SCIENCE REQUIREMENTS FOR A LONG-RANGE AIRCRAFT FOR ANTARCTIC RESEARCH

ASSESSING THE SCOPE OF MODIFICATIONS FOR AN LC-130 HERCULES

Site visit at NCAR's Research Aviation Facility, Jefferson County Airport, Broomfield, Colorado. December 18, 2003.

Report compiled by

Michael Studinger, LDEO

based on notes by

Brian Stone, NSF/OPP

URL: http://www.ldeo.columbia.edu/~mstuding/LCSB/

Palisades, April 27, 2004

TABLE OF CONTENTS

EXECUTIVE SUMMARY

On December 18, 2003, the Research Aviation Facility (RAF) of the National Center for Atmospheric Research (NCAR) hosted a site visit at Jefferson County Airport at the request of the Office of Polar Programs (OPP) of the National Science Foundation (NSF). The objective was to develop a preliminary plan for input to a community-based workshop in 2004, and to determine the scope of modifications required for the production of an NSF LC-130 long-range aircraft with research capabilities. Consideration was given to the existing NCAR/RAF C-130Q research aircraft. RAF shared its experience with a group of scientists broadly representing the Antarctic research community's interest in long-range research aircraft capability. The meeting brought together researchers and engineers to preliminary assess the scope of modifications necessary to convert an existing LC-130 for modern aerogeophysical, atmospheric and oceanographic research. The discussion addressed questions concerning three different themes: (1) key instrumentation and capabilities for each discipline, (2) aircraft modifications, and (3) operational concepts.

The key findings include:

- An LC-130 can carry a comprehensive payload of desired sensors for solid earth, atmospheric and oceanographic sciences.
- Wing attachment points for externally-mounted equipment are critical to a long-range research aircraft. The scope of modifications necessary to install hard points will depend on the wing spars of the candidate aircraft. Not every standard Lockheed C-130 Hercules has wing spars designed to accept hard points. NCAR/RAF has experience with the design, fabrication, and installation of hard point mounting brackets.
- External instrument pod systems have great potential for Antarctic science. They have multi-mission instrument capability and are non-invasive.
- A number of desired instruments require large fuselage apertures for sensor viewports or air sampling. NCAR/RAF has experience with the necessary fuselage penetrations.

- Operational and safety aspects require immediate assessment. Some issues include forward basing of the aircraft, long-term missions, and crew requirements.
- NCAR/RAF can perform and subcontract LC-130 aircraft modification work.

RECOMMENDATIONS FOR THE NEAR FUTURE

The working group came up with two recommendations for the near future:

1) Assess the scope of operational issues. This task could be achieved by a small working group representing the science community in close collaboration/consultation with NCAR/RAF and the Polar Research Support Section of NSF/OPP.

2) The solid earth, atmospheric, and oceanographic science communities should be brought together at a community workshop to discuss and formulate a joint science justification for a long-range research aircraft.

1. OVERVIEW

The Antarctic continent plays a central role in the climatic and geodynamic evolution of the Earth. Despite the strong links of the polar regions to these global systems, the atmospheric and solid earth science communities lack fundamental, first-order data from the deep interior of the continent. The key issues in solid earth and atmospheric research in Antarctica require long-range airborne platforms to be addressed. Yet, on the eve of the 50th anniversary of the International Geophysical Year, long-range measurement capabilities are not available. Since the loss of the science LC-130 (BUNO 159131) in 1987, discussions about long-range research aircraft have come up repeatedly. The current inability of the US Antarctic Program to effectively collect and integrate aerogeophysical data with other ground-based data sets has generated substantial demand for developing a long-range research aircraft.

