C-130 Investigators Handbook

Chapter 2. Research Systems Description

2.1 Structural Modifications

A number of structural modifications have been made to the C-130 to facilitate its use as a research platform. Some of the modifications provide mounting locations for standard EOL "in-situ" sensors that provide the meteorological context for more specialized and complex measurements made by the Users. Others are intended to support User supplied instruments – apertures for gas or aerosol sampling, large view ports for optical profiling, and infrastructure for mounting flow sensitive equipment on the wings are examples.

2.1.1 Standard Aperture Pads & Plates can be accessed in-flight

Five rectangular (18 cm by 27 cm), side looking fuselage apertures were added to the forward cabin to allow for the integration of "in-situ" sensors or gaseous and aerosol inlets. All of the apertures are located forward of the engine propeller line in order to avoid excessive turbulence and possible chemical contamination from engine exhausts. Three (3) are on the port side and two (2) are on the starboard side. All but one of these locations can be access from the cabin in-flight.

2.1.2 Special Aperture Plates – belly can't be accessed in-flight

A variety of additional aperture pads of various sizes (ranging from 8" to 16" in diameter) and shapes are also available on the aircraft. Two are located on top of the aircraft, along the longitudinal axis. The remainder of these "special" apertures, numbering from 4 to 6 depending on the surface configuration, are located on the belly of the aircraft. All fall aft of the propeller line, but are free of engine contamination due to the high wing arrangement of the C-130. The belly mounted apertures are underneath the interior cabin flooring and are not accessible form the cabin interior in-flight. Special conduits are provided to route sample lines between inlets and rack mounted equipment.

2.1.3 Optical Ports

Several optical viewing ports were added to the airframe to allow remote sensing of the atmosphere around the aircraft. Vertically collocated 16" clear view apertures were installed in the aft cabin along the longitudinal axis of the aircraft to provide both zenith and nadir viewing angles. Transparent fused silica windows are available for EOL for these apertures. In addition, a 45" by 10" slot, oriented longitudinally, provides another downward viewing location for remotely scanning sensors from the cabin floor. A specially constructed, pressure sealed cavity allows this aperture to be used without an intervening material to secure the integrity of the pressurized cabin if necessary. There is also a 16" by 20" roughly rectangular down looking aperture in the aft loading door. This aperture is not "nadir" pointing as the door makes roughly a 30 deg angle to the direction of motion when the aircraft is secured for flight. All of these apertures can be used to mount "in-situ" sensors when not being used as optical ports.

2.1.4 Fuselage Hard-points

The standard 3-D wind measurement system is built into the nose radome and is suitable for making high rate turbulent flux measurements. Additional instrumentation hard-points have been added to the fuselage in a ring around the aft edge of the radome. These hard-points are used to mount the standard HRT temperature and HRT humidity sensors provided by EOL. The proximity of these measurements to the gust probe system allow for the calculation heat and moisture fluxes as well. One to two of these hard-points can be made available for User supplied sensors. Each hard-point in comprised of a circular hole 2.25” in diameter that feeds into the un-pressurized nose wheel bay. The hole is secured by a square cover plate with four mounting screws 2.5” apart.

2.1.5 Radiometer “Boats”

Fuselage nadir and zenith hard-points along the longitudinal axis of the aircraft are limited. In situations where multiple radiometric sensors need to be deployed, the aircraft can be equipped with additional aerodynamic fairings (“boats”) that provide multiple apertures for mounting radiometric sensors. Each “boat” can accommodate up to 4 sensors, with circular apertures of 9 inches in diameter. The “boats” are mounted in such a fashion that all of the sensors will be level with respect to the aircraft airframe. This allows the User to monitor the orientation of the sensors through the research IRS system that provides pitch, roll and track angles. While the bottom “boat” is fully pressurized, the top “boat” is not. Wires and optical fibers in the top boat pass into the cabin through a centralized aperture that provides the pressure seal. The cabling must use either bulkhead connectors or potted feed throughs.

2.1.6 Wing Hard-Points & Pods

Modifications were made to the wings of the C-130 to accommodate the integration of various EOL instruments and to provide mounting locations for flow sensitive User wing stores. Small instrumentation hard-points were added to the underside of both wings. However, none of these locations are available for User equipment. Pylons were added to both wing tips. Each are capable of supporting 2 PMS style instrument canisters. In addition, two external instrument pods were attached to the wings outboard of engines #1 and #4. These pods can be used for housing a variety of EOL or User supplied sensors that can be controlled remotely. The pods have already been adapted to handle certain cloud physics instrumentation, including 3 additional PMS style instrument canisters per pod, and are also suitable for scanning radiometers or other rotating scanners because the front of the pods extend beyond the leading edges of the wings. Note that the payload weight limit for each pod is 275 kgs and that the instrumentation has to be mounted in a configuration that will keep the center-of-gravity of the pod within fairly tight limits.

