EXPERIMENTS ON ATMOSPHERIC PROCESSES

by

William W. Vaughan
Atmospheric Sciences Division
Space Sciences Laboratory

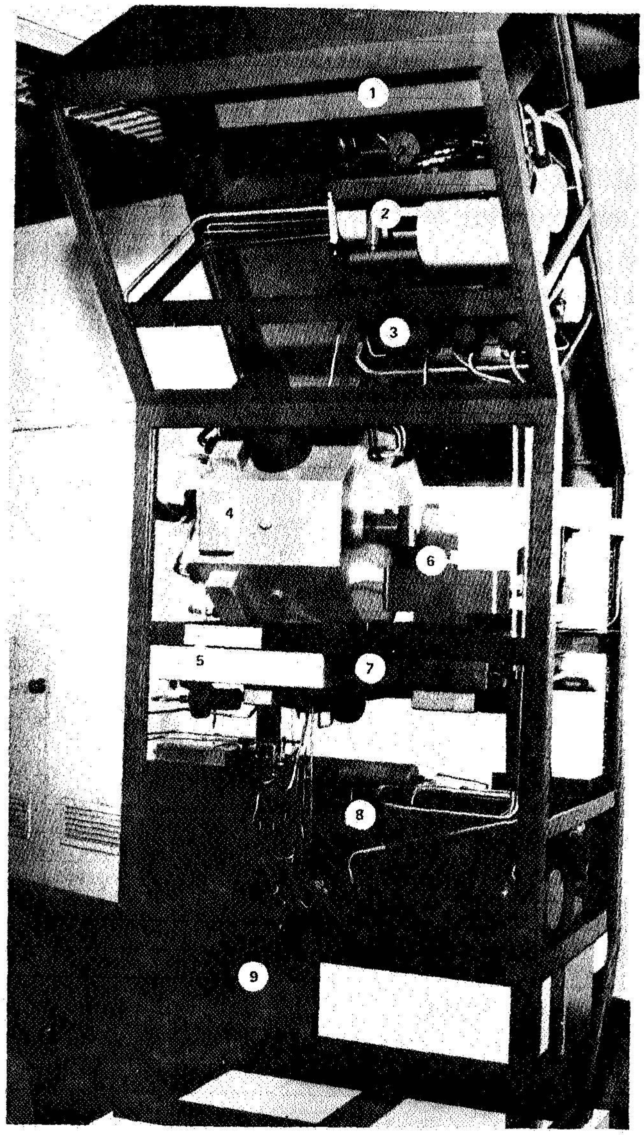
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

INTRODUCTION

With the advent of the Space Shuttle and the Spacelab, an opportunity is being provided to significantly increase the application of space technology in the area of weather and climate. In the past two decades space technology has been applied very successfully in the area of automated satellites using various remote sensing instruments to probe and observe the behavior of the Earth's weather patterns, composition, thermodynamics, and kinematics. The forthcoming Spacelab will provide the necessary facilities and payload capability to permit laboratory experiments on atmospheric processes where benefits can be realized from the low gravity environment of an orbiting Spacelab. NASA is currently engaged in research on two planned Spacelab payload laboratory experiment efforts. They are entitled "Atmospheric Cloud Physics Laboratory" and "Geophysical Fluid Flow Cell." Both payloads are currently being developed for flight on an early Space Shuttle Spacelab mission. Another atmospheric processes' experiment activity by NASA is entitled "Atmospheric Variability Experiments" and is concerned with satellite sensor-ground truth correlative studies with emphasis on severe storms. All three involve the participation of many scientific and engineering talents in these important and basic areas of research in atmospheric processes.

ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL)

An artist's conception of the ACPL, based on studies conducted to date, is shown in Figure 1. The objectives of the investigations to be conducted in the ACPL are to increase our knowledge of the microphysical cloud processes and our understanding of atmospheric behavior, thereby improving our ability to understand and predict the effects of inadvertent weather modification (i.e., air pollution) and, ultimately, to modify and/or control the weather. The research performed in the ACPL will be directed primarily to those areas of experimentation which cannot be accomplished effectively in terrestrial laboratories because of the effects of gravity on cloud drops within the chamber. The low gravity level in Earth orbit of the Spacelab enables the experimenter to eliminate sedimentation and convective air motions from the system. Thus, he is able to establish a completely static environment which greatly simplifies experiment procedures and data interpretation. The initial emphasis is planned toward the conduct of research dealing with the study of precipitation and cloud-forming