The REVEAL workshop (Remote Views and Exploration of Antarctic Lithosphere) was held in August 2002 in Denver. The workshop focused on the potential of airborne geophysical capabilities and identified key issues in Antarctic research that require long-range fixed-wing platforms. This workshop was followed by FASTDRILL in October 2002, held at the University of California, Santa Cruz. FASTDRILL was a multidisciplinary workshop that recommended a strategy to move forward with the development of rapid mobile access drilling capabilities. The workshop framed a set of future targets for drilling and sampling that would maximize the interdisciplinary scientific payoff. The third workshop was targeted at the Structure and Evolution of the Antarctic Plate (SEAP) from a seismological perspective and was held in March 2003 in Boulder. The goal of this workshop was to compile the scientific justification for a program to develop seismic infrastructure in and around Antarctica. All three workshops concluded that long-range aerogeophysical capabilities are crucial for the success of these initiatives.

The International Polar Year is presently being planned for the 2007-08 period. One of its goals is to advance our understanding of large-scale environmental change in the polar regions by means of enhanced observations and modeling. A ski-equipped science C-130 is expected to play an important role in this endeavor by transporting novel and comprehensive instrumentation to many parts of Antarctica to provide observations of key processes taking place in the atmosphere, ice sheet, solid earth and ocean. Only with much greater understanding it will be possible to isolate any anthropogenic impacts on the polar climate system from those caused by natural variability.

The planning of the International Polar Year and the recommendations of the community workshops provided the justification to invite a group of scientists, broadly representing the Antarctic research community, to asses the scope of aircraft modifications necessary to outfit an LC-130 Hercules for modern aerogeophysical, atmospheric, and oceanographic research. The group of scientists met with researchers and engineers of NCAR's Research Aviation Facility (RAF) at Jefferson County Airport on December 18, 2003, in order to learn from RAF's experience with aircraft modifications. The site visit's primary objective was to assess whether the modifications for an LC-130 are similar or significantly different compared to the modifications of the NSF/NCAR C-130Q for atmospheric research. The outcome of the site visit is intended as input for a future community workshop in order to facilitate a discussion about a science LC-130 and to help understand the scope of the undertaking.

2. KEY INSTRUMENTATION AND CAPABILITIES

2.1 AEROGEOPHYSICS

The list of key instruments and measurements for solid earth science has previously been discussed at the REVEAL workshop, and the working group used this community-supported list as the basis for discussion. Key instrumentation proposed at the REVEAL workshop consists of:

- Multi-frequency ice-penetrating radar, including a deep radar sounder and a shallow fine-resolution sounder — an accumulation radar

- A synthetic aperture radar (SAR) that can be used for imaging and interferometric studies both in bistatic and monostatic modes. Bistatic mode would require a second aircraft.
- Swath laser and laser altimeter
- High-altitude radar altimeter (~2000 m)
- Aerial, digital photography
- Gravity
- Magnetics and possibly gradiometry

The primary concern for operating an ice-penetrating radar on a long-range research aircraft is the external antenna structures. The aircraft must have hard points on the wings to hang antennas and run cables within the wing structure to connect antennas to radar transmitter and receiver. The antenna structures must be capable of operating under the demands of survey flight at about 300 knots. This problem has been successfully addressed for long-range aircrafts, including the seminal work resulting in the lost NSF LC-130 science aircraft flown in Antarctica throughout the 1970s, as well as more recently for the NASA P-3 flown in Greenland.

A number of other instruments require a nadir-directed viewport. The University of Kansas' accumulation radar employs a horn antenna that was successfully fielded on NASA's Lockheed P-3 aircraft in Greenland. Laser altimetry and aerial photography also require nadir-directed viewport capability.

Measurements of the magnetic field can be achieved by using either a towed magnetometer system or wing-tip mounted magnetometers that have the additional capacity of measuring horizontal gradients. Towing magnetometers from the wing-tips like the refueling hoses used in the KC-130 fleet might be a possibility. Both systems have pluses and minuses, but it seemed the preference would be to avoid towed systems if possible.

