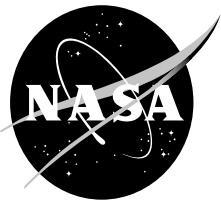
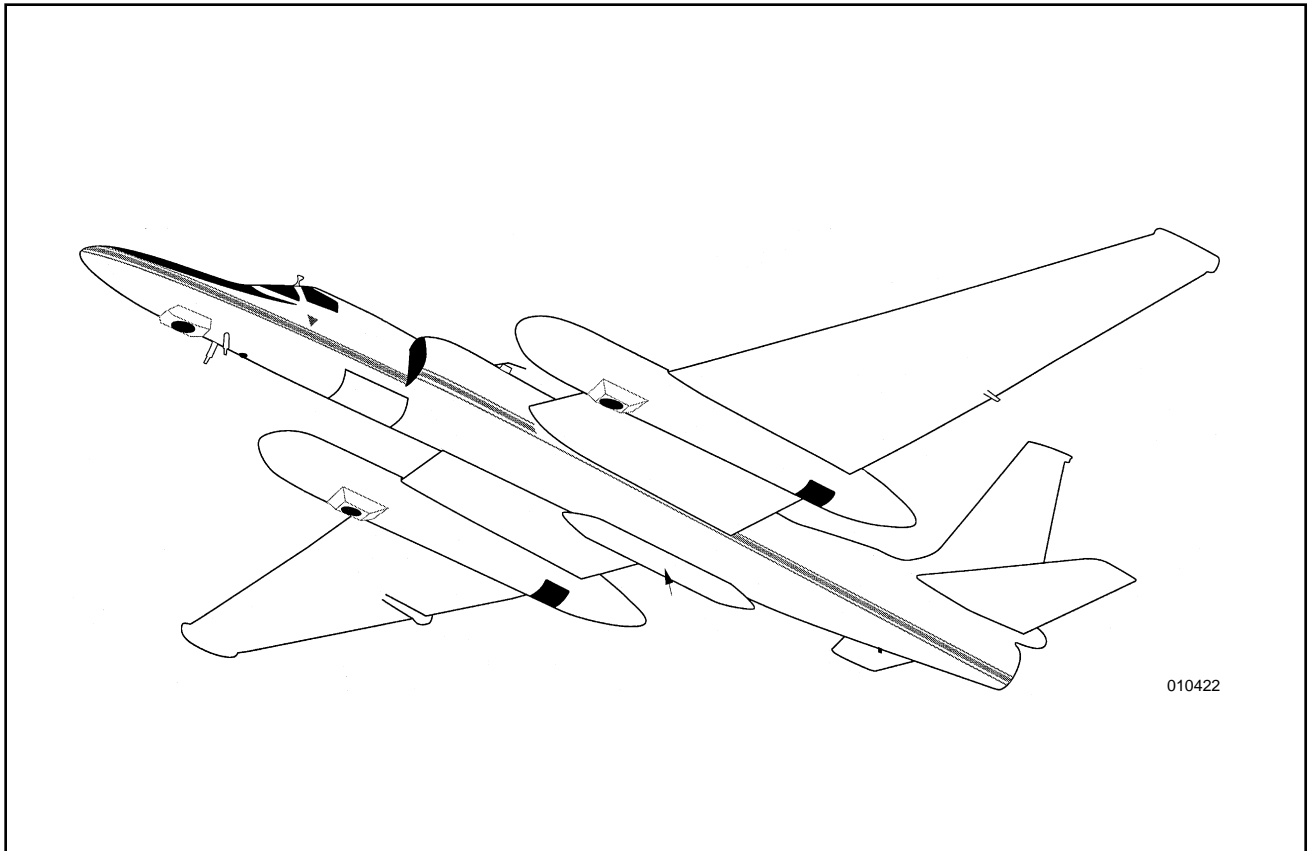


# ER-2 AIRBORNE LABORATORY EXPERIMENTER HANDBOOK



National Aeronautics and Space Administration  
Dryden Flight Research Center  
Edwards, CA 93523-0273

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**INTRODUCTION**

The Lockheed ER-2 was developed for the National Aeronautics and Space Administration (NASA), to serve as a high altitude scientific research aircraft. The ER-2 has been utilized to conduct scientific studies of stratospheric and tropospheric chemistry, land-use mapping, disaster assessment, and preliminary testing of satellite sensors. These two aircraft, outfitted as flying laboratories, are based at Dryden Flight Research Center (DFRC); Edwards, California. Missions may be flown out of DFRC or from remote bases worldwide, according to the research requirements.

Powered by a single jet engine, the ER-2 carries a single pilot and up to 2,550 lb (1,156 kg) of payload to altitudes approaching 70,000 ft (21 km). Typical ER-2 missions last 6.5 hours and cover a range of 2,200 nm (4,000 km). It is possible to accomplish missions of up to 8 hr duration ranging to 3,000 nm (5,400 km). Ferry flights to and from deployed locations can be planned for longer than 8 hr.

Airborne research missions for the ER-2 are planned, implemented, and managed by the DFRC Airborne Science Directorate. A designated mission manager is responsible for all phases of the assigned mission and is the official point of contact for experimenters as well as for ground support and flight operations groups. The engineers of Lockheed Martin Logistics Management, with oversight by NASA, perform integration of any instrument payload at DFRC.

The purpose of this handbook is to acquaint prospective ER-2 researchers with the aircraft and its capabilities. The contents of this book should be considered guidelines, and Lockheed or NASA can provide additional detail or clarification on any area. The handbook also contains procedures for obtaining approval to fly experiments, outlines requirements for equipment design and installation, and identifies the personnel and facilities that are available at DFRC for supporting research activities. This handbook is revised from time to time. Therefore, before arranging for experiments it is advisable to contact the Dryden Airborne Science Directorate for a current issue.

For information about the overall Dryden Airborne Science Program, including aircraft schedules and Airborne Science Flight Request procedures, and for an electronic version of this and other experimenter handbooks, look on the World Wide Web at:

<http://www.dfrc.nasa.gov/airsci/>.

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**NOMENCLATURE**

<b>AC</b>	<b>alternating current</b>
<b>ADF</b>	<b>automatic direction finding</b>
<b>ATC</b>	<b>Air Traffic Control</b>
<b>BCD</b>	<b>binary coded decimal</b>
<b>CCB</b>	<b>Configuration Control Board</b>
<b>CDR</b>	<b>critical design review</b>
<b>DC</b>	<b>direct current</b>
<b>DCP</b>	<b>Dryden Centerwide Procedures</b>
<b>DFRC</b>	<b>Dryden Flight Research Center</b>
<b>ECP</b>	<b>experiment control panel</b>
<b>ECS</b>	<b>environmental control system</b>
<b>EIF</b>	<b>Experiment Integration Facility</b>
<b>EIP</b>	<b>electrical interface panel</b>
<b>EMI</b>	<b>electromagnetic interference</b>
<b>EVE</b>	<b>estimated vertical error</b>
<b>FAA</b>	<b>Federal Aviation Administration</b>
<b>FOM</b>	<b>figure of merit</b>
<b>GPS</b>	<b>Global Positioning System</b>
<b>HDOP</b>	<b>horizontal dilution of precision</b>
<b>HF</b>	<b>high frequency</b>
<b>IDLH</b>	<b>immediately dangerous to life and health</b>
<b>ILS</b>	<b>instrument landing system</b>
<b>INS</b>	<b>Inertial Navigation System</b>
<b>Mil-spec</b>	<b>military specifications</b>
<b>MIL-STD</b>	<b>military standard</b>
<b>MSDS</b>	<b>Material Safety Data Sheet</b>
<b>NAS</b>	<b>National Aerospace Standard</b>
<b>NASA</b>	<b>National Aeronautics and Space Administration</b>
<b>NAVREC</b>	<b>navigation recorder</b>
<b>NM</b>	<b>nautical mile</b>
<b>PDR</b>	<b>preliminary design review</b>
<b>PVC</b>	<b>polyvinyl chloride</b>
<b>RF</b>	<b>radio frequency</b>
<b>SPDT</b>	<b>single pole, double throw relay</b>
<b>TACAN</b>	<b>tactical air navigation</b>
<b>TLV</b>	<b>threshold limit value</b>
<b>UHF</b>	<b>ultra high frequency</b>
<b>UPD</b>	<b>up-date data</b>
<b>UTC</b>	<b>Coordinated Universal Time</b>
<b>VDOP</b>	<b>vertical dilution of precision</b>

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<b>VHF</b>	<b>very high frequency</b>
<b>VOR</b>	<b>VHF omni-directional range</b>
<b>WGS</b>	<b>World Geodetic System</b>
<b>TLV</b>	<b>threshold limit value</b>
<b>UHF</b>	<b>ultra high frequency</b>
<b>UPS</b>	<b>uninterruptible power systems</b>
<b>UTC</b>	<b>Coordinated Universal Time</b>
<b>VDC</b>	<b>volts of direct current</b>
<b>VHF</b>	<b>very high frequency</b>
<b>VOR</b>	<b>VHF omnidirectional ranger</b>
<b>W</b>	<b>watts</b>
<b>WGS</b>	<b>World Geodetic System</b>



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CHAPTER 1

AIRCRAFT PERFORMANCE

1. Basic Aircraft Performance

A normal mission profile begins with a short takeoff roll followed by a steep initial angle of climb and a high rate of climb. Depending upon launch weight, the aircraft will reach the intermediate cruise altitude of 60,000 ft (18 km) within 30 to 45 min of launch. At this time the cruise climb is initiated, and the autopilot is engaged to hold a constant Mach number. As fuel is burned off, the weight of the aircraft decreases and altitude increases. Depending on payload weight, the aircraft can climb as high as 70,000 ft (21 km). Local air conditions will have marked effect on the cruise climb performance of the aircraft. Colder air will allow a more rapid climb, whereas warmer air will reduce climb performance. Approximately 30 min prior to landing, the descent from high altitude will be initiated. This results in a rate of descent of approximately 2,000 ft (610 m) /min. A mission profile for a typical 6.5 hr flight is presented in figure 1-1. The mission profile will vary with changes in takeoff weight, planned range, or planned endurance.

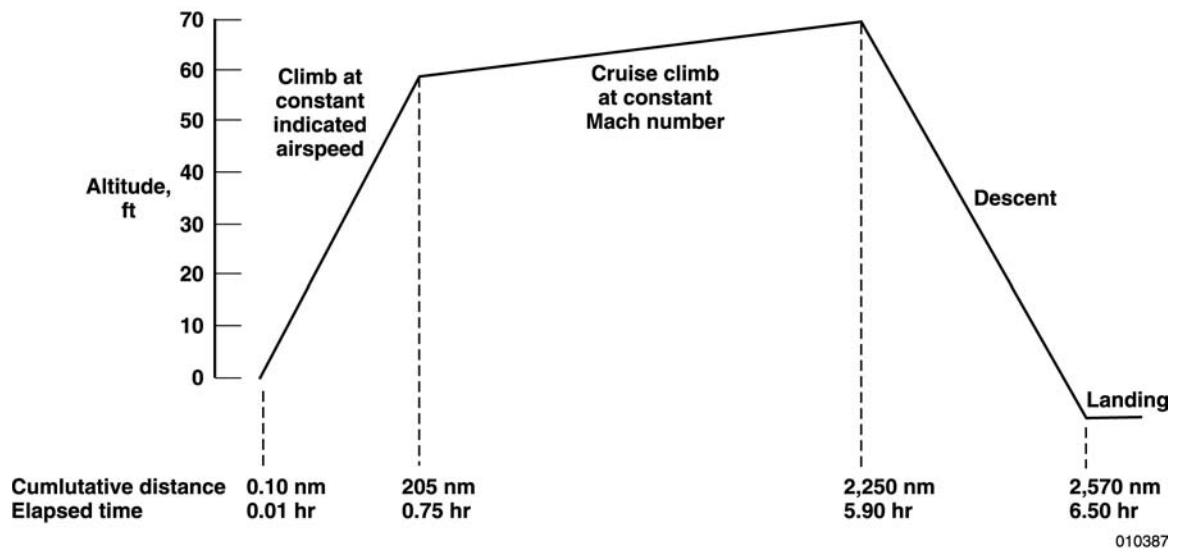


Figure 1-1. Typical 6.5 hr mission profile.

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Basic aircraft performance in standard atmospheric conditions is summarized in the following subsections. Adding external instrument pods or pylons that increase drag will reduce performance parameters correspondingly.

**A. Operating Altitude**

The cruise climb segment of a typical mission will begin no lower than 60,000 ft (18 km), and will terminate no higher than 70,000 ft (21 km). It is possible to operate the aircraft at lower altitudes with the concurrence of the operations staff. The operating range of the aircraft is reduced by sustained flight at altitudes below 52,000 ft (16 km), due to a slower true airspeed. The scientific justification for such missions will be weighed against the risk levels to the pilot and the aircraft.

**B. Speed**

At cruise altitude the Mach number is held constant at  $M = 0.715$ . This is equivalent to a TAS (true airspeed) of approximately 410 kn (210 m/sec). At normal ER-2 operating altitudes, the airspeed cannot be adjusted from this design point. At lower altitudes, below 52,000 ft (16 km), the pilot has some additional flexibility in airspeed.

**C. Range and Endurance**

A normal 6.5 hr mission will cover a range of 2,400 nm (4,430 km). This will provide for approximately 5.5 hr of data collection at altitudes above 60,000 ft (18 km). An 8 hr mission will cover a distance of 3,000 nm (5,530 km) and produce 7 hr of collection time at altitude.

**D. Payload**

A maximum of 2,550 lb (1,156 kg) can be distributed between the Q-bay, the nose area, and the wing-pods. Installation weight and sizing limitations for these areas are specified in chapter 5. The distribution of weight between payload areas may adversely affect the center of gravity of the aircraft, resulting in reduced allowable payload in some areas.

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**E. Turn Radius**

**Table 1-1. Turning capability at altitude, 410 kn (210m/sec) TAS.**

Bank Angle, (deg)	Turn Diameter (nm)	
	nm	km
5	56.2	104
10	27.9	52
15	18.3	34
20	13.5	25
22 (standard)	12.2	22.6

**2. Frequency and Duration of Flights**

The guidelines for ER-2 operations are based upon more than 40 years of Air Force and NASA experience in this type aircraft, current FAA rules and regulations, medical opinions and directives, real time safety assessments, common sense and fiscal realities. By design there are three firm rules:

**A. Flight Duration**

Routine flight duration for the ER-2 is 6.5 hours. Flights longer than 6.5 hr require written justification and approval from DFRC flight operations.

**B. Duty Day**

The crew duty day for an ER-2 pilot is limited to 12 hr. The 12 hr limit can be waived to a maximum of 14 hr for ferry flights to and from deployment locations. The duty time begins at pre-mission report time and ends with engine shutdown after the mission.

**C. Off-Duty Time**

ER-2 pilots and maintenance crews must have at least 12 hr of off-duty time between leaving the flight line after one flight and reporting back for the next flight. Pilots flying ER-2 missions of more than 8 hr will be given the following physiology recovery time: (a) first day after flight—no duties (including mobile duties), (b) second day after flight—mobile duties only.

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The maintenance crews should have at least 12 hr of off-duty time between leaving the flight line after one flight and reporting back for the next flight. Under certain restricted conditions this may be shortened to 10 hr off-duty time.

Additional guidelines for operational scheduling are given in chapter 8, Flight Operations.

### **3. Payload Area Environment**

Pressurized and environmentally controlled air is supplied to the cockpit, the nose, the Q-bay, and the forward two-thirds of the wing-pods. This air is bled from the engine compressor stages, and cooled by a heat exchanger to a nominal temperature of 60 °F (16 °C). The actual temperature in the cockpit is selected by the pilot and depends on his desired comfort level. This pressurization system is used primarily to pressurize the equipment areas. Heating in the equipment areas is controlled by additional heaters placed in each area.

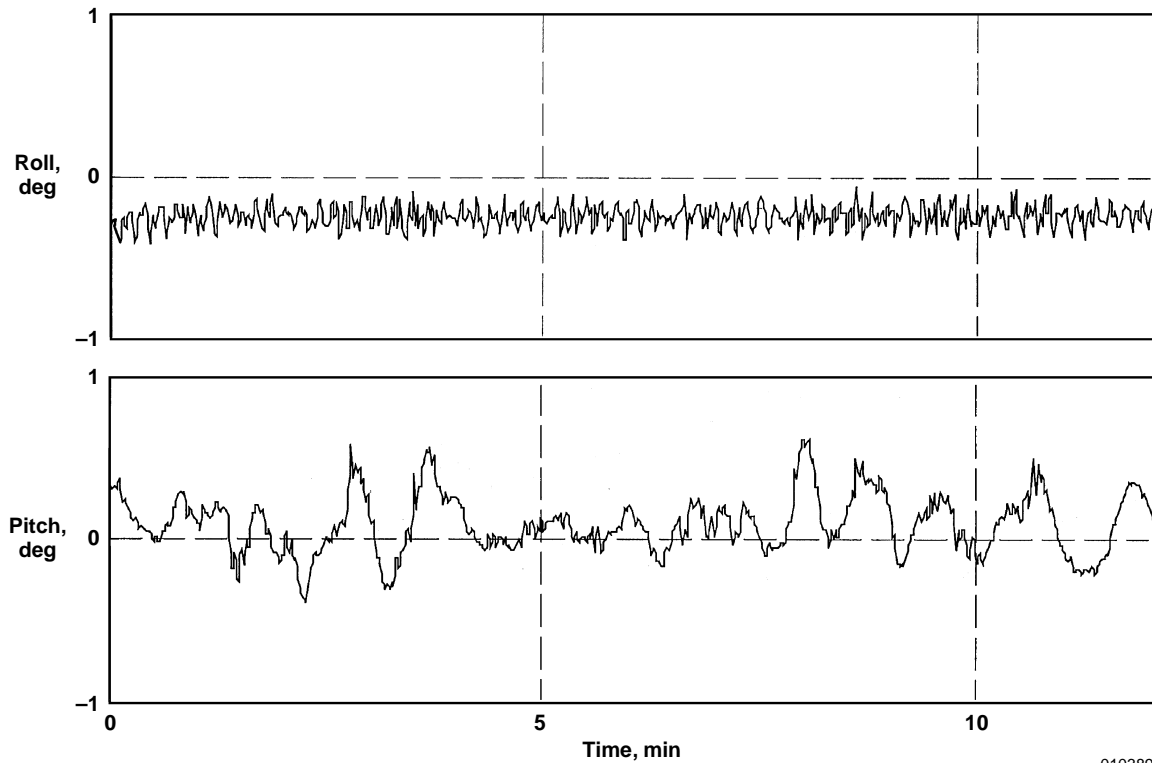
The environmental control system (ECS) automatically regulates pressurization levels. The payload areas and cockpit remain unprocessed below 7,900 ft (2.4 km) pressure altitude. As the aircraft climbs through 7,900 ft altitude, the ECS switches to an isobaric control mode. In this mode, a pressure altitude of 7,500 ft (2.3 km) is maintained below an aircraft altitude of 18,300 ft (5.6 km). Above the 18,300 ft level, a pressure differential of 3.88 psi between the ambient and cockpit/payload areas is established. In the areas receiving pressurized air, this pressure differential produces a pressure altitude of approximately 30,000 ft (9.1 km/4.5 psia) at an aircraft altitude of 70,000 ft (21.3 km). The amount of airflow through the payload areas is low, typically 0.5 to 3 lb/min, at cruise power setting. Fans with or without additional heat can be used to circulate air within the payload areas, either to reduce condensation from windows or optics, or to distribute heat.

At cruise altitudes in the stratosphere, relative humidity is low. However, during descent and landing, relative humidity can reach 100 percent, and condensation can form on all surfaces, especially those that have been cold-soaked at altitude.

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**4. Aircraft Stability**

The automatic flight control system on the ER-2 provides stability augmentation in the yaw, pitch and roll axes. Plots of the pitch-to-time response, as well as the roll time response, are shown in figure 1-3. The automatic flight control system also incorporates autopilot functions that include Mach hold and automatic navigation via the inertial navigation system (INS).



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**Figure 1-3. Pitch response and roll response.**

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**5. Aircraft Attitude**

In standard cruise climb, the ER-2 pitch angle is normally level (zero), and varies approximately  $\pm 1$  deg as the autopilot seeks a constant Mach number. During takeoff and climb out, pitch attitudes can reach 20 deg nose-up; and 10 deg nose-down during descent. Bank angles are a function of desired turn radius, but are normally held to less than 30 deg.

When parked or taxiing, the aircraft is at approximately a 4 deg nose-high attitude. Installing the tow-bar on the aircraft, which is normally how the aircraft is hangared, reduces this angle slightly.

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**CHAPTER 2**

**COMMUNICATION AND NAVIGATION**

**1. Basic Equipment and Operation**

The ER-2 is equipped with UHF (ultra high frequency), VHF (very high frequency) and HF (high frequency) radio systems for two-way voice communication. A transponder with mode C altitude reporting enables Air Traffic Control (ATC) surveillance radar to identify the aircraft via coded transmissions.

**2. Inertial Navigation Systems (INS)**

The inertial navigation system (INS) on the ER-2 operates by sensing accelerations from a gyro-stabilized, all-attitude platform. This information is integrated by a digital computer to provide an indication of present position (latitude and longitude), attitude data (pitch and roll), and course line computation referenced to great circle routes. A control display unit in the cockpit allows the pilot to store navigation waypoints and to change the flight track enroute. A self-contained system, the INS offers worldwide navigation capability.

An update function allows for global position system (GPS) updating of the INS to provide navigation independent of the drift errors. GPS accuracy is typically better than  $\pm 20$  m.

A backup or secondary navigation system allows the aircraft to safely return to base or to an alternate landing site should the primary INS fail. It is not readily programmed for science missions.

**3. Optical View Sight**

The optical view sight offers the pilot visual coverage of the terrain underneath the aircraft for navigation purposes. The pilot may select a viewing angle of up to  $70^\circ$  with respect to nadir in any direction. Extra elevation is available for horizon viewing in the extreme forward and aft scanning positions. A field of view of  $15^\circ$  or  $37^\circ$  is available in the 1X and 0.4X magnification settings. The view sight is commonly used to check the extent of the cloud cover or other scene conditions at the time of data collection.



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**4. Radio Navigation Systems**

The ER-2 is equipped with several systems which enable navigation with respect to ground based radio beacons as selected by the pilot. Included in these are low-frequency automatic direction finding (ADF), tactical air navigation (TACAN) for bearing and range information, and a VHF omni-directional range/instrument landing system (VOR/ILS).

**A. Frequencies and Interference**

The frequency ranges of the navigation and communication equipment are listed below. Experimenters are cautioned to engineer their equipment to prevent spurious response at these frequencies.

**Table 2-1. Frequencies and interference.**

Equipment	Frequency (MHz)	Receive	Transmit
VHF Radio	108 to 151.975	●	●
UHF Radio	225 to 400	●	●
HF Radio	2.0 to 30.0	●	●
Low frequency (ADF)	190 to 1750	●	
Localizer receiver (LOC)	108 to 112	●	
Glidescope receiver (GS)	329.3 to 335.0	●	
VHF omni-range (VORP)	108 to 118	●	
DME and tactical air nav (TACAN)	962 to 1213	●	
ATC transponder	Receive 1030	●	
	Transmit 1090		●
Global Positioning System (GPS)	1575.42 (±2.0)	●	

**B. Radio System Specifications**

Detailed specifications for the aircraft radio equipment are listed in the table below.

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**Table 2-2. Radio system specifications.**

<b>System</b>	<b>Power Output</b>	<b>Type of Emission</b>	<b>Type of Antenna</b>	<b>Operating Range</b>
UHF	AM: 10 W carrier	Amplitude modulated; double sideband, full carrier	Vertically polarized, 1/2 wave monopole	Line-of-sight
VHF	10 W carrier			
HF	AM: 125 W carrier SSB: 400 W peak emitted power	Amplitude modulated; upper sideband, lower sideband	Slot in vertical fin	5,000 nm*, depending on ionosphere condi- tions
ATC Transponder	500 W transmitter	Coded rf pulse pairs	Vertically polarized, l-band omn-directional radiation pattern	Line-of-sight
TACAN				
ADF				
VOR/ILS			Slot-type (ILS)	Localizer: 45 nm* Glide scope: 25 nm*
GPS			Receiving only	Worldwide

\* nm = nautical mile (1,852 m)

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**CHAPTER 3**

**INTERIOR DIMENSIONS AND SUPPORT FACILITIES**

**1. General Information**

The ER-2 aircraft can provide experimenters with a wide array of payload accommodation areas. These include the Q-bay, the nose, the wing-pods, and the fuselage centerline tank. Additionally, a fuselage centerline tank can be mounted on either wing at the wing-pod mounting locations. Figure 3-1 shows the ER-2 configuration for these payload areas. Aside from these primary areas, several smaller areas exist where instruments can be accommodated. These are the System 20 pod, the fuselage aft cavity, the tail cone, and the wingtips and left/right cheek area.

The instrument integration process will include an evaluation of all payloads for both weight and balance concerns, for aerodynamic effects that may alter the stability characteristics of the aircraft, and for total electrical power consumption. The overall mission configuration must remain within weight and center of gravity limits for safe flight.

**2. Payload Areas**

**A. Q-bay**

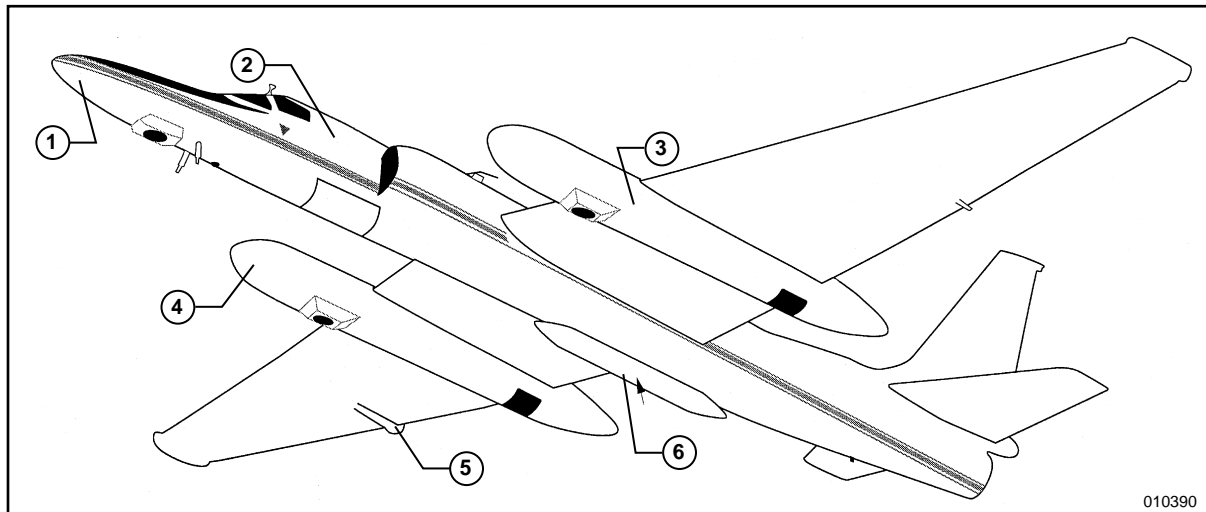
The primary payload compartment on the ER-2 is the Q-bay, sometimes referred to as the equipment bay. This fuselage compartment behind the cockpit provides 64.6 ft<sup>3</sup> (1.83 m<sup>3</sup>) of volume and features removable upper and lower hatches. There are a variety of upper and lower Q-bay hatches that can be configured to accommodate a wide variety of specialized sensors.

The payloads are installed on rack assemblies that are hoisted into the Q-bay through the lower hatch opening and attached at structural mounting points. The combined weight carried in the forward fuselage area (Q-bay and nose area) will normally be limited to 1,300 lb (579 kg). This includes the payload mounting racks, electrical interface panels, and the payload itself. In some cases this weight may be exceeded but only with the specific approval of Lockheed Engineering.

