A Multi-Use Airborne Research Facility

NASA Cooperative Agreement NCC5-503

Final Report

1 July 2000 – 30 June 2003

Michael R. Poellot

Department of Atmospheric Sciences

University of North Dakota

PO Box 9006

Grand Forks, ND 58202-9006

Introduction

Much of our progress in understanding the Earth system comes from measurements made in the atmosphere. Aircraft are widely used to collect in situ measurements of the troposphere and lower stratosphere, and they also serve as platforms for many remote sensing instruments. Airborne field measurement campaigns require a capable aircraft, a specially trained support team, a suite of basic instrumentation, space and power for new instruments, and data analysis and processing capabilities (e.g. Veal et al., 1977). However, these capabilities are expensive and there is a need to reduce costs while maintaining the capability to perform this type of research. To this end, NASA entered a Cooperative Agreement, Grant Number NCC5-503, with the University of North Dakota (UND) to help support the operations of the UND Cessna Citation research aircraft. This Cooperative Agreement followed in form and substance a previous agreement under NASA GRANT Number NCC5-193.

The Cooperative Agreement has benefited both NASA and UND. In part because of budget reductions, the NASA Airborne Science Office has elected to take advantage of outside operators of science research platforms to off-load some science requirements (Huning, 1996). UND has worked with NASA to identify those requirements that could be met more cost effectively with the UND platform. This has resulted in significant cost savings to NASA while broadening the base of researchers in the NASA science programs. At the same time, the Agreement has provided much needed support to UND to help sustain the Citation research facility. In this report, we describe the work conducted under this Cooperative Agreement.

Objectives

The objectives of the Agreement were to:

- Provide NASA with a cost-effective multi-use airborne research aircraft;
- Collaborate with NASA in deploying new instrumentation on the Citation; and
- Provide initial support for deployment of the Citation in future NASA missions.

The limited funding under this proposal was expended primarily to develop the capability to satisfy NASA mission requirements. Although some aircraft deployment time and costs were included, full funding for major field campaigns required additional funding from the specific programs supporting the field campaigns. Deployments and instrumentation tasks are discussed below.

Accomplishments under the Cooperative Agreement

In meeting the objectives of the Agreement, the Citation participated in a number of field measurement campaigns using a variety of new instrumentation systems. While much of the cost of the field campaigns was borne by the individual projects, the base support funding under this Agreement helped to defray the costs of integrating new systems and also the fixed costs associated with the aircraft.

Field Measurement Campaigns

UND has supported a number of NASA science initiatives dating back to 1984. Table 1 presents the Citation field measurement campaigns, during the term of this Agreement which were funded wholly or in part by NASA.

Table 1. NASA-Supported Field Campaigns

Dates	Project	Location	Measurement Objectives
7/00 – 9/00	COBRA	Continental U.S.	Atmospheric Carbon Budgets
1/01 – 2/01	ABFM	Florida	Electric Field Measurements
5/01 – 7/01	ABFM	Florida	Electric Field Measurements
7/02	CRYSTAL-FACE	Florida	Tropical Anvil Microphysics
5/03-6/03	COBRA	Northern U.S., Southern Canada	Atmospheric Carbon Budgets

COBRA

The CO2 Budget and Rectification Airborne Study-North America (COBRA) is a study of the budgets of CO2 and other trace gases over various locations in North America. Its goals are:

- To obtain comprehensive measurements of the vertical and horizontal distributions of CO2 and other tracer gases in and above the planetary boundary layer during summer and winter, and
- To utilize these data to develop a better understanding of how the changes in meteorological conditions affect the surface concentrations of CO2 on diurnal and seasonal time scales.

Correlation between the diurnal and seasonal dilution of the boundary layer and the photosynthesis/respiration cycle increases the mean surface concentrations and cannot be easily distinguished from a net terrestrial source. Funding for this portion of the project

was provided by NASA and NSF/Harvard. NOAA participated in the project but no funding was received by UND from NOAA for this portion of the project.

The first significant field deployment was conducted in August, 2000. This study consisted of two basic mission types. One set of flight patterns was designed to sample air upstream and in the vicinity of ground sites in Wisconsin and Maine. The second consisted of long transect missions with periodic descents to the surface to collect larger scale observations. A summary of the flight operations for this project is given in the Table 2.

Table 2. COBRA Missions 2000

Date	Mission Type	Flight Hours
July 28	Test	2.2
Aug. 1	Trajectory	5.1
Aug. 2	Trajectory	4.3
Aug. 4	Transect	2.3
Aug. 6	Transect	3.0
Aug. 8, 9	Transect	7.0
Aug. 11	Trajectory	4.9
Aug. 18	Trajectory	5.6
Aug. 19	Transect	4.9
Aug. 23, 24	Trajectory	12.1
Sept. 15	Calibration	3.3
	Total	54.7

The second COBRA flight study took place in May and June of 2003 (Table 3). For this project, the Citation aircraft flew over the central portion of North America to measure greenhouse gas emissions. The flights also included measurements of ozone-depleting gases and other pollutants from major metropolitan areas. There were excursions over the Pacific Ocean from Eureka, Calif., and over the Atlantic from Pease, N.H., to Sable Island, to examine coastal influence of marine air and the mixing processes between maritime and continental air. Transcontinental transects were flown across southern Canada as well. NOAA funding for this project supplied a laser hygrometer for measurement of water vapor concentrations.

