Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS)

R. T. Bluth,* P. A. Durkee,+ J. H. Seinfeld,# R. C. Flagan,#
L. M. Russell,+,@ P. A. Crowley,& and P. Finn+

ABSTRACT

A remotely piloted aircraft research facility is described that will provide new capabilities for atmospheric and oceanographic measurements. The aircraft can fly up to 24 h over remote ocean regions, at low or high altitude, and in various other challenging mission scenarios. The aircraft will fly research missions at speeds of 40 m s^{-1} and provide high spatial resolution measurements. Data will be transmitted in real time to a ground station for analysis and decision-making purposes. The facility will expand the opportunities for universities to participate in field measurement programs.

1. Introduction

The Office of Naval Research (ONR), the Naval Postgraduate School, California Institute of Technology, and Princeton University are developing a joint research facility, the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS), to support scientific research and technology development. CIRPAS is developing and will operate three types of remotely piloted aircraft (RPA) that can support many traditional atmospheric or oceanographic measurements, as well as unique measurement strategies that would be difficult or impossible with a manned aircraft.

This paper describes CIRPAS and the flight and research capabilities of the RPAs and presents a series of proposed applications. We list a set of research activities that we anticipate will make significant advances under CIRPAS. The list comes from numerous discussions with the science and technology development communities but is not exhaustive. We expect the capabilities of the RPAs to encourage development of many new measurement techniques and strategies.

*Office of Naval Research, Arlington, Virginia.
+Naval Postgraduate School, Monterey, California.
#California Institute of Technology, Pasadena, California.
@Princeton University, Princeton, New Jersey.
&Department of Energy, Germantown, Maryland.
Corresponding author address: Robert Bluth, Office of Naval Research, 800 N. Quincy St., Arlington, VA 22217-5000.
E-mail: bluthr@onrhq.onr.navy.mil
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2. The CIRPAS concept

The main goal of CIRPAS is to expand investigator access to airborne and remote sensing data by providing state-of-the-art capabilities at the lowest possible costs. CIRPAS will provide investigators with new capabilities for long-duration observations at very high or low altitudes. CIRPAS platforms will operate at uniquely low air speeds allowing high-resolution in situ observations. Low operational cost of the CIRPAS platforms will be achieved primarily by innovative use of small aircraft. Use of a satellite communications and data management system, and support of scientific instrument miniaturization, will allow a much smaller aircraft to perform similarly to traditional larger aircraft. Use of a satellite data link provides a "virtual" in-flight working environment through real-time access to scientific data and flight attitude information. A satellite data link will allow broader user access to flight operations, ranging from remote terminals over the modem link to group operations in the flight ground control facility. New technologies and concepts are under development to miniaturize airborne atmospheric and oceanographic instruments without reducing instrument fidelity or resolution.

3. CIRPAS remotely piloted aircraft

To support diverse mission needs, three types of aircraft will be operated by CIRPAS:

- Pelican—The Pelican RPA is intended primarily for lower-tropospheric observations. Pelican is an optionally piloted aircraft that can be flown with a pilot onboard or remotely by a pilot on the ground. Optional piloting of Pelican provides flexibility to perform the extensive training and testing required to develop remote flight capabilities.
- Altus—The Altus RPA is intended for upper-tropospheric–lower-stratospheric observations. Altus, developed by National Aeronautic and Space Administration/Environmental Research Aircraft and Sensor Technology (NASA/ERAST) Program, is a high-altitude derivative of the Department of Defense Predator Unmanned Aerial Vehicle (UAV).
- Aerosonde—The Aerosonde RPA is intended for tropospheric profiling with relatively small payloads. Aerosondes are also inexpensive and can support measurement strategies that have a high risk of platform loss (Holland et al. 1992).

The use of these three RPAs will substantially increase the spatial area of the marine environment over which airborne measurements can be made. Currently, marine observations are limited by the number of islands having sufficiently long airstrips to accommodate full-scale research aircraft. The RPAs and their ground stations could be transported by ship to virtually any island having even a rudimentary airstrip. RPAs have the potential for allowing access to previously unreachable areas and can open up many remote regions to airborne observation.