Atmospheric Cloud Physics Laboratory

1. Cameras and Optics Storage Center
   -protects sensitive equipment during launch and re-entry
2. High Humidity Flow Generation and Air Cleaning Module
   -flow control and air cleaning components for preparation of chamber air
3. Low Humidity Flow Generation and Air Cleaning Module
   -flow control and air cleaning components for preparation of experiment aerosol
4. Expansion Chamber Assembly
   -research chamber which simulates formation of real (adiabatic) clouds
5. Continuous Flow Diffusion Chamber Assembly
   -research chamber which determines cloud condensation nuclei (submicrometer aerosol) characteristics
6. Static Diffusion Liquid Chamber Assembly
   -research chamber which provides an environment for cloud droplet growth experiments
7. Saturator Assembly
   -humidifies air and aerosol samples
8. Aerosol Generation Conditioning and Characterizations Module
   -generates and conditions particulates to provide required size and concentration for experimentation
   -counts, sizes and establishes total mass of aerosol entering the research chambers
9. Electronic Assemblies/Air Flow Control
   -data management auxiliary equipment
   -power control and conditioning equipment
   -power supplies
   -air pumping and storage equipment

Figure 1. Atmospheric Cloud Physics Laboratory (ACPL).

processes where the ice phase does not occur and in the area of aerosol physics. Following the initial flights, modification and additional equipment will extend the early capabilities into such areas as precipitation and cloud-formation processes where the ice phase occurs, ice-crystal growth, scavenging, electrification, controlled turbulent mixing of cloudy and ambient air, etc.

With every technology gain there usually exists some technology challenges. The ACPL and geophysical fluid flow cell (GFFC) are no exception. Figures 2 and 3 list some of the current engineering technology challenges which these Spacelab payload developments are providing. Our preliminary design studies have demonstrated that these challenges can be met satisfactorily. They are, nevertheless, engineering technology challenges which may interest or intrigue some of the attendees at this symposium.

- TEMPERATURE CONTROL OF EXPANSION CHAMBER WALLS
- HIGH UNIFORMITY TEMPERATURE SURFACES
- AEROSOL LOSS AND FLOW MEASUREMENT AT CONDITIONS FLOW DIFFUSION CHAMBER INPUT
- CONTAMINANT CONTROL IN SATURATOR

Figure 2. Some Atmospheric Cloud Physics Laboratory engineering technology challenges.

- MECHANISM OF THE FLUID FLOW VISUALIZATION TECHNIQUES
- TEMPERATURE GRADIENT TO "DRIVE" FLUID
- "ENCAPSULATING" ROTATING SECTION OF EXPERIMENT

Figure 3. Some geophysical fluid flow cell engineering technology challenges.

The preliminary ACPL design consists of eleven subsystems — aerosol generation, aerosol characterization, expansion chamber, continuous flow diffusion chamber (CFD), and static diffusion liquid chamber (SDL), plus the necessary support subsystems. The experimenter will be able to choose an aerosol (size distribution, concentration, and chemical composition), characterize it with common types of instrumentation, and then study its behavior in any combination of three cloud chambers. The system flexibility allows a broad range of physical processes to be studied. Some pertinent points of each of the engineering technology challenges for the ACPL listed in Figure 2 follow.

Temperature Control on Expansion Chamber Walls

As the gas (air) within the chamber expands and cools the walls must be cooled to match. The key challenges are: (1) high temperature uniformity in a steady state (temperature constant to ±0.01°C over surface of a 30 liter chamber, (2) rapid cool down at low power (6°C/min to 0°C), (3) high uniformity during cool down (±0.1°C at 3°C/min or less), and (4) accurate measurements during cool down — including measurement of uniformity.

High Uniformity Temperature Surfaces

Control and knowledge of the water vapor content in the continuous flow diffusion (CFD) and static diffusion liquid (SDL) chambers and the saturator require large surfaces of very high, measurable, temperature uniformity (±0.01°C). These three units have the following characteristics:

CFD — two plates at different temperatures, 35 × 45 cm, 1.5 to 2 cm spacing between plates

SDL — two plates at different temperatures, circular 15 to 30 cm diameter, 1.5 to 2 cm spacing between plates

Saturator — two or more plates at same temperature, 20 × 36 cm.

Aerosol Loss and Flow Measurement at Continuous Flow Diffusion Chamber Input

The requirement is to measure the air flow rate (approximately 0.5 cm^3/s) to 1 percent and also get the aerosol sample into the chamber with less than 1 percent loss by diffusion of small particles. The sample must be introduced such that any velocity perturbations in the flow field decay prior to the aerosol reaching the activation zone.

