levitation of Charged Solution Droplets by an Electric Field in a One-g Static Diffusion Chamber" was presented at this review. This feasibility study was also included in the Third Quarterly Report under this contract.

2. Continuing technical assistance with the design and development of the Atmospheric Cloud Physics Laboratory (ACPL). This effort was concentrated between October 9 and November 1 during the Critical Design Review (CDR) for ACPL at MSFC.

3. Design, development, and assembly of a prototype static diffusion chamber with applied electric field for droplet levitation studies.

4. Development of the gravimetric test for performance evaluation of a precision ACPL prototype saturator. A summary of the development work on the levitation chamber and the gravimetric test follows:

II. Results

The levitation chamber itself is nearly complete. Thermal plates for the chamber are provided by the end plates of a prototype expansion chamber. These thermal plates utilize counter-flow in adjacent equal-flow channels and are expected to provide the high degree of steady state thermal uniformity desired for precision studies of cloud microphysical phenomena. The chamber sidewalls, end plates, and material for thermal insulation and electrical isolation have been assembled. A 3 k V and a 15 k V power supply have been obtained. Several controlled temperature fluid circulators are available in the laboratory, as are various standard aerosol generation systems.

The remaining subsystems to be assembled are the optical components and the temperature measurement system. Finishing touches are still required for the chamber end plates, including anodizing the interior aluminum plate surfaces. The most significant technical problem at this time (and one which is also of great concern for ACPL) is the choice of a suitable end plate wicking surface. For concept testing, various felts or filter papers are expected to be adequate. However, for precise work, an improved wicking surface is expected to be required. Readily available materials, such as nylon net and pure cellulose membranes are being tested for this prupose; however, the General Electric project scientist for ACPL (Larry Eaton) has recommended the ebonized copper mesh which is being used in ACPL.

Several sensors have been acquired for the gravimetric test. A moisture monitor sensitive to a few ppm of water vapor is being connected to the water trap outlet to determine trap efficiency. Pressure and temperature sensors have been acquired and tested and are considered to be adequate for evaluating the gravimetric test concept. High - purity Matheson dry air has been ordered and suitable bottles for locally available MSFC missle-grade air have been located. Preliminary calibration testing is expected to begin in late November.

III. Planned Effort

During the first three months of the coming contract year, work is expected to be accomplished in five principal areas.

1. Continuing technical assistance, as required, with the design and development of the ACPL. The magnitude of this effort will become much clearer after the final results of the ACPL CDR are in.

2. Final development of the gravimetric test as a means of evaluating saturator performance. Concurrently with this work will be a comparison of the gravimetric and vapor pressure techniques for testing the saturator, and the evaluation of a plasma (glow discharge) technique for cleaning the wicking surface on the saturator and other chambers.

3. Design, construction, and testing of the prototype levitation chamber and evaluation of various droplet-sensing and droplet-generation techniques.

4. Numerical solution of the CCN activation polynomial and preparation of a professional paper on the results. This work may also be extended to include a treatment of electrical effects (for use in the levitation studies) and surface energy characteristics.

5. Final documentation of the following research:

   a. Sensitivity of warm cloud development to cloud updraft and aerosol nucleus spectrum.

b. Sensitivity of warm cloud formation to composition, aerosol spectrum, and initial temperature and pressure of the carrier gas.

c. Verification of saturator performance.

IV. First Annual Report

Significant accomplishments during the past contract year and plans for the new contract year are summarized in the First Annual Report (see inclusion).

USRA

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PROGRESS REPORT

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

JULY 1, 1979 - SEPTEMBER 30, 1979

SUBMITTED TO: N.A.S.A.

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

PROGRESS REPORT: July 1, 1979 - September 30, 1979

Research Study: Warm/Cold Cloud Processes

Contract NAS8-33131

As in the previous two quarters, Mr. David A. Bowdle has continued to work under the direction of Dr. B. Jeffrey Anderson as USRA Visiting Scientist. His research during this period is described fully in the attached report.

No problems are known to exist that may impede progress.

Mr. Bowdle will continue as USRA Visiting Scientist during the next reporting period.

Respectfully submitted,

M. H. Davis
USRA/Boulder
Program Director

Distribution:

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	ES84	3

USRA 2

THIRD QUARTERLY REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: June 1 - August 31, 1979

BY: David A. Bowdle, USRA Visting Scientist, Marshall Space Flight Center

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three months work has been accomplished under this contract in five principal areas:

1. Continuing technical assistance as needed in support of the Atmospheric Cloud Physics Laboratory (ACPL).

2. Attendance at the ACPL prime contractor's (General Electric) Interim Design Review (IDR) and the Principal Investigator's (PI) Preliminary Requirements Review (PRR) . June 5-7 at Marshall Space Flight Center (MSFC).

3. A brief study of selected factors affecting warm cloud formation (as a result of concerns which were raised by the PI's during the IDR and PRR meetings). This study showed that the time of cloud formation during an arbitary expansion is independent of carrier gas composition for ideal gases and independent of aerosol concentration for low concentrations of very small aerosols.

4. Laboratory tests of the equipment and procedures for gravimetric evaluation of a precision saturator. The plumbing and flow controls have been completed and several tests have been run on the cold trap. The trap inlet froze shut during the initial runs; this problem was solved by replacing the original plastic inlet tubing with heated copper sheath tubing. Moderately large ice pellets or ice clusters ($\sim$0.5cm) were ejected from the trap outlet during portions of several runs. Heating the inlet line appeared to reduce this problem; but did not completely eliminate it. The inlet and outlet lines have been redesigned, replumbed, and are now ready for use. The present trap configuration is expected to achieve the high trapping efficiencies ($\sim$99.95%) required to develop a test procedure with a resolution of 0.05%.

5. A numerical feasibility study for the stable levitation of charged solution droplets by an electric field in a one-g static diffusion chamber. This technique is expected to be useful both for basic research in cloud microphysics and for evaluation of various low-gravity droplet handling techniques. This feasibility study was prepared for presentation at the NASA Severe Storms and Local Weather Review in Huntsville, Alabama, on September 12 and 13. The results of the study are described in Section II below.

II. Results

A. Concept and Operating Principles

The levitation technique uses an electrical potential (V) applied between two parallel plates separated by a distance (H) to support a layer of charged droplets against gravity (Fig.1). The interior surfaces of the two plates are covered with a thin layer of pure water. The top plate is maintained at a temperature slightly higher than the bottom plate. This temperature difference produces at steady state a linear temperature gradient (T) and a linear water vapor pressure gradient (P_w) between the plates (Fig. 2). The exponential dependence of the equilibrium water vapor pressure (P_s) on temperature produces a parabolic supersaturation profile (P_w/P_s) within the chamber, with saturation at each water surface.

If a charged salt aerosol (e.g., NaCl) is introduced into the chamber between the plates, each solution droplet which forms from the salt aerosol will, at steady state, achieve a stable equilibrium at some given level in the lower portion of the chamber. This stability arises because of the simulataneous force balance on the droplet (between the electrostatic force and the gravitational force) and thermodynamic equilibrium of the droplet (ambient water vapor pressure equal to the equilibrium water vapor pressure at the droplet surface). If the droplet rises above this equilibrium position in the chamber, it encounters an ambient water vapor pressure higher than its equilibrium value and tends to grow in response. However, the resulting increase in mass disturbs the force balance, and the increased gravitational force tends to bring the droplet back to its equilibrium level. Similarly, if the droplet falls below its equilibrium level, it tends to evaporate and hence to be returned toward its equilibrium level.

Obviously, this type of stable equilibrium is possible only in the portion of the static diffusion chamber where the supersaturation increases with height. Hence, the levitation technique will work just as well in a diffusion chamber with a subsaturated lower plate surface. This configuration may be obtained by substituting for the pure water surface on the bottom plate either an aqueous salt solution, as Sun _et al_ reported, or a flat surface of solid ice.

The levitation technique described here differs from that reported by Sun et al in several ways. Most importantly, this levitation technique takes advantage of the Kohler theory (Fig. 3) for the equilibrium water vapor supersaturation over the surface of an inactivated solution droplet of a given size and containing a given salt mass. Sun et al had minimal control over their salt masses, and, therefore, they probably utilized the metastable equilibrium of activated droplets (depicted on each Kohler curve by points to the right of the maximum). This type of operating condition apparently restricted them to a droplet layer at or near saturation (100% relative humidity), which condition can be achieved only in a diffusion chamber with a subsaturated bottom plate.

B. Applications

The modification proposed here offers a great deal of flexibility. For example, if a monodisperse dry salt aerosol can be produced with a monodisperse charge distribution, and if the salt mass is small enough so as to remain unactivated by the highest supersaturation in the chamber, then a single thin layer of monodisperse droplets will be supported at some given level in the lower portion of the chamber. In this configuration, the chamber can be used to study a wide range of cloud microphysical problems (Table 1). For example, if the salt mass changes during the course of an experiment, the equilibrium conditions for the droplet will change in a measurable way. Hence, this technique can be used to investigate gas and particle scavenging with a sensitivity not even approachable with standard microchemical trace analysis. It can also be used to investigate other areas of aerosol physics and droplet growth, such as measurement of phoretic forces and aerosol soluble mass, verification of Kohler theory and the new CCN theory described in the 2nd quarterly report, and growth of unactivated and nearly activated or just activated droplets. It may also be possible to use this technique to map changes in steady state vapor fields produced by perturbations at the chamber boundary or near probes inserted into the chamber.

Alternate configurations would utilize a polydisperse charge distribution on a monodisperse salt aerosol, resulting in distinct multiple layers of droplets in the chamber. This configuration would, of course, be limited to small charge numbers so that one droplet layer could easily be distinguished from another. The logical extension of this configuration is a polydispersity of both salt mass and droplet charge, resulting in a continuous cloud of droplets throughout the lower portion of the chamber.

Several areas of investigation in ice physics seem accessible using the various configurations described above. For example, freezing of isolated solution droplets could easily be observed. Water vapor profiles around ice crystals, particularly those which are neither growing nor evaporating, could be observed with a thin droplet layer. Transient vapor fields around growing ice crystals may be observable with a thick droplet layer. Finally, using a configuration very similar to that of Sun et al, except with colder temperatures, it may be possible to produce a stable layer of free-floating ice crystals or to study an isolated free-floating crystal. One might also suspect, if this technique is feasible for studying ice crystals, that it may be applicable for studying other types of crystals in a free floating mode as well.

C. Operating Limits

This levitation technique obviously offers a great deal of flexibility and versatility, although not without a price. The electrical fields or charge numbers required to support even moderate droplet sizes can quickly become impractical or unattainable in the laboratory. More seriously, the electrostatic and hydrodynamic forces on the droplets can actually alter the microphysical quantities of interest, such as the equilibrium water vapor pressure, droplet growth and evaporation rates, and even droplet shapes and radii of curvature. The following section describes the operating range and limits of the levitation technique.

The levitation technique is limited by Brownian motion to particle diameters larger than about 0.3 to 0.5 μm (Fig. 4). The average Brownian displacement for particles smaller than this size quickly becomes significant, particularly over the extended experiment time for which this technique is well suited. In fact, the instantaneous Brownian velocity of a given droplet at any given time is significantly larger than its average Brownian velocity; this instantaneous velocity remains larger than the sedimentation velocity for particle sizes well above 0.5 μm diameter. It may well turn out that these large instantaneous velocities prevent these very small droplets from achieving stable equilibrium. In addition, these small droplets are difficult to detect using the required remote telescope (by comparison, the optics for the Atmospheric Cloud Physics Laboratory (ACPL) cloud chambers are designed to detect 2 μm radius droplets; some improvement is possible in the laboratory by increasing light intensities). The combination of these two effects may restrict the operating range of the levitation technique to droplets somewhat larger than 0.5 μm diameter.