a. The Pelican RPA

Pelican is a highly modified Cessna 337 Skymaster RPA that has been reconfigured as a single-engine pusher to allow sampling of unperturbed air from over 70% of the aircraft and for better field of view from the nose. Figure 1 shows a schematic view of the Pelican aircraft. The ONR and NASA/ERAST programs are jointly sponsoring General Atomics Aeronautical Systems Corporation to develop a remote flight control system for the Pelican RPA. An existing Aeronautical Systems Predator flight control system will be adapted for use with the Pelican aircraft. The Pelican RPA will be an optionally piloted aircraft. Pelican can be flown with a pilot onboard or remotely by a pilot on the ground. With a pilot onboard, flights are limited to 8 h. Pelican remotely piloted flights can perform 24-h measurement strategies allowing observations of diurnal processes that are unobtainable with onboard-piloted aircraft. Since many missions will require flights of only a few hours, missions of 8 h or less can be flown with onboard pilots, at lower cost, and with larger mission payloads than the longer 24-h remotely piloted missions. Onboard pilots will also allow missions overflying high-population areas where remotely piloted flights would not be possible. Both flight modes will have real-time access to scientific data and flight information from a satellite data link.

Pelican will have the following capabilities:

- optional piloting (i.e., conventional or RPA),
- endurance of up to 24 h of RPA operations and 8 h for onboard-piloted missions,
- range of 2500 km,
- mission altitude ranging from 20 to 4000 m,
- loiter speed as slow as 40 m s^{-1},

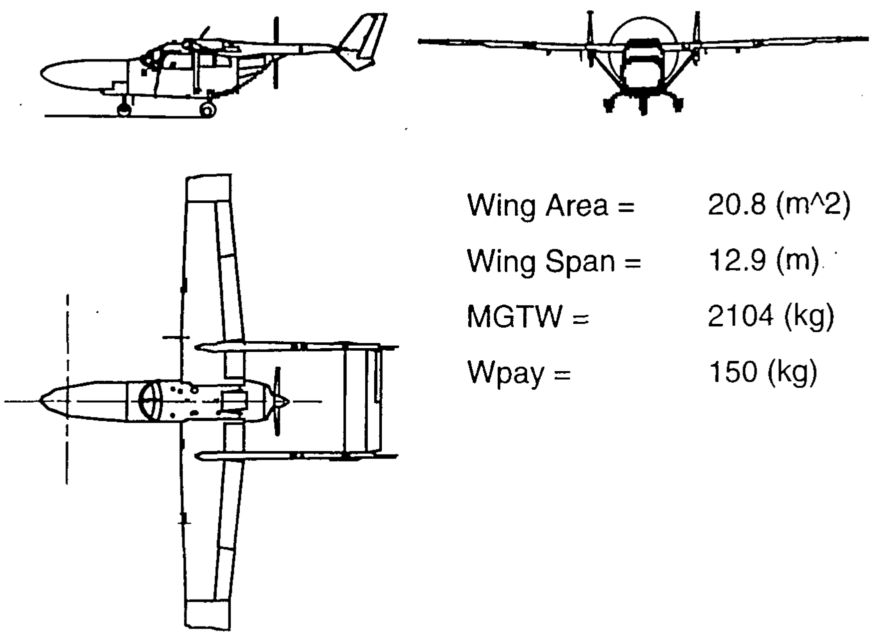

FIG. 1. A three-view diagram of Pelican.

- 150-kg payload for 24-h missions and 500 kg for 2-h missions,
- fuselage nose volume of 1 m^3,
- main cabin payload volume (for manned missions) 0.33 m^3,
- standard wing mounts for interchangeable pylon-mounted payloads at 50 kg each,
- palletized instrument capability,
- payload power = 1 kW at 28 V, and
- satellite interactive communications for over-the-horizon operations.

Variations of the Pelican design can provide further mission flexibility. The current version has a single reciprocating engine in the rear. Another option under consideration is the installation of a turboprop engine in the rear for shorter-duration flights to altitudes above 10 km. A version of Pelican without the capability for remotely piloted flight, but with a data management and satellite communication system, could also be developed to support broader utilization of this type of research aircraft.

b. The Altus RPA

ONR and the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program are jointly sponsoring General Atomics Aeronautical Systems Corporation to acquire an Altus aircraft for operation by CIRPAS (Fig. 2). Altus, developed by the NASA/ERAST program, is a high-altitude derivative of the Department of Defense Predator UAV. The Altus RPA is intended for upper-tropospheric–lower-stratospheric in situ observations or high-altitude remote sensing. Altus will be able to attain altitudes of 20 km by using a two-stage turbocharged rotex engine with extended wings and fuselage and hardened electronics. Altus will have real-time access to scientific data and flight information from direct line-of-sight UHF communications. Satellite interactive communications for over-the-horizon operations are under consideration for future development.

