Interface Control Document
Autonomous Modular Sensor

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1 System components

Autonomous modular sensor (AMS) subsystems include the scan head, digitizer/data system, Applanix strap-down navigation system enclosure, solid-state disk enclosure, GPS antenna and assorted cabling. To date, AMS has several hundred operational hours on UAV platforms (Altair and Ikhana) in support of wildfire detection and mapping efforts and for tens of hours on a Piper Caravan for fire and flood mapping.

2 Sensor characteristics

The AMS is an airborne multi-spectral imaging line scanner. It builds an image by raster-scanning across its direction of travel and accumulating lines of pixels as it moves. By interchanging optical components (primary apertures), it can support pixels sizes of 1.25mR, 2.5mR or 5mR. The swath width is always 716 pixels across, giving total angular widths of roughly 43° or 86° respectively. There are three spectrometers which can be interchanged on the scan head, each providing a different selection of spectral channels. For some channels, a selection of band-defining filters is available to be swapped in to tailor the spectrometer for particular applications. Table 1 below shows the approximate spectral bands (in μm) for each spectrometer. At present only the first two spectrometers have been configured to operate with the new scan head. Scan rates are continuously adjustable from (roughly) 2 scans/sec to 33 scans/sec, depending on the specific configuration. Spatial resolution is determined by altitude and the primary aperture size.

Table 1 Spectral characteristics of available spectrometers

UAV H2O Vapor Configuration (Land I)		UAV Wildfire (Land II)		UAV Atmospheric Mapping Configuration		UAV Ocean Color Configuration (OCI)	
1	0.42-0.45	1	0.42-0.45	1	0.45-0.52	1	0.412
2	0.45-0.52	2	0.45-0.52	2	0.52-0.60	2	0.443
3	0.52-0.60	3	0.52-0.60	3	0.57-0.67	3	0.490
4	0.60-0.62	4	0.60-0.62	4	0.60-0.73	4	0.510
5	0.63-0.69	5	0.63-0.69	5	0.65-0.83	5	0.555
6	0.69-0.75	6	0.69-0.75	6	0.72-0.99	6	0.620
7	0.76-0.90	7	0.76-0.90	7	0.83-1.05	7	0.670
8	0.91-1.05	8	0.91-1.05	8	6.54-6.90	8	0.770
9	1.36-1.39	9	1.55-1.75 1.88	9	10.26-11.26	9	0.860
10	1.86-1.91	10	2.08-2.35	10	11.54-12.49	10	1.024
11		11	3.60-3.79			11	11.5
12	6.54-6.90	12	10.26-11.26				

3 Subsystem dimensions and mounting points

3.1 Scan head

Overall dimensions of the scan head are shown below in Figure 1. There are three available spectrometer heads, one of which can be mounted at a time on the scan optics. The Wildfire (Land II) spectrometer is shown below (upper cylinder above oval plate). Mounting hard-points in the oval baseplate attach to a sheet-metal frame, which is in turn shock-mounted to an aircraft in a typical installation. Locations of the mounting holes are shown in the upper left of Figure 1. A more detailed drawing is shown in appendix B. In that figure, acceptable areas for mounting tabs are also shown in the upper left and right of the drawing. These areas are symmetrical across the horizontal (along track) axis. All lines in the drawing within the oval outline of the scanner baseplate hang from the bottom of the baseplate. The through holes accept ¼" bolts. The "back porch" area of the baseplate carries power supplies, the LN-200 INU and scan head electrical connectors. The assembly reaches the edge of the oval baseplate and is slightly shorter than the spectrometer assembly. The LN-200 is recessed into the top of the back porch so that its connector does not protrude beyond the top of the spectrometer.

The orientation of the scan head with respect to the airframe is with the vertical axis (up, in the two bottom views of Figure 1) vertical in flight. If there is significant nose up or down angle of attack in flight (more than a few degrees) the mounting should compensate in the opposite direction. The flight direction is left to right in the lower left view of Figure 1 (scan motor is on the aft end of the scan head). For accurate geo-correction of the image data using the POS/AV, the relationship between the LN-200 INU, scan head and GPS antenna must be known. Applanix recommends that the antenna to INU "lever arm" be measured to within "a few cm"; their software accepts measurements to 1mm precision.

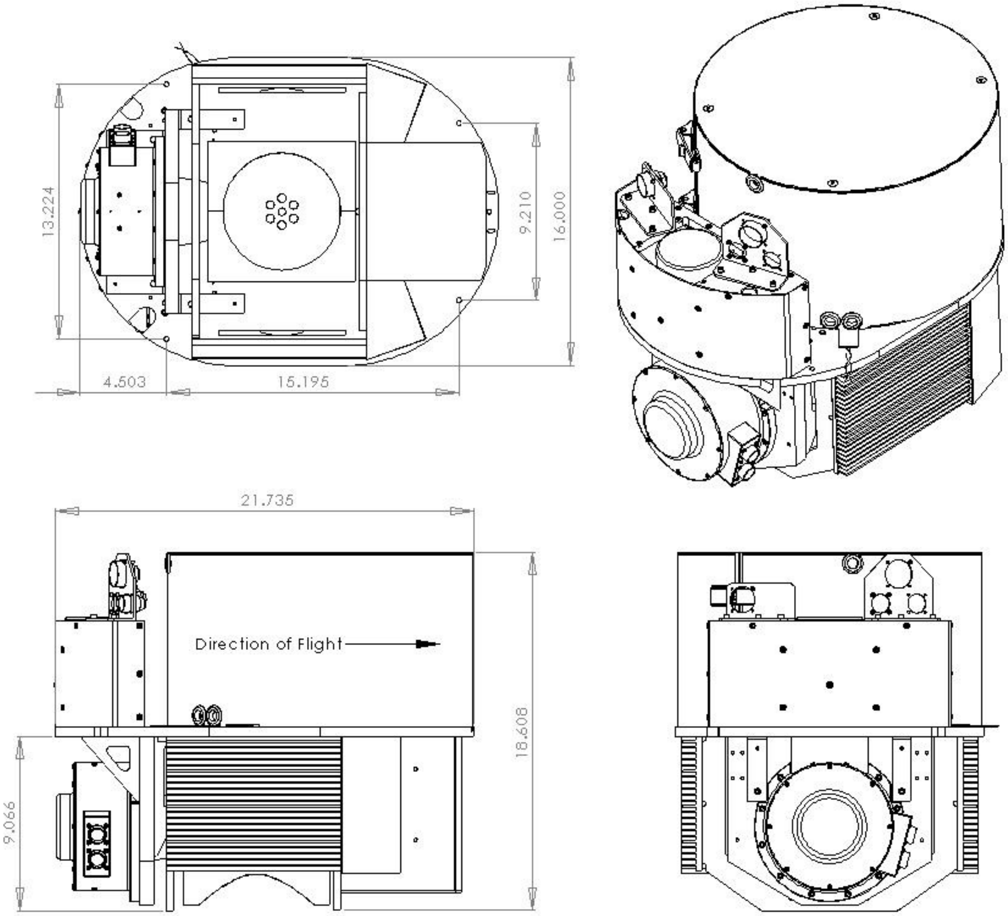


Figure 1 Scan head envelope

All three instrument configurations look through an open port in the aircraft belly. The along-track dimension is typically 7”, allowing 0.5” clearance from the instrument field of view. The cross-track dimension depends on the distance from the scan mirror axis to the aircraft skin. Figure 2 shows minimum cross-track dimensions for the port. Practically, 0.5” clearance should be added on each side. Note that each inch of additional vertical separation between the scanner and the aircraft skin requires another 2.07” of slot width. Figure 3 shows minimum along-track slot dimensions and Table 2 shows slot dimensions for various skin distances with a slightly different assumption (90º) for the clear FOV.

