

ER-2: Flying Laboratory for Earth Science Studies

Robert Navarro

NASA Dryden Flight Research Center, Edwards, CA 93523, USA – robert.navarro@mail.dfrc.nasa.gov

The National Aeronautics and Space Administration (NASA) Dryden Flight Research Center (DFRC), (Edwards, California, USA) has two Lockheed Martin Corporation (Bethesda, Maryland) Earth Research-2 (ER-2) aircraft that serve as high-altitude and long-range flying laboratories. The ER-2 has been utilized to conduct scientific studies of stratospheric and tropospheric chemistry, land-use mapping, disaster assessment, preliminary testing and calibration and validation of satellite sensors. The ER-2 aircraft provides experimenters with a wide array of payload accommodation areas with suitable environment control with required electrical and mechanical interfaces. Missions may be flown out of DFRC or from remote bases worldwide.

The NASA ER-2 is utilized by a variety of customers, including U.S. Government agencies, civilian organizations, universities, and state governments. The combination of the ER-2's range, endurance, altitude, payload power, payload volume and payload weight capabilities complemented by a trained maintenance and operations team provides an excellent and unique platform system to the science community.

Keywords: Earth Science platform, ER-2 aircraft, high-altitude, long-range.

1. INTRODUCTION

The Lockheed Martin Corporation (Bethesda, Maryland) ER-2 aircraft at the NASA Dryden Flight Research Center (Edwards Air Force Base, Edwards, California, USA) is a high-altitude flying platform that serves the Earth Science community. The ER-2 designation was first applied to NASA's version of the Lockheed Martin U-2C aircraft; NASA has since acquired and used the Lockheed Martin U2-R or TR-1 aircraft, but has retained the ER-2 descriptor. The newest ER-2 aircraft (the U2-R) was built and delivered in 1989 and is one of NASA's youngest aircraft. The ER-2 aircraft differs from the United States Air Force U-2 aircraft in the lack of defensive systems, absence of classified electronics, completely different electrical wiring to support NASA sensors, and different paint scheme. Scientific instruments flown aboard the ER-2 aircraft can be mounted in various payload areas. On a single flight, the ER-2 aircraft can carry over one ton of instruments to altitudes above 70,000 ft (21.3 km) and outside 95 percent of the Earth's atmosphere.

A primary goal of the ER-2 project is to provide standard and specialty data products and equipment interfaces to our customers to achieve 100 percent mission success in support of their airborne facility systems. All instruments are integrated at Dryden by NASA engineers and technicians. Data collection missions may be conducted from other bases that meet the needs of customers' objectives.

The ER-2 aircraft facility takes advantage of NASA Dryden's high altitude, mission execution, and engineering to increase success in

meeting customer expectations and objectives. This paper describes the ER-2 aircraft and its capabilities.

2. DESCRIPTION OF THE ER-2 AIRCRAFT

The ER-2 aircraft, shown in figure 1, is an extremely versatile aircraft that is well-suited to multiple mission tasks (NASA, 2002). The ER-2 aircraft is 30 percent larger than the original U-2 aircraft and has a twenty-foot longer wingspan and a considerably increased payload capacity over the older airframe. The ER-2 aircraft has four large pressurized experiment compartments and a high-capacity AC/DC electrical system, permitting a variety of payloads to be carried on a single mission. The modular design of the ER-2 aircraft permits rapid installation or removal of payloads to meet changing mission requirements. Both NASA ER-2 aircrafts were re-engined with new General Electric Company (Fairfield, Connecticut, USA) (GE) F-118-101 engines in the late 1990s, at the same time the U-2 aircraft fleet was re-engined, providing much-improved range, endurance, altitude, and reliability. The ER-2 aircraft has a flight range beyond 6,000 nautical miles (nm); is capable of flight duration well in excess of 10 hours, and can operate at altitudes above 70,000 ft (21.3 km) if required. Range and duration are normally restricted by pilot duty time limitations. The specifications of the ER-2 aircraft, per USAF-releasable data, are shown in Table 1.



Figure 1. The Earth Research-2 (ER-2) aircraft.

Table 1. ER-2 Specifications

Crew	one pilot
Length	62 feet, 1 inch
Wingspan	103 feet, 4 inches
Engine	one GE F-118-101 engine
Altitude	above 70,000 feet
Range	over 6000 nautical miles, subject to pilot duty time limitations
Duration	over 10 hours
Cruise speed	~400 knots above 65,000 feet altitude (~210 meters/second)

2.1 Payload Areas

Numerous instruments may be carried aboard the ER-2 aircraft in various compartments, as illustrated in Figure 2. Figure 2 depicts the volume and power specifications at each compartment.