The plate temperature differences required for stable support of droplets between about 1 and 100 μm radius lie between 0.1 and 1.0°C (Fig. 5); these conditions are readily achievable and have been used for several years in continuous flow diffusion chambers (CFD's). The very low supersaturations required for stable levitation of drops between 100 and 10,000 μm (1cm) radius would call for plate temperature differences between 0.01 and 0.1°C; these conditions are expected to be quite difficult to achieve in the laboratory (by comparison, the diffusion chambers being developed for ACPL are designed for a plate temperature spatial uniformity of 0.01°C). It may be possible to use as temperature controllers certain constant temperature physical processes whose critical temperatures differ by only a small amount (for example, phase changes near the triple point and the ice point, or phase changes with solutal freezing point depression or vapor pressure elevation). An alternate means for achieving such low supersaturations may be available with the subsaturated lower plate configuration. This configuration depresses the supersaturation everywhere within the chamber except at the top plate. By careful choice of plate temperatures and bottom plate condition, it may be possible to produce quite low supersaturations inside the chamber with good spatial resolution.

Dry aerosol sizes required to produce the desired droplet sizes range from about 0.1 μm to 2.0 μm radius for droplets between 1 and 100 μm radius and 2.0 μm to 215 μm radius for drops between 100 and 10,000 μm radius. Of course, for the very large drops, a large plate spacing would be required to prevent significant gradients in supersaturation across the drop body. The combination of the above effects may restrict the operating range of the levitation technique to droplets smaller than about 100 μm radius.

The electric field and charge number limits for the levitation technique are shown in Fig. 6 . For charge numbers at the Rayleigh limit, the effective surface tension of the drop is reduced to zero. The drop then becomes unstable and is subject either to charge loss or to large amplitude oscillations which disrupt it. For charge numbers somewhat below the Rayleigh limit, alterations in the equilibrium water vapor pressure above the drop and in drop growth and evaporation rates, due to the high drop charging, are expected to become significant. On the other hand for electric fields at the Taylor limit, the drop becomes elongated and develops a point instability at its two ends. This point then releases the instability by means of charge or mass loss, or both. For electric fields somewhat below the Taylor limit, alterations in the equilibrium vapor pressure above the drop and in drop growth and evaporation rates due to the induced charge separation and change in drop shape, are again expected to become significant. Finally, for high drop charging in high electric fields, the two effects combine to "pinch off" the operating range accessible to the levitation technique at charge and field levels significantly lower than would occur if each effect were operating independently.

The relationships presented in Fig. 6 suggest another use for the levitation technique, in which the existence of the Rayleigh and Taylor limits is used to advantage. Namely that, this technique is an ideal means by which to investigate the conditions and mechanisms of electrical breakdown in a moist, droplet filled atmosphere with a carefully controlled and accurately known relative humidity. For example, the Rayleigh boundary and the "pinched-off region" of high drop charging and high field strength can be accurately mapped. A particularly interesting region to investigate is the Taylor limit. The breakdown voltage for air tends to be in the range of ten Kilovolts per cm, and it shows significant variations with gas pressure and composition. Dawson and his colleagues at the University of Arizona performed an elegant set of experiments in which they determined the electrical breakdown mechansim at the surface of hanging water drops, as a function of drop curvature and field strength. Similar experiments have been performed for drops falling in a wind tunnel. However, no comparable experiments have apparently been carried out for free floating drops in a calm, stable atmosphere. It is conceded that the results of this type of investigation may not be directly applicable to the atmosphere; however, Dawson attempted just such an application from the results of his "hanging drop" studies. He also used the results of these studies to good advantage in the interpretation of his later work on falling drops. The results of a comparable study on stably levitated drops are expected to be similarly fruitful.

D. Sensitivity

It is useful at this point to examine the sensitivity of the levitation technique to changes (or errors) in the various parameters which enter into the equilibrium conditions (Figs. 7-11). The starting relationships are the electrical/gravitational force balance, the Kohler equation, and the static diffusion chamber supersaturation profile. (Fig. 7) Assuming that these relationships hold, the equilibrium differentials are easily determined (Fig. 8). Logarithmic forms are used for convenience in deriving the final relationships. Activation relationships (Fig. 9) are easily derivable or obtainable from Fletcher, Mason, and Byers. Finally, the equilibrium differentials can be combined as shown in Fig. 8, rewritten in terms of the activation relationships in Fig. 9, and expressed in exceedingly simple form as shown in Fig. 10. This final expression relates changes in selected parameters to changes in other parameters, assuming that equilibrium is maintanined throughout. The coefficients of these differential changes are easily evaluated and are shown in Fig. 11.

Similar sensitivity studies may be performed for the more exact expressions which incorporate buoyancy, phoretic, and Brownian effects into the force balance; electrical effects and the new CCN theory into the Kohler equation; and wall effects or subsaturated lower plates into the supersaturation profiles. Likewise, when the equilibrium differentials shown in Fig. 8 are combined, other variables can be eliminated so that the final equilibrium differential includes drop growth rates or ramp rates in the plate temperatures.

As an application of the sensitivity study which was performed, consider the problem of selecting the optimum means of measuring scavenging rates. Assume constant charge ($dq = 0$). This problem then reduces to a determination of the relative sensitivity of droplet position change (dz) for a constant electric field ($dE=0$) and the electric field change (dE) required to maintain the droplet at a constant position in the chamber. To increase the sensitivity of the detection technique, it appears to be desirable to maximize the coefficient of the scavenging term (dM_s) while at the same time minimizing the coefficient of the detection term (dE or dZ). Thus, the sensitivity of the field change technique is maximized (Fig. 11) for drops near activation ($X = r_c/r \gtrsim 1$), for which scavenging amplifications by a factor of three to five are possible. The larger amplifications which appear for conditions quite close to activation ($X = 1$) would be quite difficult to attain in practice because finite increases in soluble mass (ΔM_s) would actuallly cause activation and destablization.

On the other hand, the sensitivity of the position change technique is maximized for drops near saturation ($X = \sqrt{3}$) and drop position near $H/2$. However, these two extremes are incompatible for a water/water plate configuration. For drops near saturation and drop positions near the bottom plate, scavenging amplifications by a factor of about 2.5 are possible. For drops near activation and drop positions near $H/2$, amplifications by factors of about three to five are again reasonable. For drops roughly midway between saturation and activation, and drop positions roughly midway between the bottom plate and the chamber midpoint (i.e. near $H/4$), amplifications by a factor of three seem reasonable.

Assume that a factor of three amplification is attainable. It is then possible to determine the limiting resolution of the detection technique for scavenging. It appears that in either the case of $dz = 0$ or $dE = 0$, the detection limit will be based on the limiting resolution for position detection. We assume a limiting resolution for the unaided human eye of 0.1 mm (0.01 cm) at a distance of about 20 cm, an optical telescope with a magnification of 10X (without degraded resolution), and a droplet suspended about 1.0 cm above the bottom plate. We then find position resolution of about 0.1% and a scavenging resolution of about one-third that value, or about 0.03%. Assume a dry particle radius of about 0.1 µm, or a dry mass of about 10^{-14} gm. It then appears that this detection system may be capable of a limiting scavenging resolution as low as about 3×10^{-18} gm for these particles (about 3×15^{-15} gm for a 1.0 µm radius dry particle).

As a second application to this sensitivity study, consider the spread produced in the thin droplet layer by polydispersity in charge or soluble mass. Thus, a 10% polydispersity in charge will produce only about a 2-3% spread in droplet layer thickness for nearly activated drops about one-third of the chamber height above the bottom plate - but about a 17% spread for drops near saturation just above the bottom plate. On the other hand, a 10% polydispersity in soluble mass will produce nearly a 25% position spread for drops near saturation just above the bottom plate and about a 10% position spread for nearly activated drops one-third of the plate spacing above the bottom plate.

E. Development Plan

It can be seen that the proposed levitation technique is potentially a very versatile research tool for studying problems in cloud microphysics and techniques for low-gravity remote drop positioning as well as for evaluating particular microphysical experiments for inclusion on ACPL. We therefore propose to build a prototype levitation chamber and test it at several selected drop sizes (Table 2). Using the experience gained with this prototype chamber, we expect to develop a precision levitation chamber for careful measurements of scavenging rates and other selected cloud microphysical problems.

Auxilliary equipment required for this work will include various aerosol generation techniques. For example, very large drops which can be levitated only by very large drop charging in very high electric fields must probably be generated directly (near their final size). This restriction arises because small atomized droplets of highly concentrated solution, which can easily grow into very large drops in high relative humidities, cannot stably hold the large quantities of charge required to levitate the very large drops. Standard large-drop generating techniques are available; however, as an alternative, it may be possible to charge up drops which are beginning to grow in the chamber. For the smaller sized droplets, standard atomization techniques are expected to be adequate. Droplet position detection is expected to be accomplished using standard optical telescopes. This system is expected to be adequate for droplets larger than a few microns in radius. For smaller droplets, such arrangements as a travelling light source (laser) and a yoked detector, or other comparable configurations as well, are possible. The primary development effort is expected to be directed forward the design of the levitation chamber itself and the selection of the appropriate droplet generation techniques.

III Planned Effort

During the final three months of the current contract year work is expected to be performed in six principal areas:

1. The NASA review on 12-13 September.

2. Continuing technical assistance with the design and development of ACPL. This effort is expected to be concentrated during 9-17 October, the first phase of the MSFC Critical Design Review (CDR) at Hunstville on the General Electric Contract for ACPL.

3. Final development of the gravimetric test as a means of evaluating the saturator performance. Concurrently with this work will be a comparison of the gravimetric and the vapor pressure techniques for testing the saturator and evaluation of a plasma (glow-discharge) technique for cleaning the saturator wicking surfaces.

4. Final documentation of the following research:

a. Sensitivity of warm cloud development to cloud updraft and aerosol nucleus spectrum.

b. Sensitivity of warm cloud formation to composition, aerosol spectrum, and initial temperature and pressure of the carrier gas.

c. Gravimetric verification of the saturator performance.

5. Numerical solution of the CCN activation polynomial and preparation of a professional paper on the results.

6. (If time permits) Design and construction of prototype static diffusion chamber with applied electric field for droplet levitation studies.