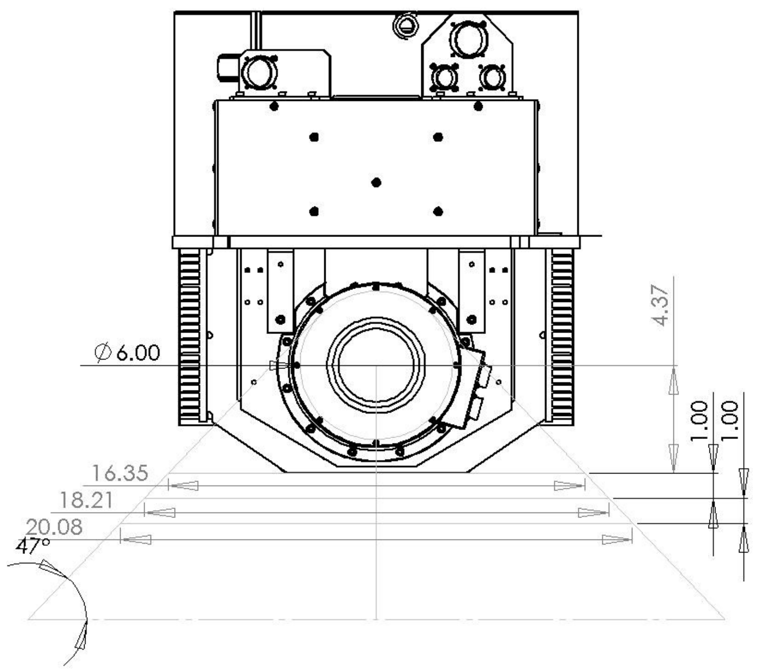


Figure 2 Cross-track port dimensions

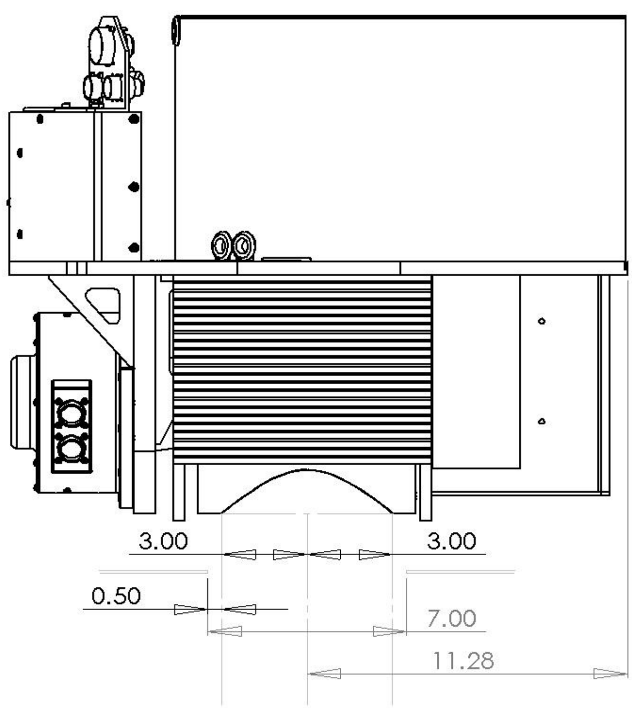


Figure 3 Along-track port dimensions

Table 2 Required field of view opening

Clearance Between Scan Head & Skin	Opening Required for 90 deg. Clear FOV
0.25”	7.00” X 17.0”
1.0	7.00 X 19.0
2.0	7.00 X 21.0
3.0	7.00 X 23.0
4.0	7.00 X 25.0

Note:

1 Calculation assumes aircraft skin thickness of 0.25”
2 Long Opening dimension to be perpendicular to flight path
3 Calculations assume skin is parallel to scanner mounting surface

To reduce air circulation through the open slot, an air fence is typically placed before its leading edge. The ER-2 fence descends roughly 2 inches and 45º down and aft. It is slotted with 3/8“ slots roughly every 1½” and extends slightly beyond the width of the scanner aperture. Two photos of the ER-2 air fence are shown below in Figure 4 and Figure 5.

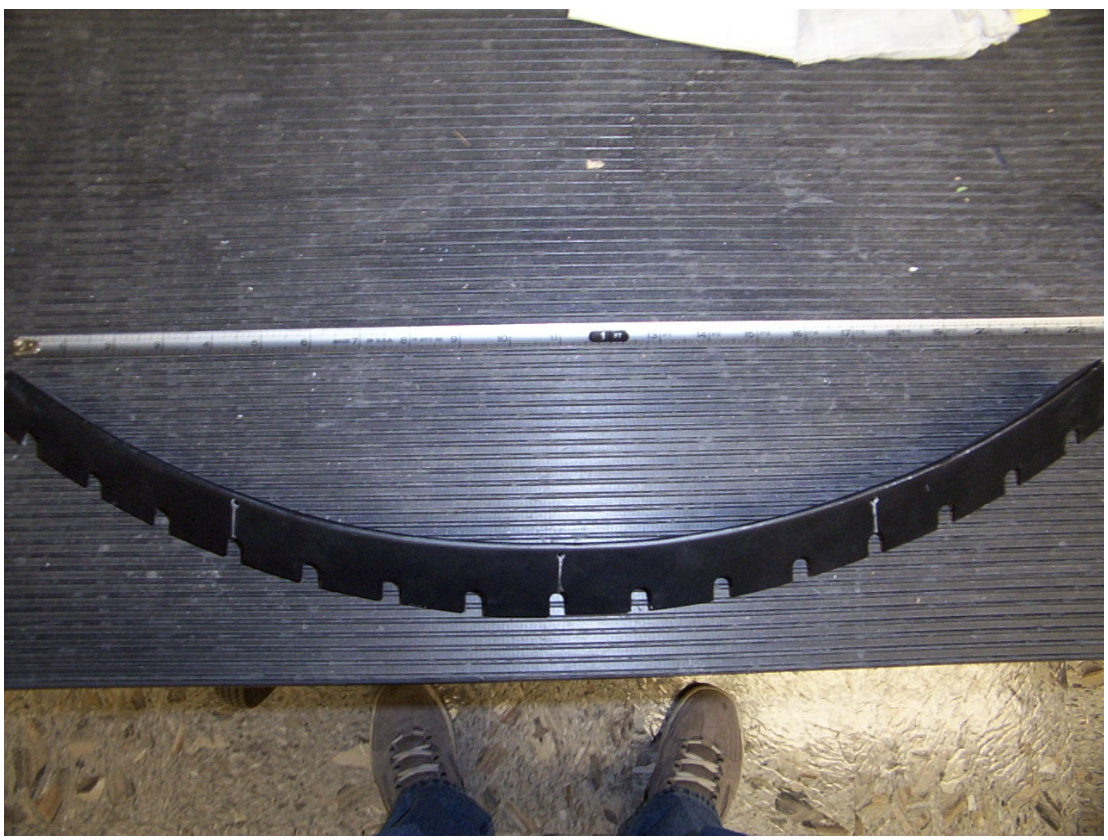


Figure 4 ER-2 air fence looking aft

Figure 5 ER-2 air fence looking up

3.1 Data System Pressure Vessel

Figure 6 shows the overall dimensions of the data system pressure vessel, together with its support frame.