Table 3. COBRA Missions 2003

Date	Flight Description	Flight Hours
15-May-03	Ferry from Grand Forks to Boulder	2
23-May-03	First test flight	3.2
25-May-03	Second test flight	2.3
26-May-03	Transit to Medford OR w/ 3 dips	3.6
28-May-03	Offshore flight	2.5
29-May-03	Transit to CYEG via Campbell River	4.1
30-May-03	Transit to CYTS via Thompson	5.1
31-May-03	Transit to Boston	5.3
03-Jun-03	Offshore flight out to Sable Island	5.9
06-Jun-03	Harvard Forest Regional Experiment	3.7
11-Jun-03	1st day of Transit back to Boulder	2.1
12-Jun-03	2nd day of Transit back to Boulder	4.9
14-Jun-03	Texas/Gulf Regional Experiment	7
16-Jun-03	ARM/CART Regional Experiment	5.3
18-Jun-03	Transit to Medford, via Eureka	4.7
19-Jun-03	Transit to CYEG via Campbell River	5.1
21-Jun-03	Transit to CYTS via Thompson	5.5
23-Jun-03	Transit to Pease via Chibougamau	4
25-Jun-03	Howland (Maine) Regional Experiment	4.8
27-Jun-03	1st day of Transit back to Boulder	3.9
28-Jun-03	2nd day of Transit back to Boulder	4
02-Jul-03	Ferry back to Grand Forks	2
11-Jul-03	Wind Calibration Flight	2.7
	Total flight hours	93.7

ABFM

The Airborne Field Mill Program (ABFM) is being supported by the Kennedy Space Center and NASA Marshall Space Flight Center. The goal of this program is to reduce unnecessary launch delays and scrubs by better defining the conditions when lightning is a threat. The two deployments in 2001 were to be split equally between February and June in order to investigate seasonal cloud differences. However, dry conditions and an almost complete lack of suitable clouds in February led to an early termination of that deployment and an early start to the other. The summer measurement program was very successful in terms of the amount of data collected. Flight summaries for both deployments are given in Tables 4 and 5. Total flight hours for these deployments were 21.4 hours and 73.7 hours.

Table 4. Airborne Field Mill Project, February 2001

Date	Flight Hours	Remarks
30-January	5.2	Ferry Flight GFK – Titusville
1-February	1.6	Science Flight
3-February	2.1	Science Flight
8-February	3.2	Calibration Flight
10-February	2.2	Science Flight
17-February	1.6	Field Mill Calibrations
23-February	5.5	Ferry Flight Shuttle Landing Facility - GFK

Table 5. Airborne Field Mill Project, Summer 2001

Date	Flight Hours	Remarks
19-May	4.8	Ferry Flight GFK – Patrick AFB
22-May	3.2	Science Flight - Anvils
24-May	3.4	Calibration Flight - Field Mils & Reverse Heading
25-May	3.6	Science Flight - Anvils
27-May	3.1	Science Flight - Anvils
28-May	3.9	Science Flight - Anvils
29-May	3	Science Flight - Anvils
2-Jun	4.2	Science Flight - Anvils
4-Jun	4.4	Science Flight - Anvils
5-Jun	3.7	Science Flight - Anvils
6-Jun	2.9	Science Flight - Anvils
7-Jun	3.1	Science Flight - Anvils
10-Jun	3.6	Science Flight - Anvils
15-Jun	2.7	Science Flight - Anvils
18-Jun	2.1	Science Flight - Anvils
22-Jun	1.7	Science Flight - Anvils, but mostly in clear
23-Jun	1.7	Science Flight - Debris
24-Jun	2.4	Science Flight - Anvils
25-Jun	2.9	Science Flight - Anvils, Field Mill Calibration
27-Jun	2.8	Science Flight - Anvils
28-Jun	2	Science Flight - Thick Clouds, Field Mill Calibration
29-Jun	2.7	Science Flight - Field Mill Calibration
1-Jul	5.8	Ferry Flight Patrick AFB - GFK

CRYSTAL-FACE

The Cirrus Regional Study of Tropical Anvils and Cirrus layers – Florida Area Cirrus Experiment (CRYSTAL-FACE) is a NASA-sponsored "measurement campaign designed to investigate tropical cirrus cloud physical properties and formation processes. Understanding the production of upper tropospheric cirrus clouds is essential for the

successful modeling of the Earth's climate."
(http://cloud1.arc.nasa.gov/crystalface/science.html)