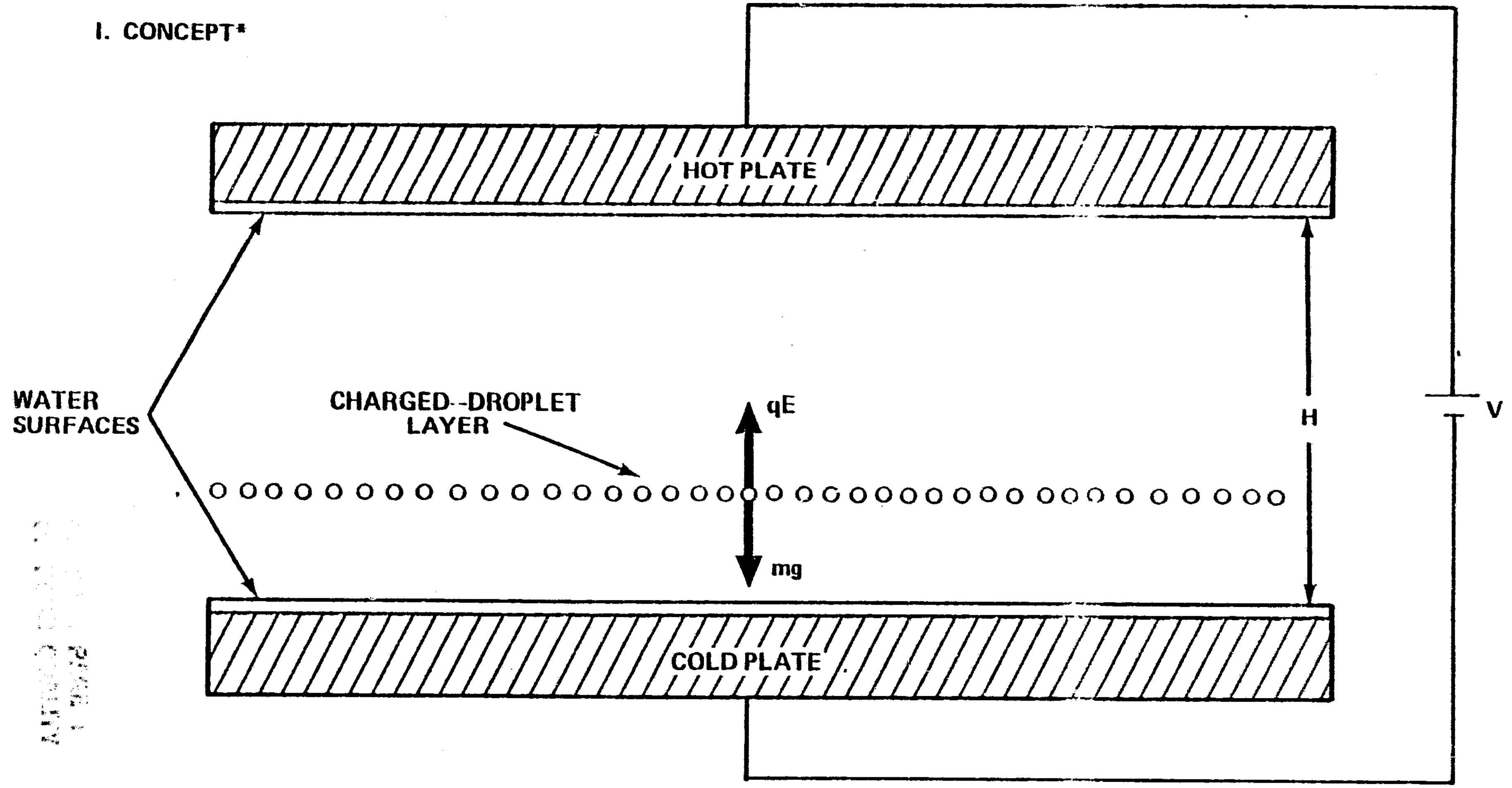
The presence of the ACPL CDR in the new quarter creates some uncertainty in the projected work list. CDR is scheduled to begin on October 9 and end on November 9. It is not yet certain how much effort will be required during CDR under this contract, outside of the known 9-17 October period. In comparison to the other tasks, this review holds a very high priority. If it is necessary to postpone or delete some of the above tasks in order to support CDR as required, Task #6 will be downgraded first, followed by Task #5.

STABLE ELECTROSTATIC LEVITATION OF A THIN, CHARGED-DROPLET LAYER IN A ONE-G STATIC DIFFUSION CHAMBER:

APPLICATIONS TO RESEARCH IN CLOUD MICROPHYSICS AND LOW-GRAVITY TECHNIQUES

DAVID BOWDLE, USRA
RESEARCH ASSOCIATE

I. CONCEPT*



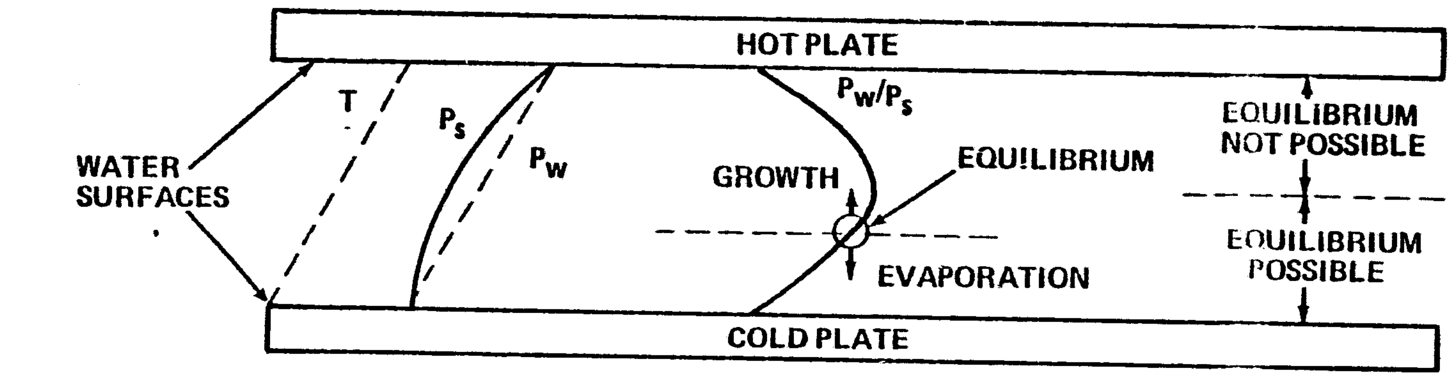
STATIC DIFFUSION (LIQUID) CHAMBER (SDL) WITH APPLIED ELECTRIC FIELD

*ADAPTED FROM — SUN, L. K., A. W. GERTLER, AND H. REISS, 1979: "MILLIKAN 'OIL DROP' STABILIZED BY GROWTH". SCIENCE, 203, 353--354.

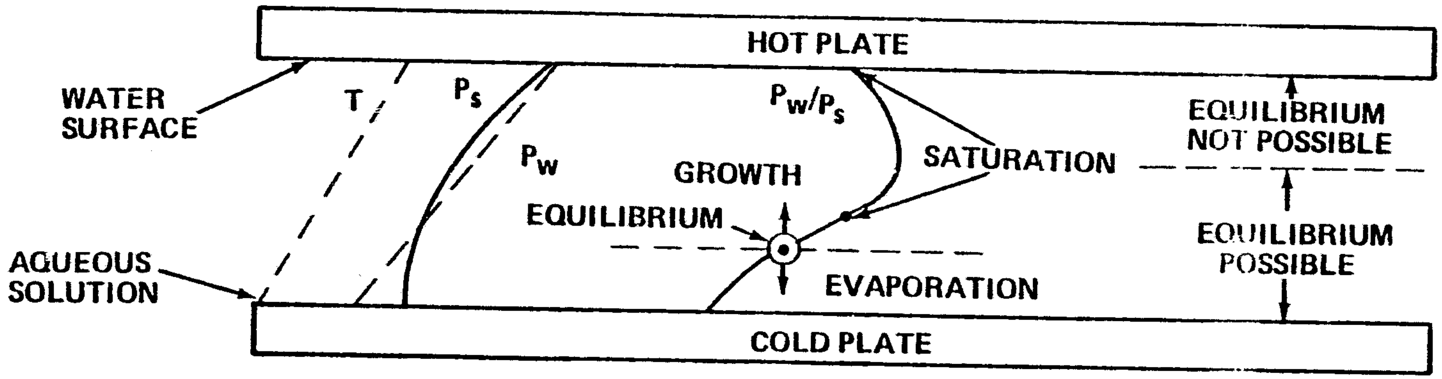
FIG 1

II. OPERATING PRINCIPLE OF STABLE LEVITATION

A. WATER VAPOR SUPERSATURATION PROFILES IN AN SDL



ORDINARY SDL, WATER ON UPPER AND LOWER PLATES



MODIFIED SDL, WATER ON UPPER PLATE, SATURATED SOLUTION ON BOTTOM PLATE.

II. OPERATING PRINCIPLE (CONTINUED)

B. EQUILIBRIUM WATER VAPOR SUPERSATURATION ABOVE THE SURFACE OF SOLUTION DROPLETS

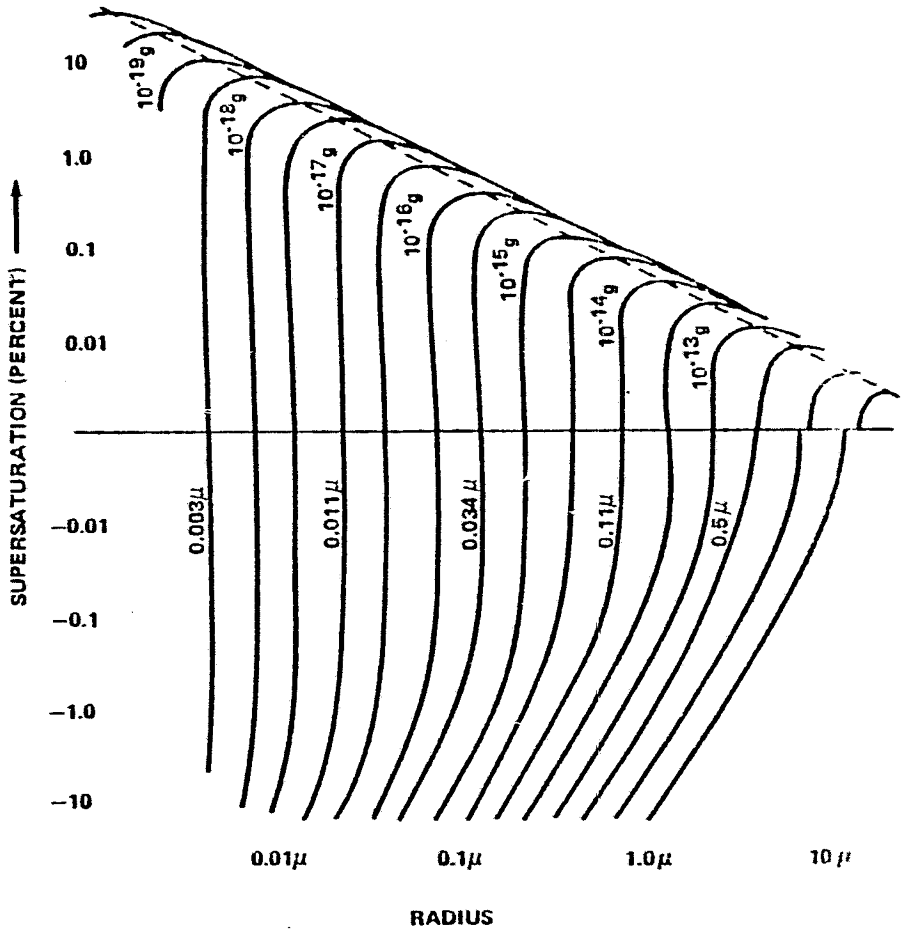


FIG. 4.7. KOHLER CURVES, RELATING EQUILIBRIUM SUPERSATURATION (OR RELATIVE HUMIDITY) TO RADIUS OF DROPLET. FOR EACH CURVE THERE IS IN SOLUTION A DIFFERENT MASS OF SOLUTE (i.e., EACH CURVE RELATES TO A PARTICULAR SIZE OF NUCLEUS, AS INDICATED ON THE INDIVIDUAL CURVES). BROKEN LINE SHOWS LOCUS OF THE MAXIMA.

FROM: TWOMEY, S., 1977: ATMOSPHERIC AEROSOLS. ELSEVIER, NEW YORK. P. 94.