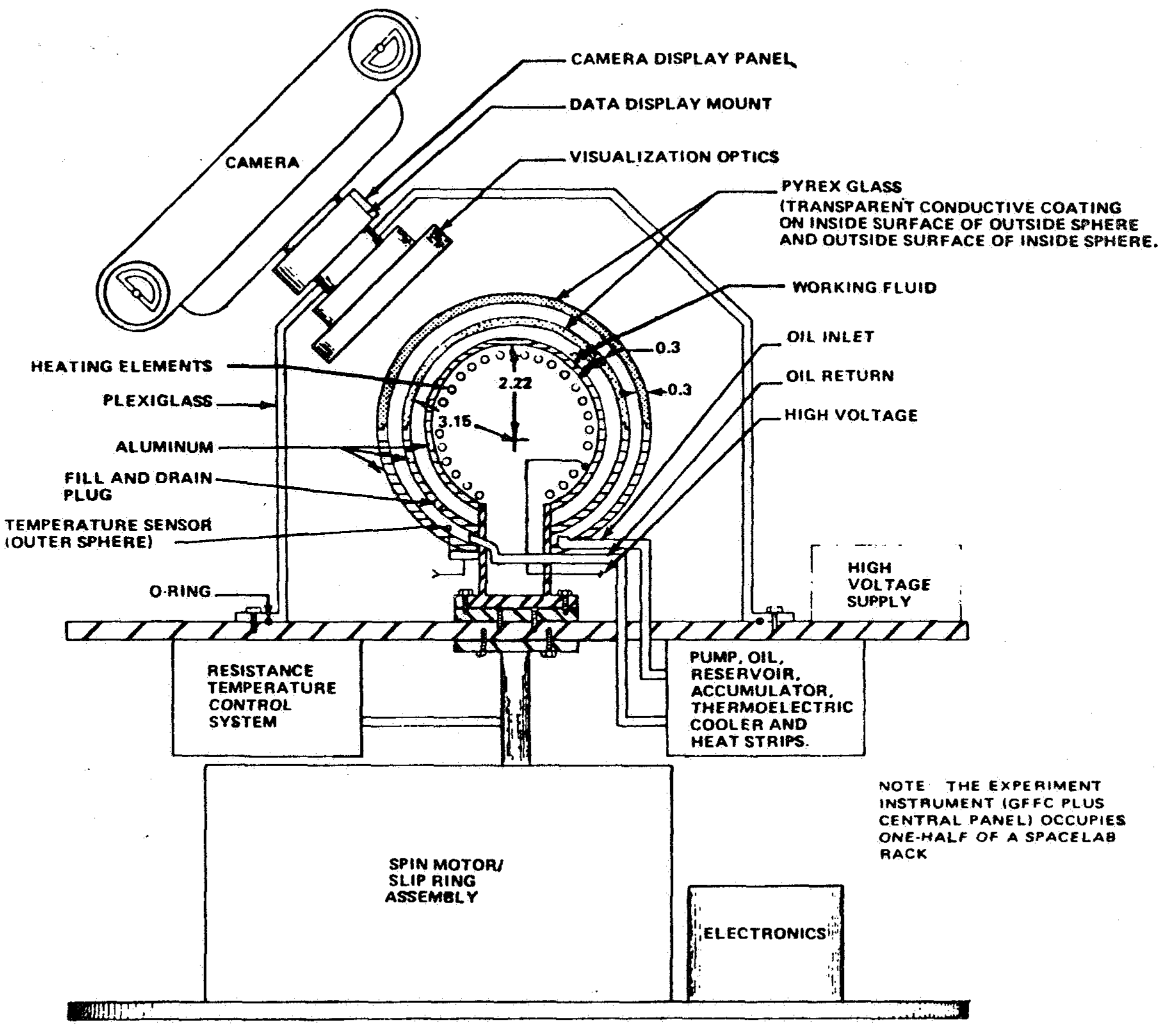
Contamination Control in Saturation

The saturator must supply 500 cm^3/s or more of air to the expansion chamber with the mixing ratio known to ±0.5% of the measured value. This will require a knowledge of temperature and pressure with varying degrees of error, depending upon the measured value of pressure and temperature. More critically, the complete absence of surface active contaminants from the wick surfaces is also required.