Altus will have the following capabilities:

- endurance of up to 24-h operations,
- range of 100 km (line-of-sight operations),
- mission altitude up to 20 km,
- loiter speed as slow as 30 m s^{-1},
- 150-kg payload for 24-h high-altitude missions,
- 0.7 m^3 payload volume,
- payload power of 2 kW at 28 V,
- fuselage nose unobstructed and available for installation of payloads, and

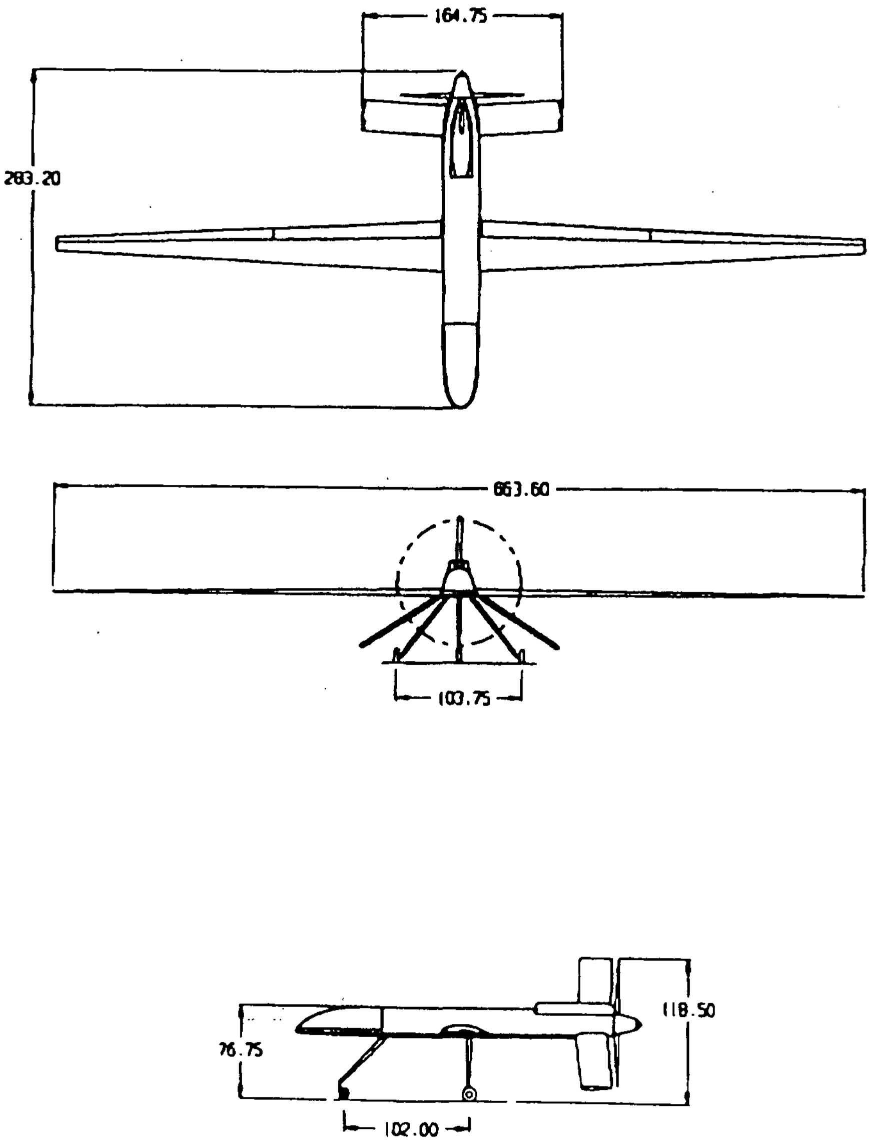

FIG. 2. A three-view diagram of Altus.

- future capability for satellite over-the-horizon operations communications.

c. The Aerosonde

ONR is sponsoring In-situ Corporation to acquire 10 Aerosonde aircraft and related support equipment to be operated by CIRPAS. Figure 3 shows a schematic view of the Aerosonde. Aerosondes are primarily intended to support atmospheric soundings and severe weather research. The Aerosonde uses two Vaisala sensor systems to acquire pressure, temperature, and humidity. The sondes receive atmospheric samples from a duct inside the fuselage and in the free stream under the wing. Winds are retrieved by a windfinding-by-maneuver algorithm, which uses only the airspeed scalar and ground speed vector as inputs. The algorithm requires 10 s of maneuvering, leading to about 200-m spatial resolution. Typical accuracy is 0.5–1.0 m s^{-1}. The Aerosondes have been operated in field conditions, including turbulent boundary layers and gust fronts in the immediate vicinity of active thunderstorms. The main technical constraint on real-time data acquisition is that the ground station requires line of sight to communicate with the aircraft. The practical maximum radius would be about 200 km if an en route ground station were placed on a mountain for extended line-of-sight communications. All other flight strategies beyond line of sight will be operated autonomously. A ground station is capable of simultaneous control of multiple Aerosondes for high-resolution vertical profiling.