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**Table 3-1. Payload Configuration**

Area	ft <sup>3</sup>	m <sup>3</sup>	lb	kg	Electrical Company	
					VAC (3 $\phi$ )	VDC
1. Nose	47.8	1.35	605	294	50A at 115/208	2kW at 28
2. Equipment Bay (Q-Bay)	64.6	1.83	1,300	590	100A at 115/208	4kW at 28
3. Left wing pod	86.0	2.43	650	294	50A at 115/208	2.2kW at 28
4. Right wing pod	86.0	2.43	650	294	50A at 115/208	2.2kW at 28
5. System 20 pod	.74	.02	45	20.4	30A at 115/208	840W at 28
6. Centerline pod	14.0	.40	350	159	30A at 115/208	840W at 28

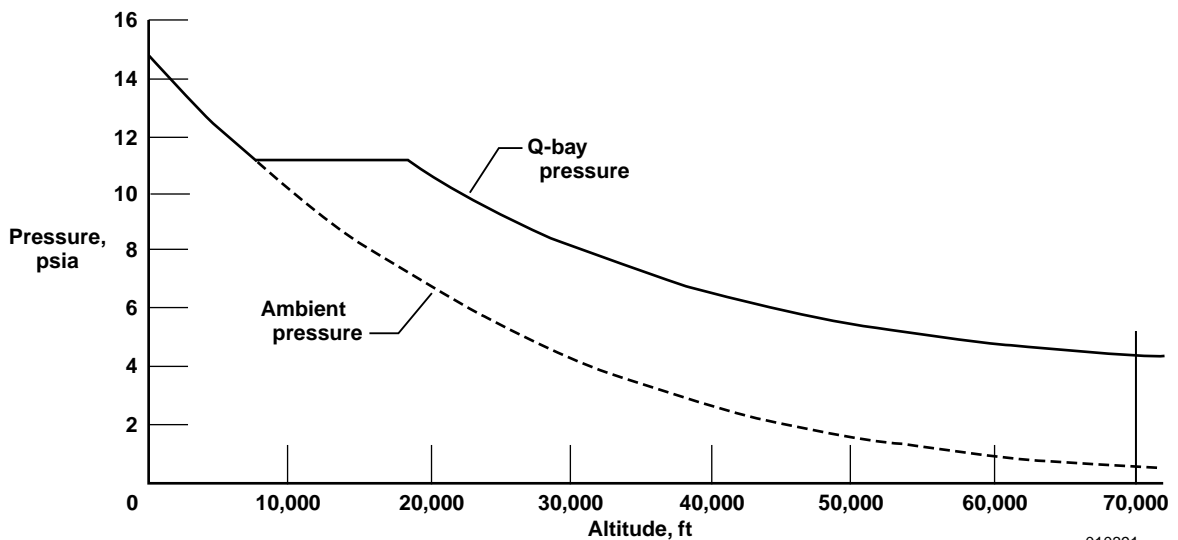


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**Figure 3-1. Payload configuration.**

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There are two regulating valves through which pressurized air enters the Q-bay. The valves are located at the bottom of the cockpit aft pressure bulkhead. The amount of bleed air leaving the engine will determine the level of airflow available to the Q-bay. Typically, the amount of bleed air available varies from 0.5 lb/min at idle to 3 lb/min at cruise power setting. While a 30,000 ft pressure altitude (9.1 km/ 4.5 psia) is normally maintained, safety considerations require that payloads be able to withstand pressure altitudes of up to 70,000 ft (21.3 km). The variation of Q-bay pressure with altitude is shown in figure 3-2.

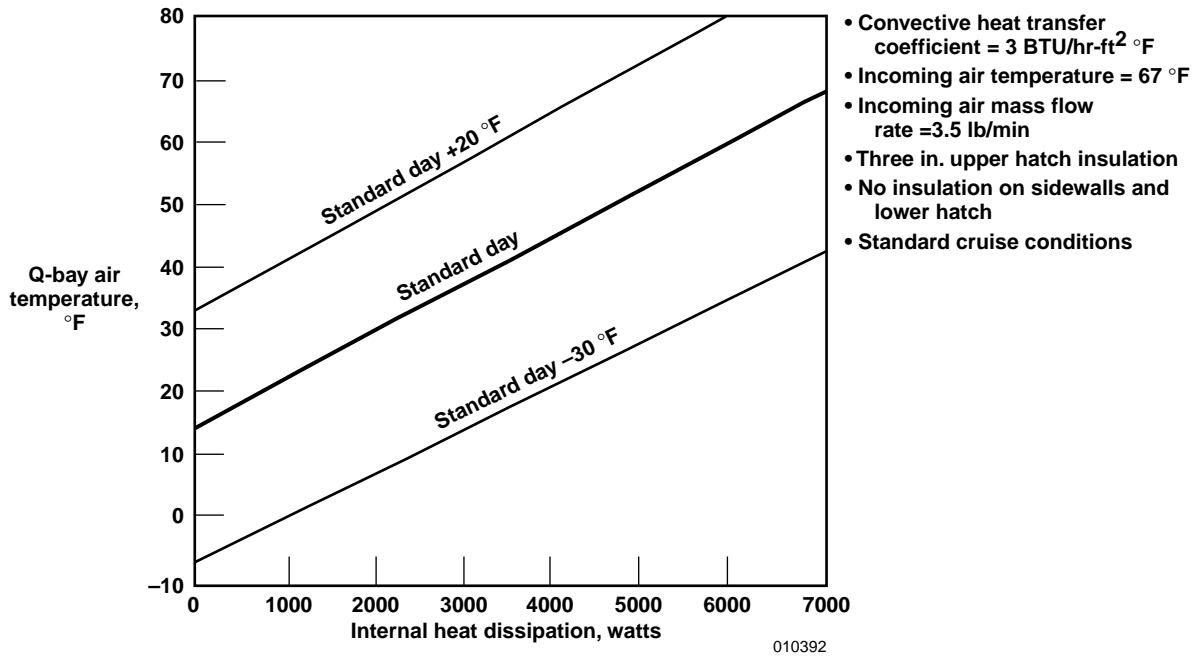


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**Figure 3-2. Q-bay pressure variation.**

While at cruise altitude, the air temperature inside the Q-bay can vary from 10 to 50 °F (-12 to +10 °C). Actual temperatures within the Q-bay depend upon the incoming air temperature, the ambient temperature, the amount of insulation used, the amount of air circulation inside the Q-bay, and the heat output of the instrument. Figure 3-3 represents the approximate Q-bay air temperature to be expected with respect to the amount of heat rejected by an instrument. During summer months the temperature inside the compartment can reach above 120 °F (49 °C) prior to launch. The size and shape of the instrument will affect the air circulation inside the Q-bay.

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**Figure 3-3. Approximate Q-bay internal temperature.**

Figure 3-4 shows the typical profile of temperature and relative humidity in the Q-bay. At altitude, the relative humidity is low. However, under certain conditions, the relative humidity could be as high as 100 percent, such as during descent from altitude.

**B. Nose**

Attached to the ER-2 fuselage via four quick release latches, the nose area provides a payload volume of 47.8 ft<sup>3</sup> (1.35 m<sup>3</sup>). The 101-in. (2.6 m) long nose compartment accepts payloads of up to 600 lb (272 kg) on custom-built racks.

At cruise operating altitude, the nose area environment is maintained at 27,000 to 30,000 ft (8.2 to 9.1 km) pressure altitude. A pilot-operated valve controls the pressurized air in the nose. The rate of air exchange is controlled by the leakage rate of the nose structure, as there are no overboard “dump” valves. The nose temperature varies in flight between +68 and -40 °F (+20 and -40 °C). Installing controlled heaters or blowers can create a limited amount of temperature control. Figure 3-5 is a representation of expected temperatures in the nose compartment for various amounts of heat generation.

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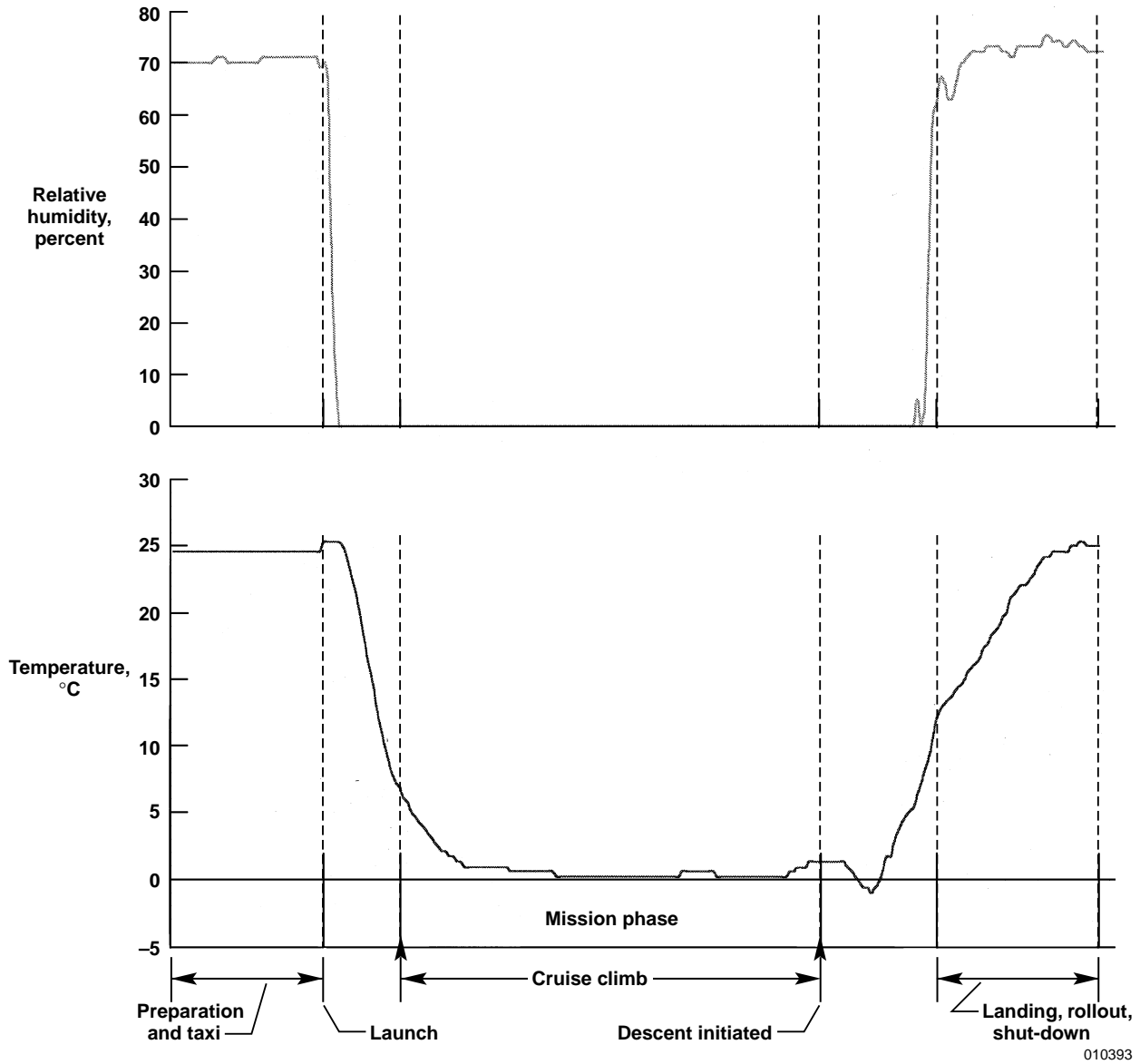
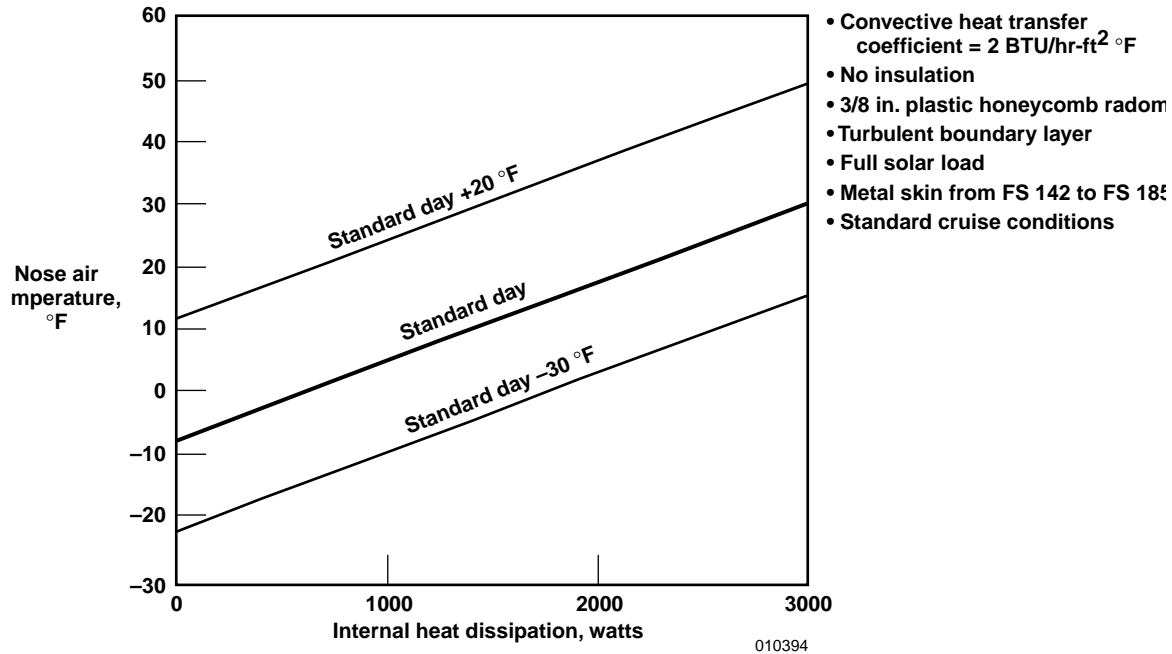


Figure 3-4. Q-bay relative humidity and temperature.



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**Figure 3-5. Approximate nose internal temperature.**

**C. Wing-pods**

The wing-pods provide approximately 86 ft<sup>3</sup> (24 m<sup>3</sup>) of payload capacity. Each pod may accommodate payloads up to a maximum weight of 600 lb (272 kg). The wing-pods consist of five individual segments: nose cone, forward pod, mid body, aft pod, and tail cone. Normal separation points via latches are at the forward and aft-ends of the pod mid body.

The forward two-thirds of the pod, including the nose, forward pod, and mid body, are pressurized. As in the aircraft nose area, there are no overboard dump valves in the pods. For this reason, the rate of air exchange is a function of the leak rate of the structure. The cruise temperature of the empty wing-pods varies from -40 to 20 °F (-40 to -6.7 °C). Internal heat sources, including heater/blowers that are normally installed in the wing-pods, will produce warmer local temperatures.

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Aero elastic effects will cause the wings to deflect upwards during flight. The measured deflection of the pods in flight is +0.86 deg from horizontal. The deflection will vary slightly with altitude, payload weight, fuel load, and atmospheric conditions. Experimenters may wish to account for this deflection in developing pointing instruments.

**D. Fuselage Centerline Tank / Wing Pylon-Mounted Tanks**

These tanks offer a payload volume of 14 ft<sup>3</sup> (0.4 m<sup>3</sup>) and 350 lb (159 kg) each. These tanks are unpressurized and lack temperature control. The most common installation is one tank attached to the underside of the fuselage aft of the main landing gear. This payload area offers an unobstructed nadir view, and a relatively easy installation. Besides the constrained volume, instruments using this area should be designed for a higher vibration environment and extreme temperatures. View ports should be designed with covers, air fences, or other protection from debris, water or ice thrown up by the main landing gear. These tanks may also be attached to the wing pylons, in symmetric pairs. This installation is not susceptible to debris from the landing gear.

**E. Miscellaneous Payload Accommodation Areas**

While normally used to house ballast to trim the center of gravity location of the aircraft, the fuselage aft cavity and the tail cone are capable of housing small instrument packages. The System 20 pod on the right wing and the left wing tip can house specialized instruments. Any instrument installed in these locations will be carefully evaluated for its effect on the trim condition of the aircraft.

For unique applications, specialized wing-pods have been designed and constructed. Examples of this include the collection of cosmic dust and other particles found in the stratosphere. Due to aerodynamic considerations, both wings must be configured with identical pods on a given mission.

**3. Payload Area Access**

The nose, wing-pod fore-bodies, and wing-pod aft bodies (tail cones) are all attached to the aircraft by latches. These can be quickly mated and demated, once the weight of the assembly has been secured on a mobile cart. Instruments should be designed to place frequently serviced items (switches, connectors, consumable replenishment valves) on the face exposed, when the nose, fore- or aft-body is removed.

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Hatches on the lower Q-bay and on the wing-pod mid bodies are also secured by quick release latches. This provides some access to the lower section of the instrument. Q-bay instruments are normally removed by using an overhead hoist to lower them onto ground handling fixtures.

Before each flight, experimenters normally are scheduled 1 hr to prepare their instrument for flight. More time can be arranged, if necessary. At the end of this "hands-on" period, all payload areas are sealed and the aircraft is towed from the hangar for fueling and the remaining pre-flight preparation. The "hands-off" period is normally 2 hr prior to scheduled takeoff. After each flight, there is a delay of approximately 20 to 30 min while the aircraft is safed and brought into the hangar. On days that the liquid oxygen dewars require servicing, an additional 30 to 45 min without instrument access will be required, either before launch or after landing.

Instruments requiring pre-flight access after the 2 hr prior "hands-off" or immediately after landing should identify this requirement early in the design stage, to allow access provisions and operational procedures to be developed.

#### **4. Support Facilities**

Facilities lending support to the experimenter's operations are listed briefly below.

##### **A. Cockpit Experiment Control Panel (ECP)**

The pilot controls all instruments by one or more switches on the ECP. This switch is simply an On/Off switch. Once power is provided to the instrument, switching, start-up, calibration, and normal operation should be handled internally.

Each cockpit control switch contains a "power on" light, and a "fail light". In general, most instruments are designed to extinguish the fail light under the following conditions:

There is power beyond the power conditioners. The data stream is operating correctly for the mode that the instrument is in.

The purpose of the fail light is generally to inform the pilot that a particular experiment is not operating, or has malfunctioned. Experimenters may design into their hardware or software specific conditions under which the fail light will illuminate. It is acceptable for the fail light to be illuminated initially while the system checks itself at

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power up. A continuous flashing fail light will not be an indicator of any normal operating condition and will not be permitted. When the pilot observes a fail lamp at any time other than normally expected, the pilot will refer to his checklist instructions for how to proceed. Normally, corrective action involves re-setting the instrument by cycling power, with some timing constraints. If the instrument failure continues, a decision will be made as to whether the mission should continue. More information about the operation light and the fail light illumination circuit is provided in the electrical interface section of this handbook.

**B. Intercom System**

Before launch, the crew chief communicates with the suited pilot by the intercom system. While it can be used for last minute instructions to the pilot or to report problems with an instrument, it is not intended for experimenters' use.

**C. Cryogen Storage**

Instruments may use cryogenics to cool detectors or electronics. Normally, liquid nitrogen or liquid helium is used for this purpose. Ideally, storage dewars should be sized to support an 8 hr ER-2 mission, with the normal 2 hr hands-off time prior to launch. Last minute access for "topping-off" cryogenics or other consumable is difficult, and must be planned for well in advance.

The system should be designed to avoid any accidental spillage of liquids during installation of the package. Liquids should be contained in such way that there is no spillage between 45 deg nose-up and 20 deg nose-down. Liquid nitrogen and liquid helium may not be discharged in any payload compartment under any circumstance.

**CAUTION: Personnel must wear personal protective gear while handling any cryogen.**

**D. Gas Supply**

Instruments may store and use consumable gases, provided the design of the storage tanks and the servicing procedures are approved by Lockheed Engineering and DFRC. Inert, non-toxic gases may be carried in high-pressure bottles up to 2000 psi. Oxygen or hydrogen is not permitted due to their extreme fire hazard potential.

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High-pressure bottles must comply with National Aerospace Standard (NAS) or Military Standards (MIL-STD). Pressure bottles should be designed to withstand twice the maximum rated pressure and tested to 1.5 times the operating pressure. Bottle size is limited only by the system weight and the available space within the payload compartment. The ultimate load factor for design of the mounting structure and hardware for high-pressure bottles is 9 g's. All pressurized bottles shall have a pressure regulator with a blowout disk or relief valve to prevent over-pressurization of lines and components downstream of the regulator. A deflector or overboard line may be required depending upon the location of the blowout device and the gases involved. Detailed drawings showing location of high pressure bottles, blow out disks, pressure regulators, relief valves, line sizes, line pressures, etc., must be submitted to Lockheed and DFRC prior to design approval. Pressure vessel certification must be performed every three years for filament-wound aluminum tanks or every five years for steel tanks.

Toxic or hazardous gases require additional safety reviews before being approved for use on the ER-2. These reviews typically address the in-flight use, how the gas is stored on the aircraft (quantity and pressure), ground handling procedures, and emergency response plans.

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**CHAPTER 4**

**VIEWPORTS AND WINDOWS**

**1. General Information**

The ER-2 has provisions for standard 16-in (41 cm) diameter viewports in the nose, Q-bay lower hatch, and wing-pod fore-bodies. These nadir-viewing ports are normally fitted with glass windows for camera or other sensor use. They are also usually equipped with heater/blower sets to minimize condensation. These glass windows may be replaced by other approved transparent materials. The ports will also accommodate aluminum plates that can be used to support smaller diameter windows, external gas sample probes, antennas, radiometers, and other lightweight units that must penetrate the exterior of the pressurized payload volume.

The aft wing-pod tail cones have open apertures to support sensors that require an unobstructed nadir view. This 8-in. (20.5cm) by 18-in. (46.2 cm) arc-length opening allows a wider field of view (up to 90 deg cross-track), and the aft pod rails can support heavier optical assemblies. Power and data can be transferred through the bulkhead feed-trough to the pressurized mid body. An air fence is routinely installed just upstream of the open aperture to reduce aero-acoustic vibration.

Other custom viewports and mounting provisions for probes have been designed for other instruments. These include zenith, forward, panoramic, and side-viewing ports.

**2. General Description**

The five locations for the standard 16-in. (41 cm) diameter window ports are the nose, the wing-pod fore-bodies, and the Q-bay (tandem). The Q-bay hatch has two window ports, fore and aft; experimenters can use one or both. The windows are interchangeable between all these payload areas. There are no shutters on these windows — the design of the ER-2 places all windows ahead (upstream) of the landing gear.

Zenith ports have been incorporated into an upper Q-bay hatch, the wing-pod aft-tail cones, and one wing-pod fore-body. Zenith ports on the nose are prohibited in order to preserve the pilot's field of view.

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**3. Configuration Details**

The frame that supports the standard window has limited load-bearing capability. Normally, heavier instruments are borne by the rack rails in the nose, wing-pod fore-body, or on the Q-bay rack attachment points; leaving no weight on the window surface itself. It is also possible to design an instrument to share load between the rack rails and the window frame. This requires careful design of the instrument to allow for the normal expansion and flexing of the aircraft structure during flight. While this has been done successfully, it has proven to be expensive, complex, risky, and greatly complicates the installation of the instrument.

**A. Window Materials**

The stock full-aperture, 16-in (41 cm) diameter windows used on the ER-2 are borosilicate crown glass (BK-7). If at all possible, these should be used before custom window designs are developed. If specialized windows are required, the following guidelines should be considered:

- 1) Materials with lower allowable stresses than BK-7 may require thicker windows than the standard frame supports. Custom frames will have to be developed if the window extends to the full 16-in. (41 cm) diameter. An alternative is to use a smaller diameter window with an aluminum insert plate that fits the standard 16-in. (41 cm) diameter opening.
- 2) Circular shapes are strongly preferred due to lower stress levels.
- 3) All edges of glass-type materials must be chamfered, and scratches, digs, or unsmoothed edge chips may disqualify a window for use.
- 4) It is mandatory that any window material be isolated from metal inserts or frames by silicone rubber gaskets (grade 40), with sufficient tolerance to prevent strain from thermal and mechanical effects.

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**B. Environmental Testing of Optical Windows**

Each custom window assembly, complete with frame and gaskets, will be tested at DFRC, or at another facility with full documentation, prior to installation aboard the aircraft. This testing is done to verify structural integrity and a pressure seal, not to measure optical properties. To allow adequate time for testing, window parts must be at DFRC at a minimum of four weeks prior to the scheduled installation.

**4. External Airflow Parameters**

Many instruments that are exposed to the external environment are sensitive to the relative direction of flow. Experimenters should contact Lockheed Engineering when selecting a potential mounting location for their probe or sensor.

The boundary layer, which is the layer of air closest to the skin of the aircraft, increases in thickness from the leading edge to the trailing edge of the wings, fuselage, and pods. The physical and chemical properties of this layer do not match that of the free stream, and therefore instruments intended to measure the properties of ambient air routinely use probes that extend out past the boundary layer. Lockheed Engineering can provide an estimate of the boundary layer thickness at the selected sensor location.

Experimenters in multi-sensor campaigns, especially those making precise chemical or physical in-situ measurements, should be aware that their environment can be affected by the exhaust or aerodynamic wake of instruments upstream of their own. Identifying these conflicts early enough to resolve them is a team effort among the individual instrument groups, the program or project scientist(s), and Lockheed Engineering.



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**CHAPTER 5**

**EXPERIMENT CONSTRUCTION AND INSTALLATION**

**1. General Information**

The installation of experimenters' equipment onto the aircraft is one of the most difficult and time-consuming aspects of airborne research. The extreme environment, the paramount need for safety, and the desire for high reliability can greatly complicate instrument design, fabrication, installation, and test beyond what is required just for science purposes. Usually, schedule and manpower constraints preclude any major re-work of an instrument after it has arrived at DFRC for installation. If major deficiencies are identified at this point, there may be no choice but to remove the instrument from the payload. To avoid such costly mistakes, the guidelines, specifications and technical requirements given in this handbook should be followed.

Lockheed is responsible for ensuring the safety and airworthiness of the ER-2 and its payloads under the oversight of NASA DFRC. For this reason, Lockheed engineers will design the instrument/aircraft interface, including the mounting structure and electrical interface.

The experimenter is responsible for the design of the instrument. The instrument construction must adhere to all guidelines and restrictions to ensure compliance with airworthiness and safety standards. Any questions concerning airworthiness or safety standards should be referred to the Lockheed engineer assigned to the integration of the instrument.

**2. General Arrangement**

While an instrument may fly by itself on the ER-2, the more usual arrangement is that a suite of instruments is assembled to make measurements for a particular campaign. Instruments are then removed from the aircraft, and may be re-installed later with a different mix of other instruments to satisfy different campaign objectives. Each payload configuration is reviewed to ensure it is within the aircraft's limitations for weight, center of gravity, and total electrical power consumption. Further, changes to each instrument must be reviewed and approved by Lockheed Engineering prior to flight.

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**3. Construction Guidelines**

**A. Load Factors**

The design of any instrument must take into consideration both design loads and ultimate loads. Design loads are the loads expected to be carried by the structure of an instrument and its components (including racks, pallets, tie-down brackets, and instrumentation), during normal flight conditions. The instrument must withstand design limit-loads without deformation or failure. It is not required that the alignment, calibration, or other operational functions of the instrument be maintained when load factors exceed design limits.

**Table 5-1. Static ultimate load factors (g).**

Location	Vertical Down (Nz)	Vertical Up (Nz)	Forward (Nx)	Aft (Nx)	Side (Ny)
<b>Fuselage</b>					
Removable Nose	+6.3	-3.3	+2.5	-2.5	±1.5
Fixed nose					
Tail cone					
Centerline tank					
Hot box			+8.0		
Aft fuselage					
Q-bay/cockpit					
E-bay			+2.5		
<b>Wings</b>					
Super pods	+9.0	-6.0	+3.0	-3.0	±4.5
Trailing wing pods	+14.25	-9.5			
Wing tips	+27.0	-24.0			

Note: Limit load factor=Ultimate Load Factor/1.5.

