Ideas for a three-aircraft planetary observing fleet

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ABSTRACT

A new generation of research aircraft, based on modern mid-sized business jets, will provide access to upper regions of the atmosphere and remote regions of the planet not reachable by the current research aircraft. Equipped with extensive research modifications, modern instruments, and advanced air-to-ground communication systems, these new aircraft will allow investigators to attack key questions in global atmospheric dynamics, global cycles of water and carbon, global energy budgets, and regional and global air quality and chemical transport. A three-aircraft fleet of these aircraft could provide unprecedented coordinated intercalibrated coverage of the planetary atmosphere and surfaces in a manner that greatly enhances the total ground, ocean, and satellite observing system.

Keywords: aircraft, observations, global observing systems

1. INTRODUCTION

Many scientific challenges require observations on a global scale. For example, understanding and quantifying intercontinental transport of pollution requires multiple north-south cross-sections of pollutant concentrations together with zonal profiles of winds. Understanding and predicting atmospheric CO_2 concentrations requires accurate measurements of continental, oceanic, and hemispheric carbon sources and sinks. Making long range weather forecasts in mid-latitude regions requires measurements as far as a quarter of the planet away and even into tropical ocean regions.

Networks of ground systems, ocean ships and buoys, satellites, robotic arrays, and aircraft all represent important components of global observation systems. Aircraft compliment ground-based measurements by providing in situ validation of remotely-sensed information, such as from ground based radars, and by connecting and extending point-based measurements of, for example, thermodynamic properties or surface fluxes. Aircraft extend research capabilities into regions not covered by ground-based systems. When research aircraft deploy dropsondes, as often happens in hurricane research and reconnaissance, the aircraft measurements provide important thermodynamic and wind profiles for hurricane track and intensity predictions in regions not covered by ground-based measurements. In many cases, aircraft follow developing weather systems as they move in and out of the effective ranges of ground-based systems. Often, researchers use aircraft to lift upper atmosphere or solar remote sensing instruments above the attenuating and scattering effects of the lower troposphere.

Aircraft measurements also compliment, extend, and validate observations made from satellites. Aircraft can carry elaborate payloads that measure a wide range of chemical properties and reactants at the flight level or that measure the actual size distribution of droplets within a cloud, to validate and extend the indirect measurements from satellites. Aircraft often serve as the test platforms for prototypes of remote sensing instruments intended for later satellite operations. Larger and more elaborate remote sensing systems on aircraft flying nearer to the surface or to atmospheric features of interest can provide higher resolution imagery of surface features or of atmospheric properties than smaller, higher satellite instruments.

Most research aircraft carry elaborate multicomponent payloads: sensitive detectors for dozens of short-lived chemical reactants; particle imagers that record size and abundance information across a full range of particle types; multi-wavelength remote sensing systems that collect a wide range of information about the atmosphere or the surface. Most research aircraft have the flexibility to change payloads, carrying chemistry instruments to measure air quality

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parameters over an urban area one month and particle probes and velocity remote sensing systems for thunderstorm research the next month. Within some altitude and range limitations, most research aircraft can carry these elaborate payloads directly to the regions of interest: into clouds, near and into hurricanes, over nearby ocean or ice regions. Most research aircraft can adapt quickly to local conditions: following a thunderstorm at a safe distance as it evolves, moving to a different altitude to sample an aerosol layer, following a plume of effluent as it disperses from a source. For many atmospheric researchers, an aircraft represents their most flexible tool and carries their most elaborate instruments.