Aerosonde will have the following capabilities:

- endurance of 12 to possibly 24 h,
- range of approximately 1500 km,
- mission altitude ranging from 50 m to 4 km,
- loiter speed as slow as 20 m s^{-1},
- 1-kg nose payload for 24-h missions,
- fuselage nose volume of 100 cm^3,
- payload power = 5 W at 12 V, and
- fuselage nose unobstructed and available for installation of payloads.

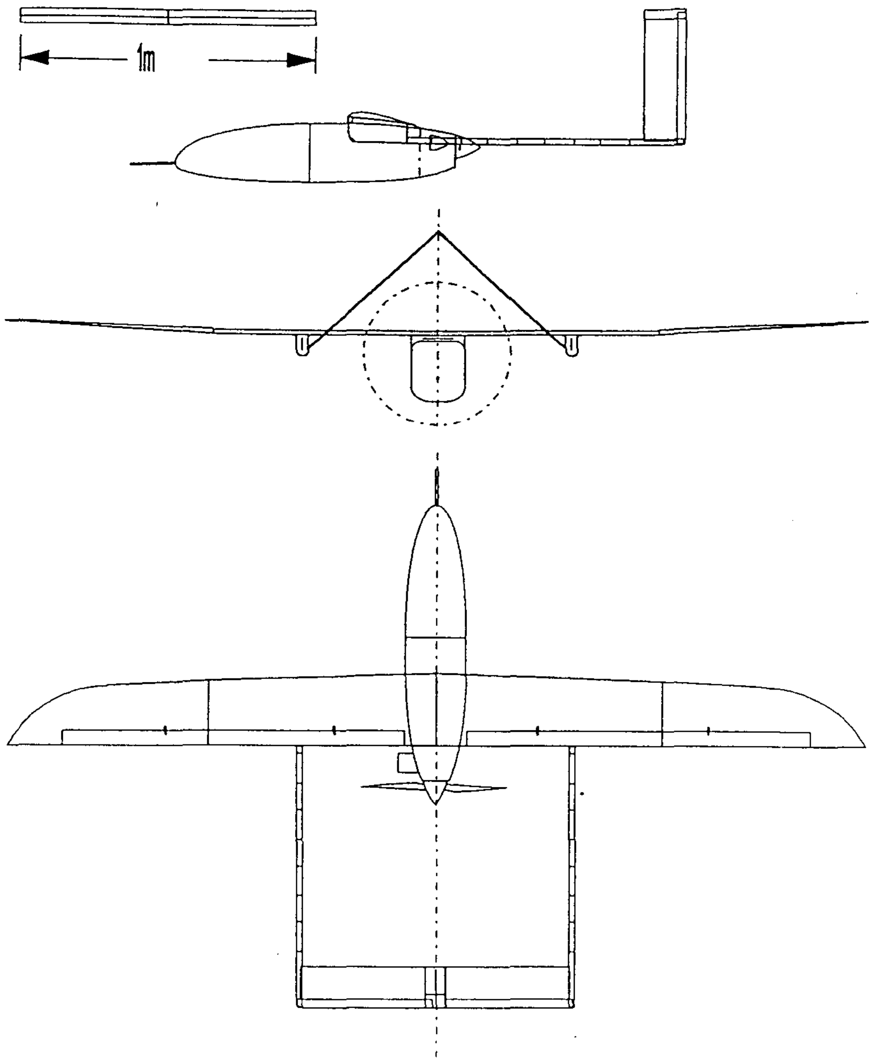

FIG. 3. A three-view diagram of Aerosonde.

4. Multiaircraft operations

All three CIRPAS aircraft can operate in coordinated measurement strategies. The Pelican and Altus use the same ground station, which has the capability to operate two aircraft simultaneously. The Aerosondes would need to be controlled independently, but operations could be coordinated for in-field experimental activity. The capability of operating all three CIRPAS platforms simultaneously allows the possibility of long-duration vertically stacked or multiplatform coordinated measurement strategies. These long-duration multiaircraft missions could support a variety of experiments allowing innovative atmospheric process studies and model validation.