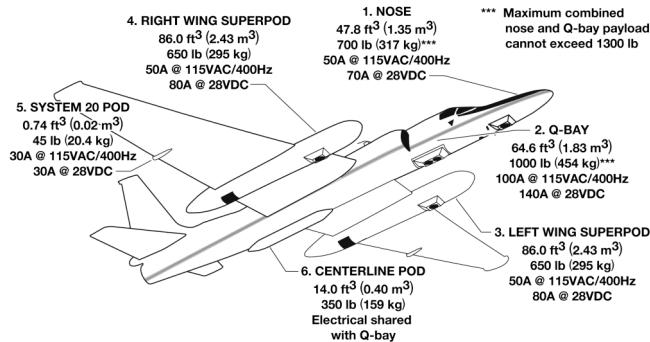


Figure 2. ER-2 basic configuration.

Various instruments can be mounted in the removable nose compartment. Attached to the ER-2 fuselage by four quick-release latches, the long nose compartment accepts payloads of up to 295 kg (650 lb) on custom-built racks. At cruise operating altitude, the nose area environment is maintained at 8.23 km to 9.14 km (27,000 to 30,000 ft) pressure altitude.

The equipment bay is the primary payload compartment on the ER-2 aircraft. Also known as the Q-bay, this compartment has removable upper and lower hatches. The upper and lower Q-bay hatches can be changed and 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 Q-Bay is pressurized to an equivalent pressure altitude of 9.14 km (30,000 ft) or lower.

The wing superpods can accommodate payloads up to a maximum weight of 295 kg (650 lb). The superpods consist of five individual segments: nose cone, forward pod, midbody, aft pod and tail cone. Normal separation points via latches are at the forward and aft ends of the superpod midbody. The forward two-thirds of the superpod, including the nose, forward pod, and midbody, are pressurized to an equivalent pressure altitude of 9.14 km (30,000 ft) or lower. The aft pod area remains unpressurized. Glass window ports are available for the forebody, while the aft tail cone has an open viewing port.

The fuselage centerline pod can be attached to the fuselage underside, aft of the main landing gear. The fuselage centerline pod can accommodate a payload of 159 kg (350 lb). The centerline pod is unpressurized and is not temperature controlled. The System 20 pods are mounted on the wings at the superpod attachment locations. Aerodynamic and inertial considerations require that both wings be equipped with the same pod type. Specialized wing pods have been designed and fabricated to support unique applications.

Electrical and data interfaces that run between the compartments provide the capability to distribute an instrument among the various compartments. The cockpit Experiment Control Panel

(ECP) allows the pilot to control the instrument and receive health status during flight.

2.2 Rate of Climb and Maximum Altitude

A typical ER-2 sortie begins with a short ground roll followed by a very high rate of climb at a high climb angle. Depending on takeoff gross weight and planned mission endurance, the ER-2 aircraft will reach the intermediate cruise altitude of 18 km (60,000 ft) within thirty to forty-five minutes of launch. At this point the cruise climb is initiated. While holding Mach number and engine exhaust temperature constant, the ER-2 aircraft will steadily climb as fuel is burned off. The cruise climb segment of a typical mission will begin no lower than 18 km (60,000 ft), and can continue to over 21.3 km (70,000 ft), depending on the total weight and configuration of the ER-2 aircraft. Figure 3 depicts a typical mission flight profile.

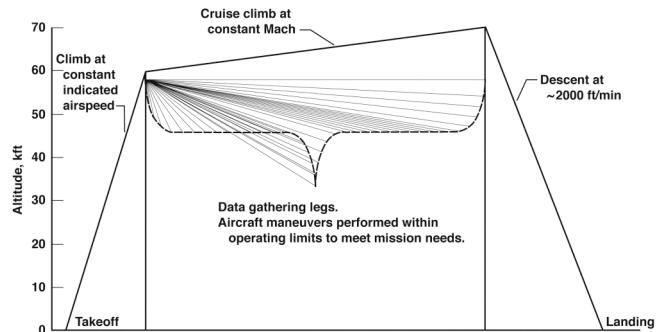


Figure 3. ER-2 typical flight profile.

For special payload operations, flights below 18 km (60,000 ft) can be performed; however, at these low altitudes aircraft and engine performance suffer, pilot workload increases, and air traffic control concerns multiply. Any request to operate at altitudes other than the nominal must be coordinated well in advance of actual operations.

2.2.1 Speed

At cruise altitude the Mach number is held constant at 0.715. This is equivalent to a true airspeed of approximately 210 m/sec (410 knots). At lower altitudes, such as on final approach for landing, the true airspeed is much lower: 90 to 100 knots.