One foreseeable problem with the wing-tip and gradient systems is that any magnetic materials within a 3-m radius from the sensor should be removed, which will be very difficult for an LC-130. One potential solution could be to use 3-m-long non-magnetic booms or stingers mounted onto the wing-tips. Stingers and booms are routinely used on aircrafts for magnetic sensors. It was unclear during the visit if bending and vibrations of the LC-130 wings during flight are large enough to cause a detectable change in distance between the magnetic sensors. This issue needs to be addressed for a gradiometer system. It was mentioned that LC-130 wings are apparently very stiff and the issue of distance change might not be a problem. It is necessary to compensate the magnetic field induced by the aircraft during flight. This can be achieved either by active coil systems or by compensating in processing. The close proximity of wing-tip magnetometers to radar antennas mounted under the wings will likely cause interference between the two systems. This issue has to be better understood for future discussions.

For gravity measurements on an LC-130, the performance and quality of the autopilot system are crucial. If a new autopilot system is to be installed on an LC-130, it should satisfy the requirements necessary for aerogravity.

2.2 METEOROLOGY AND ATMOSPHERIC SCIENCES

Because of the extensive experience RAF has with instrumentation for atmospheric research, the group adopted the key list of instruments from the NSF/NCAR C-130Q. It is important to ensure that the instrumentation and methods currently used on the NSF/NCAR C-130Q will in fact work for Antarctic applications before an LC-130 is outfitted. The atmospheric community should discuss this issue in any future workshops. The group used the following list of sensors as a basis for a requirements discussion about aircraft modifications:

- Temperature (reverse flow)
- Pressure (Rosemount 1501, etc.)
- Dew point/humidity (chilled mirror, licor for fluxes)
- Liquid water (Gerber PVM100 also DMT LWC-100)
- Cloud droplet spectra (FSSP-100)

- Cloud droplet/precipitation (260x (one-D), 2D-C, 2D-P)
- IR-surface temperature
- Up/down-welling shortwave and long wave radiation (Eppley PSP/PIR)
- Miscellaneous air chemistry/remote sensing (ex. Wyoming cloud radar)
- Altitude (GPS, radar altimeter)
- High-rate winds, temperatures (Friehe-type probe)
- Dropsondes

This list of sensors reflects measurements routinely made aboard the NSF/NCAR C-130Q. These sensors typically only make up a small part of the total scientific payload during missions. In addition to this standard set of instrumentation special instrument packages are flown on projects. For example, during an atmospheric chemistry study, racks of gas chromatographs, mass spectrometers, and laser-based instruments are utilized to measure gas or particle phase chemical composition. These measurements require racks with adjacent inlet mounting sites, i.e., window plates plus additional sampling ports, custom mounting points for large inlets for chemical and aerosol measurements, and up- and downward looking LIDAR ports. The operation of the atmospheric equipment requires between 20 and 30 kW of electrical power. During atmospheric chemistry missions, the NSF/NCAR C-130Q is filled to capacity with equipment.

The modifications on the NSF/NCAR C-130Q were designed to ensure that multiple sensors are exposed to a clean airstream in flight. That is, inlets are staggered so that instruments upstream of others do not disturb the airflow or discharge exhaust air that could potentially affect the observations of a downstream instrument. The group agreed that such a design is necessary for an LC-130 research aircraft.

The Antarctic meteorology community has been developing the Ross Island Meteorology Experiment (RIME) for many years, with field seasons scheduled for 2006-07 through 2008-09 austral summers. Atmospheric airborne measurements are viewed as critical to the success of this investigation of local and regional atmospheric processes. The capabilities discussed above for the science C-130 will provide many of the critical atmospheric measurements needed for the success of RIME, especially those dealing with cloud-radiation interactions, during the primary airborne field campaign in the 2008-09 austral summer.

2.3 OCEANOGRAPHY, SEA ICE, AND MARGINAL ICE SHELVES

Oceanographic needs and capabilities were discussed only summarily because the oceanographic community representative was unable to attend the workshop and, instead, provided a brief text and instrument list. The following paragraphs were provided after the workshop by Robin Muench.