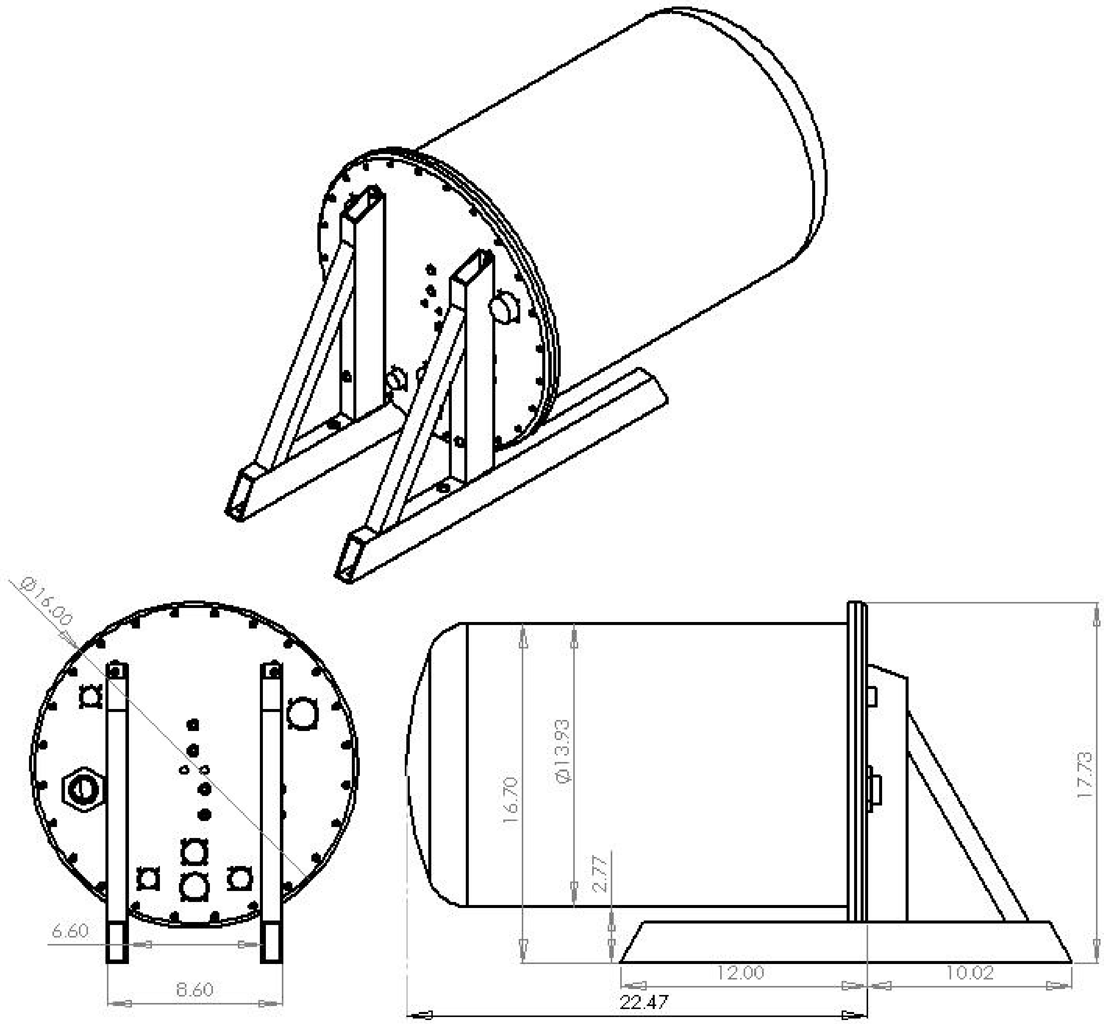


Figure 6 Data system pressure vessel envelope

The support frame attaches to a base plate with six 10-32 machine screws according to Figure 7 below.

The pressure can may be mounted in any orientation, and alternative mounting arrangements for the data system pressure vessel are possible using four 10-32 mounting points on the rear pressure flange. Hole positions are shown in below. These mounting points support internal structure and so require an interface to be present at all times. Bridging structure between the holes must dodge rear panel connectors and the flange bolt circle. Access to the console connector is required pre- and post-flight (lower center connector, Figure 8) or access may be provided via a pigtail through some small external port.

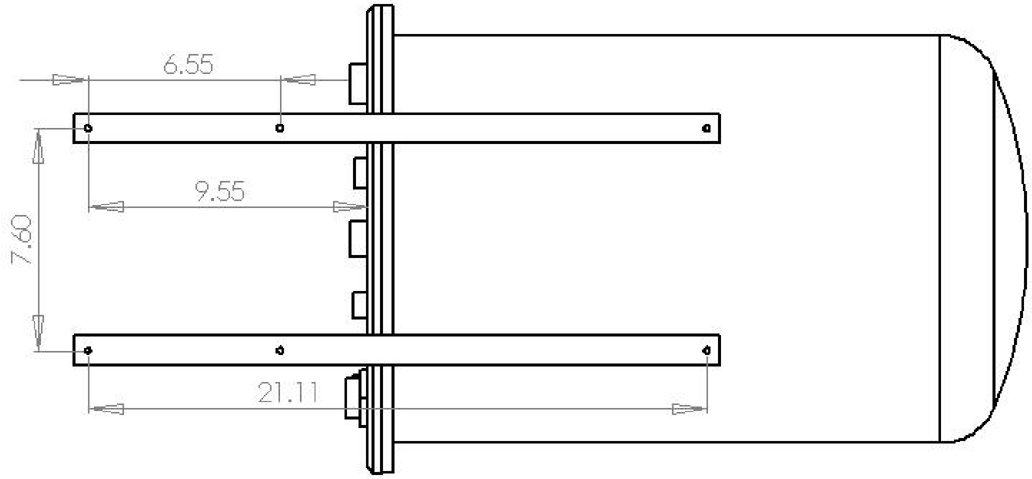


Figure 7 Data system mounting points

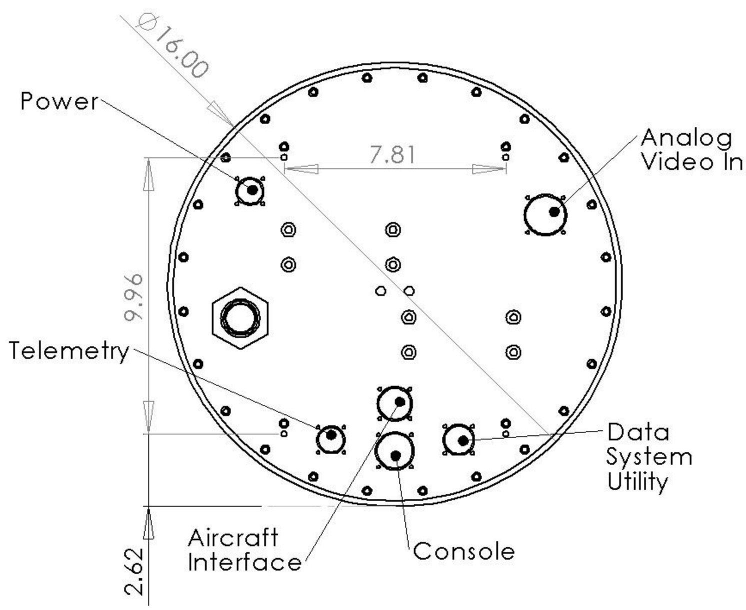


Figure 8 Rear flange hard points

3.2 Applanix Navigation Subsystem

An Applanix POS/AV strap-down navigation system provides roll correction and geolocation data for scanner imagery. Its environmental specification requires it to be enclosed in a pressure vessel for high altitude operation. Envelope dimensions for the available enclosure are the same as those of the power distributor and are shown in below in Figure 9. Appendix C contains a larger outline drawing of the enclosure and its hard points. The pressure housing is shown mounted in a sheet-metal tray via standard aircraft instrument bayonet and clamp fittings. The tray has shock mounts which interface to the aircraft structure. Both of the rectangular pressure housings can be mounted in this way. Figure 9 also shows the connector layout for the POS-AV pressure vessel.