III. APPLICATIONS OF THE LEVITATION TECHNIQUE

A. CLOUD MICROPHYSICS

1. SCAVENGING BY HAZE, FOG, AND CLOUD DROPLETS
   - PHORETIC AND BROWNIAN SCAVENGING OF PARTICLES
   - SCAVENGING OF GASES
2. DROPLET CHARGING/DISCHARGING (LIGHTNING)
3. MEASUREMENT OF PHORETIC FORCES
4. VERIFICATION OF KOHLER THEORY AND NEW CCN THEORY
5. DETERMINATION OF AEROSOL SOLUBLE MASS
6. DROPLET GROWTH RATES AND ACCOMODATION COEFFICIENTS
7. NUCLEUS ACTIVATION/DEACTIVATION
8. FREEZING OF SOLUTION DROPS

B. LOW-GRAVITY TECHNIQUES

1. EVALUATE VARIOUS REMOTE DROPLET POSITIONING DEVICES IN ONE-G
   - LASER
   - ACOUSTIC
   - E-FIELD

COMPARISON OF BROWNIAN AND SEDIMENTATION EFFECTS

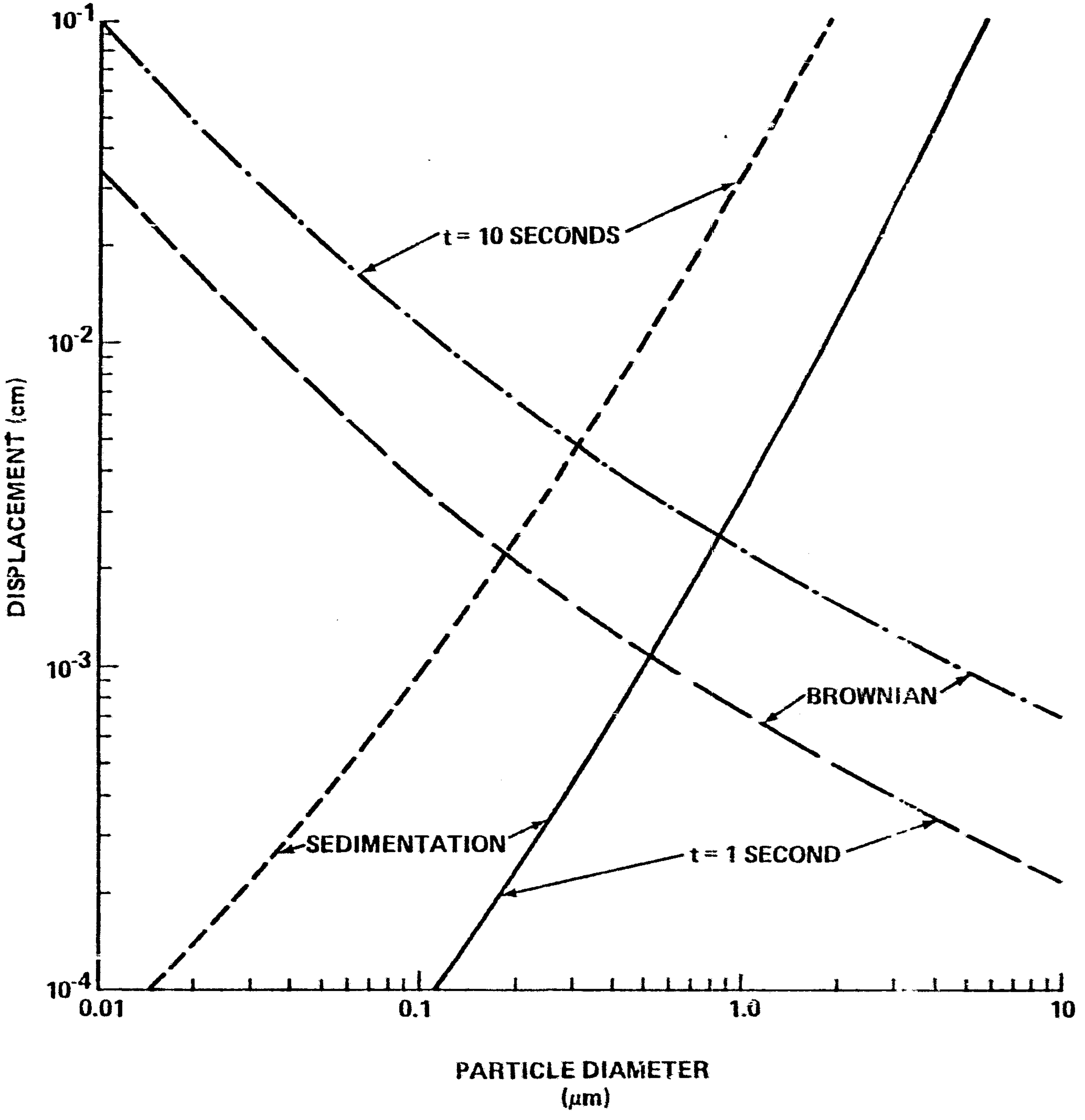


FIG 4

OPERATING PARAMETERS FOR SDL/E-FIELD LEVITATION TECHNIQUE:

SOLUTION DROPLET CRITICAL RADIUS (r_c), DROPLET RADIUS AT SATURATION (r_{100}), DRY PARTICLE RADIUS (r_d), CRITICAL SUPERSATURATION (S_c), AND SDL PLATE TEMPERATURE DIFFERENCE, ΔT (CHOSEN SO THAT $S_{MAX} = S_c$).

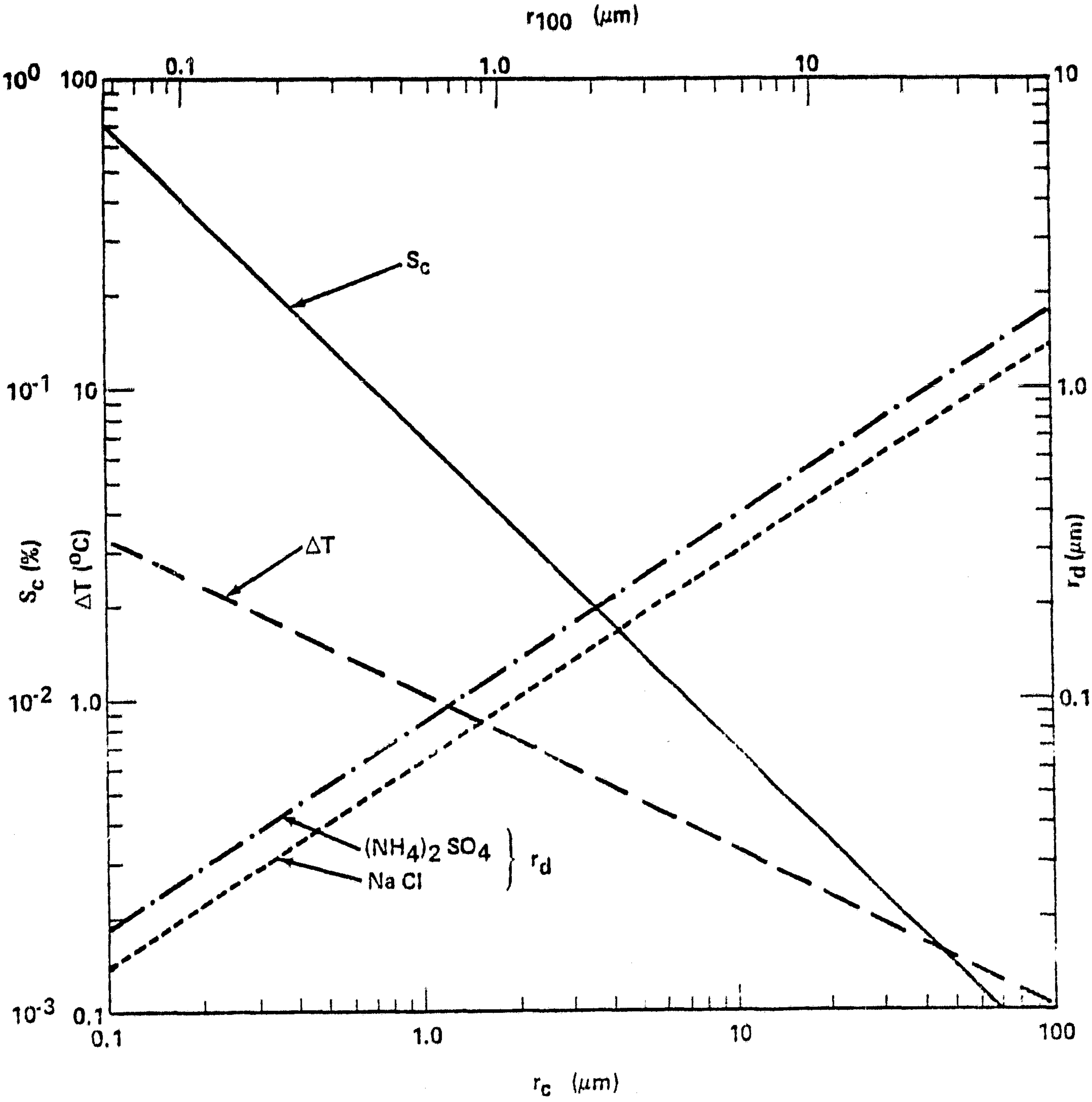
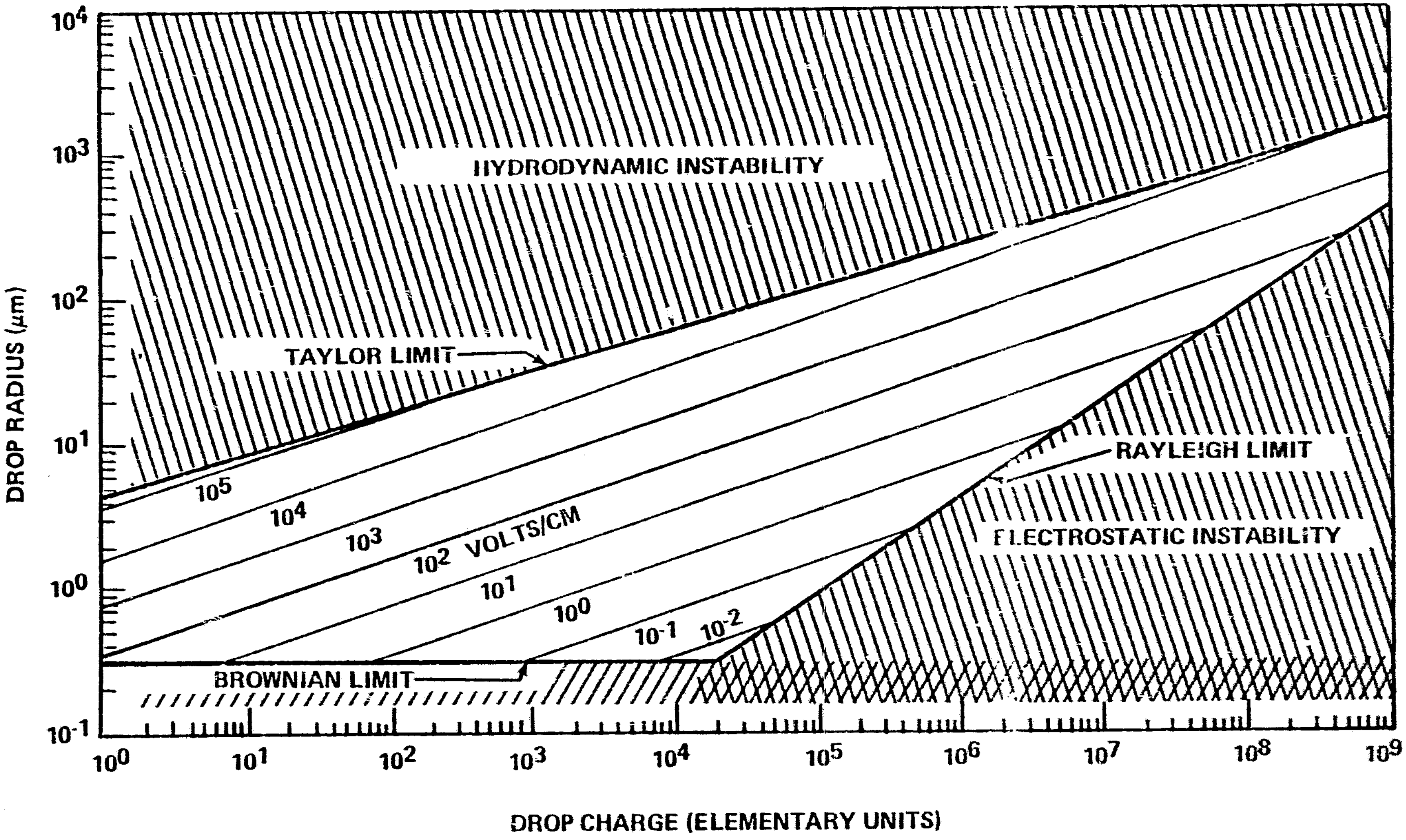