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Ultimate load factor is defined as the maximum structural load that the package will bear. Beyond the ultimate load point, structural failure is expected in one or multiple members. Ultimate loads are the design loads multiplied by a factor of 1.5. The ultimate load factor for wing-mounted instruments is 9.0 *g* ( $1.5 \times 6.0g = 9.0g$ ). Lockheed Engineering will be able to provide guidance on specific instruments.

**B. Pressure Environment**

The ER-2 operates in a low pressure, low temperature environment which may cause special problems for some equipment. The payload areas are susceptible to events such as corona discharge, or arcing between high voltage components and ground potential. It is not uncommon, particularly during operations in tropical regions, for the payload areas to experience 100 percent humidity during descent from altitude. Areas lacking pressurization, such as the aft section of the superpod and centerline tank, are particularly susceptible to these events. To reduce the effect of these problems, experimenters should ensure adequate lead separation, seal equipment in inert compounds, and avoid sharp bends. Electrical contacts or terminals in excess of 50 volts should have guards or barriers. Any high-voltage components must be clearly marked.

In general, structures designed to withstand pressurization shall be designed to an ultimate pressure of  $2 \cdot P$  with a 50 percent safety margin, in addition to acceleration and aerodynamic loads.

The design of the instrument should take into account the normal flight pressure variations in the various payload compartments. The experimenter should also take into account the ramifications of possible loss of pressure in the payload compartment where the instrument is installed. In the event of pressure loss in the payload compartment, the instrument must not react in a manner that would endanger the pilot or the aircraft. The pilot should be informed of the proper procedures to follow to protect the instrument if pressurization should fail. Unless directed otherwise, the pilot's default procedure will be to turn off power to all payloads in the affected volume.

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**C. Materials**

All load-carrying members will be fabricated from aircraft-grade structural materials. These materials include aluminum, steel, and corrosion resistant steel. All aluminum sheet metal parts will be made of clad material, with the exceptions of welded assemblies, extrusions, or machine parts. Where conditions permit, carbon and stainless steel materials may be used. No magnesium material will be allowed, due to its rapid oxidation potential.

Experimenters shall avoid using flammable materials or materials that emit toxic fumes. For example, the external cabling of commercial electronic components must have self-extinguishing insulation, such as Teflon or Tefzel. Accessories such as cable ties, clamps, or identification sleeves must be of a similar material (see chapter 6).

Polyvinyl Chloride (PVC) is not approved for use in airborne applications, due to the highly toxic fumes and dense black smoke emitted upon exposure to high temperatures (see chapter 6). Experimenters should carefully review their drawings and parts lists to ensure that PVC insulated wire, cabling, pipe or components are not specified. However, there may be situations the use of PVC insulated wiring or components is unavoidable. Lockheed Martin must approve any deviations to the above requirement. This assessment will only be done on a case-by-case basis.

Toxins, flammable gases, or corrosive liquids should not be used in an experiment (e.g. cooling systems or battery power supplies). Advance approval must be obtained from DFRC safety personnel prior to planning for the use of such gases or liquids in an experiment. See chapter 6 of this handbook for additional information about certification of hazardous materials.

The use of non-metallic materials may be acceptable in certain areas within guidelines. When using such materials, the experimenter is required to ensure that it is non-flammable and non-toxic in all design conditions. The following materials are approved for use in instrument construction:

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**1) Aluminum**

**Table 5-2 (a). Sheet stock 0.005 in. through 0.190 in. thick**

<b>Alloy</b>	<b>Temper</b>	<b>Comments</b>
2024	-T3	Clad
	-T42	Clad
7075	-T6	Clad
	-T76	Clad

**Table 5-2 (b). Machine parts**

<b>Alloy</b>	<b>Temper</b>	<b>Comments</b>
2024	-T351	Plate
	-T851	Plate
7075	-T651	Plate
	-T351	Bar
2024	-T4	Bar
	-T351	Bar
7075	-T73510	Bar
	-T76510	Bar

**Table 5-2 (c). Extrusions**

<b>Alloy</b>	<b>Temper</b>
2024	-T4 -T3510 -T3511
7075	-T6 -T76

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**Table 5-2(d). Weldable aluminum  
(fusion type welding).**

Alloy	Temper
6061	-T6 -T76

**2) Steel**

- 301 CRES sheet 0.012 in. through 0.190 in.  
1/4 Hard  
1/2 Hard  
Full Hard
- 302 CRES Sheet Annealed
- 4130 Plate Heat Treated 0.062 in. through 0.625 in.
- 4130 Plate Condition A
- 4130 Sheet Condition N 0.062 through 1.5 in.

**D. Welding**

For certain applications, welding of structural members may be acceptable. Welding must be performed by a welder currently certified to specification MIL-STD-1595. Cracks, porosity, voids and undercuts are unacceptable, as is burn-through or damage to adjacent parts. Angular or thickness misalignment, warpage, or small dimensional change due to heat from the welding operation is permitted within certain tolerances as specified by Lockheed engineers for the particular application. Welded assemblies must have an accompanying welding certification including penetrant inspection per MIL-I-6866, type 1, method A or B. **The certification of the welder must be submitted to Lockheed in writing.**

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**E. Fasteners**

Aircraft structural fasteners, military standard (MIL-STD) or National Aerospace Standard (NAS), must be used for all structural members, and should be used whenever possible for other equipment elements. Screws and bolts must also be locked in place with safety wire, cotter pins, lock nuts, nylon inserts, or locking inserts such as helicals. For a list of approved fasteners and suppliers contact the Lockheed engineer assigned to the project. **Threads that are inside aluminum structure are undesirable, and their presence will require approval from Lockheed Engineering.**

**1) Bolts and Screws**

Screw type fasteners are to be firmly secured such that there is no relative movement between the attached parts. Lock-nuts, safety wire, or cotter pins must be used to lock bolts or screws in place. Screws installed in tapped holes must be safety wired. Screws with nylon inserts, or locking inserts such as helicals, should be used whenever flush attachments are a requirement.

Except in the case of flush attachments, washers may be used under bolts or screws, as well as under all nuts. Tapped holes may be used in aluminum with locking inserts.

Bolts or screws with appropriate grip lengths will be used to avoid thread bearing at shear faces in structural members. Evidence of cross threading, mutilation, or other defects is unacceptable.

Bolts and screws must be of NAS or MIL-STD quality. The minimum diameter of bolts or screws in primary structure is 0.19 in. The minimum edge distance for bolts or screws is two times the attachment diameter, measured from the center of the hole to the edge of the surface. Two threads should show above the nut.

**2) Rivets**

When joining parts that do not normally require separation after initial assembly, rivets may be used. Rivets should be of the proper size and compatible with the parts being joined.



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Rivets may only be used in applications where the primary loading places the fasteners in shear.

Minimum edge distances are not to be less than twice the rivet diameter. This distance is measured from the center of the hole to the edge of the surface. The height of the shop head is to be 0.3 to 1.5 times the height of the shank. The diameter of the shop head is to be 1.4 to 1.5 times that of the shank diameter. When blind rivets are used, they are to be of the proper length, grip size, and material. In addition, blind rivets are to be of the mechanical locking type. Non-structural items may be attached with Lockheed-approved, low strength, blind rivets.

**Table 5-3. Structural rivets to be used.**

<b>Aluminum Rivets</b>	<b>Aluminum Blind Rivets</b>
MS20426 (Flush) MS20470 (Button Head)	NAS1739E (Flush) NAS1739E (Button Head) NAS1398D (Button Head) NAS1399 (Flush)

Note: Rivet installation specifications are available from Lockheed Engineering.

**F. Sheet Metal Parts**

**1) Minimum Bend Radius**

In-flight loads and vibration can cause subsequent, if not immediate, cracks in aluminum and steel alloy sheet metal parts using a lower than minimum bend radius. The minimum bend radii for the accepted sheet metal types is shown in table 5-4(a), 5-4(b), and 5-4(c).

**2) Sheet Metal Part Edges**

To prevent injury to personnel or damage to other parts, break and de-burr all sharp edges.



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**3) Bolt and Screw Holes**

The distance from the edge of the sheet to the center of the bolt or screw hole must be a minimum of two times the nominal diameter of the hole for flush fasteners. In order to allow the use of thinner sheets without fastener heads penetrating into substructure, and to reduce the bearing load on the head, 100 deg countersink fasteners are preferred. Bolt and screw hole sizes are shown in table 5-5

**Table 5-5. Screw/bolt hole size.**

<b>Screw Size (in.)</b>	<b>Structural Hole (in.)</b>	<b>General Clearance Hole (in.)</b>	<b>Full Float Plate Nut (in.)</b>
3/16	0.193	0.198	0.249
	0.199	0.204	0.255
1/4	0.251	0.260	0.311
	0.258	0.267	0.318
5/16	0.315	0.327	0.374
	0.322	0.334	0.381

**G. Machined Parts**

**1) Material**

The majority of machined parts will be of aluminum. Other materials may be used only when specifically approved.

**2) Drilled Holes**

Steel parts may have tapped holes. For aluminum parts, locking or helical type inserts are required unless specifically approved by Lockheed Engineering.

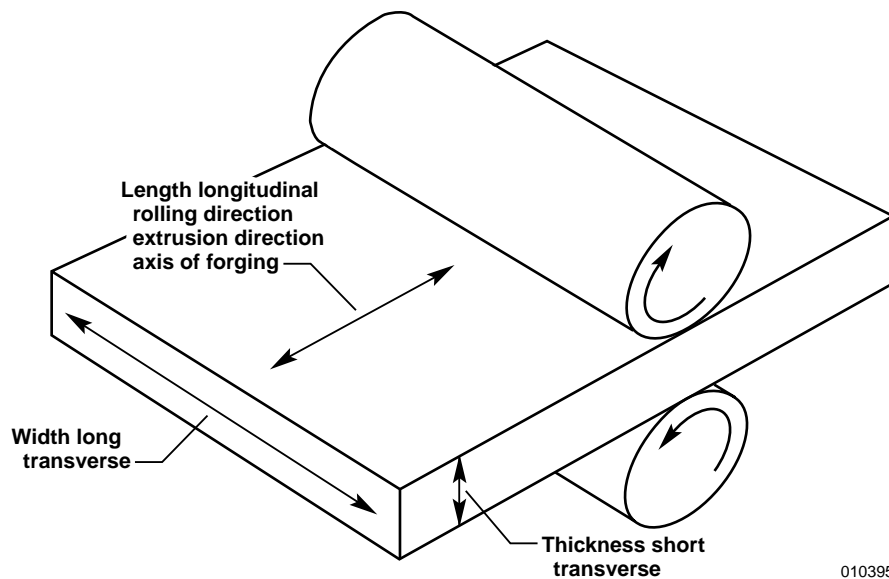
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**3) Internal Corner Radius**

Internal corner radii should be as generous as possible in order to avoid the stress concentrations associated with sharper corners.

**4) Surface Roughness**

For structural requirements, a surface roughness of 125 RMS is generally specified. Lower surface roughness numbers (indicating smoother surface finish) are required for highly loaded structural parts. Instrument drawings must show the grain direction on machine parts that are structurally critical. The grain direction should be specified in relation to the last reduction roll of the stock, as shown in figure 5-1.



**Figure 5-1. Grain direction as referred to rolled metal blanks.**

**5) Heat Treatment**

Machined parts should not be heat treated after final machining. However, if additional strength is required, machined parts may be heat treated similar to the following example:

- As received: T351
- Final heat-treated condition: T851

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**6) Welded Assemblies**

Unless high mechanical properties are required for structural reasons, welded or brazed assemblies shall be designed for the “as welded” and “as brazed” conditions.

**H. Cleaning**

All parts and assemblies must be cleaned according to standard aircraft procedures after fabrication. All excess solder, dirt, metal shavings, weld material, mold release agents, or other foreign matter must be completely removed. Specific processing questions should be referred to Lockheed Engineering.

**I. Surface Finish**

All aluminum parts must be chemically treated (Alodine or equivalent) prior to assembly. Additionally, parts should be coated with an appropriate primer for the material and the expected environment. Lockheed Engineering will provide guidance for acceptable primers. Carbon steel parts are to be plated for corrosion protection; stainless steel parts need not be painted.

**J. Electrical Fabrication**

**1) Connections**

Crimp type connectors must be used wherever possible. Lockheed Engineering will provide current specifications for crimp type connectors. Soldered connections, when necessary, must be performed such that there is no loose or excess solder present.

**2) Wiring and Cables**

Wire or cable shielding is to be insulated in a manner such that contact or shorting of current carrying parts is avoided. The ends of the braid or shielding must be secured against fraying, and there can be no evidence of burns, abrading, or pinch marks that would cause short circuits or leakage.

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**3) Clearance**

Wires and cables should be routed with sufficient clearance from heat generating parts to avoid heat related deterioration. Solder connections or bare conductors should be constructed with sufficient clearance to avoid arcing with adjacent connectors. Heat shrink tubing should cover all exposed connections.

Wires run through partitions of less than 1/8 in. thickness must be run through a suitable insulation grommet. Partitions greater than 1/8 in. thickness should possess a grommet or have the edges of the hole rounded to a minimum radius of 1/16 in. A grommet may be necessary where there is insufficient clearance to avoid chafing or abrasion.

**4) Wrapping and Tying**

Wire harnesses should be spot-tied to avoid chafing or abrasion. Plastic devices may not be used for tying coaxial or Teflon wires. A list of approved materials can be obtained from Lockheed.

**5) Bend Radius**

Electrical cable may not have a bend radius of less than five times the cable diameter to avoid the establishment of a permanent set.

**6) Sleeves**

Cable subject to flexing or bending must use a plastic sleeve. The sleeve must be self-extinguishing, non-flammable, or flame retardant. No PVC material is permitted.

**4. Aircraft Vibration**

The ER-2 is relatively free of engine-generated noise. In-flight measurements of vibration due to engine roughness indicate frequencies between 80 and 110 Hz, and maximum double amplitude (measured vertically) of less than 0.001 in. (0.33 to 0.62 g's). The normal airplane frequency is

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between 95 and 100 Hz. Operations from airfields with rough taxiways and runways have, in the past, imposed the most severe shock loading on the aircraft.

## **5. Structural Attachments**

Guidelines follow for the attachment of experimenters' equipment to the aircraft. In all cases, Lockheed Engineering will design the structural rack or framework that houses the instrument assembly and the attachment structure that secures this frame to the aircraft. Lockheed will also design any adapting hardware to install experimenter-provided probes, windows, optics, or antennas onto the aircraft. These racks or hardware are fabricated at DFRC, and the experimenter-provided equipment is attached to them during the integration process.

Dimensioned drawings of all primary payload areas are provided in appendix A. Lockheed Engineering will produce engineering drawings of the instrument interface. It is the responsibility of the experimenter to produce drawings of the mechanical and electrical design of the instrument itself.

### **A. Q-bay**

The Q-bay has structural hard points at the forward and aft bulkheads that support horizontal racks. A lower and upper rack can be installed at the same time, if there is no interference between instrument assemblies. A third, vertical rack can be attached to the aft bulkhead for small payloads. The upper and lower hatches can also be outfitted to support custom probes, view ports, antennas, or other small assemblies. No modifications to the fuselage structure between the upper and lower longerons are permitted.

#### **1) Q-bay Rack Designs**

There are three Q-bay rack designs available. These are the upper rack, the lower rack, and the vertical rack. Drawings of these rack designs are shown in appendix A. It is possible to specifically tailor a rack design for an instrument if necessary. Lockheed will perform the detailed design and fabrication of the rack assembly for all instruments. Any changes to the rack must be submitted to Lockheed for a stress review prior to accomplishing the change. The weight limitations that apply to all Q-bay racks are as shown in table 5-6.

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**Table 5-6. Weight limitations for Q-bay racks**

Rack Type	Rack Weight		Maximum Payload	
	lb	kg	lb	kg
lower rack	45	20.4	825	374.2
upper rack	23	10.4	275	124.7
vertical rack	26	11.8	115	52.2

The total weight of the instrument package and its potential effect on the aerodynamic characteristics of the aircraft will be evaluated. The aerodynamic effect of any portion of the instrument that protrudes from the aircraft will also be considered. Aerodynamic effects must be minimized in order to maintain the stability and control of the aircraft in all normal flight conditions.

The maximum payload values include the following items as part of the total instrument weight:

- Experimenter's equipment, including consumables.
- All structure such as component racks, brackets, or other structure added to the instrument to support the equipment, including hatch modifications.
- Instrument wiring and wiring supports, plugs, control panels, junction boxes, etc.
- Any ballast required to trim the aircraft for proper weight distribution.

## **2) Q-bay Hatch Modifications**

The upper and lower hatches can also mount instrument assemblies. These will usually be attached to custom adapter plates that pick up the rings on the hatch structure. A flat deck has been built on one of the upper Q-bay hatches to mount assemblies directly beneath zenith viewing

The structural and aerodynamic effects of any hatch modifications will be evaluated by Lockheed. If accepted, Lockheed



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will make the necessary modifications. Typically, a modified upper hatch can support 30 lb (13.6 kg) of additional equipment, and a modified lower hatch can support 430 lb (195 kg) total weight (including the hatch).

Examples of upper and lower Q-bay hatch designs are provided in appendix A.

**B. Nose**

The removable nose has internal rails to support a horizontally mounted rack. Bolts at the end of the rack secure it longitudinally. Instruments are integrated into the nose on a mounting rack designed by Lockheed. A nose rack typically weighs 30 lb (13.6 kg), and can support a 600 lb (272.2 kg) payload. An example of a typical nose rack is shown in appendix A.

The nadir window frame may also support a circular insert holding a custom viewport, probe or other instrument assembly. Any protrusion below the contour line must be carefully assessed to ensure it does not affect the airflow to the aircraft's pitot probes.

**C. Wing-pods**

The wing-pods fore-bodies and aft bodies have internal horizontal rails to allow easy slide-in installation of experimenter racks. The mid body has permanently installed vertical and horizontal racks that can support standard face-mount rack assemblies. Instrument assemblies may also be mounted on the nadir viewport window frame. Dimensioned drawings of the wing-pods, pod racks, and the 16-in. (40.6 cm) window installation are provided in appendix A.

**D. Fuselage Centerline Pod**

The centerline pod has been outfitted with rails for instrument mounting. Alternately, experimenters can directly attach to the rings in the centerline pod, though this will complicate the installation. The fore and aft-cones are aerodynamic fairings, and are not load-bearing.

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**E. Other Payload Areas**

Other payload areas that have been used in the past, including the wing tips, the system 20 pod, the lower aft fuselage hatch, and the lower E-bay hatch, can support small instrument assemblies. The structural and electrical connections for these non-standard installations require individual consideration. Contact Lockheed Engineering for attachment details if you are considering one of these locations.

**6. Equipment Racks**

Equipment racks that fasten directly to the rails have been designed for use in the Q-bay, nose, wing-pods, and centerline pods. Drawings of typical rack assemblies are included in appendix A. Racks are usually customized for an individual instrument assembly, and cannot be easily reused for another instrument.

The racks and other DFRC-provided structural assemblies are considered aircraft equipment, and cannot be modified by the experimenter without prior approval.

**7. Mounting Techniques**

Instrument components are installed onto the Lockheed-designed rack during the final installation. This assembly process uses NAS or Mil-Spec fasteners, and usually requires custom built angles, clips, and straps. The fabrication of some of these components is not completed until after the instrument hardware has arrived at DFRC, and any dimension-critical holes are match-drilled.

**8. Equipment Certification**

The process for integrating any instrument on the ER-2 is outlined in this section. The complexity of the integration effort will determine the timeline involved in this process.

**A. Integration Time Line**

There are three areas where the experimenter strongly influences the integration time line. They are as follows:

- 1) Initial notification of the new requirement. The standard or requested lead-time for most new instruments is twelve

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months before the first required flight. More complex or under-funded instruments may require additional leadtime.

- 2) Timely exchanges of information related to instrument design details, construction methods, interface requirements, and hazard identification.
- 3) Funding. Integration of new or modified instruments is only partially subsidized by the Airborne Science Program. The experimenter, or their sponsor, is responsible for the direct costs of engineering their instrument onto the ER-2. These costs include: engineering time; documentation, including drawings & reports; travel for reviews and inspections; stress, aerodynamic, thermal, or electrical analyses; fabrication of unique racks, clips, wire harness, and other hardware; and any re-work of experimenter equipment required at DFRC. The cost of the flight hours for the check flights is handled separately, through the standard Airborne Science Flight Request process.

If these factors are not given sufficient attention at the proper points in the integration process, significant time delays and cost overruns can occur.

**B. Instrument Integration**

New instruments are integrated at Dryden Flight Research Center at Edwards, California. Data collection missions may be conducted from other bases that meet scientific objective needs. Instrument integration will be accomplished by Lockheed engineers and technicians, with oversight by NASA.

In most cases, the interface engineering details will be sent directly to Lockheed Engineering. Scheduling, funding, and coordination priorities and responsibility will be handled by NASA. This entire process is actually a team effort between NASA, Lockheed Engineering, and the experimenter. Through cooperation, timely funding, and accurate information exchange, the integration process can proceed smoothly and efficiently.

The general steps in the integration process are outlined below. The length of time between steps depends on the complexity of the instrument, funding, and other priorities.

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- 1) The experimenter should review the information contained on the Airborne Science web page and in this handbook to assess the suitability of the ER-2 for their intended application or instrument. If additional information is needed for this assessment, contact Lockheed Engineering or the Airborne Science Program Office.
- 2) Arrange for a teleconference or briefing to DFRC to discuss the project. This should cover: research objectives; desired schedule; expected funding level; sponsoring organization; heritage of the instrument; parties involved; and any rough initial ideas of the instruments size, weight, and unique operating requirements. DFRC will provide initial feedback on the ability of the program to support your objectives, and identify points of contact.
- 3) The objectives of the new instrument will be stated on a standard flight request, which will be forwarded to NASA Headquarters for approval or rejection. DFRC can assist in gathering the information required for this form.
- 4) Approximately a year prior to the first required mission, an engineering kick-off meeting should be scheduled. DFRC attendees will include representatives from the Airborne Science Program Office, the Safety Department, ER-2 Flight Operations (pilots), ER-2 Maintenance, and Lockheed Engineering. Experimenter teams may include engineers (mechanical, electrical, software or a lead engineer), a project manager, a principal scientist, and any other specialists needed. At this time, the experimenter should address the following subjects:
  - Research objectives.
  - Instrument physics or principle of operation.
  - Desired location of the instrument on the aircraft, including requirements for view ports, probes, or field of view.
  - Any other instruments expected to be flown in combination, or if the instrument is part of a major campaign.

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Operational requirements including pilot interface, special maneuvers, and attitude constraints.

- Maintenance requirements, including installation, access, training, field operations, hazardous operations, or hazardous materials.
  - Expected weights, size, volume, electrical power requirements, and cockpit switches.
  - Ground support requirements such as lab space, power, specialized equipment, gas handling, etc.
- 5) Within four to six weeks following the kick-off meeting, an informal cost estimate and schedule will be prepared and submitted to the experimenter. The more clearly and completely experimenters are able to state their requirements, the more accurate this resource estimate will be. If de-scoping the instrument's design or requirements is needed to stay within cost and schedule constraints, this decision should be made early and communicated to Lockheed and DFRC.
  - 6) In the following months, the experimenter must send adequate funding to NASA/Lockheed Engineering.
  - 7) A preliminary design review (PDR) will be presented by the experimenter. This will normally take place five to six months prior to the initial engineering test flight.
  - 8) During detailed design and fabrication, any changes to the instrument package will be reviewed by Lockheed Engineering. Significant changes could require another PDR, or a slip in the engineering test flight schedule. Depending upon the complexity of the instrument, a critical design review (CDR) may also be scheduled.
  - 9) For instruments that include an identified hazard (see the following section), the experimenter should begin the process of obtaining operating approval from the appropriate DFRC safety organization. While many hazards and their mitigation depend on instrument design details that may not yet be known, an early start with the review process can facilitate the final approvals. Further, constraints imposed by DFRC as a

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result of an initial safety assessment may influence the instrument design or operations plans.

- 10) Lockheed will perform the final review and approval of experimenter-provided drawings at a later review. The experimenter need not be present at DFRC for this review. This review will occur according to the schedule established earlier, and will normally precede manufacture and assembly of interface hardware.
- 11) The instrument, along with an integration team of engineers and technicians, should arrive at DFRC three to four weeks prior to the scheduled first flight. At this time, the instrument assemblies will be inspected for airworthiness, compliance with drawings, workmanship, and materials. Final manufacture of assembly hardware, integration fit checks, electrical ground checks, and integration into the aircraft will then be performed. The ER-2 maintenance section will furnish up to two man-weeks of integration support at no added cost.
- 12) During the integration period, the instrument team will instruct and train the operations (pilots) and maintenance departments on the operation, maintenance, and handling requirements for the instrument. If necessary, the experimenter will conduct a safety briefing on the instrument, and supply material safety data sheets or safety plans. The experimenter will verify satisfactory operation of the instrument package during ground checks and after installation in the aircraft. The experimenter will also be responsible for providing a ground and flight checklist for operations. This checklist should include actions for normal operations, and when a failure is indicated.
- 13) The experimenter may be asked to support briefings and reviews at DFRC, which are required to receive approval to fly. These may include Configuration Control Board (CCB) meetings and technical briefings.
- 14) An operational check flight will be flown with the instrument. These flights are nominally 2 hr or shorter and intended only to verify that the instrument's operation does not interfere with any aircraft system or affect the aircraft's flying qualities. All modes of instrument operation should be exercised. For safety reasons, this flight is constrained to be conducted

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within 200 nm of DFRC, during fair weather (good visibility, ceilings, winds, etc.), and daylight hours. A successful check flight clears the instrument for general operation, and these constraints are lifted. Additional flights may be scheduled as needed to verify or improve instrument performance.

Upon successful completion of the engineering test flight the configuration of the new instrument will be considered fixed. It is recognized that changes must be allowed for the routine maintenance, repair, and replacement of identical parts, as well as the refinement of control software and operating modes. It is further recognized that minor changes may be required, such as replacing experiment internal parts with non-identical parts or the addition of minor internal parts. These changes will normally be approved after they have been communicated to DFRC and Lockheed. Changes that may not be automatically approved include: changes affecting the mechanical, structural or electrical interface with the aircraft; altering the system weight, center-of-gravity location or inertial properties; or changing the electrical power usage, or power routing between individual components of the system. Changes that may affect any of these items must be approved by NASA/Lockheed Engineering prior to implementation. This approval can be expedited by transmitting a timely and complete description of the proposed change to Lockheed. After review, a determination will be made as to whether the change is of significant magnitude to require additional review and/or another check flight.

The integration process is strongly dependent upon the experimenter being timely and accurate with the structural and electrical definition of the proposed instrument as well as the interface requirements with the aircraft. All such data should be submitted prior to fabrication, and at least eight weeks prior to the scheduled installation of the equipment aboard the aircraft. A longer lead-time may be required in cases of complex installations.

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**9. Hazardous Equipment and Materials Certification**

The operation of any potentially hazardous equipment, or use of hazardous materials at DFRC, must be reviewed and approved by the appropriate DFRC safety personnel. This applies to the shipping, operational use, and disposal of all hazardous materials, including the operation of hazardous equipment in the EIF (Experiment Integration Facility), or on the aircraft, either in flight or on the ground. Sufficient lead-time must be allowed for the necessary reviews and obtaining the proper authorization. Depending upon the specifics of the experiment, this process can take as long as several months. To help identify potential hazards that may require DFRC approval, the following equipment categorization is used.

**A. Lasers**

The use of lasers at DFRC and at DFRC controlled off-site operations is governed by Dryden Centerwide Procedure DCP-S-024, "Non-Ionizing Radiation Safety." This document must be reviewed and understood by those contemplating the installation of laser systems or the use of instruments containing lasers. Contact the mission manager for a current copy.