5. Satellite data link and data management system

Almost all measurement strategies envisioned for Pelican and Altus involve real-time control and interaction with instrumentation and on-scene decision making. An over-the-horizon communications capability will be essential to support Pelican low-altitude and, in the future, Altus remote-area operations. Real-time communications will allow scientists to interact with aircraft flight and scientific data as if they were on board the aircraft. The scheme described here for real-time transmission of data could also be applied to traditional research aircraft to expand data accessibility to investigators on the ground.

Remote communications will be conducted via a modem link allowing remote log-in to the CIRPAS central computer. Remote log-in capabilities will allow users to monitor flight information (e.g., aircraft attitude, speed, and location), to frame grab video, to view general scientific data, and to control instrumentation aboard the aircraft. The mobile command and control vehicle will provide a "virtual" research aircraft environment. The central ground control vehicle is envisioned to support several workstations and the flight control system. These capabilities will provide a forum for scientist and crew interaction similar to traditional research aircraft. Scientist and crew interaction will allow real-time decision making based on flight video, observational data, and aircraft attitude. As with traditional research aircraft operations, a flight scientist will be responsible for the scientific utilization of the aircraft, while flight duties and safety are the responsibilities of the flight crew in either mode of operation. A CIRPAS World Wide Web home page will provide in-flight and postflight interactions with the scientific community. The CIRPAS home page will include aircraft information such as flight schedules, instrument development status, instrument analysis tutorials, a general information venue to discuss utilization of platform, and aircraft technical descriptions.

A research aircraft with real-time communication capability will expand observational access to numerous investigators beyond the number a research aircraft can carry on board. This capability will also reduce the cost of participation in field experiments. Investigators will be able to design and fly missions with reduced travel requirements. The satellite data link concept will be first demonstrated with Pelican but could be a valuable enhancement to any research aircraft. This relatively low cost approach will allow dedicated flights for student projects and should encourage complex instrument development, model analysis, and remote sensing validation studies.

6. Research opportunities

The CIRPAS RPAs offer the potential for a wide variety of scientific studies. The flight capabilities of RPAs present distinct airborne research advantages. Pelican can provide the following unique measurements:

- low altitude—air–sea fluxes, surface layer and upper-ocean properties, complete vertical soundings of meteorological variables and atmospheric constituents (flight altitudes of 10–50 m above the surface will be consistently attainable);
- long duration—diurnal processes, turbulence statistics, flux measurements, small- and large-scale horizontal variability (flights of 24-plus h will be attainable);
- slow speed—aerosol and cloud measurements, air–sea fluxes, turbulence with increased spatial resolution for vertical and horizontal flight profiles (typical flight speeds will be 40 m s^{-1}); and
- payload—150-kg payload for 24-h missions or 500 kg for missions of a few hours (large payload volume and weight as compared to most RPAs).

Altus can provide the following unique measurements:

- high altitude—remote sensing and lower-stratospheric environmental variables (flight altitudes up to 20 km will be consistently attainable);
- long duration—diurnal processes, chemistry, flux measurements, small- and large-scale horizontal variability (flights of 24-plus h will be attainable); and
- slow speed—aerosol and cloud measurements, and turbulence with increased spatial resolution for vertical and horizontal flight profiles (typical flight speed will be 30 m s^{-1}).

Aerosondes can provide the following unique measurements:

- low altitude—complete vertical soundings of meteorological variables and atmospheric constituents (flight altitudes from 50 m above the surface to 4 km);
- long duration—diurnal processes, turbulence statistics, small- and large-scale horizontal variability (flights of 12-plus h will be attainable); and
- slow speed—cloud measurements and increased spatial resolution for vertical and horizontal flight profiles (typical flight speed will be 20 m s^{-1}).

The first priority for measurements on the CIRPAS platform includes basic meteorological variables, aerosol/cloud microphysics, and associated chemistry. Table 1 lists the currently funded initial set of instruments for the CIRPAS platforms. Follow-on measurements include expansion of microphysical measurements, turbulence, and expanded radiation measurements. Table 2 lists planned CIRPAS instruments for operations below 10 km.

Over the next several years, the DOE ARM–UAV payload will consist of a core payload of broadband flux radiometers and a meteorological package. In addition, three instruments will be included from those already developed for UAV deployment and those completed by September 1996. Table 3 lists the instrumentation developed by the ARM–UAV program.