FIG 5

OPERATING RANGE OF THE LEVITATION TECHNIQUE



V. EQUILIBRIUM SENSITIVITY OF LEVITATION TECHNIQUE

A. EQUILIBRIUM RELATIONSHIPS

1. FORCE BALANCE (NEGLECT BUOYANCY, PHORETIC EFFECTS, AND BROWNIAN MOTION)

$$qE = \frac{4\pi}{3} \; g\rho'_{\ell} r^3$$

2. KOHLER RELATIONSHIPS (ASSUME DILUTE SOLUTION)

$$S = \frac{K}{r} - \frac{\alpha m_s}{r^3}$$

3. SDL SUPERSATURATION PROFILES (APPROXIMATE)*

$$S = \left\{\frac{Z}{H}\right\} \left\{1 - \frac{Z}{H}\right\} \left\{2.6 \times 10^{-3}\right\} \left\{\Delta T\right\}^2$$

*ORDINARY (WATER SURFACES) SDL CONFIGURATION

FIG 7

V. EQUILIBRIUM SENSITIVITY (CONTINUED)

B. EQUILIBRIUM DIFFERENTIALS

1. $$\frac{dq}{q} + \frac{dE}{E} = 3\,\frac{dr}{r}$$

2. $$dS = -\left\{\frac{K}{r} - \frac{3\alpha m_s}{r^3}\right\}\left\{\frac{dr}{r}\right\} - \left\{\frac{\alpha m_s}{r^3}\right\}\left\{\frac{dm_s}{m_s}\right\}$$

3. $$dS = 2.6 \times 10^{-3}\,(\Delta T)^2 \left\{1 - \frac{2Z}{H}\right\}\left\{\frac{dZ}{H}\right\}$$

COMBINING EQUATIONS 1, 2, AND 3 ABOVE GIVES THE FOLLOWING RELATIONSHIP:

$$-\left\{\frac{dq}{q} + \frac{dE}{E}\right\}\left\{\frac{K}{r} - \frac{3\alpha m_s}{r^3}\right\} - \left\{\frac{3\alpha m_s}{r^3}\right\}\left\{\frac{dm_s}{m_s}\right\} = 7.8 \times 10^{-3}\,(\Delta T)^2 \left\{1 - \frac{2Z}{H}\right\}\left\{\frac{dZ}{H}\right\}$$

FIG. 8

V' EQUILIBRIUM SENSITIVITY (CONTINUED)

IT CAN EASILY BE SHOWN THAT, AT ACTIVATION,
THE FOLLOWING RELATIONSHIPS WILL HOLD:

$$r_c^2 = \left\{\frac{3\,\alpha M_s}{K}\right\} \quad \text{AND} \quad S_c = \left\{\frac{4\,K^3}{27\,\alpha M_s}\right\}^{1/2}$$

HENCE,

$$r_c^3 = \left\{\frac{3\,\alpha M_s}{K}\right\}^{3/2} = (\alpha M_s)\left\{\frac{27\,\alpha M_s}{K^3}\right\}^{1/2} = \left\{\frac{2\,\alpha M_s}{S_c}\right\}$$

ALSO,

$$S_c = \left\{\frac{2\,\alpha M_s}{r_c^3}\right\} = (2.6 \times 10^{-3})\,(\Delta T)^2 \left\{\frac{Z}{H}\right\}\left\{1 - \frac{Z}{H}\right\}$$

THEREFORE

$$(\Delta T)^2 = \left\{\frac{2\,\alpha M_s}{r_c^3}\right\}\left\{\frac{1}{2.6 \times 10^{-3}}\right\}\left\{\frac{H}{Z}\right\}\left\{\frac{1}{1 - \frac{Z}{H}}\right\}$$

V. EQUILIBRIUM SENSITIVITY (CONTINUED)

THE EQUILIBRIUM DIFFERENTIAL CAN THEREFORE BE WRITTEN AS FOLLOWS:

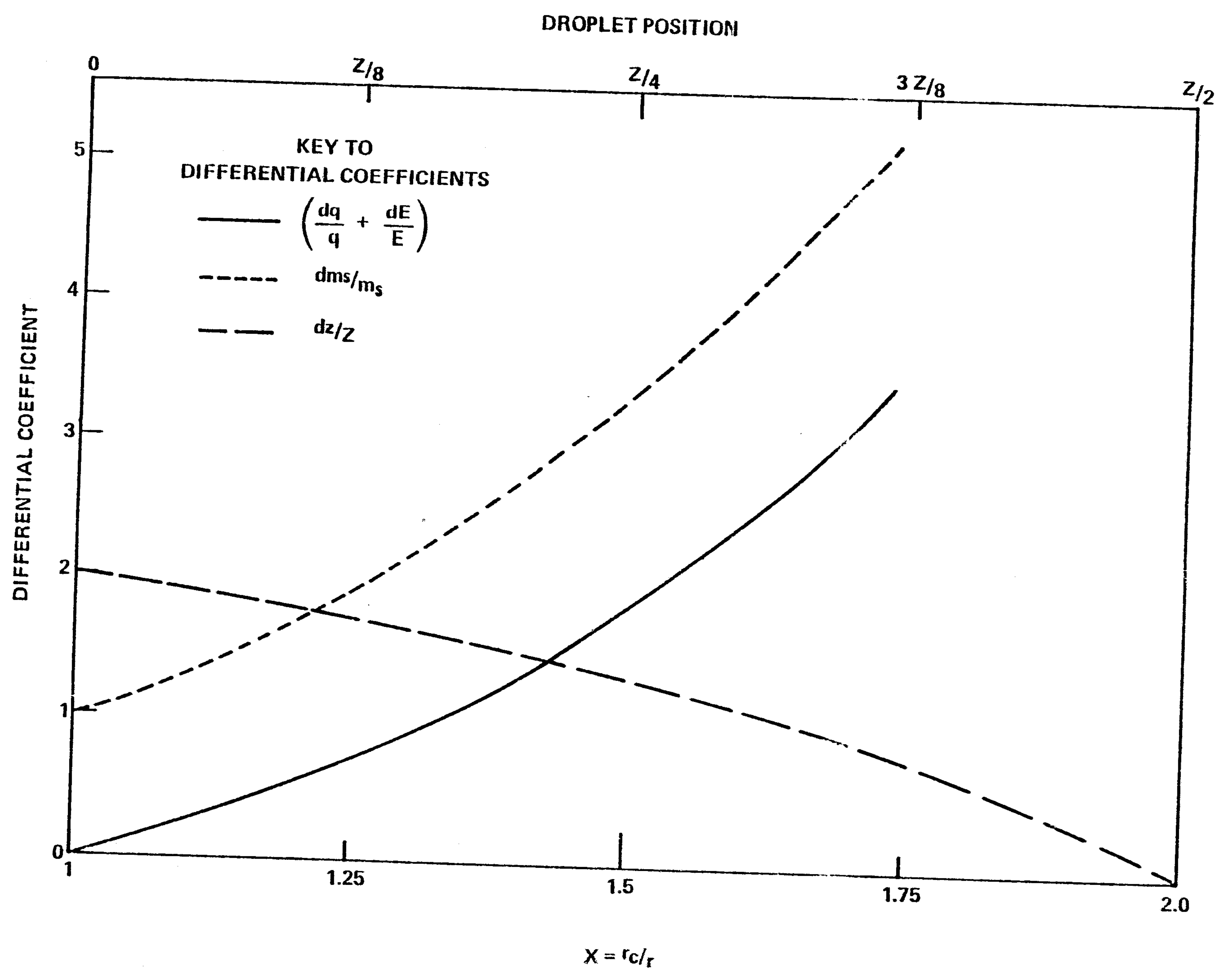
$$-\left\{\frac{dq}{q}+\frac{dE}{E}\right\}\left\{\frac{K}{r}-\frac{3\alpha M_s}{r^3}\right\}-\left\{\frac{3\alpha M_s}{r^3}\right\}\left\{\frac{dM_s}{M_s}\right\}=\left\{\frac{6\alpha M_s}{r_c^3}\right\}\left\{\frac{1-\frac{2Z}{H}}{1-\frac{Z}{H}}\right\}\left\{\frac{dZ}{Z}\right\}$$

WHICH MAY BE REWRITTEN IN THE FOLLOWING MANNER:

$$\left\{\frac{dq}{q}+\frac{dE}{E}\right\}\left\{\left(\frac{r_c}{r}\right)^3-\left(\frac{r_c}{r}\right)\right\}-\left\{\left(\frac{r_c}{r}\right)^3\right\}\left\{\frac{dM_s}{M_s}\right\}=2\left\{\frac{1-\frac{2Z}{H}}{1-\frac{Z}{H}}\right\}\left\{\frac{dZ}{Z}\right\}$$

THE VALUES OF THE COEFFICIENT OF EACH DIFFERENTIAL ARE EASILY EVALUATED, AS SHOWN IN THE FOLLOWING GRAPH:

FIG 10



DROPLET POSITION
0
Z/8
Z/4
3 Z/8
Z/2
KEY TO
DIFFERENTIAL COEFFICIENTS
$\left(\frac{dq}{q} + \frac{dE}{E}\right)$
dm_s/m_s
dz/Z
DIFFERENTIAL COEFFICIENT
5
4
3
2
1
0
1
1.25
1.5
1.75
2.0
$X = r_c/r$

VI. PROPOSED DEVELOPMENT PLAN

A. FEASIBILITY STUDY

1. BUILD AND EVALUATE PROTOTYPE SDL
   - ~3 cm PLATE SPACING, ~30 cm DIAMETER
   - COMPARABLE TO DIMENSIONS OF ACPL SDL
2. EVALUATE LEVITATION TECHNIQUE FOR VARIOUS DROPLET SIZE REGIMES
   - ~1 μm RADIUS (HAZE DROPLETS) $\Delta T \sim 1^{o}C$
   - ~10 μm RADIUS (CLOUD/FOG DROPLETS) $\Delta T \sim 0.3^{o}C$
   - ~100 μm RADIUS (DRIZZLE DROPS) $\Delta T \sim 0.1^{o}C$
3. UTILIZE PROTOTYPE SDL AS NEEDED FOR EVALUATING VARIOUS LOW-GRAVITY DROPLET "HANDLING" TECHNIQUES

VI. PROPOSED DEVELOPMENT PLAN (CONTINUED)

B. DETAILED CLOUD MICROPHYSICS STUDY

1. BUILD AND CALIBRATE PRECISION SDL
2. MEASURE SCAVENGING RATES
3. VERIFY NEW CCN THEORY
4. EVALUATE OTHER MICROPHYSICAL PROBLEMS FOR ACPL FEASIBILITY

C. EQUIPMENT DEVELOPMENT/MODIFICATION

1. AEROSOL GENERATION TECHNIQUES FOR VARIOUS SIZE REGIMES (ATOMIZERS, NEBULIZERS, MONODISPERSE GENERATORS, "PLUCKERS")
2. DROPLET POSITION DETECTORS (MICROSCOPES, LASERS, ETC)
3. DROPLET CHARGING MECHANISMS

USRA

UNIVERSITIES SPACE RESEARCH ASSOCIATION
P.O. Box 3006
Boulder, Colo. 80307

PROGRESS REPORT

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

APRIL 1, 1979 - JUNE 30, 1979

SUBMITTED TO: N.A.S.A.