The Applanix enclosure may be mounted in any orientation. Access to an ethernet connection to the unit may be required pre- and post-flight for downloading stored navigation data. This access may be provided through a pigtail to a small external port and may be routed through an ethernet hub.

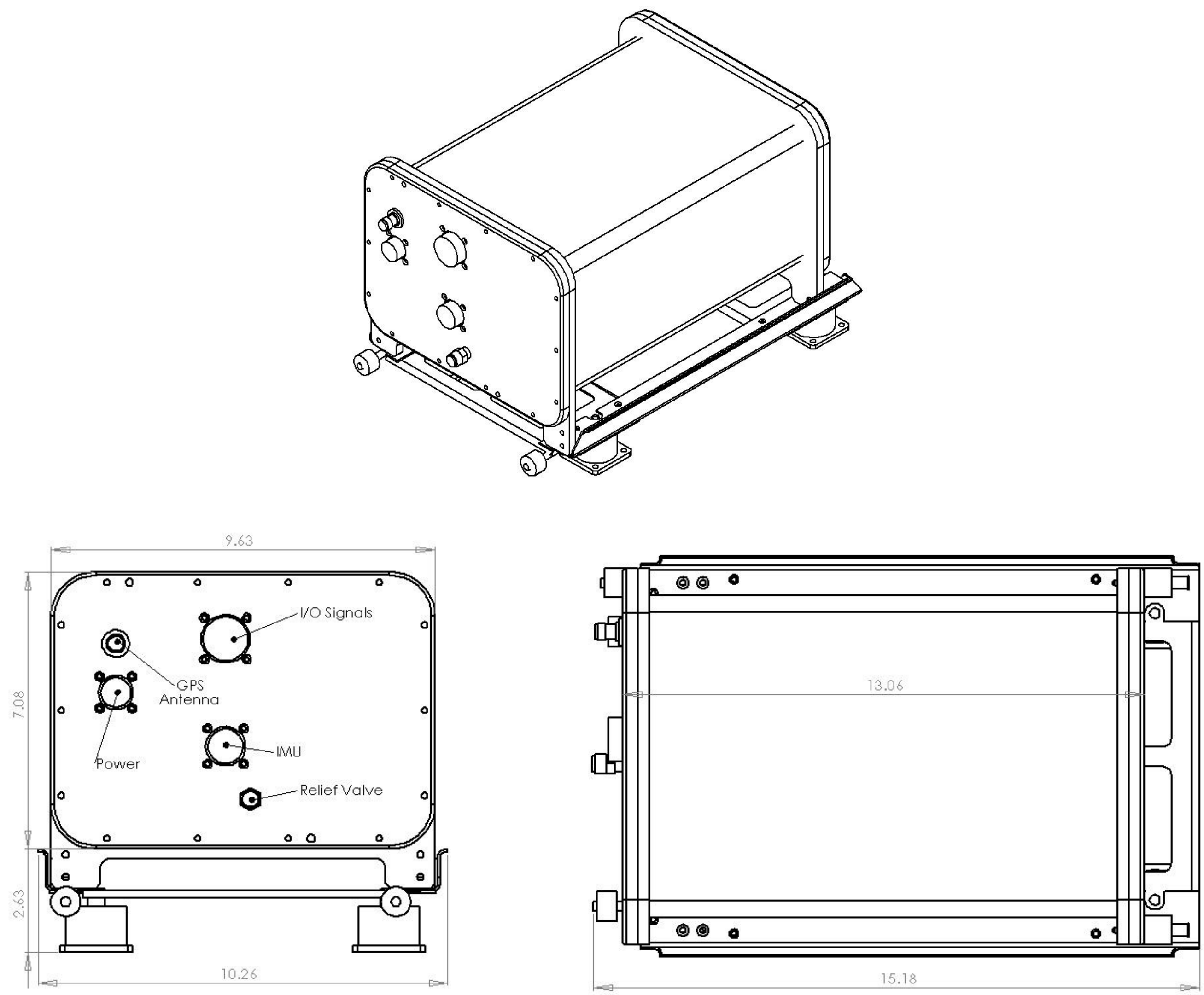


Figure 9 POS-AV enclosure envelope

3.3 Power Distributor

The power distributor enclosure can be directly mounted to a base plate or placed on a shock-mounted tray which attaches to the base plate. This enclosure may be mounted in any orientation, and pre- and post-flight access is only required if circuit breakers need to be switched or reset. Figure 10 below shows the envelope dimensions for the power distributor. Note that the feet of the pressure enclosure have mounting holes for standard avionics bayonet and clamp fittings.