Any instrument utilizing active emitters of radiation (such as radar or laser packages) which would be harmful to ground personnel or another aircraft, will be required to utilize the ER-2 altitude interlock switch. The interlock switch prohibits any emission below a preset pressure altitude. The switch can be set to operate at 47 or 31 thousand ft altitude depending upon mission safety and data collection requirements. Lasers capable of causing physical damage to windows should exit the aircraft through small holes, rather than the 16-in. windows available.

**B. RF and Microwave Emitters**

The use of radio frequency (RF) and microwave emitters at DFRC and at DFRC controlled off-site operations is governed by Dryden Centerwide Procedure DCP-S-024, "Non-Ionizing Radiation Safety" and by Dryden Policy Directive DPD-2570.1, "Radio Frequency (RF) Spectrum Management." These documents must be reviewed and understood by those contemplating the installation of RF or micro-



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wave emitters. Contact the mission manager for current copies. Experimenters should engineer their equipment to prevent direct and spurious radiation from interfering with the aircraft avionics equipment, which may cover the frequency range of 10 kHz -10 G's or more (see chapter 2).

High power emitters of RF energy may be required to use a safety interlock tied to the ER-2's altitude switch, as described above for laser operations.

**C. Cryogenics**

Use of cryogenic liquids at DFRC is controlled by Dryden Center-wide Procedure DCP-S-039, "Cryogen Safety." Contact the mission manager for a current copy. Additional guidelines are contained in appendix B of this handbook. Cryogen usage is reviewed with respect to physiological, fire, explosion or other possible hazards associated with the use and/or transport aboard the aircraft. Type, volume, storage, and usage data is required by DFRC for all cryogenics. Some cryogenics are prohibited from use and/or transport due to exceptional hazards. These cryogenic liquids include:

- Oxygen
- Methane
- Ethylene
- Ethane
- Hydrogen

**D. Compressed Gases**

Use of compressed gases at DFRC is controlled by Dryden Center-wide Procedure DCP-S-030, "Pressure Vessels and Pressurized Systems." Contact the mission manager for a current copy. All compressed gases are reviewed, like cryogenics, with respect to physiological, fire, explosion or other possible hazards associated with their use and/or transport aboard the aircraft. If the particular gas is in the extremely hazardous category, or is used in sufficient quantity to be otherwise considered a high-risk item, special design and risk mitigation practices will be required.

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**E. Hazardous Materials**

Hazardous material is defined as anything with a flashpoint below 140 °F or with a threshold limit value (TLV) below 500 ppm, below 500 mg/m<sup>3</sup> for fumes, below 10 mg/m<sup>3</sup> for dust, or with a single oral dose (if liquid) at 50 percent lethality below 500 mg/kg. Each installation is reviewed for potentially hazardous materials. A complete account must be made of all gases, and dry or liquid chemicals, toxic or otherwise. This includes all cleaning and laser dye. The use of toxic gases in the aircraft, during flight or ground operations, is of particular concern. Data on the instrument design, installation, and proposed use of the gases will be evaluated to determine the hazard level. Where it is determined that the use and/or transport of a gas presents an unacceptable risk, containment of that gas in a secondary containment vessel may be required to lower the risk to an acceptable level. Generally, secondary containment is required when full release and mixture of the gas into a 4 ft bubble (33.5 ft<sup>3</sup>) results in a concentration exceeding 50 percent of the amount known to be immediately dangerous to life and health (IDLH). Handling of hazardous materials at DFRC and at DFRC controlled off-site operations is governed by Dryden Centerwide Procedure DCP-S-038, "Hazard Communication and Material Safety Data Sheet (MSDS) Instruction Guide and Dictionary." Also see DCP-S-029, "Laboratory Safety." Contact the mission manager for current copies of both documents.

**F. Batteries**

The proper use of small commercial grade batteries (such as those used for computer clock memories) is normally acceptable for use on the ER-2. However, the use of large numbers of batteries or large capacity batteries, particularly lithium based, may present a significant hazard and therefore require DFRC review and approval. Acid type batteries with liquid electrolyte are permitted on board, but secondary containment and Lockheed approval is absolutely required. Recharging in flight is not permitted. Commercial grade batteries may be approved for installation if the instrument assembly provides secondary containment. Special approval and operating procedures are required to allow unattended operation of any battery-powered equipment aboard the aircraft.

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**G. Pressure Vessels/Systems**

High pressure and vacuum systems (including research dewars) are reviewed to assess the hazards associated with failures. Use of these systems at DFRC is controlled by Dryden Centerwide Procedure DCP-S-030, "Pressure Vessels and Pressurized Systems." Contact the mission manager for a current copy.

**H. Motors/Pumps**

All electrical motors (except the very small fan units found in most commercial electronic equipment) and motor assemblies are reviewed for electrical safety and sparking potential.

**I. Heaters**

All heater assemblies are reviewed for electrical safety, proper circuit protection devices, and the presence of high temperature exposed surfaces that might serve as ignition points for flammable gases or hot surfaces that may cause burns to personnel. Exposed surfaces that are above 130 °F (54 °C) are generally considered safety problems and must have adequate shielding and caution signs.

**J. Power Distribution Equipment**

Power distribution equipment and large power conversion equipment require special DFRC approval. All non-DFRC AC power distribution boxes require inspection and approval for electrical safety.

**K. Radioactive Materials**

The use of radioisotopes and/or radiation generating equipment involving the NASA ER-2 is controlled by Dryden Centerwide Procedure DCP-S-023, "Ionizing Radiation Safety." This document must be reviewed and understood by those contemplating the installation or transport of such systems containing radioactive materials. Contact the mission manager for a current copy.

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**L. Other Hazards**

Each installation is reviewed for potentially hazardous ground or airborne operations. Areas that will be reviewed carefully include: All materials and processes used in the instrument construction, the use of high power equipment, high voltages, high temperatures, moving equipment, optical windows, purging and filling of highly flammable and/or toxic substances. These or other such items may be evaluated as high risk and require some level of risk mitigation.

For potential hazards external to the aircraft (e.g. laser beam, RF, and microwave emissions), special approval may also be required from outside agencies, such as the military, FAA, state and local government agencies, and/or agencies in foreign countries. This approval sequence can take several months and should begin well in advance of the proposed equipment installation date (a minimum four months lead time is recommended).

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**CHAPTER 6**

**ELECTRICAL POWER**

**1. General Information**

A cockpit switch, operated by the pilot, controls aircraft electrical power to the instruments. Instruments connect to an experimenter interface panel (see EIP below) in each payload area for power, as well as data signals. Two types of power are available: alternating current (AC) at 400 Hz, 115 volt, three-phase; and direct current (DC) at 28 volts. No 60 Hz or 50 Hz AC power is available unless it is supplied by experimenter-provided converters.

The electrical interface of the instrument to the aircraft will be designed by Lockheed Engineering, based on requirements communicated by the experimenter. This design shall include the selection of signals and power types from the experimenter interface panel. The experimenter is responsible for the design of power switching, voltage or frequency conversion, and power conditioning circuitry necessary for their instrument.

**2. Power Availability and Quality**

Engine-driven generators supply the AC and DC power. The maximum amount of power to each payload area is summarized below:

**Table 6.1. Maximum power to each payload area.**

<b>Payload Area</b>	<b>400 Hz AC, 3 Phi</b>	<b>28 VDC</b>
Nose	50 A	2.2 kW
Q-bay	100 A	4 kW
Wing pod	50 A	2.2 kW
Centerline pod	30 A	840 W
System 20 pod	30 A	840 W

The actual power available to any instrument will depend on the other instruments installed on the aircraft. The integration of any instrument will include an evaluation of its effect on the total electrical balance of the complete mission configuration of the ER-2.

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Aircraft generated power is not as “clean” as that generated in a laboratory. Therefore, the experimenter should ensure that the power draw of the instrument is compatible with the aircraft power available as well as the aircraft circuit(s) to which it is connected. Special circuitry which may be sensitive to power fluctuations should be avoided whenever possible. The experimenter is responsible for providing filtering or regulating devices for any instrument that is not compatible with aircraft power. Lockheed Engineering can provide assistance in the design of these devices.

During the cutover from ground power to aircraft power during engine start, electrical transients and dropouts are common. It is recommended that experimenters shut down their instruments before engine start, and resume operation just before taxi. After landing, there is usually a 30 to 60 min minimum time lag between when engine power is lost at shutdown to when power can be restored by ground carts or hangar connections.

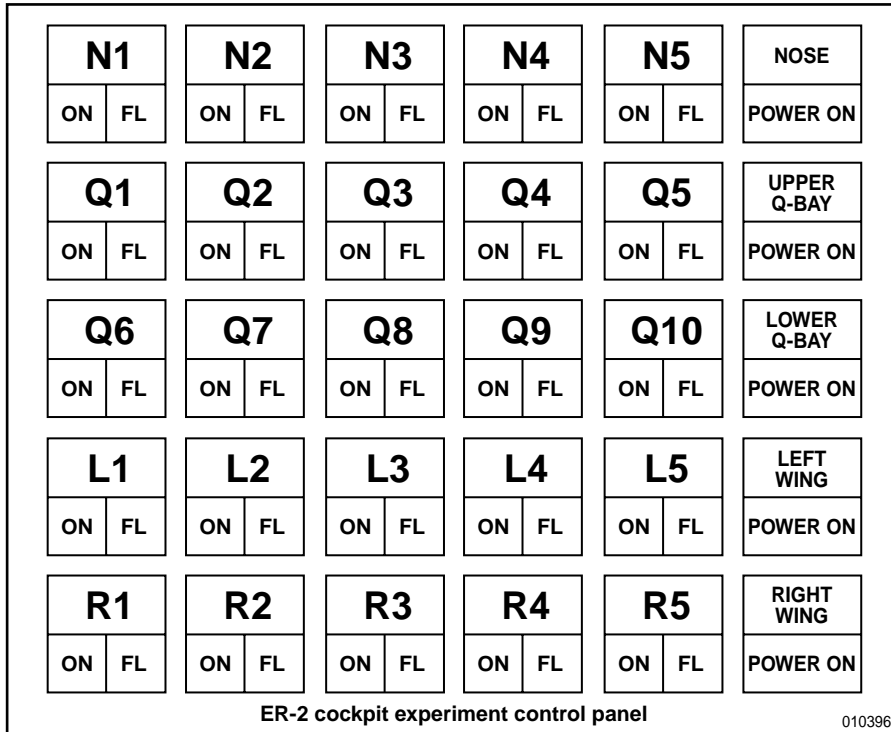
While the ER-2 has backup generators and batteries to permit continued flight in the event of a primary generator failure, these emergency systems will not power the experimenter's instrument bus. In the event of a failure of the primary generators, the instruments will be left un-powered until after landing, or when/if the primary generator resumes normal operation.

### **3. Experiment Control Panel (ECP)**

The experiment control panel (figure 6-1) is operated by the pilot and controls the instrument package. The panel contains 30 illuminated push-button switches arranged in five rows. The letter label of each switch corresponds to the various payload areas (i.e. N-nose, R-right wing-pods, L-left wing-pods, Q-Q-bay).

Switches one through five operate up to five instruments in each payload area with the exception of the Q-bay. There are ten control switches for the Q-bay corresponding to upper and lower Q-bay experiments. The control switch activates a SPDT (single pole, double throw) relay. The relay contacts are rated at 0.5 amp maximum, resistive. The contacts are user definable and are available at receptacles J1 through J5 on the experiment interface panel.

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**Figure 6-1. Experiment control panel.**

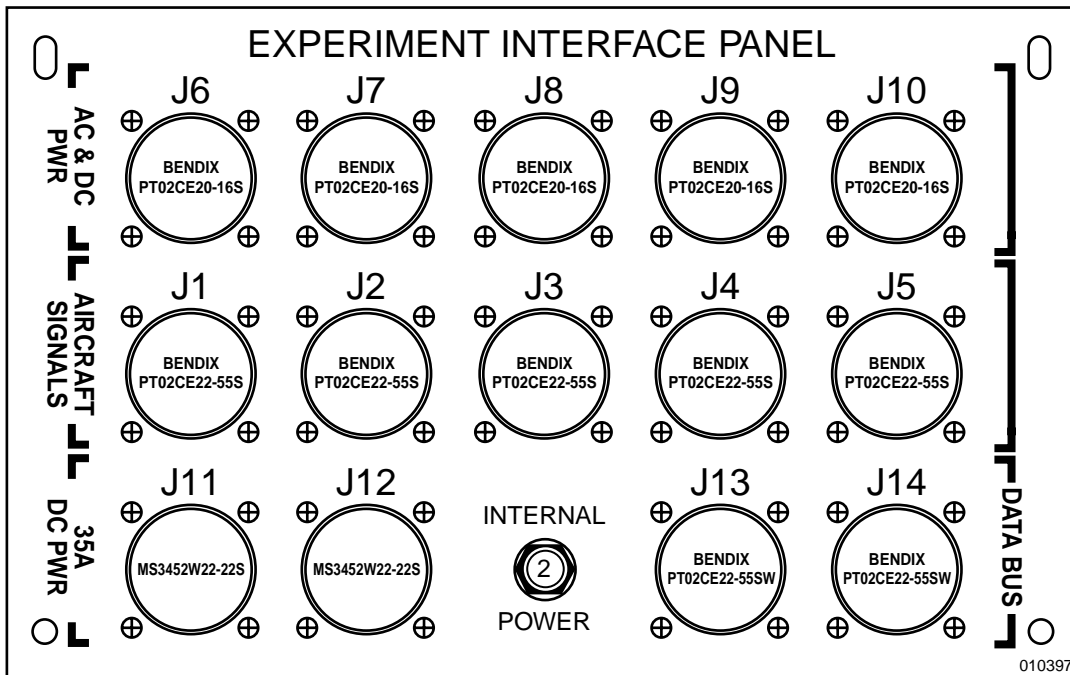
The bezel of each switch is configured like this. The top, which is amber, shows the switch number (such as Q1, Q2, Q3, etc.). The bottom right, which is red, is the fail light (FL), and the bottom left, which is green, is the “ON” light (ON). The “ON” light is activated by an interlock circuit by the experiment-grounding pin “A” of J1 through J5. When the instrument is activated but not in operation the “FL” lamp is activated. This light can be extinguished by applying a voltage of between +5 VDC and +28 VDC at 5 mA on pin “DD” of receptacles J1 through J5. The sixth switch controls the AC and DC power to the payload areas. This power is carried on receptacles J6 through J12 on the experiment interface panel (see figure pinout configurations below). The bezel of these switches is configured as follows: top (amber) - payload area; bottom (green) - power on.



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**4. Electrical Interface Panel (EIP)**

The electrical interface panel (EIP), shown in figure 6-2, links the instrument to the aircraft electrical system, the pilot control panel, and the aircraft data system. Each payload area contains one interface panel.



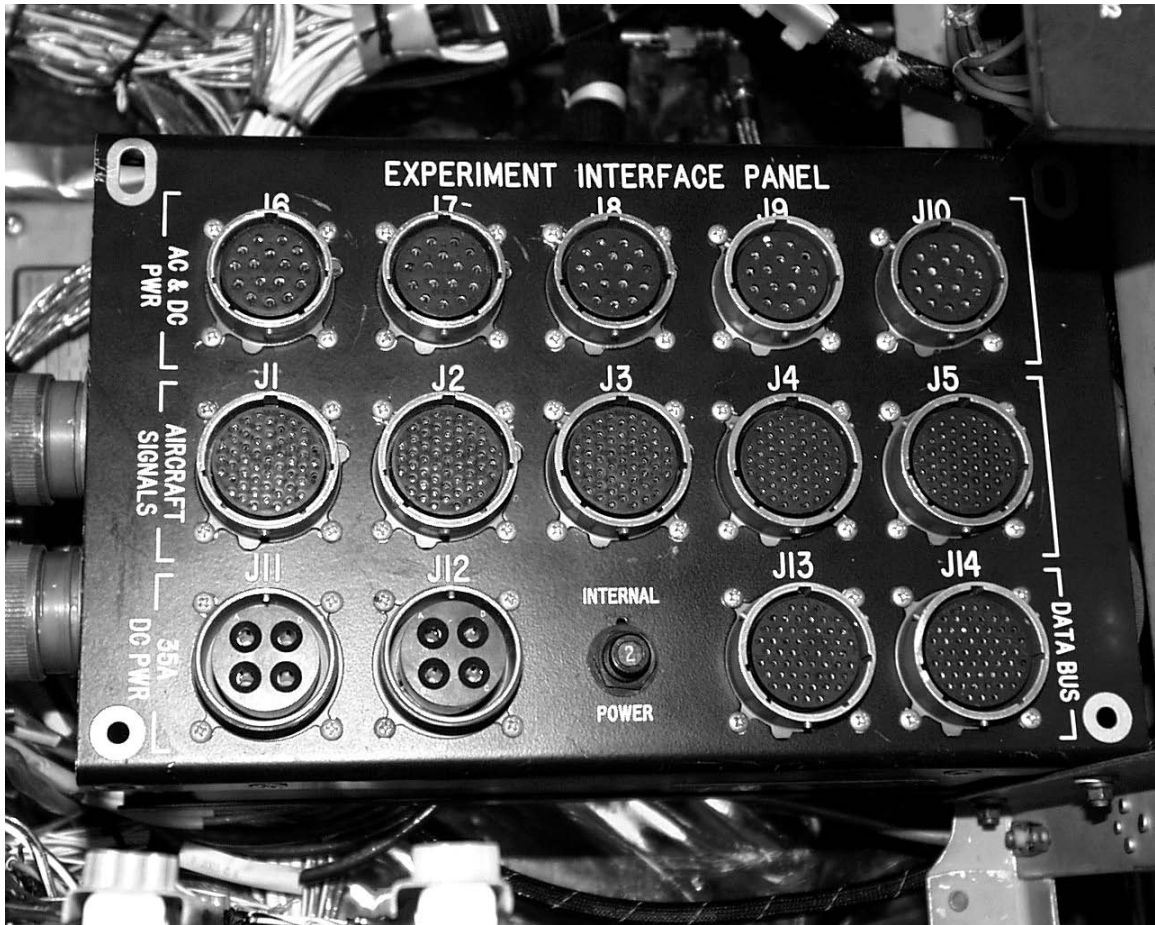
**Figure 6-2. Electrical interface panel.**

Corresponding to switches one through five on the control panel are receptacles J1 through J5. These identical receptacles provide the various timing, control and aircraft navigation signals. The pinout for these receptacles is shown in figure 6-3.

AC and DC power are provided through identical receptacles J6 through J10. These five receptacles provide a total of 25 amperes (amp) of AC current per circuit (all payload areas) or 35 amps of DC current per circuit (40 amps at the left/right wing interface panels). Each plug contains 2 circuits. Each pin is limited to a maximum of 15 amps. Figure 6-4 shows the pinout configuration for these receptacles.

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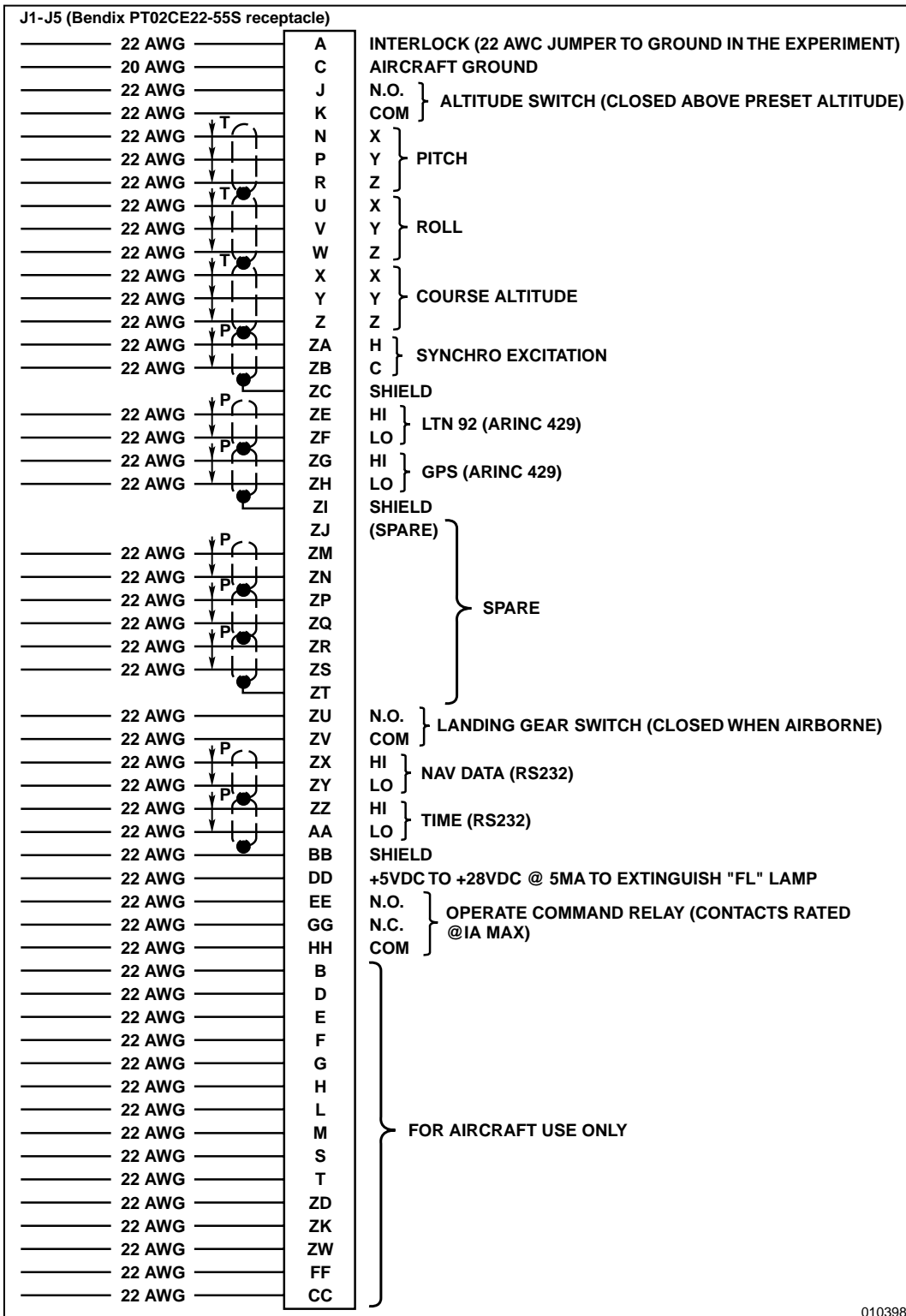
Receptacles J11 and J12 are identical and each can provide full DC power. Each plug contains 2 circuits. Each circuit can provide 35 amps of DC current (40 amps in the left/right wing interface panels). Figure 6-5 shows these pinout configurations.



**Figure 6-2 (b). Electrical Control Panel.**

Identical receptacles J13 and J14 are connected in parallel with each other and the other interface panels. These receptacles provide interface wiring between payload areas. Figure 6-6 shows these pinouts and wire types.

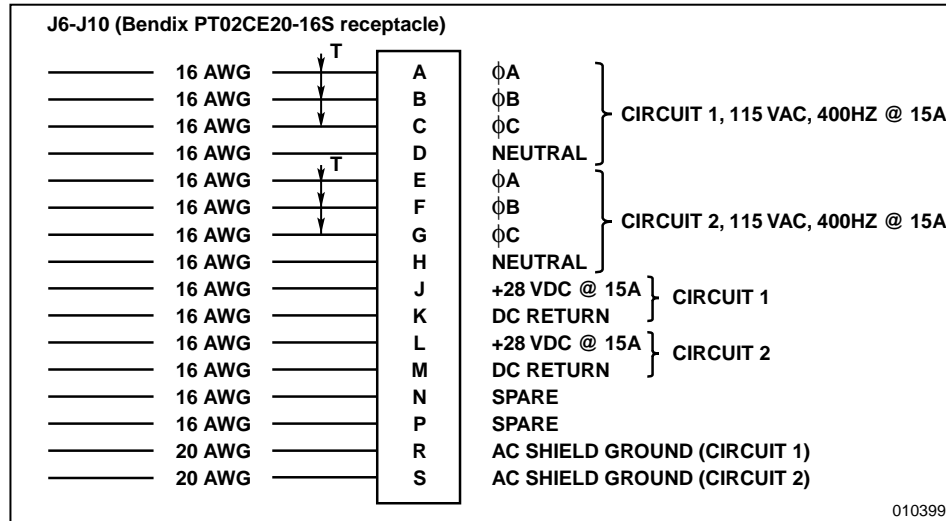
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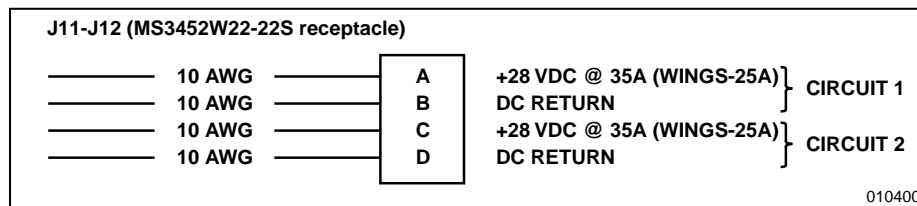
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Figure 6-3. Pinout receptacles J1-J5.

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**Figure 6-4. Pinout receptacles J6-J10.**



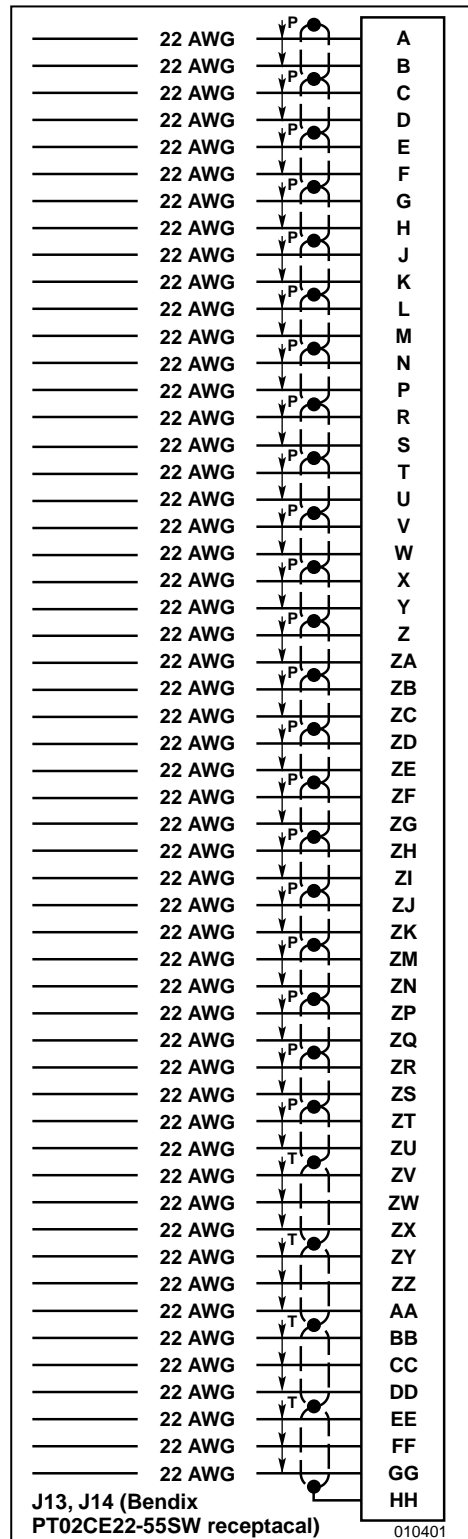
**Figure 6-5. Pinout receptacles J11-J12.**

**5. Experiment Interconnect Patch Panel**

The experiment interconnect patch panel is located in the Q-bay and provides the interconnection between the experiment payload areas and the aircraft. The panel provides access to the twelve coaxial cables from the nose and left and right wing payload areas. These coaxial cables also provide access to the twelve analog channels, available to experimenters, which are recorded by the NAVREC ( $\pm 5$  VDC).