Preparation for this field deployment actually began in January, after the grant award. Integration of this suite was a complex task in terms of number and nature of the instruments, and three of them had never been flown on the Citation before (CFDC – Continuous Flow Diffusion Chamber, CIN – Cloud Integrating Nephelometer, TDL – Tunable Diode Laser hygrometer). This suite also represented an unprecedented impact on the weight, space and electrical capabilities of the Citation, requiring several modifications. These included design and construction of a new instrument rack, the addition of electrical wiring and inverters for research power, and the design and construction of two new inlets for sampling. All aircraft modifications also required engineering and FAA approval. The design of the rack and one of the inlets, along with the engineering and FAA approvals, were all accomplished by UND. A contractor performed rack construction and the other inlet was built by the National Center for Atmospheric Research (NCAR), where a modification to the mount of the Counterflow Virtual Impactor was also done. The wiring and inverter installation was done during scheduled aircraft maintenance in April.

Integration actually began in May in Grand Forks, ND, after the Citation returned from maintenance. The most significant task was to install the CFDC, with its compressors, chamber, inlet and associated plumbing, wiring and control electronics. The new racks for the rear of the aircraft cabin were sent to CSU for pre-integration work. The racks and equipment were then sent back to UND for actual installation in June. Integration was a group effort of UND, Colorado State University (CSU), NCAR and Oregon State University personnel and was completed in time for initial ground and flight testing before deployment to Key West.

Table 6. Mission Summary

Date	Takeoff (UTC)	Land (UTC)	Hours	Comments
July 3	171444	211650	4.0	Steps and spirals
July 7	175842	214245	3.7	Steps and spirals; dense cirrus
July 9	175517	214935	3.9	Steps over east and west sites. Mixed phase over west site
July 11	142548	165155	2.5	Altostratus, Terra overpass
July 11	180651	221418	4.1	Anvil steps
July 16	183744	225329	4.2	Spirals, steps in anvils
July 18	165043	203043	3.7	Ice nucleation, anvil spiral
July 19	183648	224621	4.2	Anvil steps, spiral
July 21	183500	224852	4.2	Anvil steps, spiral
July 23	185225	232229	4.5	Anvil steps, spirals
July 25	150449	193147	4.5	Steps and spirals; samples over sites
July 26	202909	235643	3.5	Melting layer spiral descents
July 28	193833	220733	2.5	Growing tower samples; dust on descent
July 29	171101	212418	4.2	Anvil steps, spiral; dust on descent

The Citation was ferried to Key West Naval Air Station on June 30 and returned to Grand Forks on July 31. Research flight operations began on July 3 and a total of 13 research missions (66.7 hours including ferry) were flown during the experimental period. A list of these flights and primary objectives is given in Table 2. Overall, this was a highly successful measurement mission for this platform. Instrument reliability was high; excellent coordination and support was provided through pre-flight briefings and real-time coordination by the crew at the NPOL ground radar site. As seen in Table 6, a variety of conditions were sampled according to the science plan of the experiment.

Instrumentation

The new position and orientation system for the Citation is a POS-AV, manufactured by the Applanix Corporation. It is a strap-down solid-state gyro system with 3-axis accelerometers and integrated GPS. Data are recorded at a high frequency (200 Hz) on the POS computer and are also ported to the Citation data system at a lower rate in real time for integration with the other recorded parameters. This POS system replaced an aging Litton LTN-76 INS that was becoming unreliable and costly to maintain. Installation of the POS has greatly increased reliability and resulted in savings in weight, space and power requirements in the aircraft. Pre-flight alignment is also no longer necessary, which give us a faster launch response time.

To accommodate the CRYSTAL-FACE payload, several modifications were required in terms of research electrical power and rack space. Additional research power capability was added through a tap from the aircraft electrical buss and the installation of two new 60 Hz inverters. This was used primarily to meet the demands of the CFDC compressors, but will be available for other applications in the future. Two new instrument racks were also constructed to better utilize the cabin volume and provide adequate space for the CRYSTAL-FACE payload. A side-by-side dual rack was designed and built to fit across the rear of the cabin, adding 56 inches of 19-inch rack space. The racks can also accommodate instrumentation on the exterior of the cabinets. In addition, one of the original instrument racks was replaced, creating more rack space along the starboard side of the cabin. These electrical and rack projects required design and engineering support and have been approved by the FAA.

References:

Veal, D. L., W. A. Cooper, G. Vali and J. D. Marwitz, 1977: Some aspects of aircraft instrumentation for storm research. *Meteor. Monogr.*, **16**, 237-255.

Huning, J. R., 1996: The Mission of and Plans for NASA's Airborne Science Program. *Preprints, Second International Airborne Remote Sensing Conference and Exhibition*, San Francisco, CA, 24-27 June 1996, I-544-I550.

NASA, 2002: CRYSTAL-FACE Mission Overview. http://cloud1.arc.nasa.gov/crystalface/science.html National Aeronautics and Space Administration.