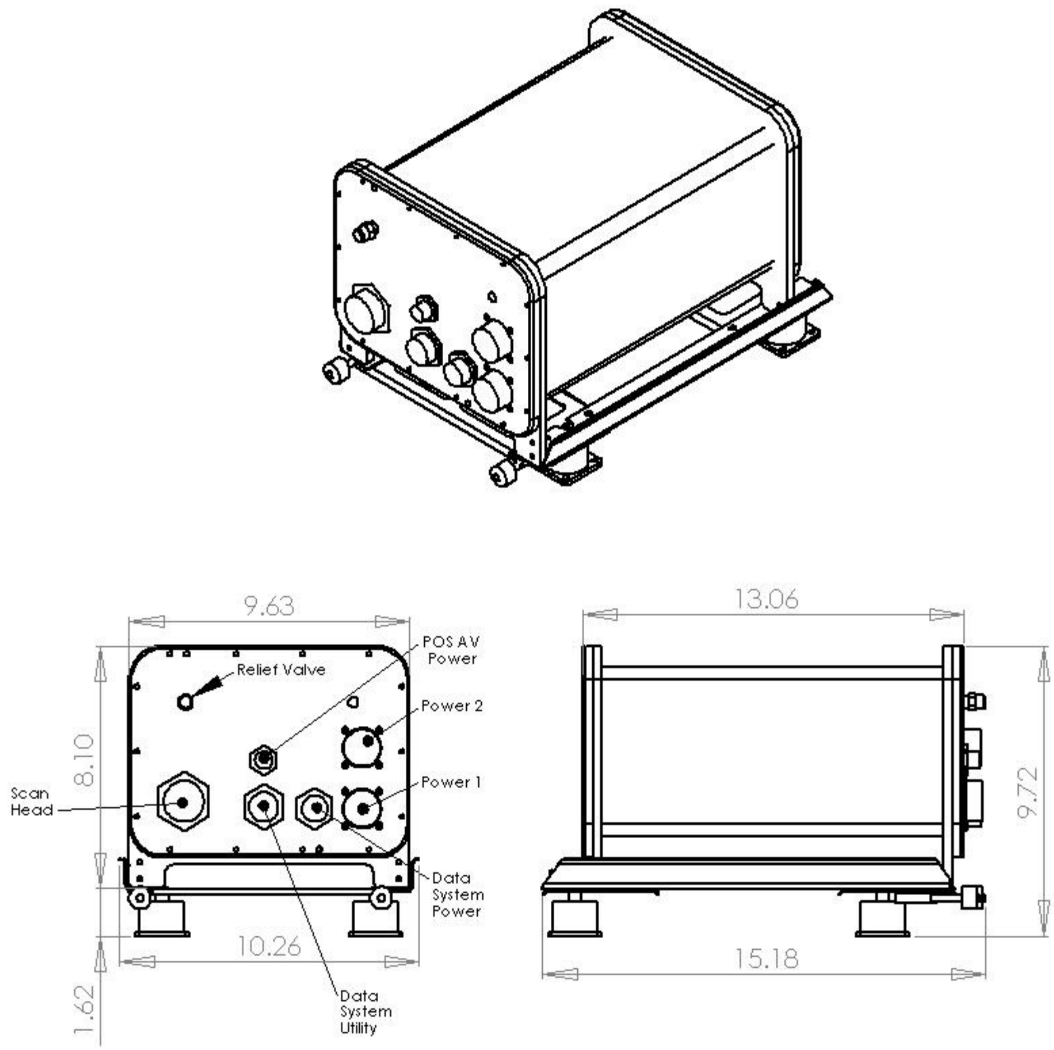


Figure 10 Power distributor envelope

3.4 External Disk Enclosure

AMS image data is stored on a set of solid-state disks in an enclosure designed to be easily removed and exchanged. Unscrewing two captive fasteners allows the enclosure to be separated from its mount. Removing the unit requires diconnecting the power connector on the enclosure and the USB connector from the data system pressure vessel. Overall dimensions of the disk enclosure are shown in Figure 11, and locations of the 1/4-20 mounting screws in Figure 12.

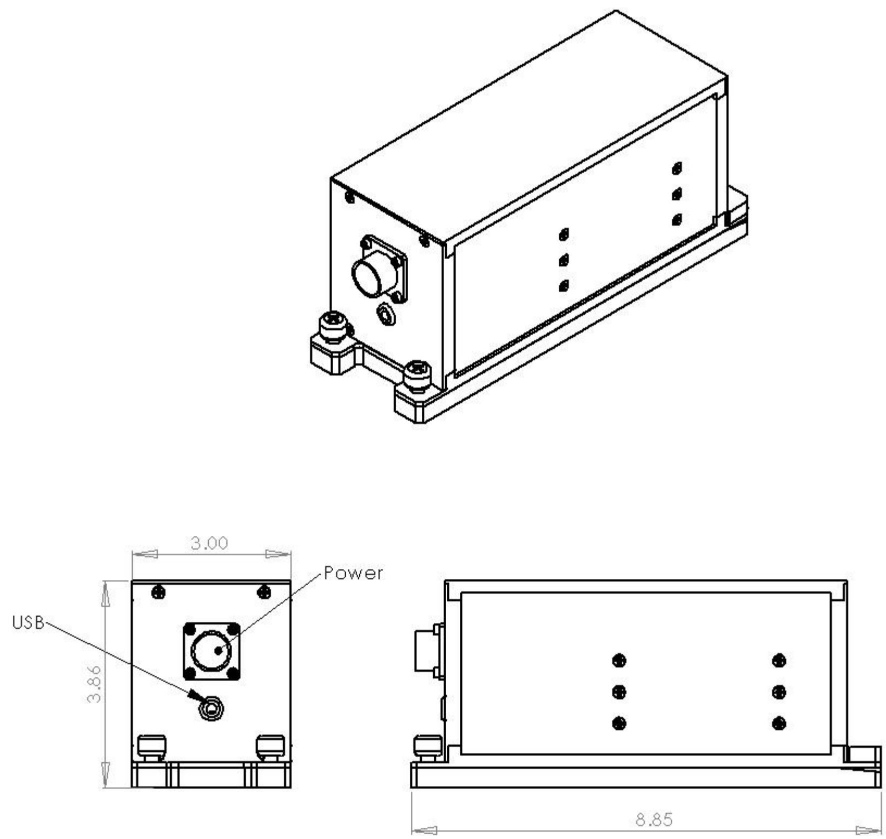


Figure 11: External disk enclosure envelope dimensions

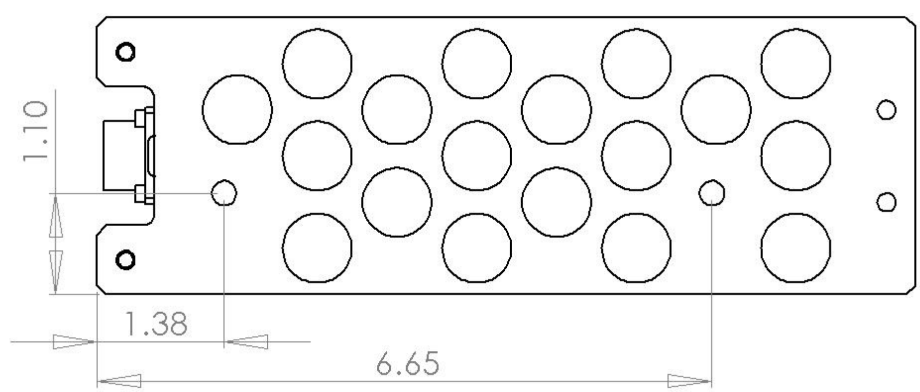


Figure 12: Mounting screw locations (bottom view)

4 Subsystem Weight and Balance

Weights of the various subsystems as-built are given below in Table 3. Weight of cabling varies somewhat from installation to installation.

Table 3 Approximate subsystem weights

Subsystem	Weight (kg)	Weight (lb)
Scan head	62.3	137.0
Data system & enclosure	22.5	49.5
Power distributor	8.6	19.0
Applanix enclosure	9.1	20.0
External disk enclosure	1.4	3.0
cabling	5.0	11.0

The center of gravity of the rectangular enclosures is within 0.5” of their geometric centers. The scan head vertical center of gravity is in the middle of the 0.5” thick oval scan optics baseplate. Its left-right CG is within 0.1” of the centerline. The fore-aft CG is 10.6” aft of the forward end of the oval baseplate. The datasystem CG is 6.6” towards the domed end of the enclosure from its flat end. Vertically, the CG is 0.5” below the axis of the cylindar, towards the mounting feet. The side-to-side CG is on the cylindar axis.

5 Temperature and Condensation

AMS has been flown for extended periods on the Altair and Ikhana UAVs without failure of the scan head. Outside air temperatures on some of these flights reached -59ºC. Other system components were placed in an insulated outer enclosure in which the temperature was higher. The data system and other subsystems experienced no failures at measured operating temperatures as low as -23ºC. On the ground, the data system has operated successfully at measured internal temperatures exceeding 55ºC.

Temperature ranges at which the various system components fail have not been established. Most of the COTS electronic equipment is rated for industrial temperature range (-40ºC - 85ºC). Typical operational temperatures in the ER-2 environment range from around or slightly below 0ºC to around 55ºC with the electronics enclosed in an un-pressurized enclosure. The scan head operates in an unpressurized section of the wing super-pod or in the primary equipment bay with an open port through the aircraft skin. Power dissipation from its electrical components and mylar film heater keep typical operating temperatures around -15ºC.