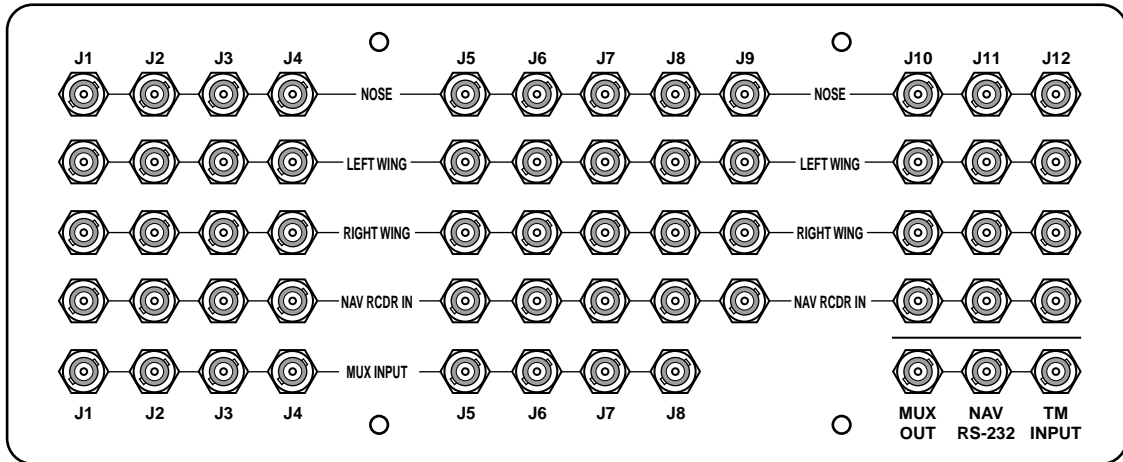
Left and right wing interconnect panels, as well as the nose panel, are similar to the type shown in figure 6-7. BNC type receptacles and 50 OHM, RG-188 A/U isolated coaxial cables are used throughout.

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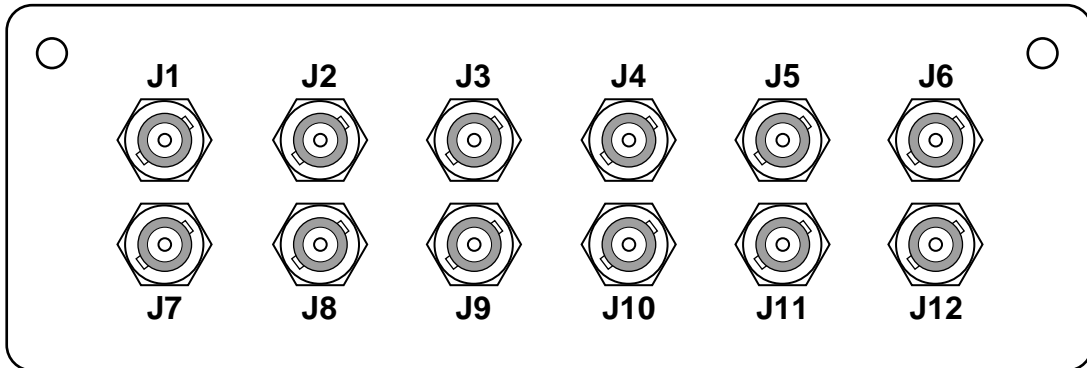


**Figure 6-6. Pinout receptacles J13 –J14.**

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**Q-Bay coax patch panel  
Kings KC96-OI insulated BNC coax receptacles (typical)**



**Nose and wing pods coax patch panel  
Kings KC96-OI insulated BNC coax receptacles (typical)**

010402

**Figure 6-7. Experiment interconnect patch panel.**

**6. Aircraft Ground System**

To avoid ground loops, it is recommended that experimenters ground their instruments through the power returns provided on the experimenter interface panel. If 115 VAC, 400 Hz power is used, the neutral return must not be grounded to the aircraft in any way.

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**7. Electromagnetic Interference (EMI)**

Power grounding as described above minimizes the possibility of generating ground loops within the aircraft structure. Also, every effort is made, in ground testing before flights, to assure that there is no interference between experiments because of their electrical power characteristics. However, occasionally such interference may show up in flight. In such circumstances it may become necessary to rearrange power distribution to eliminate mutual interference. It is incumbent upon the experimenters to assure that any minor voltage transients do not adversely affect their experiment equipment, and also to assure that operation of their equipment does not adversely affect the other experiments.

Experimenters are cautioned that transmitters on the aircraft may cause interference with their equipment. Care should be taken in the choice of grounding and shielding techniques for sensitive digital or analog circuits. Active emitters, such as TACAN or the aircraft transponder, can result in appreciable skin currents that may cause serious problems with these circuits. In order to minimize these effects, the experiment should be grounded to the experiment interface box. Refer to chapter 2, table 2-2 for a list of frequencies to be considered in experiment design. Conversely, experiment equipment must not interfere with aircraft radios, controls, displays, or navigation equipment.

**8. Electrical Safety**

Electrical safety procedures at DFRC are governed by Dryden Centerwide Procedure DCP-S-025, "Lockout/tagout"; and DCP-S-026, "Electrical Safety". These documents must be reviewed and understood by experimenters who bring their equipment to DFRC. Contact the mission manager for a current copy. Safe installation and operation of electrical equipment depends on observance of the following design considerations.

**A. High Voltage Protection**

Reduced atmospheric pressure increases the possibility of corona discharge and arcing between high voltage components and ground. High voltage leads should be sufficiently insulated to prevent flash-over at the reduced pressures expected for the payload area chosen.

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These conditions should guide equipment design with respect to lead separation: insulating high voltage components, avoiding sharp bends, solder peaks, and other rational practices. High voltage components and cables must be clearly marked and, where practical, electrical and mechanical interlocks should also be used. Contacts on terminals carrying fifty volts or more to the ground must have guards to prevent accidental contact by personnel.

All instrument boxes and panels where electrical power or signals are routed should be electrically bonded to the structure where they are mounted.

**B. Wire and Cable Insulating Materials**

Certain types of wiring may emit dangerous chemicals or gases if burned. Therefore, the experimenter must provide thorough documentation as to the type of wire that will be used. Lockheed Goldenrod wires or Teflon wire is to be used outside sealed enclosures. No PVC wiring is permitted for these applications. PVC wire is generally not permitted for aircraft use; however, it may be allowed in a sealed box under specific guidelines with the specific approval of Lockheed Engineering. Lockheed Engineering can provide guidance on specific wire selection. Teflon coated wire is acceptable inside unsealed, closed boxes. Accessories such as: identification sleeves, cable ties, chafe guards (spiral wrap), and cable clamps, should be of similar material.

Whenever practical, wiring should be color-coded or numbered. Regulations concerning color coding or numbering can be obtained from Lockheed Engineering.

In general, the wire type, size, and gauge must be compatible with the characteristics of the circuit. Conductors must be of sufficient cross section, temper, and flexibility so as to provide ample and safe current-carrying capacity and strength. No wire smaller than 22 gauge will be allowed when routing is outside sealed enclosures.

Bare hookup wire may only be used when insulated wire is not practical due to the shortness of wire run, or circuit characteristics. Lockheed Engineering will specifically approve wire type for these applications.



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**C. Current Overload Protection**

Current overload protection must be provided for the instrument through the use of fuses or circuit breakers. The aircraft circuit breakers are designed to protect the aircraft electrical system wiring to the interface box. It is the experimenter's responsibility to provide protection from the interface box to the instrument. The circuitry within the instrument must be capable of carrying the full amperage of the aircraft circuit to which it is connected. If the circuit is not capable of carrying the aircraft circuit amperage, it must contain fuses, circuit breakers, or other approved devices to limit amperage consistent with the circuit. It is the responsibility of the experimenter to provide fuses, circuit breakers, or junction boxes internal to the instrument as appropriate. Lockheed Engineering review of these devices is required.

**D. Component Selection**

Components used in the electrical circuits must be of aircraft grade; Mil-spec components are desirable. External electrical connectors must be approved for airborne use and purchased from an approved source. Lockheed Engineering can provide a current list of sources for these components.

**9. Experiment Cabling**

The cabling from the instrument to the EIP can be manufactured by DFRC, using the requirements transmitted by the experimenter. DFRC will use the proper connectors for the aircraft side of the interface and approved aircraft wiring. Usually, the wires or pins connected to the experimenter connector are left unterminated until the instrument has arrived at DFRC.

Alternately, the experimenter can fabricate his/her own harness, and the aircraft connector can be installed after arrival at DFRC. This harness will be inspected by Lockheed Engineering and the pinout verified before use. Experimenters are responsible for the cabling between two or more assemblies of their own equipment.

Service loops should be incorporated where necessary to allow for the opening of the payload access areas (pod fore-bodies or aft bodies, nose, hatch, etc.). Excessive movement of cable runs should be prevented by clamps or tie-downs.

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**10. Equipment Certification**

Experimenters are responsible for the design and assembly of electrical systems in accordance with these specifications. Experimenters should submit drawings, circuit diagrams, estimates of both DC and AC power requirements, description of fail light logic and cockpit control switch logic, and required or desired connections to aircraft data busses, to Lockheed and DFRC.

Additionally, information should be provided about all items with high or transient current draws, including electrical motors, vacuum pumps, heaters, flash lamps, etc. This information should cover: type of load, starting (inrush) current magnitude/time scale, and thermal overload protection.

Lockheed will review the material, request changes as needed, and prepare a power distribution plan for all the experiments in the payload. Final verification of electrical systems will be made at DFRC, prior to approval for installation on the aircraft.

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**CHAPTER 7**

**FACILITY INSTRUMENTATION**

**1. General Information**

A variety of systems are available to acquire aircraft flight parameters and related environmental data in support of the research activities. Some of these systems are standard on-board facilities; others can be provided on request. Outputs vary from real-time electrical signals distributed to experiments to post mission copies of film data files, as outlined in the following paragraphs.

**2. Standard Aircraft Systems**

The data acquisition systems listed below are standard to the aircraft. All data to experimenter is routed through the ER-2 NAVREC, described in further detail in appendix C.

**A. Inertial Navigation System (INS)**

The Litton 92 Inertial Navigation System provides information on aircraft position, altitude, attitude, velocity, accelerations, and winds. It is capable of operating as a pure inertial system (with no updates except manual initialization), but it is usually updated by position fixes from the GPS receiver. The DOD World Geodetic System of 1984 (WGS-84) is the convention used for all positioning and navigation purposes.

**B. Global Position System Receiver (GPS)**

The Litton 2001 GPS Receiver receives timing signals from the orbiting GPS satellite constellation, and calculates position, altitude, and velocity. This information, as well as satellite health and solution accuracy, is available to experimenters.

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**C. Temperature and Pressure Probes**

Rosemount pressure and total temperature probes measure the outside air temperature, barometric altitude, and airspeed. The raw data is measured by the NAVREC, converted to engineering units, and broadcast to all payload areas. This is also used, along with velocity information from the INS, to provide a separate calculation of wind speed and direction.

**3. Camera Systems**

For missions requiring photographic coverage, the mission manager can arrange for various camera systems. These camera systems are frequently used to obtain photographic records of the area surrounding the aircraft's flight path. Experimenters should make their camera requirements known as far in advance as possible of the planned mission.

The camera systems can be controlled manually or automatically at frame rates to accommodate most aircraft speeds and altitudes. The automatic frame rates can be controlled by either time or percentage overlap. Film is marked with Greenwich Mean Time (GMT).

More information about the camera systems available on the ER-2 is given on the worldwide web site of the Airborne Sensor Facility: <http://asap-data.arc.nasa.gov>

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**CHAPTER 8**

**NAVIGATION RECORDER SYSTEM**

**1. General Information**

The ER-2 Navigation Recorder (NAVREC) is a general-purpose data system designed for in-flight housekeeping support. It is housed in the E-bay, behind the Q-bay. The functions of this computer facility include:

- Real-time processing of housekeeping (avionics and environmental sensor) data.
- Real-time distribution of housekeeping data to experiments.
- Logging of housekeeping data for post-flight use.
- Broadcast of timing information for in-flight synchronization of payloads.
- Archiving and post-flight distribution of housekeeping data and derived products, via the Data Systems Engineering Office.

Experimenters intending to utilize the NAVREC services should identify their requirements to Airborne Science in the early stages of mission planning or instrument design. This will ensure that changes or upgrades in the NAVREC system are coordinated with experimenter's requirements and the support staff is prepared for the experimenter's requirements.

**2. Housekeeping Data Acquisition and Processing**

Navigational and environmental data from permanent aircraft sensors are acquired, processed, distributed to experiments, and recorded on flash disk. Data from the inertial navigation system (INS), global position system (GPS) receiver, and air temperature and pressure transducers are acquired at one-second intervals.

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Data acquired at a rate in excess of one sample per second is averaged over a one second period. Data is converted to engineering units and is recorded on disk at a rate of once per second. The ASCII-formatted, engineering units are distributed to experiment stations at a rate of once per second. All data is recorded with a time stamp synchronized with UTC. A list of parameters available for recording, display, and printout can be obtained from the Dryden Airborne Science Directorate.

**3. Housekeeping Data Distribution**

The NAVREC distributes aircraft housekeeping data over three serial buses. All are half-duplex (one-way), from the NAVREC to the instruments. No hand shaking is required or possible; it is the responsibility of the instrument to capture the broadcast data stream. The busses are:

**A. A Standard RS-232-C Serial Line**

This line will transmit ASCII formatted engineering units at 9600 baud. This buss contains a subset of parameters monitored from all inputs to the NAVREC. This is an easily accessible way for experimenters to retrieve basic housekeeping data with low cost circuitry and software.

**B. An ARINC 429 High-speed Serial Bus from the Inertial Navigation System**

This buss passes through the NAVREC only to electrically isolate the instruments from the INS. The NAVREC does not filter or add any words to this stream. The INS broadcasts information about aircraft position, attitude, velocity, course, and winds. Words are transmitted in binary coded decimal, and require an ARINC 429 receiver card to be installed in an instrument's data system.

**C. An ARINC 429 High-speed Serial Bus from the GPS Receiver.**

As with the INS bus, the NAVREC merely passes this information along, unmodified, to the payload areas. The GPS receiver broadcasts information about date, time, aircraft position, velocity, and the status of the visible GPS satellites.

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**4. Ground Based Support**

NAVREC personnel are available at DFRC to assist experimenters in verifying their interface with the NAVREC data distribution subsystem. These personnel do not accompany the ER-2 on deployments away from DFRC.

After each mission, post-flight processing software generates standard data products, including track plots, time-series plots of selected parameters, ASCII formatted tabular time histories of selected parameters, and a flight report which includes switch events, take-off and landing times, as well as any reported anomalies during the flight which may have affected the navigational recorder data. These products are available over a network connection, may be distributed on a removable disk, or most any other requested method.

**5. Timing Information**

The NAVREC distributes time information to each payload area. Date and time words from the GPS receiver are read, translated and formatted. Instruments can receive this timing information in two ways:

**A. An IRIG-B Analog Time Signal**

This signal is distributed to the experimenter interface panel in each payload area. The IRIG-B time code format is an amplitude-modulated signal that requires a specialized card or chip to decode and use.

**B. An RS-232-C Serial Line**

This line operates at 9600 baud. This serial line, separate and independent of the housekeeping data RS-232 line, transmits an ASCII line once per second. The string is terminated by a carriage return and line feed. The effective time begins at the first character of this frame with less than 0.1 milliseconds of delay. The output format (in ASCII) is as follows:

DATE\_ \_XXX\_ \_TIME\_ \_XX:XX:XXCRLF (27 characters total)  
where CR = carriage return, and LF = line feed

The day of year is 001 on January 1st, and the time is Greenwich Mean Time (GMT).



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**6. Data Archival and Distribution**

All raw data and processed engineering-units data (in both binary and ASCII-formats) are recorded to flash disk at a rate of once per second. All data are permanently archived at DFRC, and distributed by an anonymous ftp server for several years after each flight. Requests for older data may be satisfied with some delay.

**7. NAVREC Data Access**

The steps to accessing the NAVREC data are as follows:

- ftp to the Dryden anonymous server  
For Netscape: ftp://ftp2.dfrc.nasa.gov or ftp.dfrc.nasa.gov  
For Command Line: ftp2.dfrc.nasa.gov or ftp ftp.dfrc.nasa.gov  
Login: *anonymous*  
Password: <your e-mail address>
- Change directory to *pub/ASDS/ER-2*
- Flights are stored by fiscal year (FYxx)
- List directory, either *ls-l* or *dir*
- Change directory to the appropriate FY

Get your files and logout with *bye*.

To obtain your files uncompressed, use the *get* command and use the file-name minus the .Z extension, when in the command line mode for ftp.

On initial logon, after transferring to the ASDS directory, read the PS readme.1st.text.

For view on a PC, use "Ghostview," a free shareware found on the internet.

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**CHAPTER 9**

**FLIGHT OPERATIONS**

**1. Flight Operations**

**A. General**

It is the responsibility of the experimenter to prepare an operational checklist for the instrument. The checklist will include times at which switches must be manipulated or instruments which need to be monitored. The checklist will also include pre- and post-flight activities to be performed by the pilot. The experimenter will also provide a malfunction checklist.

**B. Pre-flight Operations**

Instrument pre-flight checks must be coordinated with the maintenance crew chief and routine pre-flight inspections must be performed by the Lockheed ground crews. The experimenter is strongly encouraged to relate sensor support needs to the Lockheed crew chief well in advance of scheduled flight times. As a general rule, the experimenter should have completed all pre-flight checks, including uploading of cryogenics, at least 2 hr prior to scheduled launch. At this time the aircraft will be fueled. During this operation, no electrical power will be available to the aircraft. For safety reasons, personnel whose tasks are not connected with this operation will not be allowed near the aircraft at this time. When fueling and oxygen replenishment are completed, external power will be connected to the aircraft (approximately 1 hr prior to launch). In order to prevent possible damage from voltage transients, the instruments will normally be shut off while external power is removed and internal power is selected. If continuous power is necessary for a particular instrument, arrangements must be made well in advance.

Since the pressure suit worn by the mission pilot restricts mobility and makes pre-flight checks difficult, a mobile pilot will arrive approximately 1 hr prior to launch to pre-flight the aircraft for the mission pilot. With the pre-flight checks completed, the mission pilot will arrive approximately 30 min prior to scheduled launch.

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The engine is started approximately 15 min prior to launch. During ground operations very little cooling is available from the ECS. While at idle thrust, engine bleed air used for air conditioning is limited and some heat build up will occur in the aircraft payload compartments. Heat will build more rapidly in the pilot's pressure suit however. For this reason the aircraft is taxied to the runway as soon as possible following post engine start-up checks.

**C. Takeoff**

To accommodate the requirements of Air Traffic Control, the ER-2 will launch on time. A limited amount of time (30 sec) is available prior to launch to turn on instruments. Extremely limited time is available during the first 5 min of flight to manipulate instruments.

**D. High Altitude Operations**

The desired altitude and range must be within the performance limitations of the aircraft. Other restrictions may be imposed due to turbulence, winds at altitude, temperature, or lack of visible horizon for attitude reference in the event of emergency. Should these or other conditions become a matter of concern to the pilot, he will decide whether the mission will be continued.

**E. Descent and Landing**

When the mission tasks have been completed the descent from high altitude will be initiated. The normal rate of descent for the ER-2 is 2,000 ft/min (610 m/min). Normally, instruments will be turned off after landing, however, instruments may remain powered for a short time for sensor calibration. As is the case in pre-flight procedures, the pilot may be subjected to overheating. For this reason only 30 sec to 1 min will be allowed for post flight, power on sensor checks.

**F. Post Flight Shutdown**

Due to the time required to inspect, service, and tow the aircraft, experimenters should allow for 30 min to 1 hr after engine shutdown before instruments can be accessed.

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**2. Operating Limitations**

**A. Duty Day Limits**

As described in chapter 1, there are three firm rules for flight days designed to manage fatigue and maintain a safe level of operations:

- 1) Routine flight duration for the ER-2 is 6.5 hr. Flights longer than 6.5 hr require written justification and approval from DFRC flight operations.
- 2) The duty day for an ER-2 pilot is limited to 12 hr. The duty time begins at pre-flight reporting and ends at engine shut-down.
- 3) ER-2 pilots and maintenance crews must have at least 12 hr of off-duty time between leaving the flight line after one flight and reporting back for the next flight.

Sustained flight operations can quickly deplete maintenance and flight crew resources. For this reason, there are a few general guidelines that should be kept in mind in order to preserve operational flexibility.

Pre-flight reporting times and effort have increased in relation to the increasing complexity of instrument packages. The arrival time for maintenance crews and flight crews is normally 3 hr prior to scheduled launch time. There are, however, some instruments requiring weather related preparations or decisions that could result in as much as 5 hr pre-launch report times for maintenance crews and 4 hr for pilots. Requirements such as these can maximize the duty day for pilots, leaving no room for delays due to weather or instrument/aircraft malfunction.

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To illustrate the difficulties of extended mission lengths on sustained operations, consider this scenario for a planned 7 hr mission:

- 10:00: Scheduled launch time.
- 06:00: Maintenance crew and pilot report time.
- 10:00: Actual launch (no delays, no problems)
- 17:00: Actual landing time.
- +2 hr: Routine post flight maintenance.
- 19:00: Maintenance crew departs flight line.

Resulting situation:

- Maintenance crew duty day is 13 hr.
- Pilot approaches maximum duty day length of 12 hr.
- Next day, earliest reporting time for crew and pilot is 07:00.
- Next day, earliest launch time is 11:00.

If the following day's flight employs sensors with requirements for high sun angles, the flight track will be constrained to remain in the vicinity of the takeoff point. Multiple days of this schedule will move takeoff times later in the day until high sun angles are not available. In some cases the NASA mission manager may require a down day for safety reasons when crews are operating at or near maximum duty days.

## **B. Flight Planning**

Normally, planned mission lengths will be below 6.5 hr. If no alternative presents itself to accomplish the mission objectives (such as flying two sorties instead of one) a longer duration flight of up to 8 hr can be flown with specific approvals.

The ER-2 operations staff will work closely with experimenters to ensure that the mission objectives can be met in the most efficient manner possible. When changes occur in the mission objectives the operations staff will do its best to accommodate these changes.

On the day prior to the scheduled flight, a briefing will be held to decide the next day mission possibilities. Flight plan options are presented and maintenance crew report times are set based on the earliest possible launch time. After this decision only limited changes, which would delay the launch time, will be considered. The following changes will not be considered:

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- A new requirement to enter warning or restricted airspace\*
- A new requirement to cross international borders\*
- A new requirement for an earlier launch time

\*Note: Coordination to enter this airspace must be made the day before the flight.

No changes will be considered less than 3 hr prior to scheduled launch time. If changes are mandatory within this time frame, the flight will be delayed or canceled as appropriate. An experimenter, pilot, crew chief or NASA manager may cancel a flight at any time prior to scheduled launch. It is in the best interest of all to report any possible changes in the mission as soon as possible.

**C. Runway Conditions**

Should wind speed or projected wind speed, in any direction; reach 30 kn, flight operations will cease. If wind speed or projected wind speed includes a crosswind component equal to or exceeding 15 kn, flight operations will cease. Snow and ice present special problems for the ER-2 landing gear. Should such conditions exist, more restrictive limits will prevail.

**D. Operations over Remote Terrain**

Due to the restricted space available in the cockpit, only a limited amount of survival equipment is packed into the pilot's ejection seat. This will not provide protection from cold weather over an extended time period. A mission designed to cover remote or inhospitable regions must take these factors into account. The decision to undertake such missions will rest with the pilots. Experimenters should be prepared to show complete and thorough justification for such missions.

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**E. Limitations on Pilot Control of Instrument**

The ER-2 is a single seat aircraft. Thus, in addition to flying the aircraft, the pilot is responsible for the operation of the communication, navigation, and aircraft systems. While some systems require little attention, others require full attention in order to maintain the safety of the flight. Monitoring these systems is further complicated by the restrictive nature of the pressure suit worn by the pilot to protect him from sudden cockpit de-pressurization at extreme altitudes. The pressure suit, along with the minimal size of the cockpit, makes even the simplest of movements quite difficult. The combination of these constraints limits the pilot's time available to devote to operation of experimenter's instrument.

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**CHAPTER 10**

**GROUND OPERATIONS**

**1. General Definition**

The full and continuous involvement of the experimenters and their teams is required during the mission integration and operation periods at DFRC. Experimenters are responsible for the assembly, installation, checkout, and operation of their equipment, to specified aircraft standards.

**2. Experiment Assembly and Checkout**

Assembly and checkout of all the experiments involve the following elements.

**A. Experiment Integration Facility**

The Experiment Integration Facility (EIF) is located on the ground floor of Building 1623. The EIF provides an area for assembly and checkout of experiments before their installation on the aircraft. Incoming equipment is delivered to this point. The EIF manager will provide supplies and other routine services on request.

EIF facilities include: 60-Hz, 400-Hz, and 28 VDC power, compressed air, a freezer for photographic film storage, and oscilloscopes. There is also an ER-2 integration test facility (EITF) which allows for power-up tests and navigational recorder interface testing with real data. Contact the mission manager to schedule time with this system. Gaseous and liquid nitrogen and helium are available for cryogenic or other use by advance request to the mission manager. The mission manager will assure a continuing supply; however, he/she should be advised well in advance of requirements for additional amounts of liquid helium. Approved fasteners and other equipment mounting hardware are also available.

Basic, general-purpose tools are available to experimenters. The majority of these tools were manufactured to inch dimensions; therefore, experimenters who need metric tools must provide their own. Most experimenters have found that their work is expedited if they bring a complete set of needed tools with them.



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All tools belonging to the experimenters are to have identification markings on them. It is expected that the tools will be inventoried and a system of control over the tools will be used during equipment installation.

The EIF is open in the morning at 7:30 a.m. and can be made available for evening work. For safety reasons two or more people must be present in the EIF at all times. Requests for evening use must be coordinated with the mission manager.

**B. Support Services**

The ER-2 maintenance crew can answer questions about required workmanship, interference, and discrepancies with the aircraft and the information published in this handbook. Lockheed engineers are responsible for airworthiness and making any changes to the basic aircraft. The mission managers can support the experimenter in obtaining additional resources, including airspace clearances, security badging, or overtime.

Engineering technicians are located near the EIF and can assist in the interfaces between the experiments and aircraft systems such as the NAVREC timing information. The technicians are assigned to the aircraft, and are not available to support work on experimental equipment. Experimenters should include an electronics technician on their team if the need for such assistance is anticipated during experiment assembly and checkout. For special needs, it is not unusual for experimenters to arrange for electronics support from local suppliers of specific equipment.

The metal fabrication shops at DFRC are equipped to make special mounting hardware. However, unless requirements are discussed, and agreement reached during the early planning phase with the mission manager, it is assumed that the experimenter will provide such items. Requests for minor adjustments or small brackets can be handled on short notice during assembly. On short notice, shop facilities support may be limited by other priorities.

**C. Inspection**

Before any equipment leaves the laboratory for installation in the aircraft, an inspection is recommended for its compliance with all airworthiness requirements. The crew chief or his designee will explain any irregularities and suggest ways of handling them.

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**D. General Procedures**

The assembly and checkout period should be used to full advantage since problems delayed until installation can impact the scheduled sequence of operations for all the experimenters. It is customary to hold daily group meetings, at which the experimenters discuss their progress and problems with the mission manager, crew chief, and pilots. Timely action will be initiated to resolve problems that may delay the installation schedule.

Each item of equipment must be weighed and its weight marked on it (removable tape may be used). Scales are available in or adjacent to the *EIF*. This will not be accepted for official weight.

**E. Safety and Emergency - Hangar**

**CAUTION: Significant Instructions for Hangar Safety are Listed Below.**

At DFRC experimenters work in an environment generally unavailable to the public. The EIF is housed in a large hangar containing a number of aircraft, and it is sometimes necessary to walk through the hangar and on to the ramp area. Therefore, a certain number of safety precautions must be observed:

- No Smoking in the hangar, on the ramp, aboard the grounded aircraft, or in any DFRC buildings.
- Look out for cables, hoses, boxes, tow bars, moving vehicles, and movement of the hangar doors when crossing the hangar floor.
- Do not walk across the ramp unless escorted by DFRC personnel.
- Do not approach aircraft with engines running. Jet exhaust or prop wash is dangerous for a considerable distance behind the aircraft.
- Wear adequate clothing and shoes that totally enclose the foot.