2.1.7 Community Exhaust System

The aircraft has been equipped with a high volume exhaust system that vents potential contaminants generated by the research payload well aft of any gas sampling locations on the fuselage. The system is comprised of 4 two inch diameter tubes that run underneath the cabin flooring. The system is completely sealed within the cabin, with aerodynamic venturis providing sub-ambient pressures within the tubing. User access to the exhaust system is provided through 8 ports located in the cabin floor - four ports to each side spaced uniformly along the length of the aircraft.

The tubing material is chemically inert, allowing the passage of almost any gaseous exhaust.

2.1.8 Sensor Release Tubes

Two apertures have been added to the cargo loading ramp that can be used to deploy small to mid-sized scientific packages in flight without de-pressurizing the aircraft. The most common usage is for the deployment of atmospheric (dropsondes) and oceanographic (AXBT's, etc) profiling devices. Specially designed tubes are available through EOL to conduct this type of operation. Both systems can be flown simultaneously.

2.2 Research Power System capabilities

- 60 Hz 115 VAC single-phase ac power of which a nominal 35 KVA is available.
- 15 KVA 115VAC single-phase 60 Hz bridge power.[1]
- 400 Hz 115 VAC single-phase ac power of which 20 KVA total is available.
- 400 Hz 115/208 VAC three-phase Wye-connection ac power of which 20 KVA is available.
- 28 VDC 5.6 kW user power is available
- 28 VDC 5.6 kW Anti-Ice total is available.

In addition, a weight-on-wheels (WOW) switch will activate 28VDC Anti-Ice after the aircraft is airborne.

Twelve 2.5 KVA frequency/power inverters are provided under the floor in the forward cable area for 115 VAC, 60 Hz power. There are six reserved for the right side of the aircraft and six reserved for the left side of the aircraft. An additional two are used for data power. The system has excellent voltage regulation and frequency stability.

The inverters shut down to prevent damage to the load, if the input voltage becomes too low (70 to 90 Vrms) or too high (125 to 132 Vrms). These inverters have an overload capability, however, the use of devices with large in-rush currents (e.g. starting a single-phase motor a vacuum pump motor) requires advance notice from the experimenter to the RAF. Special arrangements will be required to sequence the turn on to avoid power outages or damage to the converters.

Experimenters using equipment that requires AC power frequencies other than 60 or 400 Hz must provide their own converters and coordinate with RAF in advance.

2.3 Data Acquisition System & Display

All of the data provided by the suite of standard C-130 sensors are recorded on a single, centralized data station located in the cabin of the aircraft. Data from User supplied instrumentation can be included in this common data record upon request. A series of remote displays are distributed around the cabin to allow real time access to the data. The data station in manned by an RAF staff member on all research flights who serves as the dedicated operator of the system and as the facility designated "load-master" in charge of all crew activities in the main cabin.

[1] The Research Power Bus (R-Bus) 115VAC 60Hz system provides ~60 A of 115VAC 60Hz bridge power for 500m/sec for the right side power and ~60A of 115VAC 60Hz bridge for 500m/sec for the left side power for aircraft generator switching brownouts.

2.3.1 Data Acquisition System Overview

The C-130 aircraft data system (ADS3) is a modular system that utilizes data sampling modules (DSMs) in the cabin, the nose, the baggage compartment, and the wingpods (as needed). This distributed modular concept allows for straight forward expansion and for ease of installation. It also minimizes the amount of wiring required between instrumentation and the DSMs by keeping the DSM as close as possible to the installed sensors. Data from the DSMs are sent to the ADS3 server over the aircraft data acquisition network.

It was a principal design goal of ADS3 that the size of the new DSM be smaller than the older generation11-slotVMEchassis utilized for the ADS-II version of the system. To achieve this goal, the ADS3 DSM utilizes an industry standard architecture with a large selection of commercially available off-the-shelf (COTS) hardware. This design approach enables the ADS3 to accommodate a wide variety of instrumentation and will also make possible the addition of new instrument interfaces in the future without the need to always develop custom printed circuit boards. The PC-104 architecture was selected for the ADS3 due to the advantages of its smaller size and the greater availability of suitable COTS instrument interfaces. The standard PC-104 architecture utilizes the ISA 16-bit data bus, with maximum word transfers typically less than 10MHz. The PC-104 Plus circuit card contains an additional connector, which is the PCI32-bit bus capable of 33-66 MHz bus transfer rates. The additional PCI connector on PC-104 Plus boards reduces available space on the circuit card for instrument interface circuitry. The PC-104 (ISA bus) is the ADS3 standard interface. The Plus version will be made available for use in ADS3 if needed.