Despite these advantages, all aircraft have limitations. Endurance limits of 6 to 10 hours mean that, after subtracting an hour or two for ferry from the nearest airfield, researchers may only get 3 or 4 hours of mission time studying a storm system or measuring aerosol properties. More importantly, range limits of a few thousand nautical miles mean that most aircraft of the current national fleets have go to the limits of their range to reach polar regions or the central equatorial Pacific warm pool. Many aircraft of the current national research fleets do not fly at altitudes above 30,000 feet. The specialized aircraft that can fly high enough to reach the tropopause in equatorial regions carry relatively small payloads and, with their large wings, have operational restrictions related to crosswinds at takeoff and landing locations. Despite best preparations and preventive maintenance, aircraft occasionally suffer equipment failures on the ground or, rarely, in the air, that may delay or shorten a research mission at, by definition, a time of important scientific opportunity.

Data generated from aircraft missions also have limitations. Airborne mission data sets tend to represent short, albeit intense and high resolution, looks at atmospheric conditions or processes. More seriously, the multiple data sets collected by several aircraft or even by repeated missions of a single aircraft tend not to allow intercomparisons or assembly into larger composite or longer time series data sets. Each research aircraft tends to develop a set of sensors and data procedures specific to that aircraft. Even when two aircraft carry similar or even identical sensors, aircraft-specific differences in fine-scale flow regimes around each sensor, the lack of easy or routine intercomparison flights, and differences in data interfaces, data processing and data formats make comparison and utilization of data from the two aircraft very difficult. Without extraordinary efforts by researchers and research aircraft operators, as undertaken by investigators involved in a few recent multi-aircraft aerosol and radiation measurement missions, including careful and time-consuming pre- and post-mission calibrations and intercomparisons, airborne measurements of, for example, long- or short-wave radiation, trace gases, particle abundance or scattering properties, or radar reflectivity, tend not to have value in data integration or planetary monitoring applications beyond the needs of the specific project.

Despite flight performance and data limitations, most national research aircraft support a busy schedule of atmospheric research projects with several-year waiting lists of future missions. Those research projects includes studies of severe weather in coastal and continental regions, studies of local air quality and of regional chemical processes, and a variety of remote sensing missions in which sensors on the aircraft detect properties of the surface, of the extreme upper atmosphere, and of atmospheric properties between the aircraft and those distant targets. In the discussion that follows, we look at ways that new research aircraft can overcome some performance and data interoperability limitations and extend the long history of contributions of research aircraft to atmospheric and planetary research.

2. NEW AIRCRAFT

The U.S. National Science Foundation (NSF) has contracted for the development of a new long-range, high-altitude research aircraft based on a modern business jet. Through an acquisition process managed by the National Center for Atmospheric Research, NSF researchers expect access to an extensively modified Gulfstream-V aircraft as early as late 2005 or early 2006.

This new U.S. research aircraft, designated HIAPER (High-Performance Instrumented Airborne Platform for Environmental Research) will bring an array of new capabilities to airborne research. By starting from a commercially available platform, the Gulfstream-V, the HIAPER effort takes advantage of performance capabilities developed to meet the needs of long-distance business travelers and ensures present and future compatibility with international aviation certification and operation requirements.

The Gulfstream-V (G-V) has a certified maximum altitude of 51,000 feet (15.5 km), far above any other aircraft currently operated for NSF. In the U.S., only the NASA-operated extreme altitude aircraft (ER-2, WB-57F) can support research at or above 50,000 feet. Both of those aircraft require full life-support equipment for the pilot (ER-2) or pilot and observer (WB-57F) at those altitudes. Neither aircraft carries passengers and neither aircraft spends much time doing research at altitudes lower that about 50,000 feet. On the G-V, five to ten researchers will operate in a 'shirt-sleeve' environment at 50,000 feet. This G-V altitude range will provide NSF-funded researchers (including international research partners) with unprecedented access to the upper troposphere, including access to the tropopause region and lower stratosphere over much of the globe for much of the annual cycle. Researchers will use the high-altitude capability of the G-V to probe upper tropospheric chemistry and radiation, tropopause dynamics, and troposphere-stratosphere exchange. Researchers will use the full range of the G-V to conduct profiles of thermodynamic, chemical and radiative properties from near the surface to near 51,000 feet.