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**IN AN EMERGENCY**

If a DFRC employee is not available for immediate assistance, dial this number from any phone:

**911  
For Emergency Aid,  
Fire, Accident, Etc.**

This emergency number is available at any hour. Callers should also be able to describe their location, so that emergency help can respond promptly.

**F. Ground Handling Equipment**

The experimenter must provide any special equipment that is required for the handling or integration of an experiment. This requirement applies to equipment required for storage or shipping to and from deployment sites.

**3. Installation of Experiments**

Following inspection and approval of equipment for aircraft installation, ER-2 mechanics and electricians will help the experimenter team install it on the aircraft. They will be working to the installation kit drawings provided by Lockheed Engineering and the schedule or priorities set by the mission manager. The experimenters or their representative must be present during installation to advise and assist whenever an instrument is installed or removed from the aircraft.

No work may be done to an instrument installed on the aircraft unless a member of the maintenance crew is present. Electrical power from any source, including 60 Hz AC or batteries, cannot be applied to an instrument installed in the aircraft without a crew member present. Hatches and payload areas may not be opened or closed by any experimenter personnel. Extended hours, including weekends requires overtime for the ground crew and must be arranged for in advance. Budgetary limitations may preclude time in excess of two shifts on a five-day week basis.

If special positioning of the aircraft is required for experiment alignment or checkout, the mission manager should be notified a week or more in advance. This will allow time for obtaining the proper approval, and scheduling of ramp activities. Laser firings or radio transmitter tests require Air Force, NASA, and FAA approvals, which often require several weeks time.

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**A. Electrical Power**

Power is normally available on the aircraft for checkout when the aircraft is in the hangar or parked on the ramp. At these times, power comes from the ground generators producing 400-Hz AC. The stability of these sources is not necessarily as well controlled as the aircraft engine generators used in flight. 28 VDC power is provided by the transformer/rectifier assemblies in the distribution spider, or by the ground power cart.

Power distribution in the aircraft is controlled from the cockpit control panel. Experimenters are not authorized to switch power at this location. Upon request, a member of the ground crew or a pilot will switch power to the appropriate station.

Due to periodic maintenance and/or installation procedures, the ground crew may need to shut down electrical power for short periods of time. If power is needed for an uninterrupted period of time for check-out of experimenter equipment within the aircraft, the mission manager crew chief must be advised well in advance. This will allow the work of the ground crew on the aircraft to be coordinated with experimenter's needs.

Normally, a major upload is followed by a ground power check of all experiments. Each experiment's power station will be turned on sequentially to verify current draw is within aircraft limitations and that no cockpit displays or aircraft avionics experience interference. This also provides an opportunity for experimenters to check for interference from other experiments.

**B. Weight and Balance**

Instruments are weighed during their first assembly, after major changes, or following a prolonged hiatus. This information is used by the maintenance crew and operations to maintain the proper ballast and trim condition for the aircraft. Experimenters are responsible for notifying the crew chief of any changes to their instrument that affect the weight, including removal, addition or relocation of components, even temporarily.

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**C. Safety and Inspection - Aircraft**

**CAUTION: Significant Instructions for Aircraft Safety are Listed Below.**

While working near the aircraft, all participants must observe the following safety rules.

- No smoking in the hangar, on the ramp, or in any DFRC buildings.
- No repair or construction of experimenters' equipment by the experimenters will be permitted on the aircraft.
- No volatile solvents, of any kind, are permitted without prior approval of the mission manager.

The inspectors will recheck each experiment installation on the aircraft for full conformity with all safety regulations. Any deficiencies will be noted on an inspection sheet and attached to each rack. These must be signed-off before flight.

**4. The Flight Period**

During an ER-2 flight, the operations crew will maintain radio communications with the pilot. A member of each instrument team should remain within contact by phone or pager during the flight, in case issues with their instrument arise that are not covered by the checklist, or the expected return time is changed.

Normally, a daily meeting is held to plan the next day's schedule. This may occur at any convenient time, including during the mission.

**5. Post-Flight Activities**

After each flight, a mission debriefing is held to hear the pilot's report on the conduct of the mission, including weather and observed instrument performance. Copies of the pilot's notes and products from the NAVREC, if available, are distributed. Plans for the next day's mission are solidified or changed as needed based on the day's accomplishments.

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After the ER-2 has been brought back into the hangar, experimenters will have access to their instrument for the length of time required by the experimenter. However, extended time requirements may affect the next day's duty schedule. Those instruments requiring extensive time after each mission to test, trouble-shoot, or to download their instrument should make these requirements known in advance, so that this work can be adequately staffed.

When the flight period is completed, usually one day or less is allotted for downloading an instrument from the ER-2. This process is overseen by the crew chief, with support from Lockheed Engineering as needed. At DFRC, experimenter equipment is returned to the Experiment Integration Facility where research teams pack it for return shipment. The EIF manager will arrange for transport once the experiment team completes packing.

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**APPENDIX A**

**ER-2 PAYLOAD AREA DRAWINGS AND TYPICAL  
RACK DRAWINGS**

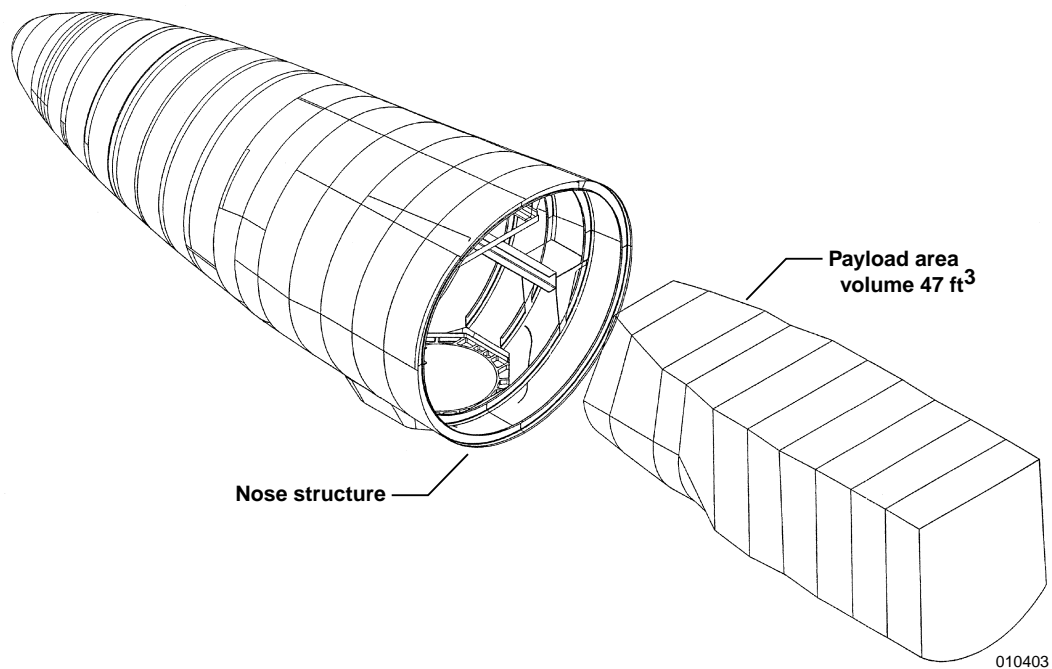
- 1) Figure A-1(a). Nose: volume and structure.
- 2) Figure A-1(b). Nose.
- 3) Figure A-2. Nose: general arrangement.
- 4) Figure A-3. Nose: usable payload volume.
- 5) Figure A-4. Nose: typical rack.
- 6) Figure A-5. Q-bay: general layout.
- 7) Figure A-6(a). Q-bay: usable payload volume.
- 8) Figure A-6(b). Q-bay looking aft.
- 9) Figure A-7. Q-bay: typical upper rack.
- 10) Figure A-8. Q-bay: typical lower rack.
- 11) Figure A-9. Q-bay: vertical rack.
- 12) Figure A-10(a). Q-bay: dual window hatch.
- 13) Figure A-10(b). Q-bay: dual window hatch.
- 14) Figure A-11(a). Q-bay: lower hatch (negative pressure box).
- 15) Figure A-11(b). Q-bay: lower hatch (negative pressure box).
- 16) Figure A-12(a). Q-bay: lower hatch (iris panoramic camera).
- 17) Figure A-12(b). Q-bay: lower hatch (iris panoramic camera).
- 18) Figure A-13. Q-bay: upper hatch.
- 19) Figure A-14(a). Super pod: general layout.
- 20) Figure A-14(b). Super pod: fore-body internal.
- 21) Figure A-14(c). Super pod: mid-body vertical rack.
- 22) Figure A-14(d). Super pod: aft-body internal.
- 23) Figure A-14(e). Super pod: mid-body internal.
- 24) Figure A-15. Super pod: typical fore-body rack.



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- 25) Figure A-16. Super pod: typical aft-body rack.
- 26) Figure A-17. 16 in. window installation
- 27) Figure A-18. Fuselage centerline/pod: general configuration.

The purpose of this appendix is to show general figures and photographs of payload areas. Please contact the Airborne Science Program Office to get specific and exact specifications for experiment design.



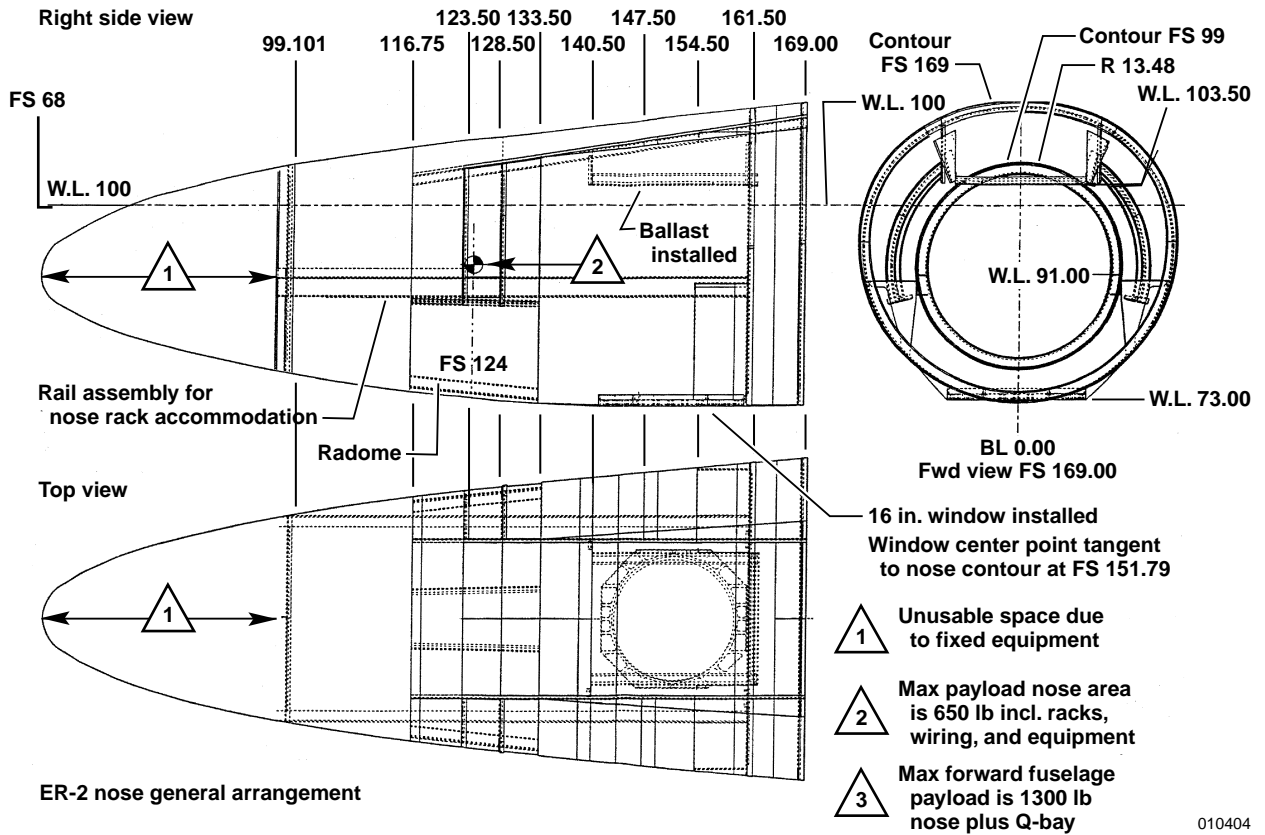
**Figure A-1(a). Nose: volume and structure.**

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Figure A-1(b). Nose.

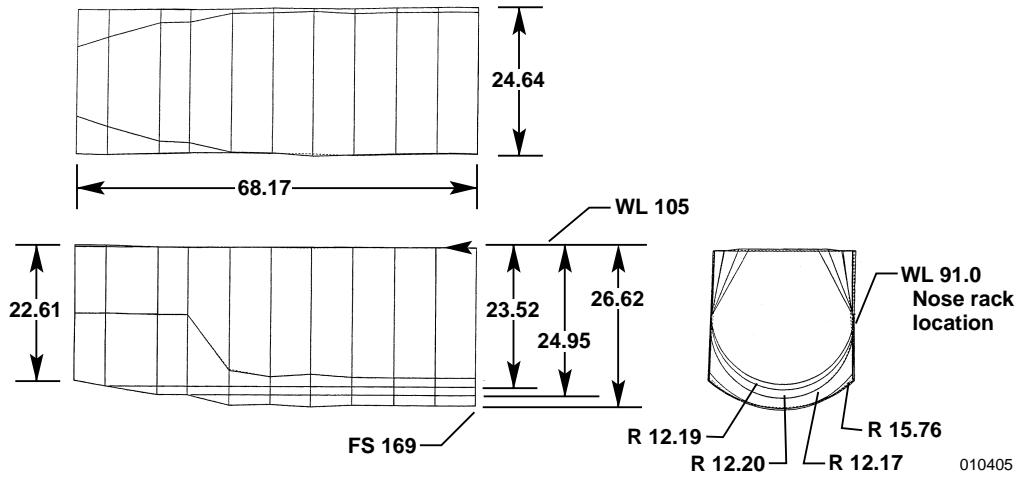
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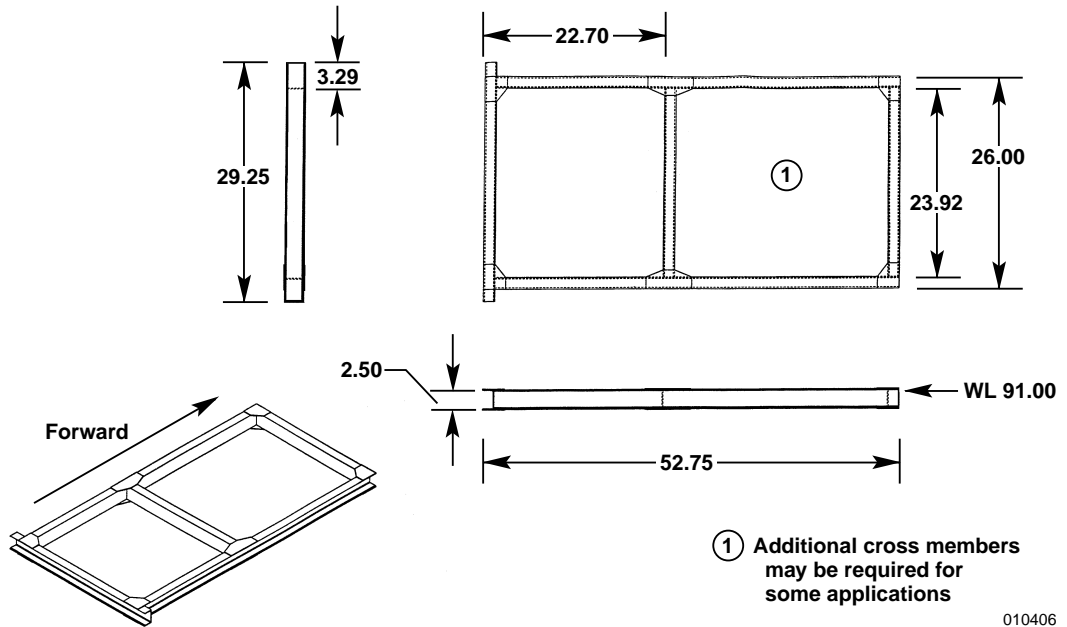
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Figure A-2. Nose: general arrangement.

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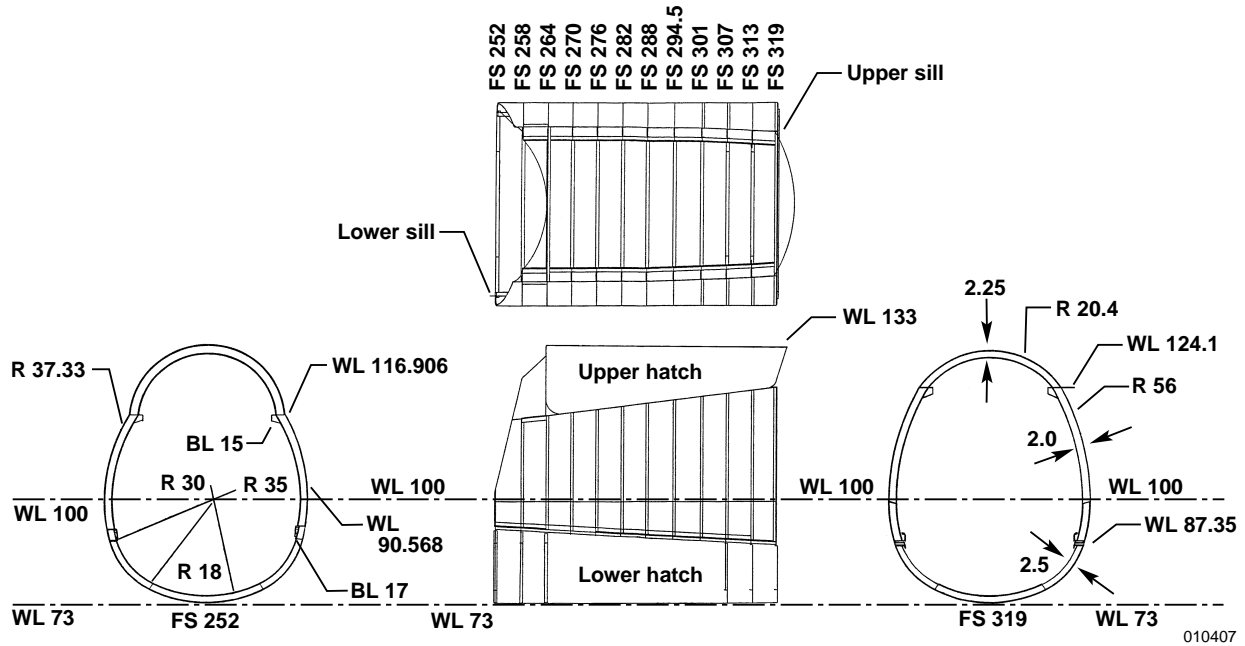


**Figure A-3. Nose: useable payload volume.**

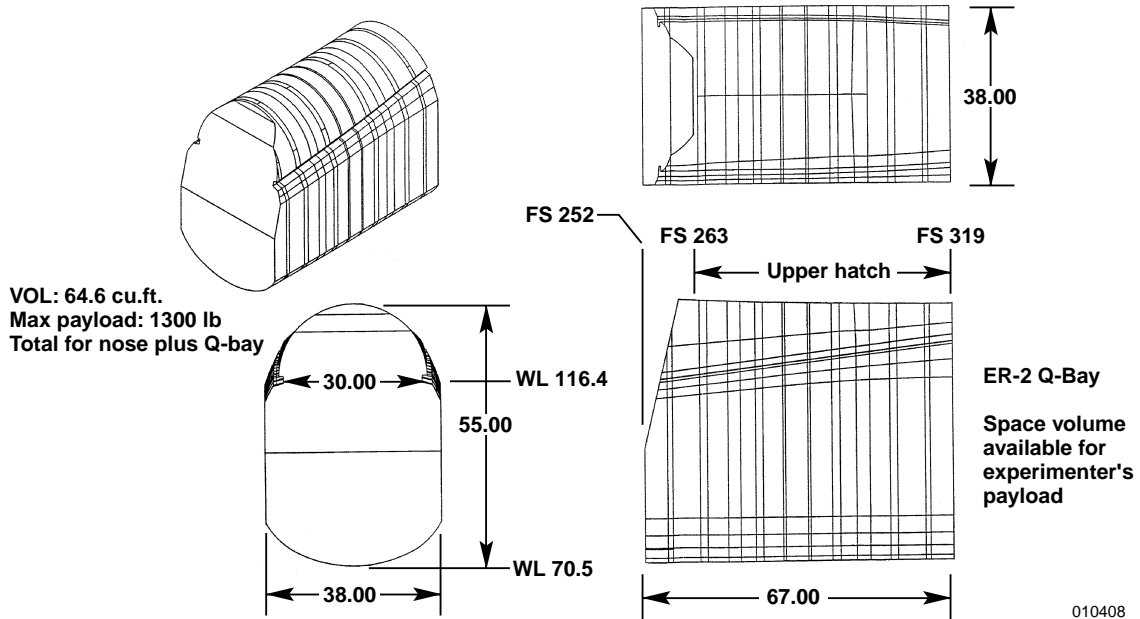


**Figure A-4. Nose: typical rack.**

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**Figure A-5.Q-bay: general layout.**



**Figure A-6. Q-bay: useable payload volume.**

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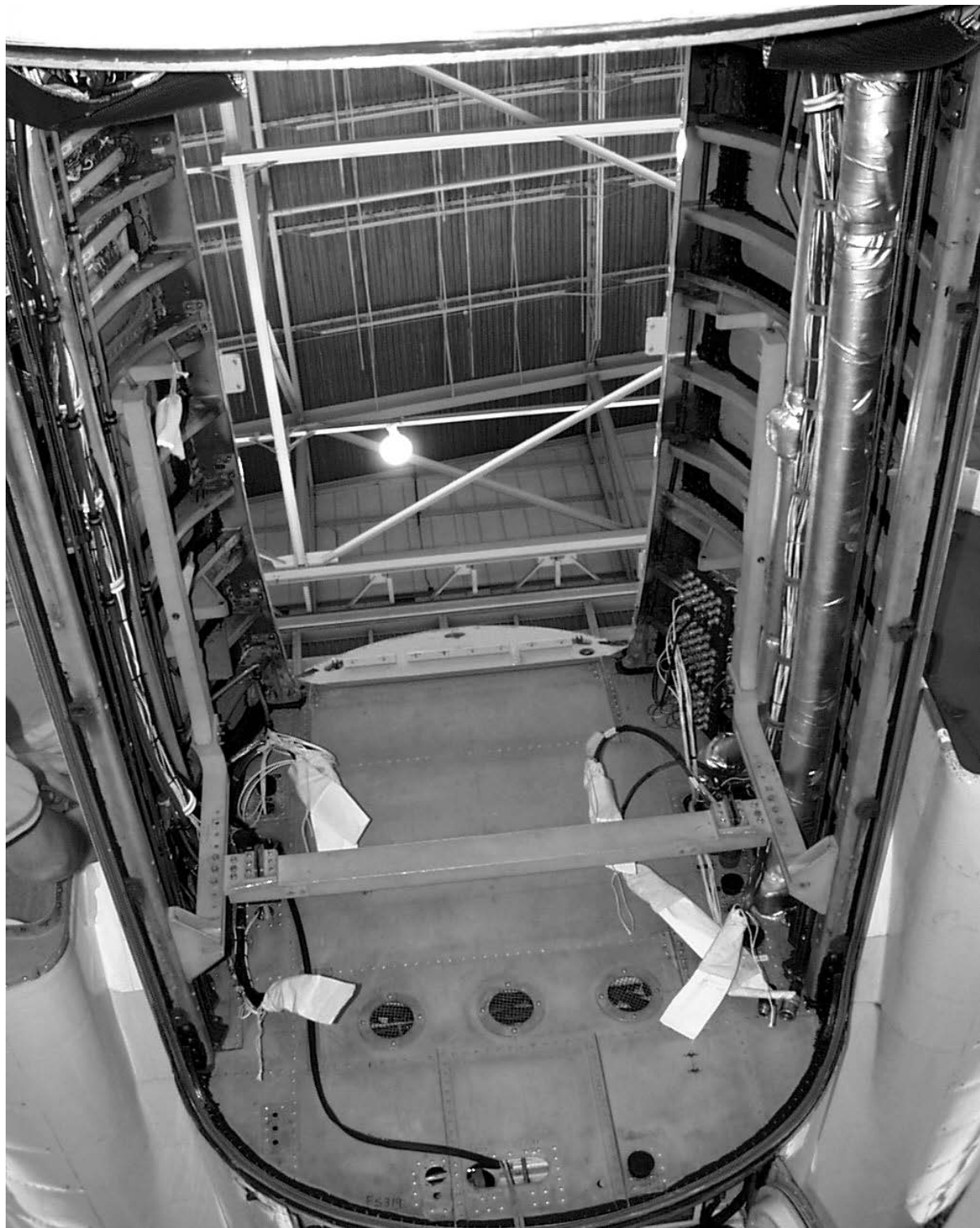


Figure A-6(b). Q-bay looking aft.