2.3.2 Data Interfaces

Analog inputs: Analog signals are connected to ADADS using twin-ax cables and differential input amplifiers. Analog connectors are referenced to the C-130 airframe through high-value resistors to prevent ground loops while maintaining reference to the airframe. Each analog channel is calibrated via precision voltage sources as part of standard pre-and post-project calibration procedures. ADADS provides analog-to-digital (A/D) conversion with16 effective bits of resolution at the above-specified sample rates below 10,000Hz. At 10,000Hz, the A/D resolution will be reduced to 14 effective bits. Analog channels are sampled simultaneously, with a maximum sampling delay between channels of 1 millisecond. Per-channel software selectable analog sample rates are 10, *100, 1000, and 10,000Hz.*

Digital inputs: Digital data collection includes the acceptance of both serial and parallel data formats. Pulse counting is also available. Data transfer rates are generally determined by the instrument and typically vary from 1 œ 50Hz. ADS3 has the capability to sample and recording rates which are multiples of 1 Hz.

Industry standard asynchronous RS-232 and RS-422 interfaces are provided in ADS3 with rates from 1200baud to 115 Kbaud. ARINC-429transmit and receive channels can be provided at both the standard high and low speeds. A single PC-104 interface card contains at least two (2) receive double-buffered channels. FIFO or dual-port memory will be highly advantageous to alleviate the need for interrupt servicing of every received 24-bit word. The industry standard HDLC synchronous protocol with clock rates up to 4 MHz and frame buffer sizes up to 4 Kbytes is also provided.

A serial interface based upon programmable logic is available that can be configured to provide custom interfaces such as bi-phase, pulse counting, and APN-232 radar altimeter serial data. In the case of pulse counting, the programmable logic interface is capable of providing at least two (2) 16-bit counters on a single board. Data are double buffered.

Note: *The older-generation PMS 1-D and2-D serial interfaces are n longer provided in the C-130 ADS3.*

Parallel Data Interfaces: The C-130 ADS3 provides a parallel digital I/O interface that can be configured for different widths from 1-bit to 32-bits. In addition, there are up to four (4) separate input/output lines that can be used for data strobes and hardware interrupts. These lines are configurable as 1x, 4x, 8x, 16x, and 32 bits.

2.3.3 Network Description

The aircraft is outfitted with multiple networks. The primary data acquisition network interconnects the DSMs and provides gigabit Ethernet over copper twisted pair Category6 wire. A similar network is provided for data display and user data traffic. (Fiber optic cable is also available and is currently installed in the wings and terminated in the cabin. This is not currently in use.) Network access is available at the eight (8) SSDBs in the main cabin, and at the SSDBs in the baggage compartment and the nose. Figures 2.15 and 2.16 show the locations of the main cabin SSDBs. Network wiring extends to a wing hard-point locations. A third network links the ADS3 server to the SATCOM link for transmission to the ground.

2.3.4 Data Recording

Data sampled by ADS3 is recorded on redundant systems as “raw“ data at sample rate and in the RAF ADS format. Data are stored on removable disk drives and/or other portable storage devices. A structured-query language (SQL) database is available for low-rate data storage/access by investigators who wish to have their data stored in a common database but not sampled through the ADS3. User data not going through a DSM maybe sent to the database via the display network.

2.3.5 System Timing and Synchronization

GPS time-of-day is distributed to the DSMs and to the entire aircraft instrumentation suite via Ethernet in both IRIG-B and network time protocol (NTP) formats. A master time server (Datum Sync Server 1000) receives the GPS time-of-day information and provides these formats through an Ethernet connection. Each DSM includes an IRIG-B time distribution PC-104 card. In addition, DSMs receive the 1 pulse per second (PPS) start-of-second signal from the GPS. The 1 PPS signal maybe used to establish the beginning of each one-second interval. The master time server and DSMs establish time-of-day during the boot-up process via the IRIG-B signal and advance time by countingthe1PPS. While the IRIG-B signal can be used by the C-130 ADS3 and by users to advance time and to identify the beginning of a one-second period, the 1 PPS time advancement method is considered to be more reliable. Both the 1 PPS and IRIG-B signals are made available to users.

2.3.6 Digital Signal Processing

Information to be provided at a later date.