The G-V has a flight range of approximately 6500 nautical miles (nearly 11,500 km). Designed to provide long-range service to business travelers, these aircraft can cross any ocean basin in a single flight. For scientific applications, the G-V will provide access to all oceanic and polar regions, often with hours of on-location mission time. No present aircraft of any national fleet offers a comparable range of operations. Researchers will take the NSF G-V around the planet, to tropical and high latitude oceans and to both polar regions, exploiting the aircraft's capability to fly nearly a quarter of the globe. The G-V range also extends new opportunities within less remote regions. A G-V could survey a substantial portion of the U.S. coastline, flying south from Oregon along California, east across Mexico and the Gulf of Mexico, then north along the Atlantic coast to Maine, monitoring coastal processes with remote sensing instruments or combining in situ and remote sensing measurements of CO_2 to understand regional carbon sources and sinks.

We do not intend this paper to represent a marketing recommendation for Gulfstream aircraft. At least one other manufacturer produces an aircraft for the long-range business market and one might expect similar products from a few additional manufacturers. Because of similar business market requirements, all these long range aircraft will have flight ceilings around 50,000 feet and flight ranges in excess of 6,000 nautical miles. Because of similar physical and regulatory constraints, all these long-range aircraft will have similar wing and fuselage sizes and configurations. Unlike the current situation, in which research aircraft generally have no common features, the inherent similarity of the long-range business jets offers important opportunities for modifications and instrumentation and for operations, discussed in subsequent sections of this paper.

Concurrent with the U.S. acquisition of a G-V, German science agencies have proposed acquisition of a very similar research aircraft for use by European researchers. Coordination during the procurement phase, particularly in assessing the capabilities of current business jets and in discussing probable modifications, coming from a long history of shared information and joint missions, stimulated the U.S. and German aircraft planning teams to examine a wide range of coordination issues related to the new aircraft. We considered (and discuss below) how these two aircraft might benefit from a common infrastructure and from interchangeable instrumentation. As discussions turned to joint science missions and global scientific challenges, we identified the need for and substantial advantages deriving from a third similar aircraft operating in the Asia region. Addition of a third similar aircraft, capable of performing similar missions and built to a common instrument interface design standard, would allow a truly international global observational effort.

3. COORDINATED MODIFICATIONS AND INSTRUMENTATION

Modifying high performance business jets for scientific research purposes involves a substantial investment of engineering and infrastructure and represents a substantial technical challenge to instrument developers. These aircraft have relatively small fuselage diameters and relatively large wing-loading capabilities. Built to modern design standards in order to maintain adequate safety margins throughout their altitude ranges, these aircraft represent an extreme modification challenge. Experience suggests that after initial structural modification and re-certification, subsequent substantial structural modifications of wing or fuselage will represent difficult (e.g. extraordinarily expensive) activities.

For these reasons, the HIAPER project will devote a large amount of time and money to initial modifications. The aircraft will have three large optical view ports in the main fuselage, several instrument mounting points on each wing, and numerous small inlet apertures and instrument mounting points along the fuselage. U.S. and German scientists have coordinated on many aspects of these modifications, to ensure eventual easy exchange of instruments. For example, the two planning teams have adopted standard optical view port dimensions, to ensure that telescopes and other optical devices built for one aircraft will fit on the other. The U.S. aircraft will accommodate a NATO standard wing instrument mounting bracket, to allow interchangeability of instrumented wing pods. Perhaps as important as common standards and instrument interchangeability, working to common standards on similar aircraft will allow the acquisition teams (especially the second and any subsequent acquisition teams) to achieve considerable cost savings by taking advantage pre-existing non-recurring engineering for the modifications.