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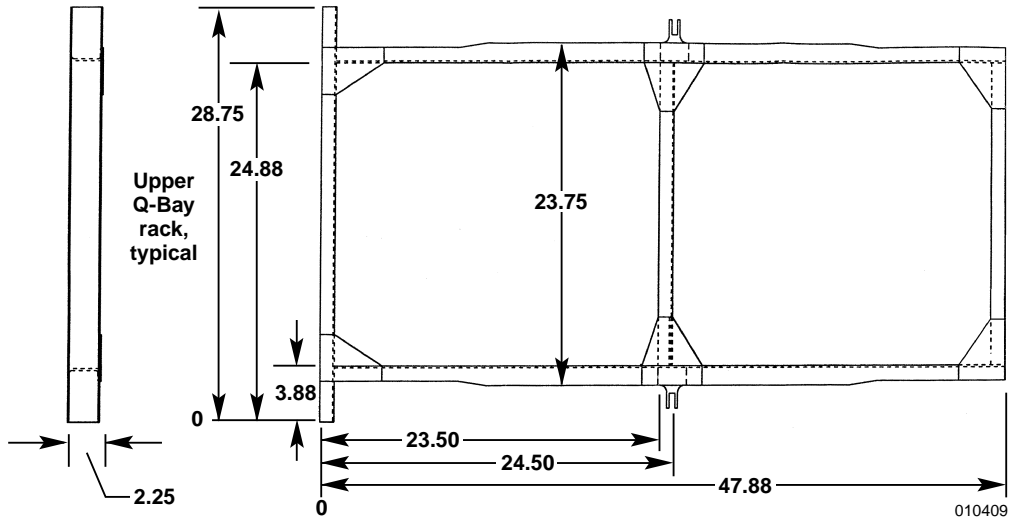
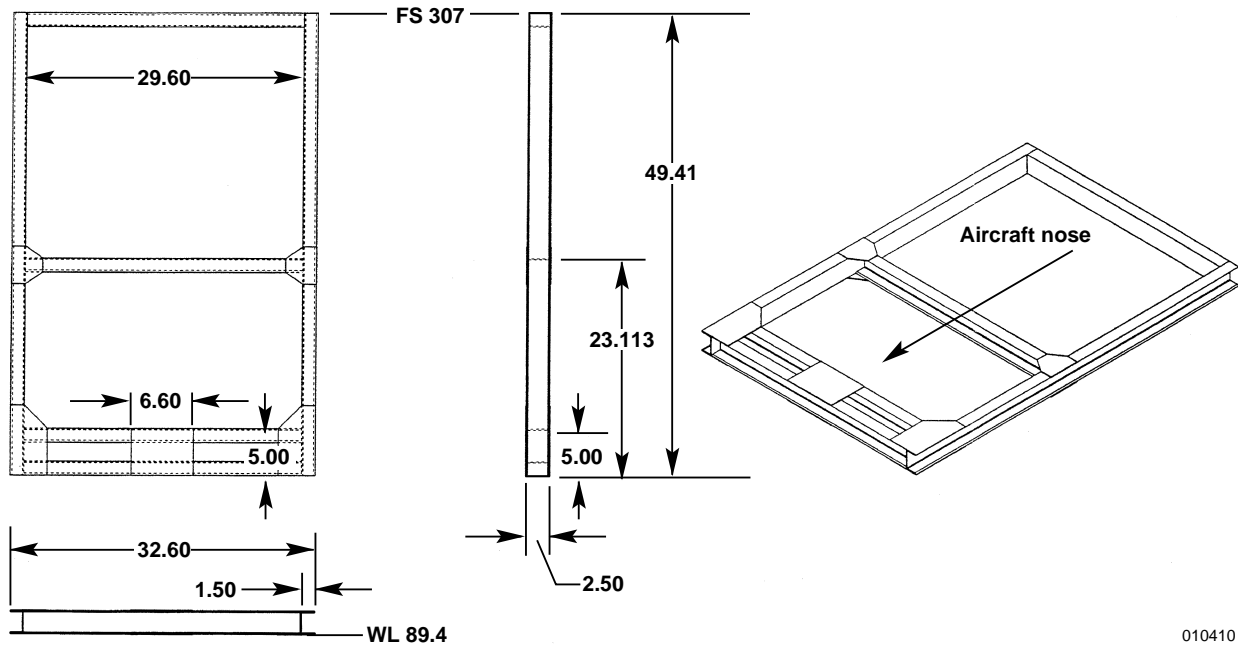


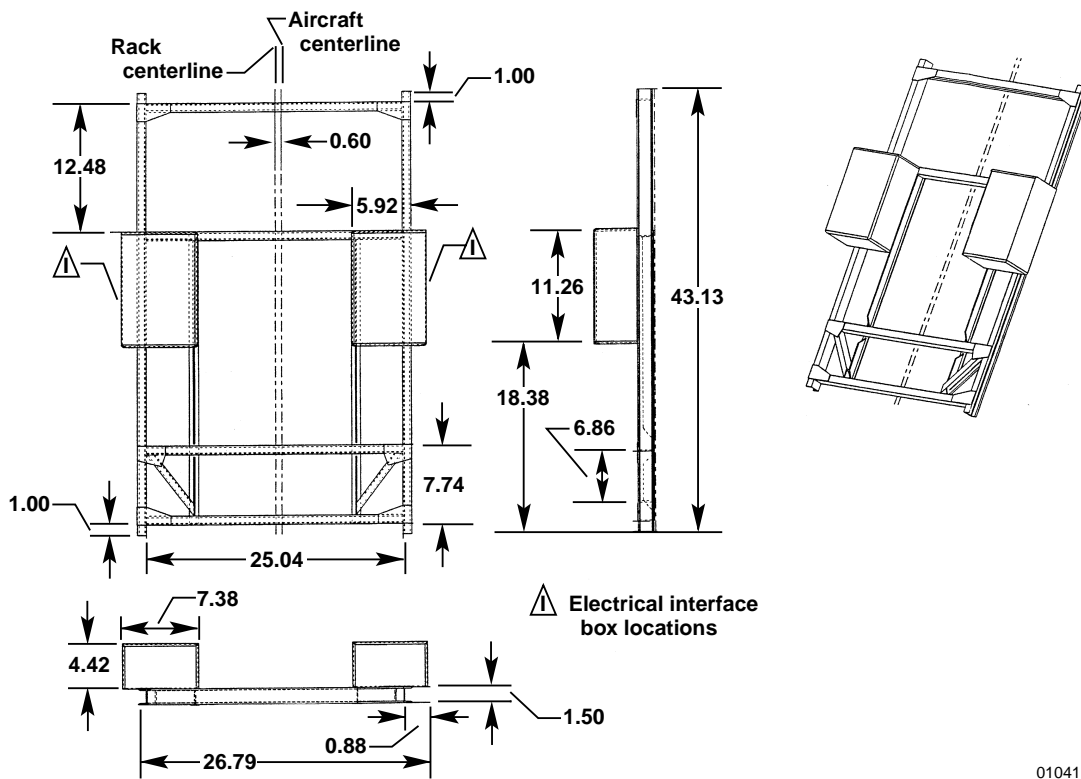
Figure A-7. Q-bay: typical upper rack.

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Figure A-8. Q-bay: typical lower rack.



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Figure A-9. Q-bay: vertical rack.



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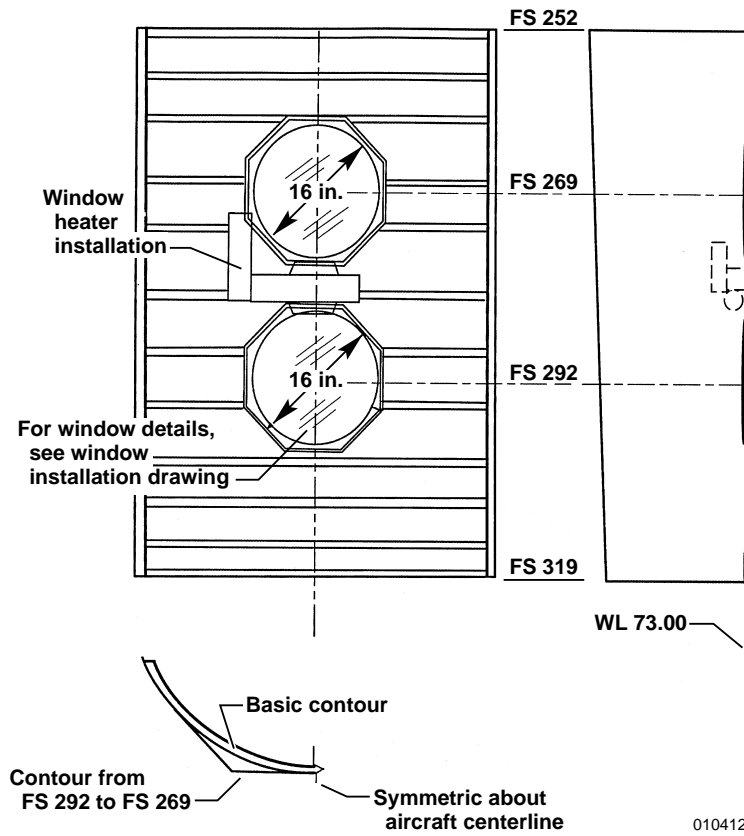


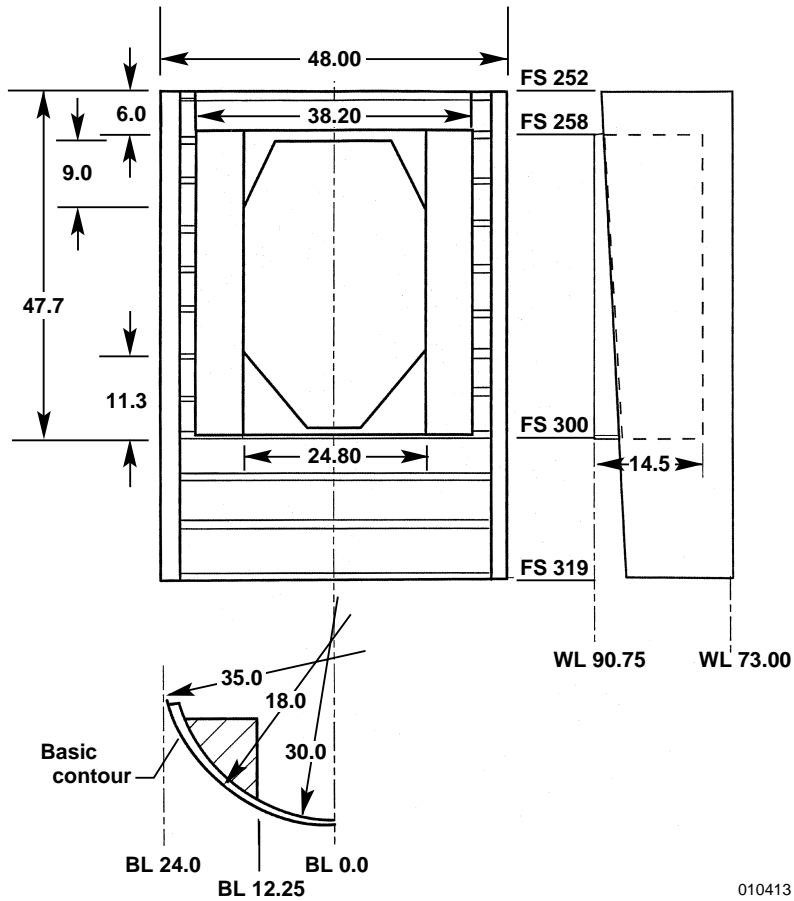
Figure A-10(a). Dual window hatch.

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Figure A-10(b). Q-bay: Dual window hatch.

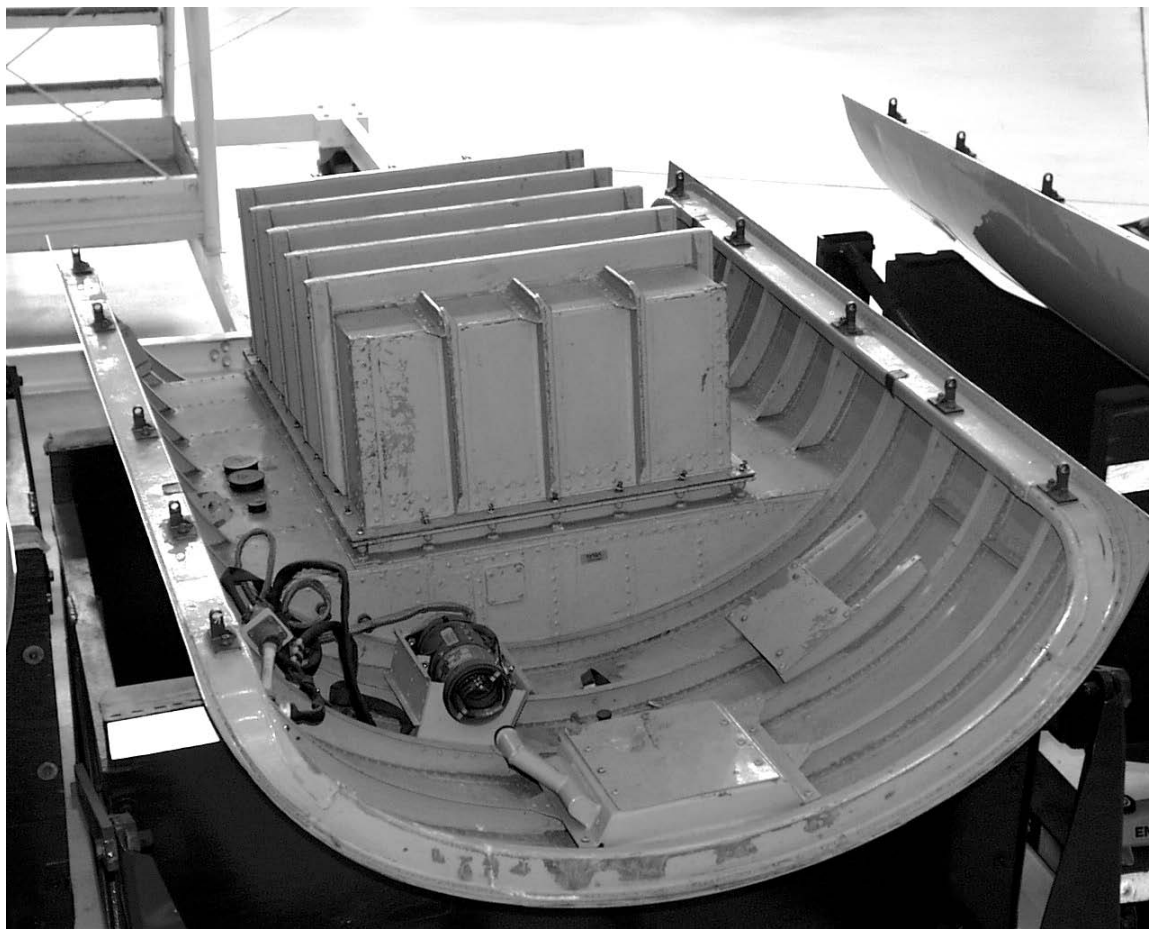
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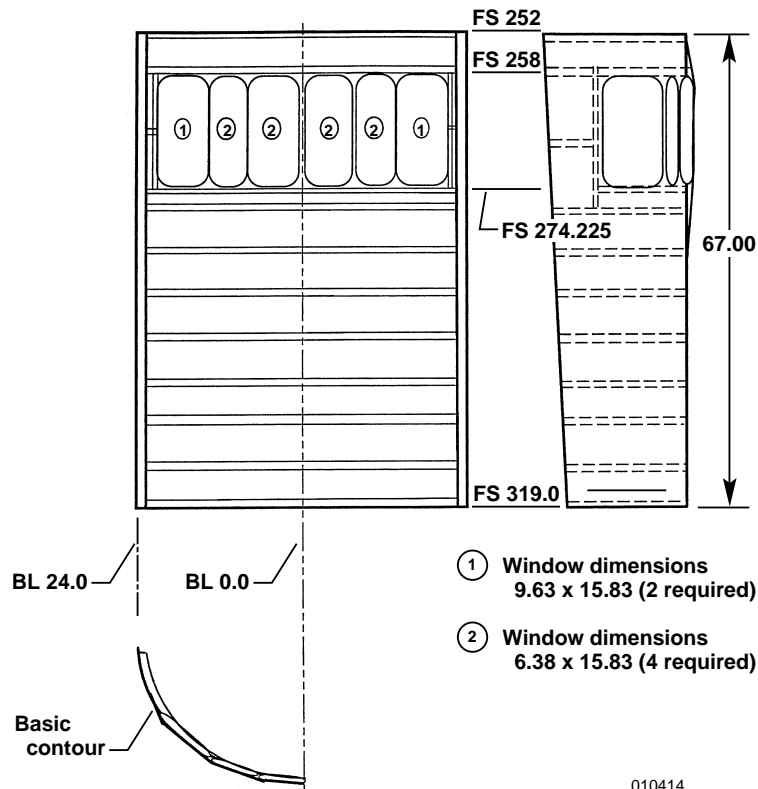
**Figure A-11(a). Q-bay: lower hatch (negative pressure box).**

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**Figure A-11(b). Q-bay: lower hatch (negative pressure box).**

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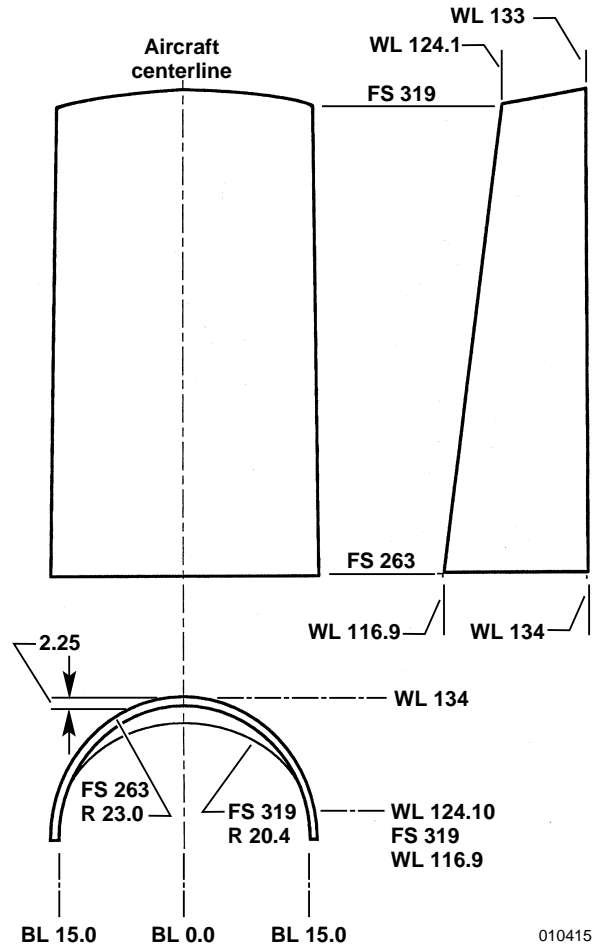
**Figure A-12(a). Q-bay: lower hatch (iris panoramic camera).**

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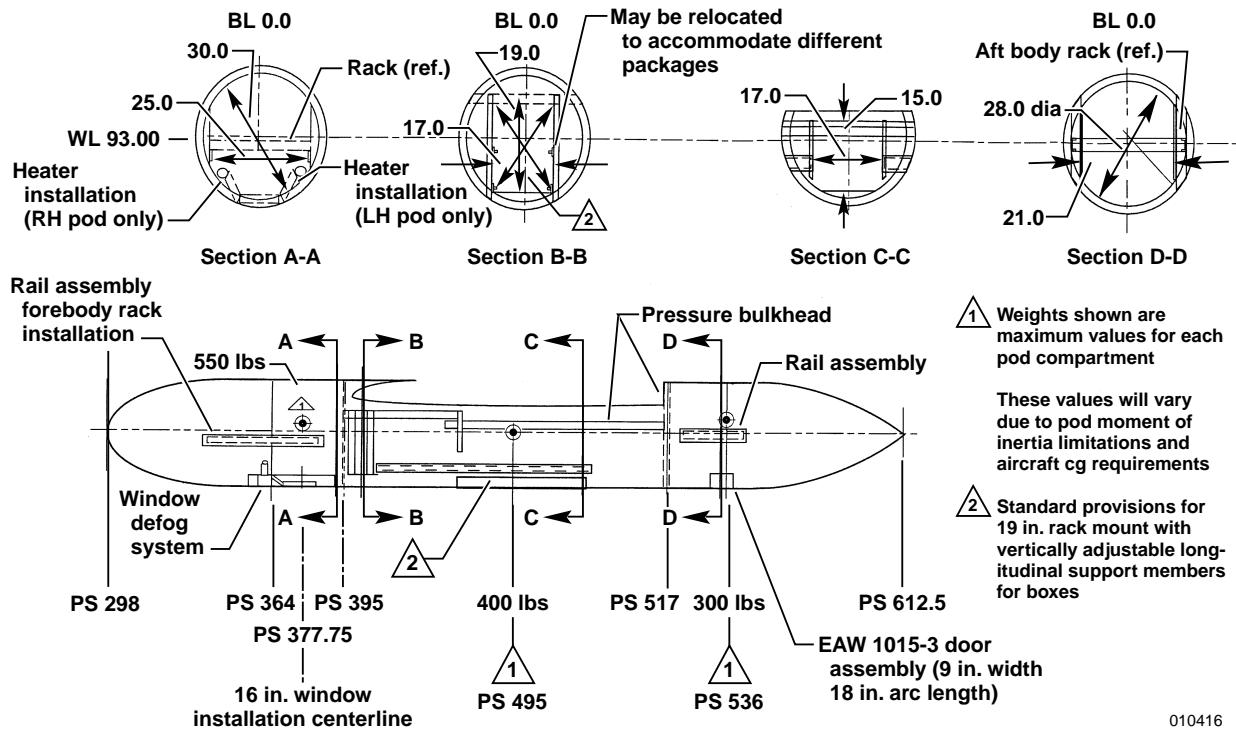
Figure A-12(b). Q-bay: lower hatch (iris panoramic camera).

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**Figure A-13. Q-bay: upper hatch.**

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Figure A-14(a). Super pod: general layout.



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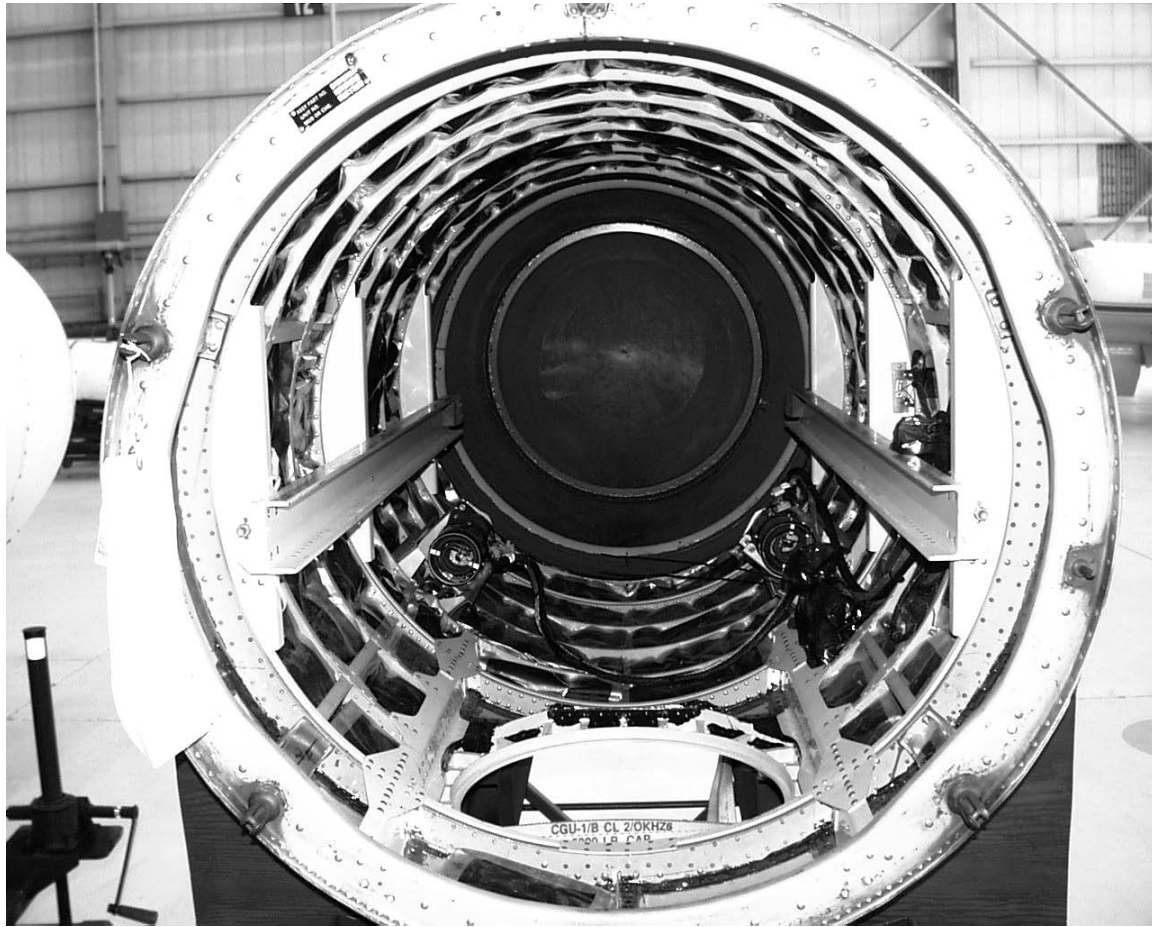


Figure A-14(b). Super pod: fore body internal.

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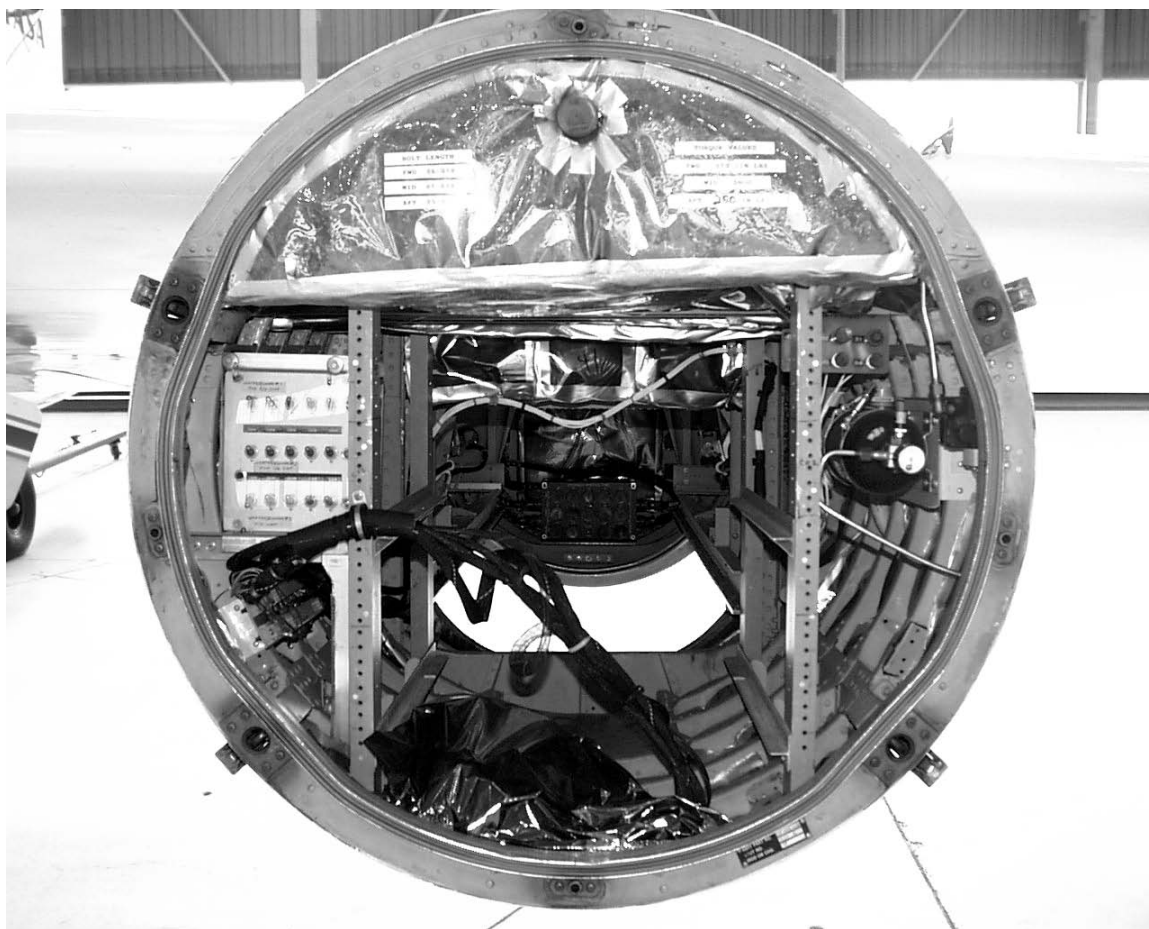


Figure A-14(c). Super pod: mid body vertical rack.

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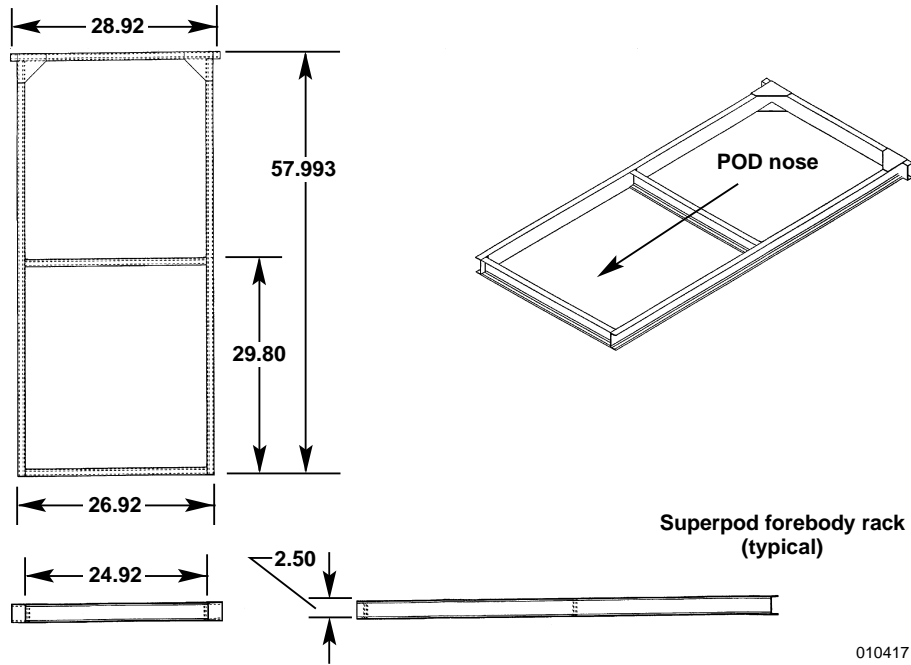
Figure A-14(d). Super pod: aft-body internal.