GEOPHYSICAL FLUID FLOW CELL (GFFC)

The planned GFFC is illustrated in Figure 4. The objective of the investigations to be conducted in the GFFC is to observe the convective flow of a fluid between two concurrently rotating spheres in the presence of spherically symmetric body forces. This is a basic technology experiment which will lead to subsequent experiments to study atmospheric type baroclinic fluid flows on rotating spherical surfaces with an imposed radially directed body force to simulate a gravitational force field. The ultimate objective is to provide a deeper understanding of large scale atmospheric circulations. The behavior of large scale atmospheric and oceanic circulations contribute directly to our major weather system developments and climatic patterns. Most theoretical and all experimental work on the effect of latitude depend coriolis force on nonlinear convection, which is thought to play a crucial role on large scale atmosphere circulations, have treated only local curvature effects. Terrestrial laboratory experiments cannot be accomplished since the Earth's gravity field radically interferes with simulation efforts. The low gravity of an orbiting Space Shuttle Spacelab will permit the accomplishment of these simulations. This offers the potential for a major step forward in geophysical fluid research which in turn may lead to a new understanding of the large scale atmospheric and oceanic circulations.

Figure 3 lists some of the current engineering technology challenges for the GFFC. Some pertinent points on each of the items listed in Figure 4 are detailed in the following paragraphs.



NOTES:

1. NOT TO SCALE
2. ELECTRICAL INTERCONNECTIONS NOT SHOWN.
3. ALL DIMENSIONS IN CENTIMETERS.

NOTE THE EXPERIMENT INSTRUMENT (GFFC PLUS CENTRAL PANEL) OCCUPIES ONE-HALF OF A SPACELAB RACK

Figure 4. GFFC mechanical layout.

Mechanism of the Fluid Flow Visualization Techniques

The primary experimental data output of the GFFC is from observation and measurement of the circulation patterns established in the fluid between the spheres (outer sphere approximately 3.5 cm radius, inner sphere approximately 2.2 cm radius). A UV excited photochromic chemical tracer is planned to provide fluid flow observation and velocity measurements. Localized temperature gradient measurements will be obtained from the Moiré fringe pattern obtained by projecting a closely spaced grid into the fluid and reflecting off the inner sphere back to the source. Both measurements will be recorded by one camera system. Since the observed system is spherical, a spherical optical system must be designed which has a focus at infinity for the Moiré fringe patterns and in the centimeter range for the photochromic flow visualization technique. The camera will not be fixed relative to the rotating spheres. The camera will be sequenced to photograph specific regions of the upper hemisphere and requires a sensitive timing system.

Temperature Gradient to "Drive" Fluid

The inner and outer sphere temperatures must be programmable and flexible to provide a variety of conditions. Outer sphere and inner sphere radial temperatures must be capable of variation from 10 to 30°C (±5 percent) and 10 to 40°C (±5 percent), respectively. This flexibility permits the inner sphere to be warmer than the outer sphere and vice versa. The temperature control technique must not interfere with the fluid observations. In addition to a radial temperature gradient, a latitudinal temperature gradient capability is also required.

"Encapsulating" Rotating Section of Experiment

An important design consideration exists in "encapsulating" the rotating section of the experiment to meet flight safety requirements. The dimensions of the spheres are determined by the dielectric constant of the fluid. The type fluid is influenced by its compatibility with the photochromic chemical. It now appears that a Dow Corning 200 fluid which has a rather low (33°C) flash point will be used. Therefore, "encapsulating" the spherical system of the experiment to meet rigorous Spacelab safety requirements, and still permit observation, measurements and necessary experiment adjustments is somewhat of an engineering challenge.

ATMOSPHERIC VARIABILITY EXPERIMENTS (AVE)

Seven NASA AVE's have been conducted over the past few years (Table 1) with another scheduled in May 1977. During selected meteorological periods lasting from one to three days, all available satellite, rawinsonde, radar, aircraft and surface observations were recorded at a 3 h or less interval for selected geographical areas within the U.S. The objectives of this research and experimental undertaking were to evaluate the accuracy and representativeness of quantitative satellite data relative to mesoscale (severe storms) identification, inputs to numerical mesoscale models, and understanding of interrelationships between the different atmospheric scales of motion. One example of the experiment scope is the employment of 54 balloon launching sites to probe the atmosphere each 3 h during a 48 h period when severe weather conditions prevailed over large areas of the U.S., while at the same time utilizing specially equipped aircraft and satellite sensors to acquire measurements.