The first scientific operation of the Pelican RPA is planned during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) in July 1996. During TARFOX, the Ames Sun-Tracking Sunphotometer (Matsumoto et al. 1987) will be flown on Pelican along with multiple radiometers, the Radial Differential Mobility Analyzer (RDMA) (Russell et al. 1996), PCASP, and Forward Scattering Spectrometer Probe (FSSP) instruments. Future uses of Pelican include the Coastal Meteorology Experiment (Summer 1996), the California Cooperative Oceanic Fisheries Investigations cruise of October 1996, and the Aerosol Characterization Experiment in June–July 1997. The first scientific operation of the Altus RPA will be during ARM at the Oklahoma cloud and radiation testbed site in the fall of 1996. During ARM, the Solar and Infrared Broad Band Radiometers, Total Direct Diffuse Radiometer (Pope et al. 1996), and general meteorological payload will be flown on Altus. Some additional areas of CIRPAS aircraft application are described below.

TABLE 1. Current CIRPAS sensors.

RDMA	High spatial and temporal resolution aerosol size distributions between 0.005 and 0.5 μm
PCASP	Aerosol size distributions between 0.1 and 3.0-μm diameter
FSSP-100	Cloud droplet distributions between 0.5 and 47.0-μm diameter
OAP-260X	Droplet size distribution between 10 and 620-μm diameter
FSSP 300	Large aerosol size distributions between 0.3 and 20.0-μm diameter
PVM 100	Droplet effective radius and liquid water content
Cloud condensation nucleus spectrometer	Spectra for 0.1% < Sc < 2.0% providing CCN size to supersaturation relationships
Pyranometer, pyrgeometer	Upward and downward solar and terrestrial radiation
Hyperspectral radiometer	0.3–1.0 μm
Multiwavelength nephelometer	Scattering between 7° and 170° at integrating 450, 550, and 700 nm
Counterflow virtual impactor	Residual particles from droplets 7 μm or less
Gas chromatograph	Sulfur species, hydrocarbons, and halogenated compounds
State variables	Temperature, pressure, dewpoint, and wind

a. Tropospheric atmospheric studies

Studies of the dynamics of the marine atmospheric boundary layer (MABL) require in situ measurements of winds, temperature, water vapor, turbulence, and other meteorological parameters. Pelican RPA operations will expand these measurements that currently rely on sparse shipboard or conventional aircraft observations, particularly in the remote ocean environment.

TABLE 2. Planned CIRPAS instruments.

OAP-2D-GB2	Droplet size distribution between 50- and 3100-μm diameter
High-resolution turbulence	3D velocity and fluctuations
Expendable instruments	Including dropwindsondes and XBTs (expendable bathythermographs)
Atmospheric pressure chemical ionization mass spectrometer	SO_2, SO_3, CH_3SO_3H, H_2SO_4, NO, NO_2, HNO_2, HNO_3, NH_3, and possibly DMS

A critical measurement in MABL studies is turbulence. The turbulent structure of the MABL controls mixing of constituents including heat, moisture, momentum, and aerosol. Boundary layer depth, cloud formation and dissipation, and horizontal transport are directly affected by turbulence processes. Typical turbulence measurement strategies with manned aircraft include 10–50-km constant-altitude legs at multiple levels in the MABL. Long flights are required to generate statistically significant estimates of turbulent mixing processes and are very time consuming. Conventional aircraft are therefore limited both in the number of flight legs possible in a single flight and in the attainable range from a landing field. Pelican RPAs will greatly expand both the number of legs and the observable regions for turbulence measurements.

Turbulent processes are particularly important in the surface layer (lowest 20–50 m) and in the inversion layer at the top of the boundary layer. RPAs will be able to make long-duration measurements at low altitudes over the open ocean and will expand direct observations of the surface layer. Additionally, due to its long-duration and slow flight-speed capabilities, the Pelican will be able to make high spatial resolution measurements in the inversion layer over large regions.

Often multiple manned-aircraft flights are used to study diurnal variations that are critical in the MABL due to the important role of radiative processes. These processes are particularly important for coastal phenomena such as sea–land breeze circulation. However, with traditional, limited-duration research aircraft, full diurnal cycles can only be inferred by forming a composite of multiple measurement periods. These composites of multiple flights are limited by imprecise collocation, gaps in timing, and contamination of the air parcel by the aircraft plume. Long-duration flights with Pelican can make direct measurements with the time and space scales necessary to study diurnal processes. The high endurance of the Pelican will provide the capability to follow a relatively large but well-defined air mass in order to examine the time evolution of the atmospheric chemistry, of aerosols, and of clouds throughout the diurnal cycle.