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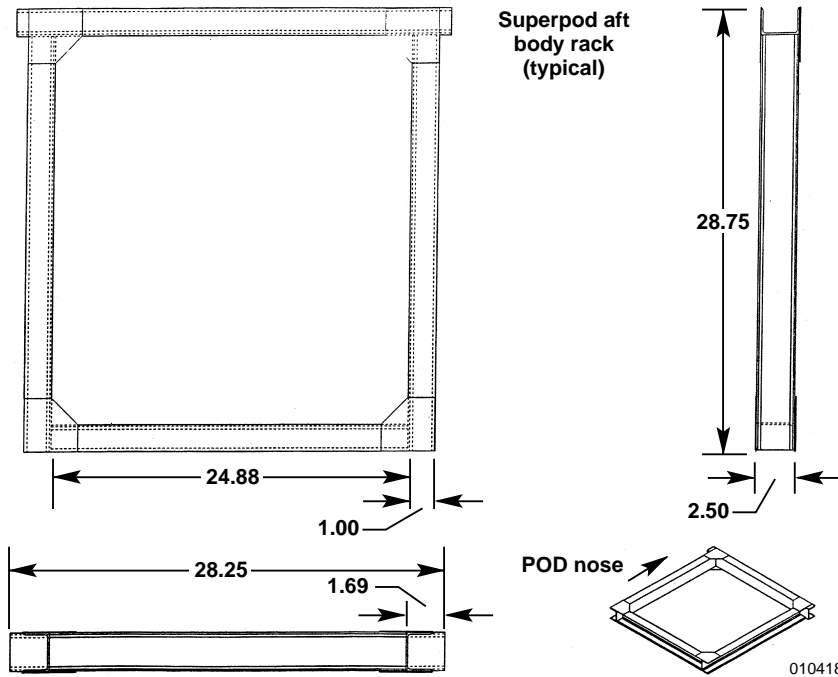


Figure A-14(e). Super pod: mid-body internal.

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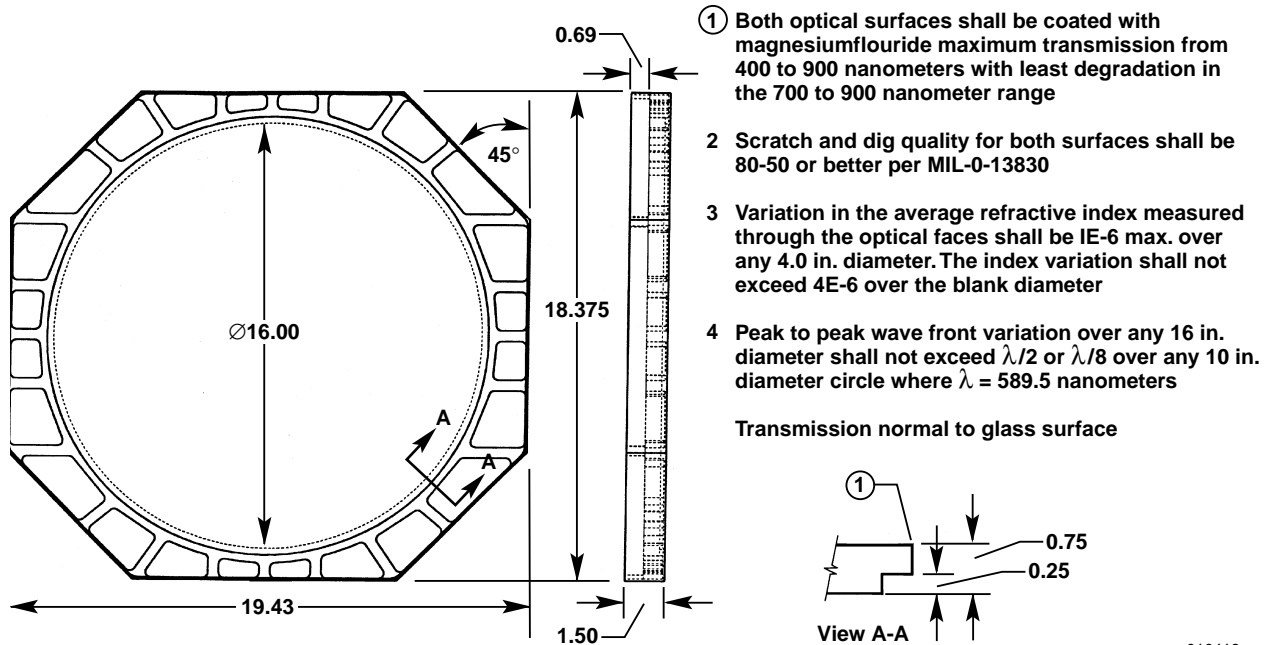


**Figure A-15. Super pod: typical fore body rack.**



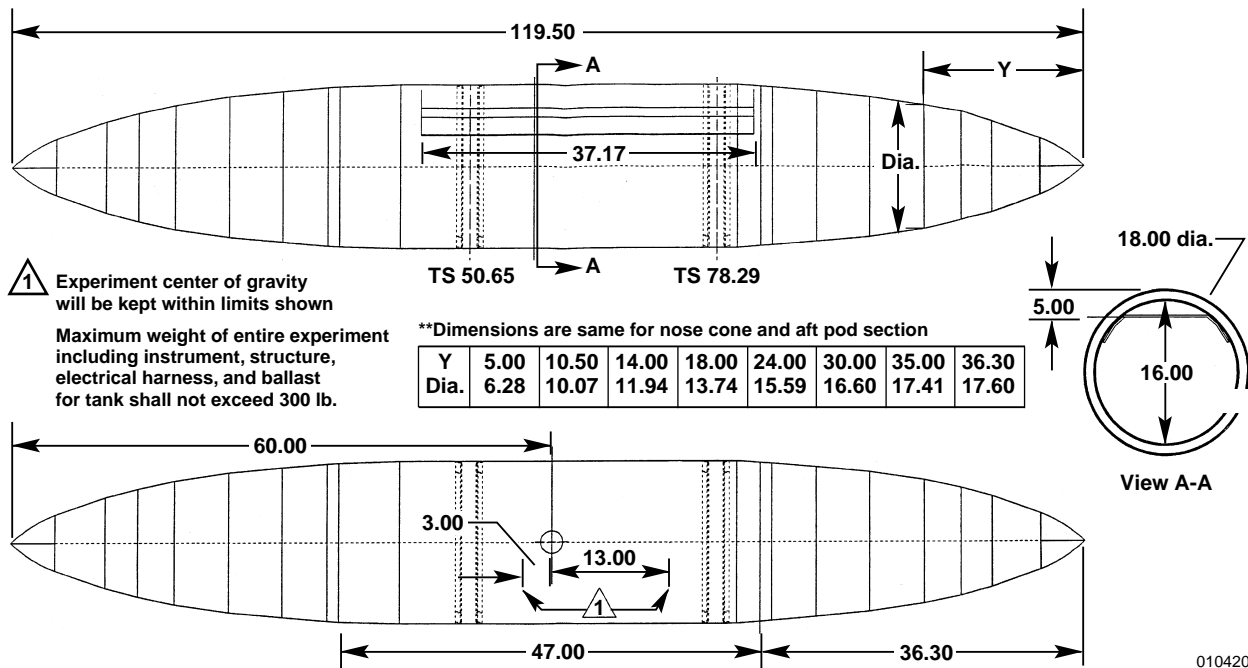
**Figure A-16. Super pod: typical aft-body rack.**

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Figure A-17. 16 in. window installation.



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Figure A-18. Fuselage centerline pod, general configuration.

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**APPENDIX B**

**DFRC AIRBORNE SCIENCE CRYOGENIC  
GROUND HANDLING PROCEDURES**

**1. Scope**

Use of cryogenic liquids at DFRC is controlled by Dryden Centerwide Procedure DCP-S-039, "Cryogen Safety." This document contains supplemental information for the use of all personnel that have a need to plan requirements, service, or handle cryogen relative to Airborne Science operations. Areas of operations are defined as any Airborne Science facility at DFRC, or on any deployment, or on the ER-2 aircraft or payloads.

**2. Purpose**

The purpose of this document is to describe the principal hazards and appropriate safety procedures associated with cryogenics that are commonly used such as liquid oxygen, hydrogen (not allowed on the NASA ER-2), ammonia, nitrogen, helium, argon, and carbon dioxide.

**3. Equipment Requirements**

- Gastech GX-82 three way gas alarm or equivalent
- Gastech OX-82 oxygen indicator or equivalent
- Gloves, cryogenic
- Apron, Neoprene or heavyweight rubber coated
- Safety glasses
- Goggles
- Full-face shield



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**4. General Properties**

Because all cryogenic fluids exist as liquids only at temperatures considerably below ambient which are temperatures in the range of -324 °F (-198 °C), normal storage facilities and fluid containment in process systems must allow for the unavoidable heat input from the environment. For ordinary operations this means good insulation, adequate pressure-relief devices, and proper disposal or recycling of the gases that are continually produced. Full containment of the fluid as a liquid at room temperature is usually not feasible: the pressure required to maintain helium at liquid density at room temperature is 18,000 psi; for nitrogen it is 43,000 psi.

The chemical properties and reaction rates of substances are changed under cryogenic conditions. Liquid oxygen, for example, will react explosively with materials usually considered to be noncombustible. Remember that condensing a cryogen from a pure gas at room temperature will concentrate the material typically 700-800 times.

Cryogenic temperatures drastically affect material properties: ductile materials become brittle, material shrinkage exceeds anticipated values, leaks can develop that are not detectable at room temperature even under considerable pressure, etc. Hence, the suitability of materials must be carefully investigated before they are employed in cryogenic service.

**5. Labeling**

Storage dewars, process vessels, piping, etc., shall be labeled with the common name of the contents. In many cases, it is also desirable to post emergency instructions, emergency call numbers, etc.

**6. Pressure Relief**

Heat flux into the cryogen is unavoidable, regardless of the quality of the insulation provided. Pressure relief must be provided to permit routine off-gassing of the vapors generated by heat input. Spring-loaded relief devices or an open passage to the atmosphere best provides such venting.

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Additional relief devices shall be provided as backup to the operational relief when the capacity of the operational relief device is inadequate in the event of an emergency. This may occur if the insulation is dependent on the maintenance of a vacuum in any part of the system, including permanently sealed dewars. Relief devices, capable of handling the maximum volume of gas that could be produced under catastrophic conditions must be provided. Frangible disks are recommended for this service.

Each portion of the cryogenic system must have uninterruptible pressure relief. Any part of the system that can be isolated from the remainder must have separate and adequate provisions for pressure relief.

All components in contact with the fluid shall be rated for cryogenic service. Careful consideration must be given to material compatibility with respect to prevention of embrittlement at cryogenic temperatures.

## **7. Hazards of Oxygen Deficiency**

Liquefied gases have a potential for creating oxygen deficiency. When expelled to the atmosphere at room temperature, they evaporate and expand on the order of 700-800 times their liquid volume. Consequently, leaks of even small quantities of liquefied gas can expand to displace large amounts of oxygen, thereby rendering an atmosphere lethal. Without adequate oxygen, one can lose consciousness in a few seconds and die of asphyxiation in a few minutes.

Calculations shall be made to determine whether a given situation of cryogen storage or use will pose an oxygen-deficiency hazard in the event of the worst possible accident. When the level of hazard potential has been ascertained, appropriate safety procedures must be taken. Where the danger is sufficient to warrant it, this may entail the use of an oxygen monitor. Positions for oxygen monitors should include the lowest point in the area because the cold, dense, escaping gases will be heavier than the warmer ambient air, at least initially. All employees working in the vicinity of an area where an oxygen deficiency could develop shall be trained as to the nature of the hazard and the appropriate response they should make in the event of cryogen release. Along with training, these areas shall be posted to remind the workers and alert visitors in the area to the hazard.

**CAUTION: Any rescue work conducted in an oxygen-deficient atmosphere must be done in self-contained breathing apparatus or airline equipment.**

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**8. Hazards of Air-Freezing Cryogenics**

Certain cryogenics, such as helium and hydrogen, are cold enough to solidify atmospheric air. The system must be pressurized in order to prevent the entry of air into such cryostats. If openings to the atmosphere exist, they are likely to become plugged by solidified air, leading to overpressure and vessel failure if they are relied on for pressure relief. Such conditions will also result in hazardous contamination of the fluid. Again, adequate pressure-relief devices must be provided to vent all gas produced in case of maximum possible heat flux into the system. Unless these fluids are handled in vacuum-jacketed vessels and piping, air will also condense on the exterior of the system. This condensate will be rich in oxygen content. The hazards created by this include frostbite from touching the cold surfaces, dripping liquid air (because it is oxygen-enriched), and exploding insulation. The latter can happen when air condenses between the metal surface and the insulating layer. On warming, the air vaporizes and can rip off the insulation with explosive force. Such insulation systems must be specially engineered to prevent air penetration.

**9. Hazards of Carbon Dioxide Toxicity**

In addition to producing an oxygen deficiency, carbon dioxide also affects the breathing rate because of its role in the respiratory process. A concentration of 0.5% carbon dioxide in the air will begin to stimulate a more rapid breathing rate; when 3% carbon dioxide is present in the air, lung ventilation will double; 10% carbon dioxide can be tolerated for only a few minutes. A condition of 10% carbon dioxide and 90% normal air actually has an oxygen concentration of 20.9%. This degree of oxygen deficiency would not be considered immediately dangerous to life or health if the contaminant gas were nitrogen, helium, or argon instead of carbon dioxide. Obviously it is important to measure the carbon dioxide concentration, especially if it is suspected that this gas may be present at levels greater than 0.5%.

**CAUTION: Any rescue work conducted in an oxygen-deficient atmosphere must be done in self-contained breathing apparatus or airline equipment.**

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**10. Hazards of Oxygen Enrichment**

Cryogenic fluids with a boiling point below that of liquid oxygen have the ability to condense oxygen out of the air if exposed to the atmosphere. This is particularly troublesome if a stable system is replenished repeatedly to make up for evaporation losses; oxygen will accumulate as an unwanted contaminant. Violent reactions (e.g., rapid combustion or explosions) may occur if the system or process is not compatible with liquid oxygen.

Oxygen enrichment will also occur if liquid air is permitted to evaporate (oxygen evaporates less rapidly than nitrogen). Oxygen concentrations of 50% may be reached. Also remember that condensed air dripping from the exterior of cryogenic piping will be rich in oxygen.

**11. Personal Protective Equipment**

The potential for freezing by contact with the extreme cold of cryogenics necessitates varying degrees of eye, hand, and body protection. When cryogenics are spilled, a thin gaseous layer apparently forms next to the skin. This layer protects one from freezing, provided the contact with the cryogenics involves small quantities of liquid and brief exposures to dry skin. However, having wet skin or exposure to larger quantities of cryogenics for extended periods of time can produce freezing of the tissue.

The most likely cause of frostbite to the hands and body is contact with cold metal surfaces. Because there is no protective layer of gas formed, frostbite will occur almost instantaneously, especially when the skin is moist.

The damage from this freezing (frostbite) occurs as the tissue thaws. Intense hyperemia (abnormal accumulation of blood) usually takes place. In addition, a blood clot may form along with an accumulation of body fluids, which decreases the local circulation of blood. Gangrene may result if the consequent deficiency of blood supply to the affected cells is extreme.

Cooling of the internal organs of the body can also disturb normal functioning, producing a condition known as hypothermia. It is very dangerous to cool the brain or heart to any great extent.

Using safety glasses with side shields is required at all times when cryogenic fluids are present. Goggles provide the best protection for the eyes. If a cryogen is poured or if the fluid in an open container may bubble, a full-face shield is required. This additional protection is also recommended when valves are actuated on piping systems, etc., unless the operator is shielded from leaks at potential failure points.

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Hand protection is primarily required to guard against the hazard of touching cold surfaces. Loose, non-asbestos insulating gloves, that can be tossed off readily in case they become soaked with cryogen, may be worn. Special gloves made for cryogenic work are required.

Cryogenic handlers should wear boots and cuff-less trousers extending over the boot. All persons handling cryogenics shall wear closed-toe shoes that cover the top of the foot. Industrial clothing made of nonabsorbent material is usually satisfactory. Long-sleeved clothing is recommended for arm protection. An apron made of Neoprene or heavyweight rubber coated material is required for use with cryogenics. Where exposure to drenching is possible, a full protective suit with supplied air should be considered; however, the system should be engineered to prevent the possibility of such an exposure.

Tongs or other tools should be used to lift objects out of the liquid or liquid baths.

## **12. Immediate Treatment for Frostbite**

- Warm the affected area rapidly by immersion in water not to exceed 105 °F, with body heat, or by exposure to warm air. Safety showers with warm water should be provided where there is a sufficient probability of the occurrence of such an accident. In the event of massive exposure, remove clothing while showering. Do not expose the body to open flame. Maintain the affected area of the victim at normal body warmth until professional help arrives.
- Calm the victim and avoid aggravating the injury. People with frost-bitten feet should not walk on them. Do not rub or massage the affected parts of the body.
- Prevent infection--use a mild soap to clean the affected area. Dressings need not be applied if the skin is intact.
- If affected, flush eyes with warm water for at least 15 min.
- Report to NASA DFRC Health Unit for medical attention promptly.

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**13. Training Procedures and Safety Notes**

Only personnel fully aware of the properties of cryogenic fluids should handle cryogenic materials and equipment. They should be mindful of the consequences of misadventure. Operators should be selected on the basis of capability to understand the hazards and the equipment, mature judgment, and the ability to follow established procedures. Copies of the appropriate MSDS shall be posted in the vicinity of the cryogen being used, handled, or stored.

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**APPENDIX C**

**NAVIGATION RECORDER OUTPUT**

**1. RS 232 Navigation Data Output to Payload Areas**

The data from all navigation data inputs is accumulated in a buffer for one second. The data is processed and output to the RS232 data bus at 9600 Baud. This results in a delay of one second between the actual time the data is received and the time it is output on the RS232 data bus. The time is correct to one millisecond. The output format is shown in table C-1.

**Table C-1. RS 232 Navigation Data Output to Payload Areas.**

<b>Parameter</b>	<b>Units</b>	<b>Output Format</b>	<b>Byte Size</b>	<b>Source</b>
header, GPS status	'SOH' (G/N)	ASCII XX	2	inserted
UTC time (GMT)	days:hrs:min:sec	ASCII XX:XX:XX:XX	12	GPS
present pos. latitude	deg	ASCII N/S XX.XXXXX	9	INU
present pos. longitude	deg	ASCII E/W XXX.XXXXX	10	INU
true heading	deg	ASCII XXX.XX	6	INU
pitch angle (up+)	deg	ASCII ±XX.XXXX	8	INU
roll angle (rt.+)	deg	ASCII ±XX.XXXX	8	INU
ground speed	m/sec	ASCII XXX.XX	6	INU
track angle true	deg	ASCII XXX.XX	6	INU
inertial wind speed	m/sec	ASCII XX.X	4	INU
inertial wind direction	deg	ASCII XXX.X	5	INU
body long. acceleration	G	ASCII ±X.XXX	6	INU
body lat. acceleration	G	ASCII ±X.XXX	6	INU
body norm. acc.	G	ASCII ±X.XXX	6	INU
track angle rate	deg/sec	ASCII ±XX.X	5	INU
pitch rate	deg/sec	ASCII ±XX.X	5	INU
roll rate	deg/sec	ASCII ±XX.X	5	INU



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<b>Parameter</b>	<b>Units</b>	<b>Output format</b>	<b>Byte Size</b>	<b>Source</b>
inertial vertical speed	m/sec	ASCII $\pm$ XX.XX	6	INU
GPS altitude	m	ASCII XXXXX.X	7	GPS
GPS latitude	deg	ASCII N/SXX.XXXXX	9	GPS
GPS longitude	deg	ASCII E/WXXX.XXXXX	10	GPS
static pressure*	mbar	ASCII XXXX.XXX	8	analog
total pressure	mbar	ASCII XXXX.XXX	8	analog
differential pressure	mbar	ASCII XX.XXX	6	analog
total temperature*	°C	ASCII $\pm$ XX.XX	6	analog
static temperature*	°C	ASCII $\pm$ XX.XX	6	derived
barometric altitude*	m	ASCII XXXXX.X	7	derived
Mach no.*	N/A	ASCII X.XXX	5	derived
true airspeed*	m/sec	ASCII XXX.XX	6	derived
wind speed*	m/sec	ASCII XX.X	4	derived
wind direction*	deg	ASCII XXX.X	5	derived
sun elevation	deg	ASCII $\pm$ XX.XX	6	derived
sun azimuth	deg	ASCII XXX.XX	6	derived
analog channels (12)	V	ASCII $\pm$ X.XXX	6(72 total)	analog
end of frame	LF, CR	ASCII	2	inserted

\*.These values are not valid for an aircraft altitude below 10km.

Note: Each parameter is followed by a space. The values for each of the 12 analog channels are separated by space.

## **2. RS 232 Time Channel Data Format**

The NAVREC provides GPS data to all payload areas in ARINC 429 format. The GPS ARINC 429 output format is shown in table C-2.

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**Table C-2. RS 232 Time Channel Data Format.**

Binary Label	Parameter	Output Rate (Hz)	Numeric Range	Units	Significant Bits*	Resolution	Positive Sense
072	inertial latitude	8	± 90	deg	20	0.000172	north from zero
073	inertial longitude	8	± 180	deg	20	0.000172	east from zero
076	GPS altitude	1	± 131,072	ft	20	0.125	up
101	GPS HDOP	1	0-1024	m	15	0.031	always positive
102	GPS VDOP	1	0-1024	m	15	0.031	always positive
103	GPS track angle	1	± 180	deg	15	0.0055	CW from north
110	GPS latitude	1	± 90	deg	20	0.000172	north from zero
111	GPS longitude	1	± 180	deg	20	0.000172	east from zero
112	GPS ground spd.	1	0-4096	kn	15	0.125	always positive
114	desired track**	2	± 180	deg	15	0.005493	CW from north
116	cross track	4	± 128	nm	15	0.004	right
120	GPS latitude-fine	1	0-0.000172	deg	11	8.38E-8	north from zero
121	GPS longitude-fine	1	0-0.000172	deg	11	8.38E-8	east from zero
130	GPS integrity limit	1	0-16	nm	18	6.1E-5	N/A
136	GPS vert. FOM or EVE	1	0-32,768	ft	18	0.125	always positive
150	UTC (BCD format)	1	23:59:59	hr: min: sec	17	1.0	always positive
165	GPS vert. velocity	1	± 32,768	ft/min	15	1.00	up

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Binary Label	Parameter	Output Rate (Hz)	Numeric Range	Units	Significant Bits*	Resolution	Positive Sense
166	GPS N/S velocity	1	± 4,096	kn	15	0.125	north
174	GPS E/W velocity	1	± 4,096	kn	15	0.125	east
247	GPS horiz. FOM	1	0-16	nm	18	6.IE-5	always positive
260	date	1	N/A	BCD	6	1 day	N/A
273	GPS sensor status	1	N/A	DIS	19	N/A	N/A

\*.Does not include sign bit.

\*\*.Outputs magnetic information when magnetic mode is selected. True mode is selected for Arctic/Antarctic navigation (latitudes above 73 deg N or below 60 deg S).

### 3. ARINC 429 Output to Payload Areas (INS)

In addition to GPS data, the NAVREC provides INS data to all payload areas. The INS parameters are output to all payload areas in the ARINC 429 output format as shown table C-3.

**Table C-3. ARINC 429 Output to Payload Areas (INS).**

Binary Label	Parameter	Output Rate (Hz)	Numeric Range	Units	Significant Bits*	Resolution	Positive Sense
310	present position lat (UPD)	8	± 90	deg	20	0.000172	north from zero
311	present position long. (UPD)	8	± 180	deg	20	0.000172	east from zero
312	ground speed	32	0-4096	kn	15	0.125	always positive
313	track angle true	32	± 180	deg	15	0.005493	CW from north
314	true heading	32	± 180	deg	15	0.005493	CW from north
315	wind speed	16	0-256	kn	15	0.007813	always positive

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Binary Label	Parameter	Output Rate (Hz)	Numeric Range	Units	Significant Bits*	Resolution	Positive Sense
316	wind direction true	16	± 180	deg	15	0.005493	CW from north
317	track angle (magnetic)**	32	± 180	deg	15	0.005493	CW from north
320	heading (magnetic)**	32	± 180	deg	15	0.005493	CW from north
321	drift angle	32	± 180	deg	15	0.005493	right
322	flight path angle	32	± 180	deg	15	0.005493	up
323	flight path acceleration	64	± 4	G	15	0.000122	forward
324	pitch angle	64	± 180	deg	15	0.005493	up
325	roll angle	64	± 180	deg	15	0.005493	right wing down
326	body pitch rate	64	± 128	deg/sec	15	0.003906	up
327	body roll rate	64	± 128	deg/sec	15	0.003906	right wing down
330	body yaw rate	64	± 128	deg/sec	15	0.003906	nose right
331	body long. acceleration	64	± 4	G	15	0.000122	forward
332	body lat. acceleration	64	± 4	G	15	0.000122	right
333	body normal acceleration	64	± 4	G	15	0.000122	up
334	platform heading	32	± 180	deg	15	0.005493	CW from zero
335	track angle rate	64	± 32	deg/sec	15	0.000977	CW
336	pitch att. rate	64	± 128	deg/sec	15	0.003906	up
337	roll att. rate	64	± 128	deg/sec	15	0.003906	right wing down
360	potential vert. speed	64	± 32,768	ft/min	15	1.00	up

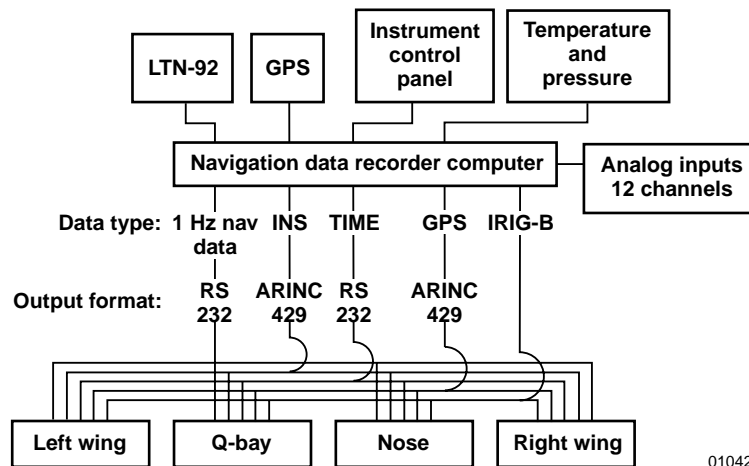
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Binary Label	Parameter	Output Rate (Hz)	Numeric Range	Units	Significant Bits *	Resolution	Positive Sense
361	inertial altitude	32	± 131,072	ft	20	0.125	up
362	along trk horiz. accel.	64	± 4	G	15	0.000122	forward
363	cross trk horiz. accel.	64	± 4	G	15	0.000122	right
364	vertical acceleration	64	± 4	G	15	0.000122	up
365	inertial vertical speed	32	± 32,768	ft/min	15	1.00	up
366	N/S velocity	16	± 4096	kn	15	0.125	north
367	E/W velocity	16	± 4096	kn	15	0.125	east

\*.Does not include sign bit.

\*\*..Information not valid when latitude is greater than 73 °N or 60 °S (Arctic/Antarctic navigation).

Note: UPD (updated data from GPS)



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**Figure C-1. Navigation data recorder – payload area interface.**