Condensation is not expected to be a problem for components enclosed in pressurized enclosures. Purging with dry gas could be done if necessary. The scan head is expected to be wet on descent. This is main cause of degradation of scan head components, and should be held to a minimum. In ER-2 operations, a descent heater/blower with settable power up to 1200W capacity is available. Typically, its 750W setting is used. In addition, the scan head is fully powered in flight and on descent to take advantage of dissipation from the motor and blackbody references. Additional protection for the scan optics could be provided by an electrically operated door over the open slot, but this may not be practical.

6 Electrical and Data Interfaces

Electrical power for the data system is distributed by the power distributor. Aircraft power enters the power distributor through two identical 5-pin connectors. There are four separate 28VDC circuits on these connectors, allowing subsystems to be independently controlled. There are both 8 and 12 gauge pins on these connectors, allowing ample safety factor for worst-case loads. There are seven circuit breakers inside the power distributor as shown in Table 4. The separate circuits are intended to be closed when the power distributor enclosure is sealed, and energized simultaneously by the aircraft power system. AB denotes 8-gauge pins and DE 12-gauge.

Table 4 Power distributor circuit breaker capacities

Circuit breaker	Capacity	Circuit
Data system	10A	J4-DE
Blackbody controller	20A	J4-AB
Scan Head power	5A	J4-DE
Subsystem heaters	15A	J6-AB
Motor controller	10A	J4-DE
Head heater	10A	J4-AB
POS AV	5A	J6-DE

Lab measurements of actual power requirements are given below in Table 5. The data system current requirements include the Applanix and Ag132 GPS receiver. Descent heater power requirements are not included; on the ER-2, the descent heater uses 115VAC 400cyc power, and can draw up to 1500W. Scan motor current load is based on a scan rate of 33 scans/sec. At 6.25 scans/sec, the scan motor draws 1.4A. Subsystem heater load depends on the state of several controllling thermostats.

Table 5 Subsystem power requirements

Subsystem	Voltage	Peak current (Amp)	Steady state current (Amp)
Data system	18-36VDC	6.75	6.6
Blackbody controller	28VDC	16	10
Scan head	18-36VDC	3	2.7
Head heater	28VDC	9.7	9.7
Scan motor	28VDC	2.8	2.8
POS AV	18-32VDC	2.5	1.5
Subsystem heaters	28VDC	7 (approx.)	7(approx)
Total:		47.75	40.3

7 Shock, Vibration and G-Loading

No structural analysis or laboratory load testing has been performed on any part of the system. The general form of the enclosures and internal components has been designed to meet ER-2 requirements for 5G loading without structural failure which might endanger the aircraft. Some of the electronic equipment is commercial non-aircraft grade. All such commercial equipment is enclosed in some way so as to prevent them from becoming a hazard to the aircraft under high accelerations. All electrical connectors have latching features or have added clips to prevent their unmating under G loading. No failures or effects due to shock or vibration have yet been seen during normal operations.

Some unscientific testing on the data system internal cantilevered assembly has been done to put limits on the tolerable G stress. With the system in the orientation shown in the lower right of Figure 6, the internal electronics rack was loaded with approximately 70kg for several seconds without failure (in fact without significant flexure). This loading corresponds to more than 10G on the internal structure.

The standard scan head mounting consists of an aluminum frame surrounding the head perimeter which mounts to a rack with four shock/vibration isolators (Barry Controls 5220H). This frame or a different arrangement may be used at the integrator’s discretion. Figure 13 shows the currently-used shock/vibration isolation mounts.

No special shock or vibration mounts for any other system components are required.

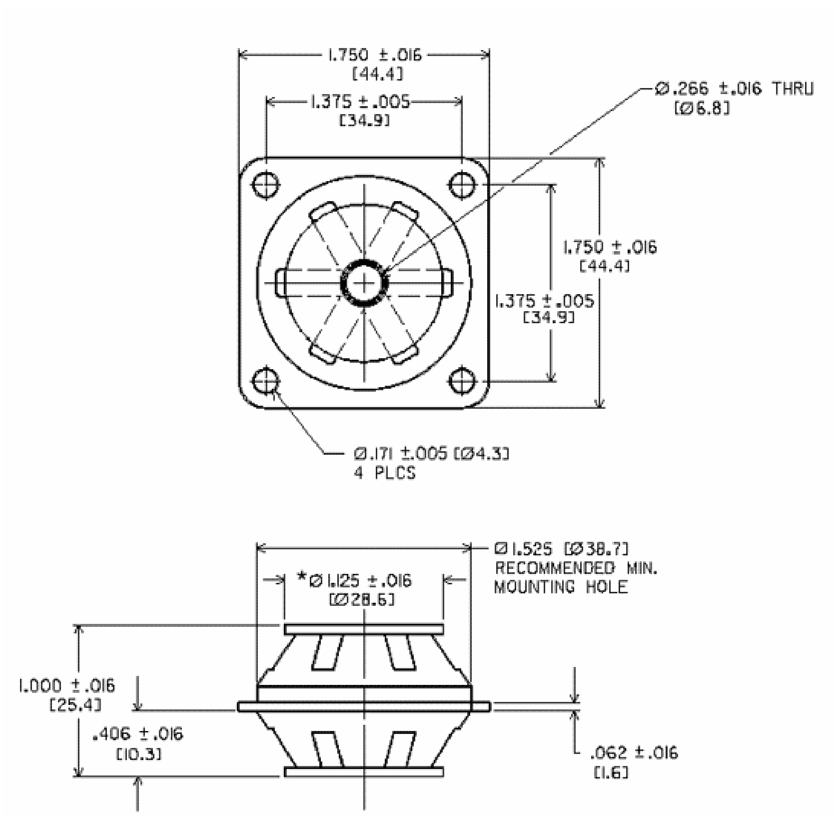


Figure 13 Shock/vibration isolator drawing

8 Subsystem Interconnects

Figure 14 below shows the cable interconnects between subsystems. Typical cable lengths can be up to 30ft in some installations. Cable lengths shorter than 10ft are highly desirable. Appendix A gives a more complete interconnect diagram, including connector specifications.