Pelican will significantly increase light-scattering measurements for validation of satellite-derived scattering properties. In those few cases where in situ scattering measurements complement satellite observations, many of the in situ measurements were made at ground level. Both humidity and aerosol composition change with height in the marine atmosphere and influence light scattering. A platform that can obtain high-resolution vertical profiles of the aerosol light-

TABLE 3. ARM–UAV instrumentation.

Hemispheric radiometers (upward and downward)	Solar broadband (0.3–4.0-μm wavelength), IR broadband (4.0–50 μm), Total direct–diffuse (7 channels, 0.3–1.6 μm)
Meteorological package	Temperature, pressure, dewpoint, and frost-point
Scanning solar polarimeter	80 channels (0.4–4.0 μm) including polarization
Cloud detection lidar	Eye-safe, backscatter lidar for cirrus cloud detection
Multispectral pushbroom imaging cloud radiometer	9 channels (0.58–11.5 μm)
Atmospheric emitted radiance interferometer	Upward and downward radiance (3–20 μm at 0.5 cm^{-1} resolution)
Hemispherical optimized net radiometer	Broadband solar and IR, hemispherical flux, and net flux
Millimeter-wave radar	95-GHz frequency

scattering coefficient in conjunction with satellite observations will be a significant step forward in accurate interpretations of satellite-based observations.

Propagation of electromagnetic radiation is strongly affected by the temperature and moisture structure of the atmosphere. Sharp temperature and moisture gradients produce anomalous refraction and can change radar range by hundreds of kilometers. Propagation models are currently based on very few observations in the remote ocean environment and the nature of horizontal variability, and its effects are poorly known. Most operational analysis of radar propagation characteristics relies on single or very few measurements of the vertical temperature and humidity profile. Critical variations in the temperature and humidity profile are known to occur on short time and space scales (0.5–5 km and 30–60 min). The magnitude and scale of these variations in different regions of the world's oceans are poorly known. RPA platforms will greatly expand the horizontal coverage and diurnal timescales of the observational database on which radar propagation predictions rely.

b. Stratospheric atmospheric studies

Studies of atmospheric radiation require in situ measurements of gaseous constituents, cloud microphysics, aerosol properties, and other meteorological parameters. Altus RPA operations over 24-h periods will lead to improved understanding of radiative transfer processes and of the interaction of radiation with clouds, water vapor, and aerosols. This will lead to the development of improved parameterizations of these processes for numerical climate models. The understanding of concentrations and temporal evolution of many chemically active trace gases in the atmosphere will also benefit from long-duration Altus observations. Atmospheric chemistry influences many greenhouse gases. Methane and the proposed chlorofluorohydrocarbon substitutes are removed from the atmosphere by oxidizing reactions with radical species, the concentrations of which are controlled by a complex photochemistry. Thus long-term observations of the oxidizing capacity of the lower stratosphere is a key observation needed to understand determining factors for several greenhouse gas lifetimes. Altus could also monitor the variability of the stratosphere–troposphere interactions and the influence of the stratosphere on tropospheric climate.

Altus will also support the DOE ARM program. The ARM program's primary scientific focus is on radiation–cloud interactions. Uncertainties in how clouds interact with the earth's solar and thermal radiation account for almost the entire factor-of-three variation in the model-predicted temperature rise for a doubling of atmospheric CO_2. While some of these uncertainties can be addressed by the ground-based measurements being made in the ARM program, others require measurements from within the atmosphere. For example, the measurements of atmospheric heating in an atmospheric layer requires the measurement of the net fluxes at the top and the bottom of the layer as well as the relevant cloud properties and water vapor profiles. Satellite-based measurements are a natural way of extending these process measurements to larger scale but would benefit from the additional calibration and validation that high-altitude aircraft measurements can provide.

Driven by these consideration, ARM airborne measurements will focus on three classes of observations. The first is radiative fluxes, in which the Altus RPA is used to make high-accuracy measurements (~1%) of the solar and infrared radiative transport throughout the troposphere under a variety of clear, cloud, aerosol, and water vapor conditions. The second is cloud properties in which remote sensing techniques are used to develop and validate retrieval techniques for obtaining cloud reflectivity, phase (ice or water), effective droplet size, etc. The third science area focuses on satellite calibration and validation where the Altus RPA is used to indirectly calibrate sensors on operational satellites as well as to validate retrieval algorithms for such derived quantities as flux divergence, cloud properties, and water vapor profiles.