Oceanographic use for an aircraft in study of the waters underlying sea and shelf ice is limited because the ocean is three-dimensional and we can only measure, with the exception of expendable probes, in two dimensions from an aircraft or spacecraft. A research aircraft has nonetheless the potential to provide valuable information of both a primary and ancillary nature. Presence of sea ice is a primary difference between the Antarctic seas and temperate oceans, and it this very ice cover that makes high latitude regions especially sensitive to climate change. To be useful for oceanographic and ice studies, instrumentation must be capable of measuring ice thickness and the percentage of open water within the pack. Visual records of ice can also prove useful, and special circumstances might occur where specific instrumentation can provide records useful for satellite ground truthing. Altimetric, thermal and visual observations can be invaluable in assessing shelf ice conditions such as those that impacted the Larson B ice shelf in 2001, causing its disintegration. While satellites can provide records of temperature, altimetry and other variables, the satellite orbits are inflexible and do not allow for traverses that are closely spaced geographically or in time. For example, multiple occupations of a measurement transect over an ocean tidal cycle might provide data instrumental in analysis of tidal impacts on a floating ice shelf.

While the underlying ocean is generally sampled from a research vessel, airborne instruments can significantly supplement shipboard observations and perhaps even be used for stand-alone work. Surface temperature and color can be measured over open water and can be useful, especially in studying frontal systems or in assessing upper ocean primary productivity. New sensor development is planned to allow airborne surface salinity measurement as well. Sensor probes are available that can be dropped from an aircraft and which can obtain vertical profiles of ocean temperature, salinity and current speed. With the above in mind, the following sensors might be included:

- Radiometers (sea and ice surface temperatures with an accuracy of 0.02°C)
- Surface salinity (new multiband microwave sensor being developed)
- Multiband radiometers (sea surface color)
- Line scanner systems that measure ice thickness (currently in use by AWI)
- Laser altimeter (ice freeboard and for altimetric work on shelf ice)
- Launch mechanisms for expendable probes such as air-dropped expendable XBTs (temperature), XCTDs (temperature and conductivity) and XCVs (current velocity)
- Downward-looking, high resolution digital cameras
- Solar radiation balance - consists of upward and downward looking sensors mounted above the fuselage between the wings and under the fuselage in the tail section. Positions have to be optimized to suppress shading effects by parts of the aircraft such as landing gear and rudder.

Because these sensors will measure parameters at some distance from the aircraft, they are less likely to be impacted by other sensors mounted upstream. Very good navigational and altitude data for the aircraft, along with a stable power supply, will be essential.

3. AIRCRAFT MODIFICATIONS

The working group devoted a significant amount of time to discussions about the scope of aircraft modifications that will be necessary to accommodate the wide spectrum of instrumentation described above. The following sections provide a summary of these discussions.

3.1 WING ATTACHMENT POINTS

There was a clear agreement within the group that the importance of wing attachment points (a.k.a. "hard points") cannot be over-stated in the planning for the aircraft. Hard points are critical for mounting the antennas used in radar sounding, as well as other externally-mounted equipment such as instrument pods. The wing spars on some of the standard Lockheed C-130 Hercules models are designed to accept hard points, but hard points are not necessarily installed routinely. NCAR/RAF installed hard points on their C-130Q on each wing just past the two outboard engines (No 1 and No 4). After NCAR/RAF took delivery of the aircraft, staff at NCAR/RAF designed, fabricated, and installed the hard point mounting brackets. RAF currently uses these hard points for external instrument pods on their C-130Q. It has been recognized that the existing attachment points on the NSF/NCAR C-130Q run perpendicular to the wing, as opposed to parallel to it. Prasad Gogineni suggested that it might be possible to develop a log-periodic antenna that would use the existing wing hard points and would be compatible with both of the current radar sounding systems in operation.

As pointed out in at least two of the presentations, the distance of the antenna from the wing is also an important consideration of any antenna or hard point design. For the dipole antennas commonly used in radar sounding, the required separation distance is one quarter wavelength, corresponding to 1.25 m at 60 MHz or 50 cm at 150 MHz. Log-periodic antennas inherently require a vertical distribution of elements, with dimensions determined through the design process. The LC-130 is a high-wing aircraft and clearance under the wings was not seen as a problem.