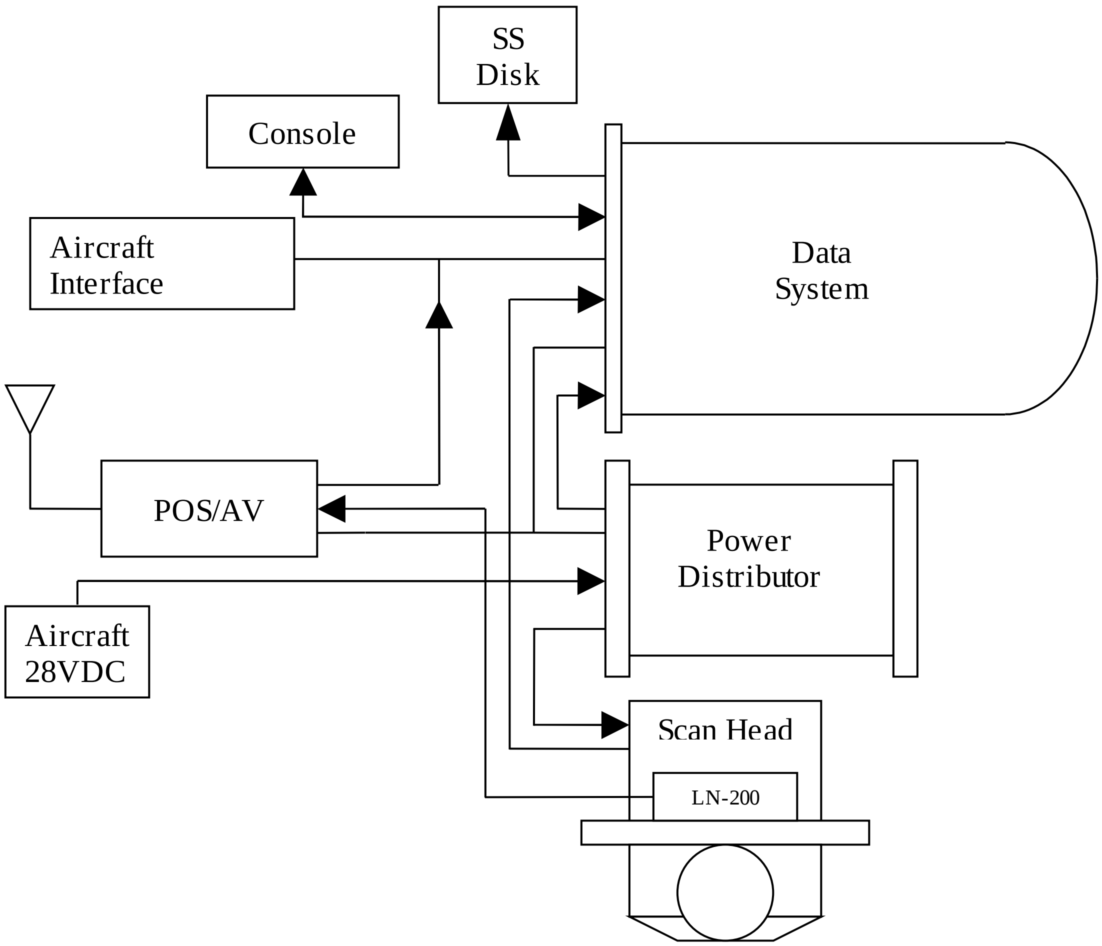


Figure 14 Subsystem interconnect block diagram

Interconnect cables comprise the following:

1. System power cable

   This cable terminates in two MS3106A20-14S connectors. Four 28VDC power circuits are available, two on 8-gauge pins and two on 12-gauge pins. All system power enters the system here.

2. Aircraft interface cable

   Signals from both the POS AV and from the aircraft enter the data system on this cable. Aircraft interface signals are designed to interface with the ER-2 (and WB-57) experimenter interface panel (EIP), though they can be adapted to other configurations also. Aircraft signals include a record switch input, a FAIL light output, RS-232 navigation data input, roll synchro input and interlock pins which announce instrument presense to the EIP. Several signals between the POS AV and data system use this cable, including high-speed serial navigation data, POS AV event marker for scan motor index and subsystem temperature monitor signals. Finally, there are provisions to control 3 external system blowers from 28V power relays inside the data system.

3. GPS antenna cable

    At the POS AV enclosure, this cable terminates in a TNC connector. Aircraft-end termination depends on the provided antenna.

4. POS AV power cable

    A short cable bringing in 28VDC power for the POS AV and independent power for strip heaters in the POS AV enclosure.

5. Power distributor utility cable

    Carries communications between the power distributor and the data system, including RS-232 links to the motor and blackbody controllers, subsystem temperature monitor serial data and scan motor encoder signals.

6. POS AV IMU cable

    Used for serial RS-422 communication between the POS AV and the IMU and for IMU power.

7. Disk enclosure USB cable

    This cable is permanently attached to the external disk enclosure. It is a standard USB cable carrying image data to the solid-state disks.

8. Data system power cable

    28VDC power cable from the power distributor to the data system. There are two circuits, one for computer power, the other for heaters in the data system enclosure.

9. Telemetry interface cable

    An optional cable, used only when high-speed telemetry is available. Currently the telemetry interface uses RS-422 signalling and HDLC protocol as configured for operations on the NASA Ikhana or General Atomics Altair UAVs.

10. Console cable

    Most signals on this cable are used only during ground operations or in installations in which an operator is present. Connections are available for USB mouse and keyboard and for SVGA analog video. A 10BaseT ethernet connection is also present which is used in flight for ethernet interface to the POS AV. It can be used to download POS AV data via FTP.

11. Scan head video cable

    Analog video signals pass from the scan to the data system on this cable.

12. Scan head utility cable

    All signals from the power distributor and data system to the scan head follow this cable. These include scan motor power, heater power, spectrometer assembly power, encoder signals, blackbody signals and subsystem temperature monitoring sgnals. At the scan head end, the cable splits into three sections, two of which are dedicated to the two blackbody references.

9 Pressurization

Data system and power distributor electronics require pressurization to ensure sufficient cooling. As yet, neither pressure vessel has been leak tested. If the pressure vessels are tight, no other measures need be taken. If there are significant leaks, a compressed air source may be required. Both pressure vessels have 1/8-27 NPT threaded holes to accommodate connections to a compressed air source and relief valve. The data system pressure vessel is designed to withstand 1 atmosphere total internal pressure.

Laboratory testing of the data system pressure vessel suggests that leak rates at 1 atmosphere overpressure are acceptable for missions up to at least three days duration without an external source of pressurized air.