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

PROGRESS REPORT: April 1, 1979 - June 30,1979

Research Study: Warm/Cold Cloud Processes

Contract NAS8-33131

Mr. David A. Bowdle continued working during the reporting period as USRA Visiting Scientist under the direction of Dr. B. Jeffrey Anderson of MSFC. Mr. Bowdle's report on his activities during this period is attached.

No problems exist that may impede progress.

During the next reporting period, Mr. Bowdle will continue as USRA Visiting Scientist.

Respectfully Submitted,

M. H. Davis
USRA/Boulder
Program Director

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SECOND QUARTERLY REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

QUARTER: 1 March - 31 May, 1979

BY: David A. Bowdle, USRA Visting Scientist, Marshall Space Flight Center

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three months, work has been accomplished under this contract in six principal areas:

1. Continuing familiarization with and technical support of the Atmospheric Cloud Physics Laboratory which is planned for use on the Space Shuttle.

2. Continuing development of procedures and equipment to test a prototype precision saturator of the type to be used on ACPL. A thorough error analysis of the gravimetric test which has been under development has shown that the achievable limit of resolution of the test itself is probaly nearer to 0.5% than to the desired 0.05% resolution. An additional procedure, which uses direct measurement of water vapor pressure was also explored.

3. Continuing evaluation of the results of expansion chamber simulations using the General Electric ACPL Numerical Simulator.

4. Continuing theoretical evaluation of the activation of mixed (soluble/insoluble) cloud condensation nuclei. A more detailed account of these studies is given in the following section.

5. Preliminary numerical evaluation of a new technique for experimentally verifying the theoretical results in #4 above.

6. Attendance at the University of Tennessee Space Institute (UTSI) one week short course on Atmospheric Optics.

II. Results of Mixed Aerosol Studies

When the Kohler expression (Fletcher, 1969) for the equilibrium supersaturation over a solution droplet of a given size is analyzed carefully, the following expression results:

$$X^6 - AX^4 - BX^3 + C = 0$$

where $X = r/r_d$, the ratio of the solution droplet radius to the dry radius; the coefficients A, B, and C are, to first order, constants; and the solutions to the polynomial equation describe the conditions at activation. For aerosol particles which either are large or contain large amounts of soluble mass, the first two terms dominate, and the solution is identical in form to Fletcher's traditional solution. However, for smaller aerosol or aerosol covered by only a small amount of soluble material, variations in solution properties (density, surface tension, etc.) begin to become important, the coefficients can no longer be considered as constants, all coefficients have about the same [illegible] magnitude, and the form of the solution begins to change. The values of the critical radius found in this case differ from Fletcher's values by as much as 15%, and the values of the critical supersaturation in turn vary by as much as a factor of two to three. It turns out that the form of the solution begins to change for dry aerosol (CCN) which can be treated as a monolayer of soluble material (e.g. salt) on the surface of an insoluble, wettable core. These results are expected to have important consequences for studies of the effects of aerosols on cloud microphysical properties - for example in studies of inadvertent weather modification due to urban, industrial, and agricultural air pollution. These results are also expected to provide a more sound theoretical basis for the studies of mixed aerosols which are planned for later ACPL missions.

For dry aerosol covered by less than a monolayer of soluble material, the importance of the second term rapidly diminishes and the polynomial equation takes the form:

$$X^6 - BX^3 + C = 0$$

which should be easily solvable. However, in this region, the variation of solution properties with concentration begins to become extremely important, and the coefficients B and C themselves may actually be strong functions of X. In addition, surface effects due to the insoluble core also begin to become important. This region has not yet been analyzed, but is expected to be investigated during the next quarter. These theoretical results differ considerably from these found in Fletcher (1969), Mason (1971), Junge and McLaren (1971), and Fitzgerald (1973). Hence it is of considerable importance that the theory be experimentally verified. ACPL is ideally equipped to perform studies of this kind but hard experimental data from ACPL are still several years away. Investigations are therefore underway to develop techniques which will allow a "quick and dirty" experimental look at this problem in a terrestrial laboratory.

III. Planned Effort

During the coming three months, work directed toward technical support of ACPL is expected to continue as required. Experimental verification of the saturator performance is expected to be completed (although it appears unlikely that the desired 0.05% verification level will be reached) and documented. Results of the Expansion Chamber studies will also be documentd. Physical chemistry data from such sources as the International Critical Tables will be used to compile coefficients for the polynomial equation which results from a theoretical analysis of CCN activation. This equation will be solved numerically and the results compared to those found using various standard approximations from the literature. This work is expected to form a professional paper. The experimental work on verifying the new CCN theory is also expected to begin.

References

Fitzgerald, J. W., 1973: Dependence of the supersaturation spectrum of CCN on aerosol size distribution and composition. J. Atmos. Sci., 30, 628-634.

Fletcher, N. H., 1969: The Physics of Rainclouds. Cambridge, University Press, pp. 58-62

Junge, C., and E. McLaren, 1971: Relationship of cloud nuclei spectra to aerosol size distribution and composition. J. Atmos. Sci., 28, 382-390.

Mason, B. J., 1971: The Physics of Clouds, Second Edition. Oxford, Clarendon Press; pp 24-29

USRA

P R O G R E S S   R E P O R T

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

JANUARY 1, 1979

THROUGH

MARCH 31, 1979

SUBMITTED TO:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER

ALABAMA 35812

UNIVERSITIES SPACE RESEARCH ASSOCIATION

P.O. Box 3006

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(303) 449-3414

RESEARCH STUDY: WARM/COLD CLOUD PROCESSES

Contract NAS8-33131

PROGRESS REPORT FOR THE PERIOD 1/1/79 - 3/31/79

Mr. David A. Bowdle continued during the reporting period as USRA Visiting Scientist working with Dr. B. Jeffrey Anderson at Marshall Space Flight Center.

Mr. Bowdle prepared a Progress Report covering his first three months at MSFC which is attached.

Progress is satisfactory, and no problems have appeared that are expected to interfere with contract performance.

Respectfully submitted,

M. H. Davis
USRA/Boulder Program Director

FIRST QUARTERLY REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: November 27, 1978 - February 23, 1979

BY: David A. Bowdle, USRA Visiting Scientist, Marshall Space Flight Center

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the past three months, preliminary work has been accomplished under this contract in five principal areas:

1. General familiarization with the concept and instrumentation of the Atmospheric Cloud Physics Laboratory (ACPL) and with the individual experiments planned for early ACPL missions on the Space Shuttle.

2. General support of the ACPL program through technical advice, particularly concerning warm cloud processes and the nature and importance of atmospheric aerosol particles in various meteorological processes.

3. Development of equipment and procedures to test a prototype saturator (a precision humidifier manufactured by Desert Research Institute, Reno, Nevada) and to verify its performance to 0.05%. These test procedures can then be used on the ACPL. The supporting test equipment is about 60 percent complete at this time.

4. Evaluation of the effects of variations in the spectrum of cloud condensation nuclei (CCN) on the potential accuracy of photographic determinations of cloud droplet number density in the Expansion Chamber (E-Chamber) which will be used on the ACPL.

5. Theoretical re-evaluation of the Kohler equation describing the behavior of CCN near their critical (or activation) radius, and extension of this treatment to nuclei composed of both soluble and insoluble components. The results of this study, combined with the results from study #4 above, will have a direct impact on the evaluation of results from droplet growth and cloud-forming experiments on early ACPL missions.

II. Planned Effort

During the coming three months, work directed toward general familiarization with and technical support of ACPL is expected to continue as required. Experimental verification of the saturator performance will also continue throughout this period. The E-Chamber cloud forming studies are nearly complete and will be documented early in this period. Numerical techniques will be used to solve the basic equations which describe CCN activation, and a professional paper on the theoretical results of this CCN study will be in preparation. Preliminary investigation is expected to begin on experimental techniques for verifying these theoretical results.

III. Results

Cloud-forming experiments of the type to be performed in the ACPL E-Chamber have been carried out using the Adiabatic Expansion Numerical Simulator developed by General Electric. In this simulator, a parcel of air with a specified temperature, dewpoint temperature, and pressure (290°K, 290°K, 1000 mb in this study) is subjected to a forced adiabatic cooling. The CCN spectrum and the driving force for the cooling used as input to the model can also be specified.

For example, simulation runs were performed at four different updraft speeds for each of three different CCN spectra, as shown in Tables 1 and 2 below.

Table 1: Updraft as a Function of Simulated Cloud Type

Updraft Speed (cm sec^{-1})	1.0	10	100	1000
Simulated Cloud Type	Fogs	Stratus	Cumulus	Cumulonimbus

Table 2: CCN Spectrum as a Function of Simulated Aerosol Type*

CCN Spectrum	$N = 234\ S^{0.7}$	$N = 3523\ S^{2.0}$	$N = 2280\ S^{0.9}$
Simulated Aerosol Type	maritime	transitional	aged continenta

*N is the number concentration (cm^{-3}) of CCN activated at a supersaturation of S (%)

The first set of simulations was run with six particle classes to locate approximately the separation between those CCN which were activated and grew to detectable size and those CCN which remained unactivated 'haze' droplets throughout the simulation. Additional runs were performed with a larger number of particle classes near the critical separation point. The final set of runs was performed with the CCN spectrum subdivided in such a manner that the i^{th} particle class near the critical separation contained 3% of all the CCN with smaller supersaturations, or:

$$\Delta N(I) = (0.03) \sum_{i=1}^{I-1} \Delta N(i)$$

Figures 1 and 2 show the results of such a simulation for maritime and continental cumulus clouds. It can be seen that the drop size spectrum for the maritime cumulus narrows much more rapidly than for the continental cumulus. Thus, the last activated class reaches 1 μm radius at about 25 sec and 2 μm at 30 sec in the maritime case; by contrast, the last activated class in the continental case reaches 1 μm radius near 70 sec and has not reached 2 μm by the end of the simulation. Hence, a droplet detection system with a minimum detectable size of, say, 2 μm radius, as is presently called for in the ACPL E-Chamber, could achieve 3% counting accuracy in 30 sec for the maritime case; but it could not possibly achieve 3% accuracy in less than 100 sec in the continental case.

In general, the problem of an initially broad droplet spectrum is present when the ambient supersaturation is reduced and droplet growth rates are correspondingly retarded. Low ambient supersaturations may be produced either by weak updrafts (or small expansion rates), by high CCN concentrations, or by moderate updrafts together with moderate CCN concentrations. Factors such as these, therefore, must be carefully considered in the planning and evaluation of the various cloud-forming experiments to be performed on the ACPL.