It is desirable to have the ability to mount multiple antennas distributed across the wings and in a variety of configurations in order to allow for more sophisticated radar data processing. The previous science LC-130 had a four-element antenna array oriented cross-track beneath one wing. The group at the

University of Kansas plans to develop an antenna array for array processing to address the clutter problem in crevassed areas. In order to accommodate multiple antennas, multiple wing hard points have to be installed on a standard LC-130 model. It was mentioned that it might not be difficult to do the engineering required for additional wing hard points, if they were to be used only for lightweight radar antennas. Furthermore, any preparatory depot-level maintenance on an LC-130 would most likely include removal of the wing leading edge, such that additional hard points could be installed and power and data cabling could be run, affording reduced effort and cost.

Any SAR imaging radar will require appropriate antenna mounting. Such systems typically employ low-profile planar antenna arrays that can be mounted flush on the underside of the aircraft wings or on the side of the fuselage, as implemented on the NASA DC-8 for the AIRSAR system.

3.2 EXTERNAL INSTRUMENT PODS

The instrument pod system used by RAF caught substantial interest amongst the visitors. After looking at the various pod configurations RAF had put together for the NSF/NCAR C-130Q, the group agreed that the idea of developing pod-mounted sensors for the LC-130 is an area of great potential. The two external instrument pods currently used by RAF are modified fuel pods from the 'A' model C-130s. The pods can house a variety of instruments for geoscience research. Each pod has a payload of approximately 600 lbs.

Instrument pods are particularly attractive for systems that function best with no window, such as cameras and LIDAR systems. Pod-mounted camera systems might be a possible alternative for aerial mapping applications instead of a 30" viewport in the aircraft. The group considered the possibility that pod-mounted systems might even be compatible with other C-130 aircraft platforms such as the NSF/NCAR C-130Q or 109th AW LC-130s. If pod systems could be compatible with multiple aircraft, this could provide significant multi-mission capability for science. It was mentioned that the US military has extensive experience with pod-mounted systems that might be very applicable to the types of operations the Antarctic research community is looking to support with a science LC-130.

The group also discussed power and connectivity to pod systems. It was recommended that during preparatory maintenance on an LC-130, power and data cabling should be run in anticipation of wing pod systems. Specifically, running optical and data transfer cabling suitable for future expansion of instrumentation requirements should be considered whenever major maintenance such as leading edge wing removals is undertaken.

3.3 FUSELAGE APERTURES

The NSF/NCAR C-130Q Hercules has 11 large apertures in the fuselage and ramp. RAF uses these large fuselage apertures quite extensively as viewports and for air sampling. Two of these apertures in the ramp were installed by the Navy for the long TACAMO antenna. The other 9 apertures have been installed at NCAR after delivery of the aircraft. The NSF/NCAR C-130Q has numerous smaller penetrations in the fuselage as a result of the modifications by the Navy for TACAMO use. RAF uses these previously existing fuselage apertures for various purposes. In order to determine the cost and baseline configuration of a science LC-130, it is important to note that a modification of an existing LC-130 for research will start with a different configuration than that of the NSF/NCAR C-130Q aircraft. Given RAF's experience with the design and installation of large fuselage apertures, the group agreed that penetrations in the fuselage are not too difficult if the size of the apertures is small enough to fit between major structures of the airframe.

4. OPERATIONAL CONCEPTS

There was agreement within the group that it is feasible to install and operate the desired sensors for solid earth, atmospheric, and oceanographic studies aboard an LC-130, but that is important to start assessing operational concepts and safety aspects in the near future.

The primary advantage of an LC-130 platform, as opposed to wheeled long-range aircraft, would be its capability to operate from remote field camps.

Recent investigations and discussions have estimated an operational radius from McMurdo of approximately 1800 km for wheeled long-range P-3 Orion aircraft as operated by the Navy and NASA. There are many scientific targets more than 1800 km from McMurdo and the accessibility of these targets provides perhaps the greatest scientific incentive for building a dedicated LC-130. The advantage of an LC-130 derives from: a) support of deep field operations (beyond the 1800 km radius); b) a longer field season; and c) lower weather related abort rate and an additional margin of safety provided by lower ceiling/visibility minimums and the possibility of diverting away from McMurdo. South Pole station and Dome C have been suggested as possible candidates for deep field aircraft basing, because jet fuel can be delivered to these field sites on overland traverses. The logistic impact of additional personnel, equipment, life support, and aircraft maintenance at these sites needs to be discussed.