10 Command, Control and Status Data Interface

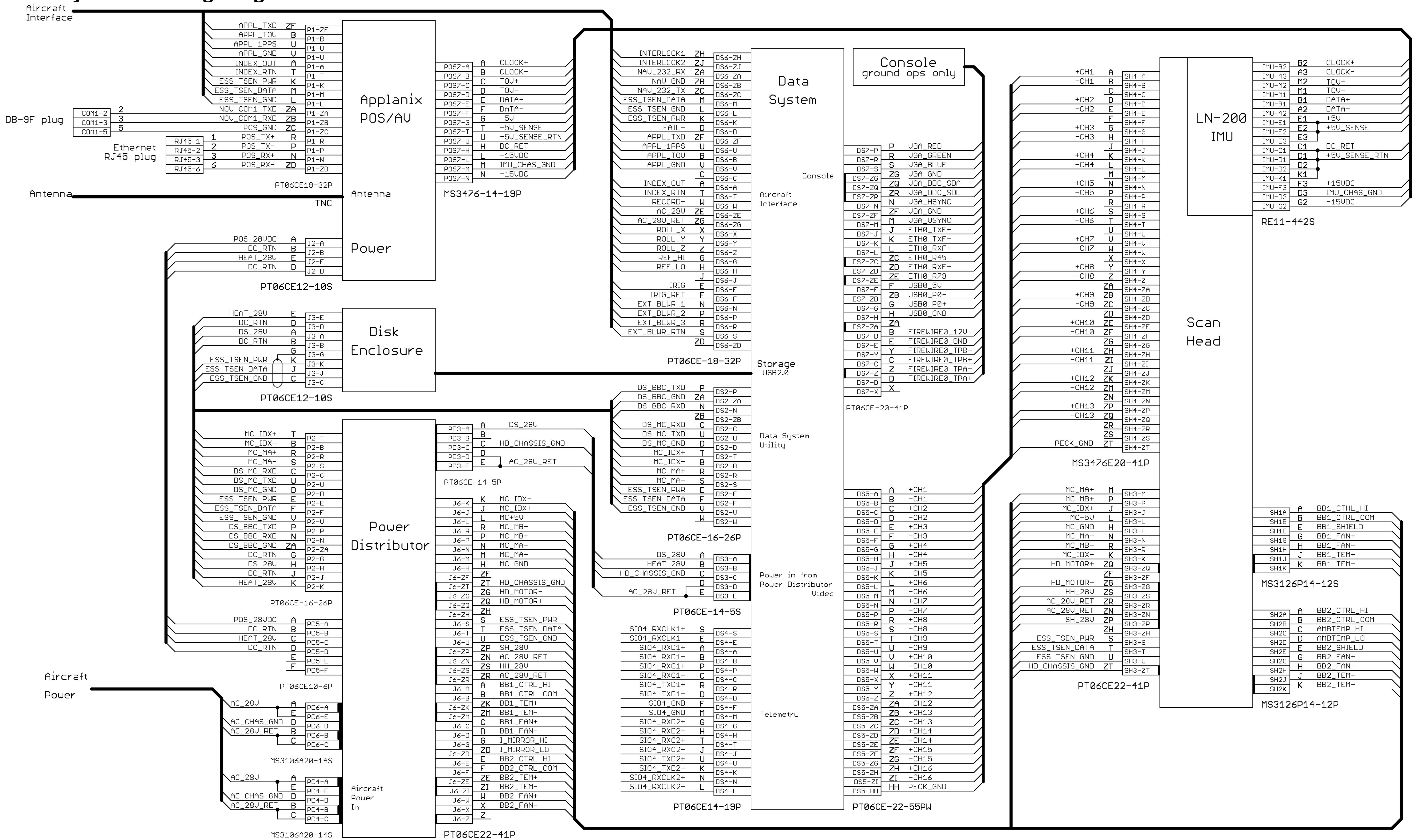
Several methods of operating the AMS are available from different system interfaces. The simplest is used for unattended operation, as on the NASA ER-2. In this mode, the system initializes when it is powered and records data when a switch is closed. Major system failures are indicated by a FAIL indicator signal. A record of events is available post-flight by reading the error log file from the system computer. When operating in this mode, some critical parameters (scan rate, BB temperature setpoints, BB turn-on delay, etc) are specified in a control data file on the system computer.

If an operator is present, there are several options. An operator console (video display, keyboard and mouse) can be directly connected to the data system. There is a graphical user interface (GUI) that allows the operator to directly command and monitor all aspects of the system operation. Alternatively, an ethernet connection to the system from a stand-alone (linux) computer allows an operator to connect to the data system using SSH protocol and run the operator console remotely.

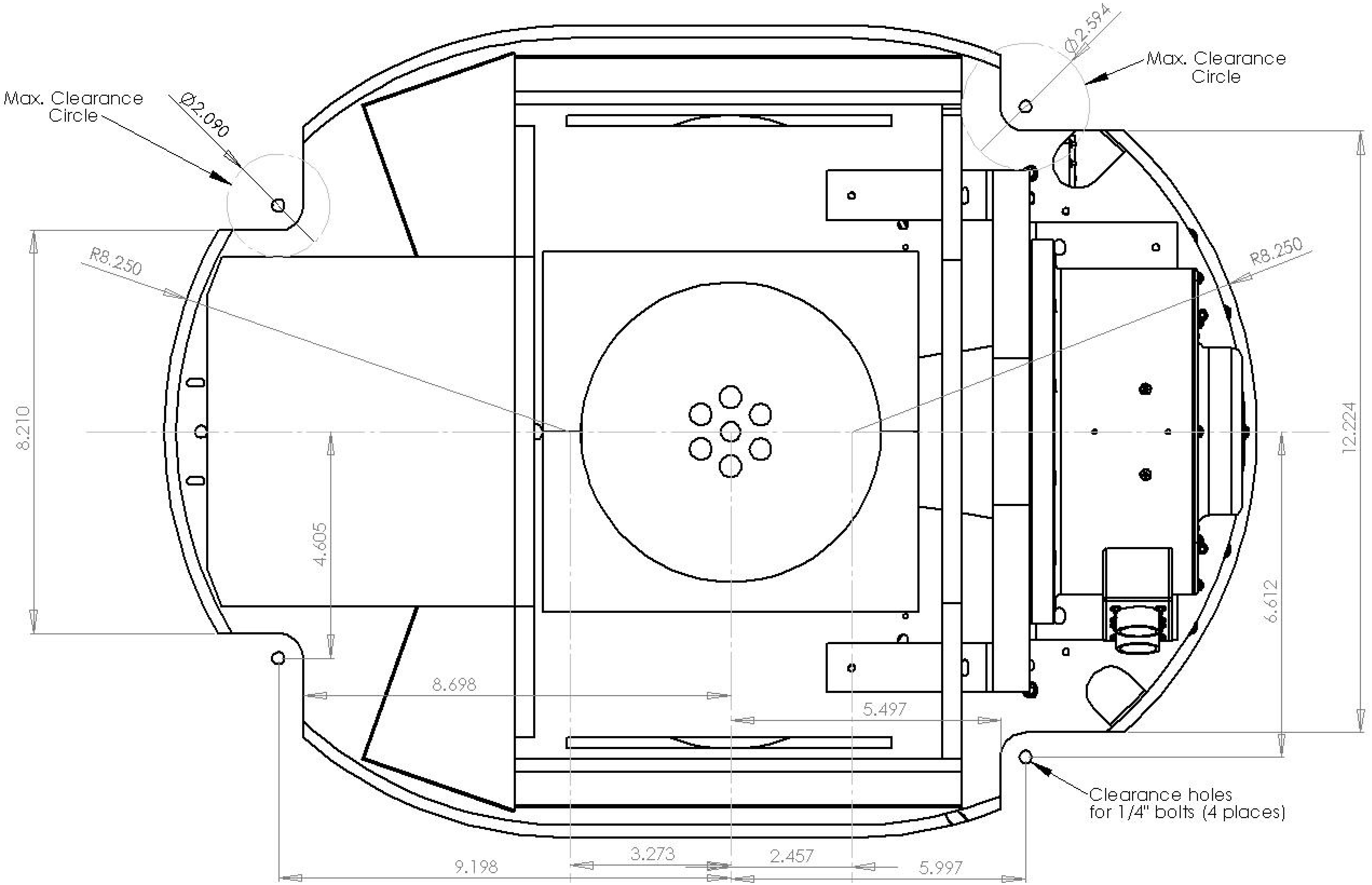
For unattended operations through a telemetry link, there is a remote operator console program that can control the system and monitor status through a TCP/IP connection. This mode requires very little telemetry bandwidth (it has been used over a 9600 baud link shared with another user). At present, the remote operator program requires linux, but there is some prospect of porting the application to MS Windows also.

The link module portion of the data system includes a high-speed serial communication adapter which handles HDLC protocol. It is currently programmed for the Ku band satellite telemetry system on the NASA Ikhana and General Atomics Altair. With some engineering effort, it could be used for several different synchronous or asynchronous serial data protocols operating at up to 10Mb/s data rates.

A. System Cabling Diagram



B. Scanhead mounting details



C. Rectangular pressure vessel mounting detail

Below is a bottom-side view of the mounting trayfor the rectangular pressure boxes. The shock mounts are Barry Controls model T44-AB-10. Mounting holes are clearance holes for #10 machine screws.