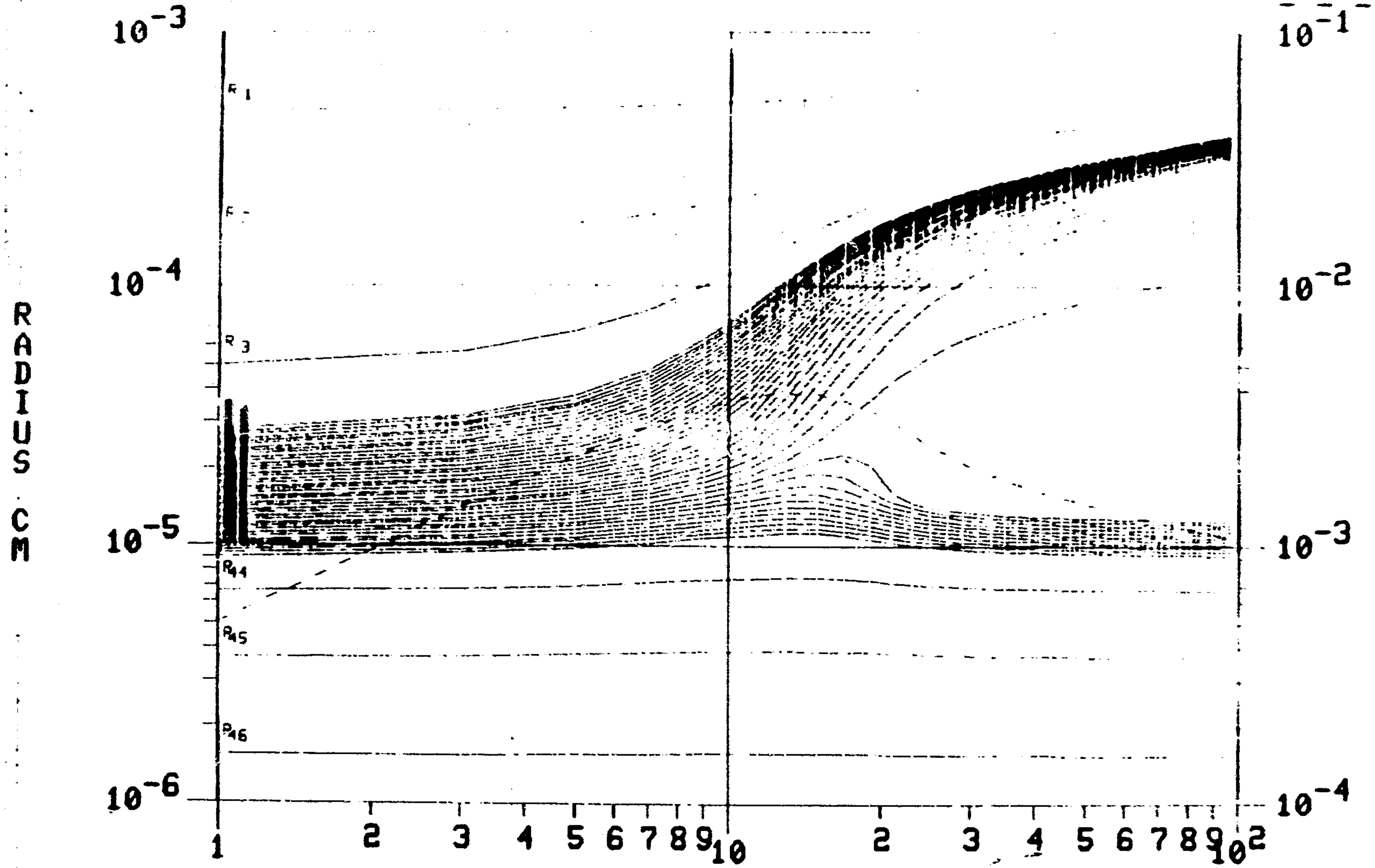
Figure Captions

Figure 1. Time history of droplet radii for a simulated maritime cumulus cloud (updraft = 100 cm/sec; CCN spectrum is described by $N = 234\ S^{0.7}$). The dashed line shows decimal supersaturation and the solid lines show droplet radii. The number of CCN in each category is shown in Table 3.

Figure 2 Same as Fig. 1 except for continental cumulus cloud (CCN spectrum is $N = 2280\ S^{0.7}$). The number of CCN in each category is shown in Table 4.

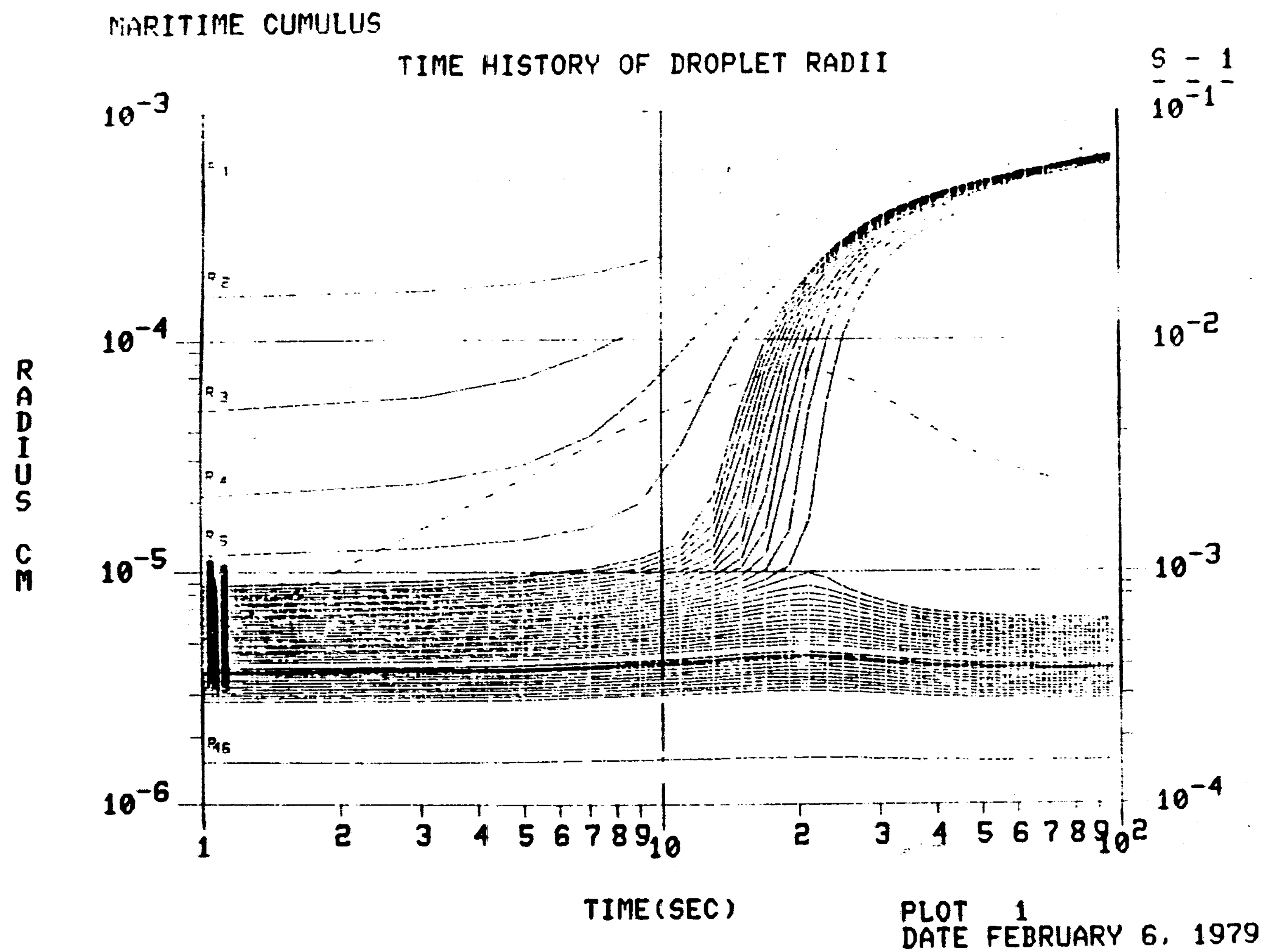
CONTINENTAL CUMULUS

TIME HISTORY OF DROPLET RADII



PLOT 1
DATE FEBRUARY 7, 1979

Figure 1



MARITIME CUMULUS
TIME HISTORY OF DROPLET RADII
RADIUS CM
10^{-3}
10^{-4}
10^{-5}
10^{-6}
S - 1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
R1
R2
R3
R4
R5
R16
1 2 3 4 5 6 7 8 9 10 2 3 4 5 6 7 8 9 10^2
TIME(SEC)
PLOT 1
DATE FEBRUARY 6, 1979

Figure 2

Table #3

INPUT PARAMETERS FOR ADIABATIC EXPANSION CHAMBER EXPERIMENT

INITIAL PRESSURE	0.10000D 04 MB
INITIAL TEMPERATURE	0.29000D 03 DEG K
INITIAL VOLUME	0.10000D 01 CC
SATURATOR PRESSURE	0.10000D 04 MB
SATURATOR TEMPERATURE	0.29000D 03 DEG K
START TIME	0.0 SEC
END TIME	0.10000D 03 SEC
INTEGRATION TIME INCREMENT	0.50000D-02 SEC
PRINT TIME INCREMENT	0.10000D 01 SEC
THERMAL CONDUCTIVITY COEFF.	0.10000D 01
CONDENSATION COEFFICIENT	0.30000D-01
SURFACE TENSION	0.75000D 02 DYNES/CM
NUMBER OF PARTICLE CLASSES	46

# PART.	CRIT. SUPERSATURATION
0.71000D 01	0.90000D-04
0.15900D 02	0.28000D-03
0.35600D 02	0.89000D-03
0.31900D 02	0.21100D-02
0.47800D 02	0.37500D-02
0.29300D 01	0.50700D-02
0.29900D 01	0.52200D-02
0.30500D 01	0.53700D-02
0.31100D 01	0.55300D-02
0.31800D 01	0.56900D-02
0.32400D 01	0.58600D-02
0.33100D 01	0.60300D-02
0.33800D 01	0.62000D-02
0.34400D 01	0.63900D-02
0.35100D 01	0.65700D-02
0.35900D 01	0.67600D-02
0.36600D 01	0.69600D-02
0.37300D 01	0.71700D-02
0.38100D 01	0.73700D-02
0.38900D 01	0.75900D-02
0.39700D 01	0.78100D-02
0.40500D 01	0.80400D-02
0.41300D 01	0.82700D-02
0.42100D 01	0.85200D-02
0.43000D 01	0.87600D-02
0.43900D 01	0.90200D-02
0.44800D 01	0.92800D-02
0.45700D 01	0.95500D-02
0.46600D 01	0.98300D-02
0.47500D 01	0.10120D-01
0.48500D 01	0.10420D-01
0.49500D 01	0.10720D-01
0.50500D 01	0.11830D-01
0.51500D 01	0.11360D-01
0.52600D 01	0.11690D-01
0.53700D 01	0.12030D-01
0.54700D 01	0.12380D-01
0.55900D 01	0.12740D-01
0.57000D 01	0.13110D-01
0.58200D 01	0.13500D-01
0.59300D 01	0.13890D-01
0.60500D 01	0.14300D-01
0.61800D 01	0.14710D-01
0.63000D 01	0.15140D-01
0.64300D 01	0.15590D-01
[illegible]	[illegible]