2.3.7 Data Display Overview

Real-time display of data on board the C-130 is provided by the NCAR Airborne Environment Research Observing System (AEROS) software package. Complete information about AEROS and instructions for use of the software are available in the *Aircraft Data Acquisition and Display System (ADADS) Reference Manual*. Briefly, the AEROS package operates on both Windows and Linux based computer systems and provides investigators with the capability to generate and view the following types of plots: timeseries, XversusY, track, skewT, ASClist, statistics,and sizedistribution. Only data streams recorded on the GVADS3 can be displayed on board using AEROS.

2.3.8 Data Broadcasts

A configurable ASC serial feed is provided to investigator equipment. The serial port output is typically set to 38,400baud withN81 for parity data and stop bits once per second. While the configuration of the serial feed changes on a per-project basis, the data stream format always consists of the following parameters in the order given: date, time, and selected and configured variables. Values included in the serial feed are separated by a space, and the line is terminated by a carriage return/line feed pair. A sample ASC serial feed stream is given below:

YY/MM/DD HH:MM:SS 1.234956e+008.325723e+02 … . \r\n

An Ethernet broadcast of data that is identical in format to the ASC serial feed is also provided on board the GV. This broadcast consists of a UDP/IP packet sent once per second.

2.4 Satellite Data Communication Link

As outlined in Section 1.6.2 of Chapter 1, both Iridium and Inmarsat SATCOM systems are installed on the C-130. Both systems provide voice and fax communications and data transfer capabilities. The near-global coverage and high bandwidth (128kbps) characteristics of the Inmarsat system also provide the capability for controlling instruments and the C-130 ADS3 from the ground during flight.

The transmission of data products to and from the C-130 is limited by the available bandwidth of each system (2.4 kbps for the Iridium system and 128kbps for the Inmarsat system). In the case of the Inmarsat SATCOM system, the available bandwidth must be partitioned between voice communications, instrument control needs, time series and image data transfers, and text messaging in bi-directional mode. An on board computer controlled prioritization algorithm is configured for each C-130 project to provide control of Inmarsat bandwidth traffic flow and to ensure that critical data and messages are transmitted in a timely fashion. EOL personnel are currently sti developing and implementing the software tools that will be required for utilization of the C-130 SATCOM systems for data transfer and instrumentation control. Further information on these utilities will be provided in this section as it becomes available.

EOL personnel are currently developing and implementing the software tools that are required for utilization of the C-130 SATCOM systems for data transfer and instrumentation control. Several tools are already available that will allow real-time web access to either direct field project participants, student groups or even common individuals with a casual interest in aviation research. Direct participants can communicate with onboard observers via text “chat” and the link can be used to transmit radar or satellite images, weather maps or sounding data to help provide in-flight guidance to modify research flight tracks and enable better sampling of targeted phenomena. Data access to in-situ measurements includes up to 20 variables and can include jpeg files taken from digital cameras documenting the flight environment. Outside groups or individuals can access some of this information via the EOL web site (www.eol.ucar.edu) that uses an interface to Google Earth which adds the aircraft track to their global display technology. This web site provides a summary of all ongoing EOL field activities at any time.

2.5 Ground Support Computing

Depending on the region of operations and the location of the operations center, there will typically be a ground based server that will be connected to a LAN where data will be processed post-flight and distributed to users who are connected to the LAN. In real time during a flight the ground server will also be gateway for two-way data communication between the aircraft and the ground. Often connections to a local ISP will be established and data (realtime and post flight) can be accessed from remote sites.

2.6 Data Products

Following each C-130 research flight, EOL personnel use the EOL/RAF Nimbus software package to process the collected data. Nimbus outputs data products in the network Common Data Form (netCDF) format. More information on netCDF is available on-line at http:my.unidata.ucar.edu/content/software/netcdf/index.html. Preliminary data files generated following the completion of research flights are used by RAF personnel to perform initial quality checking of collected and derived data products. These preliminary files are also made available to investigators for initial review and analysis.

Data from investigator instruments that have been recorded on the C-130 ADS3 will be processed by Nimbus and released in the primary aircraft netCDF data file. Investigators who elect to record data on stand-alone data systems will be responsible for the processing and release of their own collected data products.

EOL has established a data policy governing the collection and release of data sets collected from EOL-supported atmospheric observing facilities, including the NSF/NCAR research aircraft. This policy can be viewed on-line at http:www.eol.ucar.edu/dir_off/datapolicy.html. Investigators are strongly encouraged to review and become familiar with this policy in advance of the start of the designated field program.