Differences in survey designs between solid earth and atmospheric studies make several sensor or instrument configurations of a science LC-130 necessary. Furthermore, during an atmospheric chemistry study the NSF/NCAR C-130Q is filled to capacity with racks of gas chromatographs, mass spectrometers, and laser-based instruments leaving little or no room for solid earth or oceanographic sensors. The possibility and ease of converting the aircraft/sensor configuration from atmospheric research to geophysical or oceanographic missions needs to be discussed. With careful design it should be possible to build much of the equipment as roll-on/roll-off suites that can interface with the appropriate through-hull ports and sensors. Building as much as possible into external wing-mounted pods could greatly increase the flexibility of the aircraft, and ease of converting between mission configurations during the field season.

Besides forward basing of the aircraft and instrument configurations, long-term missions, and additional crewing are among the operational issues that need to be addressed. It was felt that the scope of NCAR's staffing requirements to support the full range of aircraft modifications and field operations should be discussed.

5. APPENDIX

5.1 LIST OF PARTICIPANTS

Name	Affiliation	Telephone	E-Mail
Albright, Gerry	NCAR/RAF	303-497-1039	albright@ucar.edu
Bromwich, Dave	BPRC/Ohio State	614-292-6692	bromwich.1@osu.edu
Brozena, John	NRL	202-404-4346	john.brozena@nrl.navy.mil
Dunbar, Steve	RPSC	720-568-2012	steve.dunbar@USAP.gov
Eisele, Fred	NCAR/GeorgTech	303-497-1483	eisele@ucar.edu
Gogineni, Prasad	U of Kansas	785-864-7734	gogineni@ITTC.ku.edu
Holt, John	UTIG	512-471-0487	jack@ig.utexas.edu
Jensen, Jorgen	NCAR/RAF	303-444-0469	jbj@ucar.edu
Lord, Mark	NCAR/RAF	303-478-1046	lord@ucar.edu
Muench, Robin*	ESR	206-726-0522	muench@esr.org
Mullins, Jerry	USGS	703-648-5144	jmullins@usgs.gov
Parish, Tom*	U of Wyoming	307-766-5153	parish@uwyo.edu
Peters, Matt	UTIG	512-471-0485	mattp@ig.utexas.edu
Scheuermann, Mike	NSF/OPP	703-292-7453	mscheuer@NSF.gov
Stith, Jeff	NCAR/RAF	303-497-1032	stith@ucar.edu
Stone, Brian	NSF/OPP	703-292-7458	bstone@NSF.gov
Studinger, Michael	LDEO	845-365-8598	mstuding@ldeo.columbia.edu

*Unable to attend, but provided input.

5.2 RELEVANT URLS

FASTDRILL 2002 Workshop

http://www.es.ucsc.edu/~tulaczyk/fastdrill.htm

International Polar Year 2007/08

http://us-ipy.org/

NASA's Airborne Synthetic Aperture Radar (AIRSAR)

http://airsar.jpl.nasa.gov/

National Science Foundation/Office of Polar Programs

http://www.nsf.gov/home/polar/

Remote Views and Exploration of Antarctic Lithosphere (REVEAL)

http://crustal.usgs.gov/antarctica

Research Aviation Facility in the Atmospheric Technology Division of NCAR

http://raf.atd.ucar.edu

Ross Island Meteorology Experiment (RIME)

http://polarmet.mps.ohio-state.edu/RIME-01/RIME.htm

Structure and Evolution of the Antarctic Plate (SEAP)

http://anquetil.colorado.edu/seap2003

UNOLS Scientific Committee for Oceanographic Aircraft Research

http://www.unols.org/scoar