TABLE #4

INPUT PARAMETERS FOR ADIABATIC EXPANSION CHAMBER EXPERIMENT

INITIAL PRESSURE	0.100000D 04 MB
INITIAL TEMPERATURE	0.290000D 03 DEG K
INITIAL VOLUME	0.100000D 01 CC
SATURATOR PRESSURE	0.100000D 04 MB
SATURATOR TEMPERATURE	0.290000D 03 DEG K
START TIME	0.0 SEC
END TIME	0.100000D 03 SEC
INTEGRATION TIME INCREMENT	0.500000D-02 SEC
PRINT TIME INCREMENT	0.100000D 01 SEC
THERMAL CONDUCTIVITY COEFF.	0.100000D 01
CONDENSATION COEFFICIENT	0.300000D-01
SURFACE TENSION	0.750000D 02 DYNES/CM
NUMBER OF PARTICLE CLASSES	46

# PART.	CRIT. SUPERSATURATION
0.352000 02	0.900000-04
0.992000 02	0.280000-03
0.278000 03	0.890000-03
0.114000 02	0.160000-02
0.117000 02	0.165000-02
0.120000 02	0.170000-02
0.123000 02	0.175000-02
0.126000 02	0.180000-02
0.129000 02	0.185000-02
0.133000 02	0.191000-02
0.136000 02	0.196000-02
0.140000 02	0.202000-02
0.144000 02	0.208000-02
0.147000 02	0.214000-02
0.151000 02	0.220000-02
0.155000 02	0.227000-02
0.159000 02	0.233000-02
0.163000 02	0.240000-02
0.168000 02	0.247000-02
0.172000 02	0.254000-02
0.177000 02	0.262000-02
0.181000 02	0.269000-02
0.186000 02	0.277000-02
0.191000 02	0.285000-02
0.196000 02	0.294000-02
0.201000 02	0.302000-02
0.206000 02	0.311000-02
0.212000 02	0.320000-02
0.217000 02	0.329000-02
0.223000 02	0.339000-02
0.229000 02	0.349000-02
0.235000 02	0.359000-02
0.241000 02	0.370000-02
0.247000 02	0.380000-02
0.254000 02	0.391000-02
0.261000 02	0.403000-02
0.267000 02	0.415000-02
0.274000 02	0.427000-02
0.282000 02	0.439000-02
0.289000 02	0.452000-02
0.297000 02	0.465000-02
0.304000 02	0.479000-02
0.312000 02	0.493000-02
0.829000 03	0.667000-02
0.139200 04	0.118600-01
[illegible]	[illegible]

FIRST ANNUAL REPORT

CONTRACT: NAS8-33131, Warm and Cold Cloud Processes

FOR: The National Aeronautics and Space Administration (NASA)

WITH: The Universities Space Research Association (USRA)

PERIOD COVERED: November 27, 1978 - November 15, 1979

BY: David A. Bowdle, USRA Visting Scientist, Marshall Space Flight Center

TO: M. H. Davis, Program Director, USRA Boulder

I. Past Effort

During the 1979 contract year, technical support in the area of aerosol properties, warm cloud physics, and cold cloud processes was provided by USRA to NASA under Contract NAS8-33131. This effort supported three principal objectives of the Atmospheric Sciences Division at Marshall Space Flight Center:

1. To develop in-house technical and laboratory expertise in warm and cold cloud processes and in cloud microphysics research methods.

2. To provide technical assistance as needed to the design and development of the Atmospheric Cloud Physics Laboratory (ACPL).

3. To develop new research techniques for studying problems in cloud microphysics in low gravity as well as in earth based laboratories.

Significant accomplishments during the past contract year are listed in Table 1 and briefly described below.

II. Results

1. The sensitivity of warm cloud development to the cloud condensation nucleus (CCN) spectrum and the cloud updraft velocity was determined using the General Electric numerical simulator. Updraft velocities of 1, 10, 100, and 1000 cm/sec (simulating fog, stratus, cumulus, and cumulonimbus clouds respectively), and CCN spectra simulating maritime, transitional, and continental aerosols, were used as inputs to a numerical model of an adiabatically expanding air parcel. The results of these simulations showed that weak updrafts or high CCN concentrations tend to develop significantly broadened droplet spectra. Under these conditions the most recently activated droplets grow in a reduced supersaturation environment; these droplets, therefore, require significant growth time to achieve a given minimum detectable size (2μm radius on ACPL). These results will assist timeline planning for cloud forming experiments on ACPL.

2. The sensitivity of cloud formation time to initial conditions of temperature, pressure, gas composition, and aerosol concentration was determined using a simple analytical approach. This study showed that the time of cloud formation during an arbitary expansion is independent of aerosol concentration for very small aerosols. Uncertainties in particle size, and hence in activation supersaturation, give rise to significant uncertainties in the time of cloud formation, as do uncertainties in the initial temperature and pressure. In addition, if moderately high concentrations of larger aerosol are present, the latent heat associated with their deliquescence and subsequent growth in sub-saturated conditions can also cause a shift in the time of cloud formation. These effects would be important to ACPL cloud forming experiments in adiabatic conditions, for which the temperature of the expansion chamber walls is matched to the temperature of the expanding moist air.

Mismatches in wall and gas temperature due to uncertainties in the time of cloud formation and the associated release of latent heat could then degrade the experiment.

3. The Kohler equation, which relates the equilibrium solution drop size to the dry aerosol size and the ambient supersaturation, was re-evaluated for the case of mixed (soluble/insoluble) nuclei. The conditions at activation were found to be expressed as a simple sixth-order polynomial, which reduces to the standard Fletcher/Mason solution except when the soluble shell of the aerosol approaches a monolayer in thickness. These results are expected to simplify parameterization of cloud microphysical effects of mixed aerosols.

4. A gravimetric test with a cryogenic water trap has been under development to verify the performance of a precision prototype saturator to 0.5%. The plumbing system for this test is essentially complete. Pressure and temperature sensors have been acquired and tested. A moisture monitor sensitive to a few ppm of water vapor has been acquired on loan and is being tested for suitability. Extremely dry missile grade air available at MSFC has been determined to be acceptable for early testing; suitable air bottles have been located. High quality commerical gas has been ordered for final testing. The major development challenge at this point is the design of the cold trap and its inlet and outlet configurations. Recent tests with the present cold trap showed occasional ejections of ice pellets or ice clusters. This type of response prevents calibration at the desired level of resolution. Efforts are underway to modify the inlet and outlet to eliminate ice ejection. Preliminary calibration testing is now expected to begin in late November.

5. A numerical feasibility study has been completed for the Stable

Levitation of Charged Droplets in a One-G Static Diffusion Chamber. The results of this study suggest that a wide range of cloud microphysical phenomena can be investigated in such a chamber; it appears to be particularly well suited to studies of aerosol physics, diffusion chamber physics, electrical breakdown, and scavenging of trace gases or particles. A prototype levitation chamber is under construction and is expected to be operational by mid - January. The most significant technical challenge at this point is the choice of a suitable wicking medium for the chamber end plates. A number of materials are suitable for concept testing, but most of these are probably unacceptable for precision work. A significant amount of development time is expected to be required for evaluating the various wicking materials under standard operating conditions in the levitation chamber.

6. Also included in the past contract year was attendance at the following conferences:

a. One week course in atmospheric optics (May 7-11, 1979) at the University of Tennessee Space Institute, Tullahoma, Tennessee.

b. NASA Severe Storms and Local Weather Review, (September 12-13, 1979) at Huntsville, Alabama. The feasibility study for the levitation technique was presented at this review.

III. <u>Planned Effort</u>

During the 1979 - 1980 contract year, work is expected to be accomplished under this contract in the following major areas.

1. Continuing technical assistance as required, with the design and development of ACPL. The Critical Design Review for ACPL is almost over, and NASA will shortly thereafter evaluate the results of the review. Preliminary indications are that Marshall Space Flight Center will become much more closely involved in the ACPL development effort than it has in

the past. If this involvement does occur a large portion of the total work under this contract is expected to be devoted directly to ACPL.

2. Final development and documentation of the saturator calibration procedure, the warm cloud sensitivity studies, and the cloud nucleus activation relationships.

3. Design, development, and laboratory testing of the stable drop-levitation concept, hardware, and procedures. As the levitation system is shown to be feasible, a precision diffusion chamber will be developed. If the prototype chamber performs as well as is expected, it may be possible to upgrade the prototype chamber for precision work rather than to build a completely new system. For example, upgrading may require only such auxiliary changes as new wicking material, increased optical magnification or focal length, or rebuilding the chamber sidewalls.

4. Literature review on scavenging of trace gases and particles by water drops in preparation for laboratory scavenging studies.

5. Evaluation of the levitation technique for the study of various other problems in cloud microphysics, low gravity techniques, and perhaps in materials processing.

6. Preliminary investigation of three potential areas of warm and cold cloud research:

a. Measurement of aerosol flux as a function of particle size between about 0.1 and 10 μm diameter near land surfaces, on the turbulent, cumulo-meso, diurnal, and synoptic time scales. This work could probably be done in conjunction with the Bureau of Reclamation's HIPLEX program in Montana in 1981.

b. Effects of small-scale turbulence on the development of cloud droplet size distributions. This work would involve laboratory experimentation in conjunction with the GE numerical simulator.

c. Lightning initiation in warm and mixed phase clouds. This work would utilize the levitation chamber for laboratory studies.

TABLE I

TITLE: Warm and Cold Cloud Processes, NAS8-33131

RESEARCH INVESTIGATOR: Dave Bowdle, USRA
ES83/MSFC, AL 35812
205-453-5218

SIGNIFICANT ACCOMPLISHMENTS FY-79:

1. Determined sensitivity of warm cloud development to cloud condensation nucleus (CCN) spectrum using General Electric numerical simulator
2. Developed equipment for gravimetric evaluation of precision saturator
3. Determined numerical sensitivity of warm cloud initiation to carrier gas composition
4. Refined theory of activation of mixed composition CCN aerosols
5. Completed numerical feasibility study for stable drop-levitation technique

CURRENT FOCUS OF RESEARCH WORK:

1. Comparison of gravimetric and vapor pressure methods for saturator performance verification
2. Numerical solution of equations from new CCN theory, comparison with approximations

PLANS FOR FY-80:

1. Preliminary laboratory evaluation of stable drop-levitation in prototype static diffusion liquid (SDL) chamber
2. Build and calibrate precision SDL with electric field
3. Literature review of scavenging by water drops in preparation for laboratory scavenging studies in FY-81

RECOMMENDATIONS FOR NEW RESEARCH:

1. Utilize levitation techniques for investigation of other problems in cloud microphysics (Kohler theory, lightning initiation, drop growth rates, ice physics) and for evaluation of their suitability for study in low gravity.

USRA

PROGRESS REPORT

WARM/COLD CLOUD PROCESSES

CONTRACT NAS8-33131

AUGUST 1, 1978

THROUGH

DECEMBER 31, 1978

SUBMITTED TO: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
THE GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

UNIVERSITIES SPACE RESEARCH ASSOCIATION
P.O. Box 3006
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(303) 449-3414

RESEARCH STUDY: WARM/COLD CLOUD PROCESSES Contract NAS8-33131

Progress Report for the Period: August 1, 1978 through December 31, 1978.

Mr. David A. Bowdle, formerly associated with the Department of Atmospheric Sciences of the University of Washington, Seattle, Washington, agreed in September, 1978 to a year-long appointment as USRA Visiting Scientist at Marshall Space Flight Center to work with Dr. B. Jeffrey Anderson. Mr. Bowdle actually began there November 27, 1978.

As of December 31, 1978, $1816.86 had been spent out of the total Budget of $24741.00, leaving $22924.14.

Progress is satisfactory, and no problems have appeared that will interfere with contract performance.

Respectfully submitted,

M. H. Davis
USRA/Boulder
Program Director