c. Oceanographic studies

Pelican, Altus, and the Aerosondes will also provide opportunities for unique oceanographic observations. RPAs have the potential to augment ocean measurements in two ways. First, radiative measurements of the ocean with remote sensing instruments will provide high spatial and temporal resolution observations of ocean surface features. Ocean surface skin temperature and color can be routinely measured from conventional aircraft and could be easily integrated into RPAs. Although significant instrument development would be required, radar backscatter measurements may also be feasible from RPAs. The advantage of RPA-based measurements would be longer duration flights (24-plus h) at reduced cost per flight hour. Second, expendable instrument packages that measure temperature, salinity, and currents, for example, could be deployed from RPAs. Long-duration RPA missions would extend the bounds on time and space scales forced by the limitations of ships and conventional aircraft.

d. Remote sensing studies

Current weather forecasting practices use satellite data in a variety of ways, including both qualitative and quantitative analysis by forecasters, as basic input data to numerical models and to monitor temporal and spatial changes in cloud and surface characteristics. Altus and Pelican can support research and development of systems to generate these products. The development of more effective use of satellite sounding data is particularly important in conventionally data-sparse areas. The derivation of methods to perform remote sensing processing requires a full knowledge of all facets of scientific principles underlying the satellite observations. These include radiative transfer theory, spatial mapping, and a fundamental understanding of the properties of an image. RPAs will provide the frequent observations in vertical profiles of atmospheric properties necessary for validation of remote sensing methods.

Another unique application for the Pelican RPA will be observation of the aerosol light-scattering coefficient over the open ocean. As with many other quantities, measurements of light scattering over the open ocean are sparse. The scattering of electromagnetic radiation by aerosols is an important determinant of visibility, signal propagation, and the global energy balance and climate. The effect of aerosol backscatter is most important over the oceans due to the low albedo of the sea surface relative to land surfaces. Clearly, our ability to model global climate and to assess the impact of anthropogenically produced pollutants would be substantially increased if we had more knowledge of what is present in the atmosphere and the processes and mechanisms responsible for anthropogenic and natural production of aerosols over the ocean.

7. Summary

CIRPAS will be able to support a broad user community both by providing services and by demonstrating the feasibility of a new class of research vehicles. A Pelican aircraft equipped with a satellite data link but without a remote flight capability could be an affordable platform for acquisition and operation by university research programs. The National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration, and NASA, and a few universities operate atmospheric research aircraft, but between federal agencies and academia the United States operates less than a dozen. Of these aircraft, only about five are major platforms capable of distant tropospheric marine observations. Large aircraft costs limit their availability and use. Pelican, if successful, would be able to provide cost effective atmospheric and oceanographic observations to users who currently do not have access to airborne measurements.

The heads and chairs of departments of atmospheric and oceanographic sciences, in discussing the needs in meteorological and oceanographic education, concluded that,

> emphasis must be given, throughout the academic and research communities, to atmospheric measurements, observational methods, instruments, and national observing facilities. To fail to do so will jeopardize the ability of our science to adequately address our future challenges in operations and in research (Serafin et al. 1991).

CIRPAS and possibly a wider use of Pelican-type vehicles will help to meet those needs.

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References

Holland, G. J., T. McGeer, and H. Yongren, 1992: Autonomous Aerosondes for economical atmospheric soundings anywhere on the globe. *Bull. Amer. Meteor. Soc.,* **73,** 1987–1986.

Matsumoto, T., P. Russell, C. Mina, W. van Ark, and V. Banta, 1987: Airborne tracking sunphotometer. *J. Atmos. Oceanic Technol.,* **4,** 336–339.

Pope, S. K., F. P. J. Valoro, and P. Flatau, 1996: Preliminary ARESE results: Radiative fluxes measured in clear and cloudy skies. *Proc. DOE Atmospheric Radiation Measurement (ARM) Science Team Meeting,* Department of Energy, San Antonio, TX.

Russell, L. M., M. R. Stolzenburg, R. Caldow, S. H. Zhang, R. C. Flagan, and J. H. Seinfeld, 1996: Radially classified aerosol detector for aircraft-based submicron aerosol measurements. *J. Atmos. Oceanic Technol.,* **13,** 598–609.

Serafin, R., B. Heikes, D. Sargent, W. Smith, E. Takle, D. Thomson, and R. Wakimoto, 1991: Study on observational systems: A review of meteorological and oceanographic education in observational techniques and the relationship to national facilities and needs. UCAR–AMS Special Rep., 51 pp. [Reprinted in *Bull. Amer. Meteor. Soc.,* **72,** 815–826.]