Some of the AVE project accomplishments include: (1) advances in developing regional numerical prediction models, (2) identification of significant convection patterns which are indistinguishable in the conventional 12 h measurements of the atmospheric structure, (3) determination of the variances in expected convective cloud trajectories, relative to ambient winds, due to rotational effects of these clouds, and (4) an improved method to retrieve temperature profiles from cloud contaminated satellite radiance data. The principal engineering challenge is in the area of rapid mass data handling and assessment where heterogeneous input sources are involved. No one measurement system seems capable of providing the data base needed to meet all atmospheric scales of motion, forecast, and modeling requirements. Each system has a rather selected role to play, yet all must be integrated in a timely and creditable manner.

In summary, NASA's role in weather and climate relative to Earth observations now encompasses an extensive range of space technology efforts. These range from the area of remote sensors on satellites to observe and probe atmospheric phenomena, correlative field experiments and analytical modeling, and actual on-orbit laboratory scale research on atmospheric processes.

TABLE 1. SUMMARY OF NASA's AVE AND AVSSE* EXPERIMENTS

Experiment	Dates	Observation Times (GMT)	Experiment Size and Location	Significant Meteorological Conditions
AVE I	19-22 Feb 64	2/19 — 00,03,06,09,12,15,18,21 2/20 — 00,03,06,09,12,15,18,21 2/21 — 00,03,06,09,12,15,18,21 2/22 — 00,03,06,09,12,15,18,21 2/23 — 00	Thirty rawinsonde stations were utilized in 18 states stretching from Nebraska, Kansas, Oklahoma, and Texas eastward to the middle Atlantic and southeastern states.	Surface cyclonic system developed over the Gulf of Mexico and moved into the northeastern states accompanied by strong upper level thermal and wind fields.
AVE II	11-12 May 74	5/11 — 12,15,18,21 5/12 — 00,03,06,09,12	Fifty-four rawinsonde stations encompassing most of the states east of 105° W longitude.	Complex frontal and upper level system moved through the Missouri Valley and midwest and interacted with an active cut-off low over the lower Mississippi Valley. Convective activity and strong horizontal temperature gradients were present.
AVE III	6-7 Feb 75	2/6 — 00,06,12,15,18,21 2/7 — 00,06,12	Forty-one rawinsonde stations covering most of the states east of 105° W longitude, excepting most regions near the Canadian border, extreme southern Texas, and southern Florida.	A strong polar air mass moved through the Mississippi and Ohio Valleys accompanied by snowfall in the cold air and convective activity near the frontal system.
AVE IV	24-25 Apr 75	4/24 — 00,06,12,15,18,21 4/25 — 00,06,12	Forty-two rawinsonde stations were utilized within the same area as AVE III.	A major tornado outbreak occurred from Missouri and Oklahoma eastward into Tennessee and northern Alabama.
AVSSE I	27-28 Apr 75	4/27 — 12,15,18,21	Twenty-four rawinsonde stations were used which covered parts of 13 southwestern and southern states from New Mexico and Colorado eastward to Tennessee and Georgia.	Tornadoes and other severe storms occurred primarily in Nebraska and Oklahoma in conjunction with a cold front through the central Plains states and a developing upper level low over South Dakota.

TABLE 1. (Concluded)

Experiment	Dates	Observation Times (GMT)	Experiment Size and Location	Significant Meteorological Conditions
AVSSE II	6-7 May 75	5/6 — 12,15,18,21 5/7 — 00,03,12	Twenty-three rawinsonde stations covering almost the same area.	A major tornado occurred in Omaha. Other tornado and funnel activity developed from Oklahoma and Arkansas northward to South Dakota associated with a cold front.
AVE V	10-12 June 76	6/10 — 00 6/11 — 12,15,18,21 6/12 — 00,03,12	Twenty-three rawinsonde stations in 15 of the north-central states were utilized from Montana, Wyoming, and Colorado eastward to Michigan, Ohio, Tennessee, and Alabama.	Tornadoes and other severe storms developed primarily in North and South Dakota associated with a cold front in that region.

*Atmospheric Variability and Severe Storms Experiment (same as AVE measurements).

BIBLIOGRAPHY

Anonymous: Announcement of Opportunity for Space Experimentation in the Atmospheric Cloud Physics Laboratory (ACPL). NASA Headquarters Document No. AO: OA-77-2, March 1977.

Hart, John E., J. Toomre, P. Gilman, and G. Fichtl: Geophysical Fluid Flow Experiments on the First Spacelab Mission. Proposal to NASA Headquarters in Response to AO-OSS-1-76, October 1, 1976.

Hill, Kelly and Robert Turner: NASA's Atmospheric Variability Experiments (AVE). Bulletin of American Meteorological Society, February 1977.