The U.S. G-V and similar aircraft present a technical challenge to instrument developers and to aircraft infrastructure such as inlets. These business jets fly higher and faster than current research aircraft. Instruments will have to accommodate these performance factors in their size, weight, power consumption, and response times. Inlets will have to work at lower pressures and temperatures and at higher flow speeds. Advanced communications, again driven by business traveler preferences, will allow ground-to-air remote data access and instrument control for many of the new systems. These technical challenges represent both need and opportunity for international collaboration on modern research instrumentation to match the availability of modern research aircraft. Collaboration on instrument design to meet the performance challenges of the new aircraft will increase the probability of similar designs and data interchangeability. Taking advantage of modern computation fluid dynamics calculations of flows around these aircraft, and of flows around various pods and protuberances, will allow unprecedented shared understanding of sampling performance of inlets and instruments. Designing instruments from the start to fit on two similar aircraft will minimize aircraft-specific design divergence and offer researchers the hitherto unusual opportunity to compare instrument performance by exchange back and forth among aircraft. It seems abundantly clear to us that building instruments to a common design and data standard rather than to accommodate the idiosyncrasies of distinct aircraft represents an important step forward in airborne research and in international partnerships, a step that would benefit enormously from an additional similar aircraft and additional partners.

4. COORDINATED RESEARCH MISSIONS

Three aircraft operating from North America, Europe, and Asia could provide full simultaneous coverage of either hemisphere from pole to equator or continent to ocean, giving an unprecedented view of planetary-scale processes that transport heat and moisture, of sources and sinks of important compounds such as carbon dioxide, and of hemispheric transport of aerosols and gaseous pollutants. Working together in a single region, three aircraft could provide full 24-hour coverage of evolving cloud and weather systems, of continental or oceanic biogeochemical fluxes, and of regional air quality impacts. With carefully intercalibrated interchangeable instrumentation, the three aircraft could begin to build reliable composite global data sets and provide almost unlimited calibration and validation possibilities for satellite sensor systems.

With similar performance capabilities allowing matched flight speeds, climb rates, and endurances, one can easily imagine remote sensing on one or more aircraft coordinated with in situ measurements on a third, to improve understanding of multi-wavelength or multiparameter (e.g. reflectivity and depolarization) signals from atmospheric scatterers and reflectors. Using highly-accurate time and position information from GPS signals and real-time high bandwidth communications, one can also imagine transmit capabilities on one aircraft coordinated with direct detection capabilities on a second and off-angle (reflected) detection on a third, to more fully understand the absorbing, attenuating, or scattering properties of an atmospheric volume under coordinated observation by the three aircraft.

Individual researchers and instrument developers associated with these three aircraft would experience a vast extension of their capabilities and opportunities. Airborne science, from planning through data analysis, would become a more integrated and more powerful component of the global observational system.

5. SUMMARY

Research aircraft provide a primary means of carrying highly specialized instrument systems and investigators to regions of the atmosphere important for understanding weather, air quality, and climate variability. Aircraft provide payload flexibility so that investigators can assemble instrument arrays specific to each mission's requirements. Advanced inlet and sensor technologies allow measurements of short-lived highly reactive compounds or of small fragile particles from large rapidly moving airborne platforms. A wide range of atmospheric research involving increasingly complex instrument payloads will continue to rely on the flexible capabilities of conventional piloted aircraft.

For the next two decades at least, research aircraft derived from modern business jets will perform a large workload of research missions. Driven by research opportunities and by physical constraints, instruments will get smaller but payloads will get more complex as researchers increasingly combine direct and remote sensing measurements, push to combine real-time measurements of chemistry and dynamics, and work to understand interactions among gaseous and particulate components of the atmosphere.

A coordinated observing fleet will provide local investigators using a single aircraft with the ability to assemble highly advanced payloads from an international array of interchangeable and intercalibrated instruments. More important, it will allow groups of international investigators to deploy a coordinated observing system of three aircraft to investigate planetary-scale issues. Adopting a common aircraft infrastructure, including instrument interface and data standards, will make acquisition and operation of these aircraft less expensive and stimulate international efforts in research, in the development and deployment of new instrumentation, and in coordination and validation of present and future global observing systems.