2.2.2 Range and Endurance

A normal eight-hour mission will cover a range of 3000 nm, and yield approximately seven hours of high-altitude operations. Missions of 10 hours or more are possible, but impose additional risks to the pilot, aircraft, and sensors. Every effort is made to minimize these risks, and extended missions require additional justification. Missions of this length will also strongly affect the available crew resources for ensuing flight operations.

2.2.3 Stability

At cruising altitude, the ER-2 aircraft is a very stable aircraft. The automatic flight control system augments stability in the yaw, pitch, and roll axes. Pitch and roll excursions are typically less than one degree over a flight line.

2.2.4 Turn Radius at Altitude

Table 2 depicts bank angle turn diameter in nautical miles and in kilometers. At a constant Mach number, banking the wings to turn the aircraft inevitably imposes a loss of lift and thus a loss of altitude. This altitude loss can be up to 0.30 km (1000 ft) which is gradually recovered over the next straight-and-level flight leg.

Table 2. ER-2 Bank Angle Turn Diameter

Degrees	Nautical miles	Kilometers
5	56.2	104
10	27.9	52
15	18.3	34
20	13.5	25
22 (standard)	12.2	23

2.3 The On-Board Aircraft Systems of the ER-2 Aircraft

The ER-2 aircraft is equipped with communication and navigation systems not only for pilot use but to aid in meeting science requirements.

2.3.1 Radio Navigation and Communications Systems

The ER-2 aircraft is equipped with ultra high frequency (UHF), very high frequency (VHF), and high frequency (HF) radio systems for two-way voice communication. An air traffic control (ATC) transponder enables surveillance radar to identify the aircraft via coded transmissions.

The ER-2 aircraft can navigate by ground-based radio beacons, as selected by the pilot. Navigation aids used for this include low-frequency automatic direction finding (ADF), Tactical Air Navigation (TACAN) for bearing and range information, and a VHF Omnidirectional range/instrument landing system (VOR/ILS).

2.3.2 Inertial Navigation Systems

The inertial navigation system (INS) on the ER-2 aircraft operates by sensing accelerations from a gyroscope-stabilized, all-altitude 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 positioning system (GPS) updating of the INS to provide navigation independent of the drift errors. The GPS accuracy is better than +/-100 meters, depending on satellite orbit geometry.

2.3.3 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 degrees 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 degrees or 37 degrees is available in the 1x and 0.4x magnification settings.

2.3.4 Navigation Recorder (NAVREC)

The navigation data recorder on the ER-2 aircraft is an electronic intermediary between the aircraft avionics and the experimenter hardware. The recorder performs the following functions:

- Opto-isolates the experimenter hardware from the aircraft avionics.
- Broadcasts navigation data parameters in-flight to all payload areas. These parameters include the ER-2 aircraft's attitude, position, velocity, heading, outside air temperature and pressure, etc.
- Broadcasts a consistent time base to all payload areas, in both IRIG-B time code format and an RS-232 serial line.
- Samples and records a variety of general analog and digital inputs.
- Stores navigation data for post-flight analysis, dissemination, and archival.

The navigation recorder is a custom-built 486-class computer with a removable hard drive. Stored data is usually available to investigators post-flight within an hour after the ER-2 aircraft lands.

2.4 The Operating Bases of the ER-2 Aircraft

The ER-2 aircraft is operated by the NASA Dryden Flight Research Center at Edwards Air Force Base, Edwards, California, USA. Dryden is the home base for the aircraft and support personnel as well as the center for all ER-2 aircraft operations, maintenance, and engineering.

In the event that scientific objectives preclude the use of Dryden for data acquisition flights, several other locations may be established to support ER-2 aircraft operations. These include Wallops Flight Facility at the Goddard Space Flight Center, Wallops Island, Virginia, USA; and the NASA Johnson Space Center, Ellington Field, Houston, Texas, USA. At these two locations, year-round fuel and ground support equipment are maintained.

It is possible to operate the ER-2 aircraft from other U.S. bases. Additional lead time would be required.

2.4.1 Foreign or Overseas Operating Bases

The ER-2 aircraft may be operated from a foreign country when the requirements of the proposed mission justify such action. One example of this requirement was the Airborne Antarctic Ozone Experiment. This required basing the ER-2 aircraft in Punta Arenas, Chile, to place the aircraft within reach of the Antarctic.

3. CONCLUSIONS

The NASA Dryden Flight Research Center has a Lockheed Martin Corporation (Bethesda, Maryland) Earth Research-2 (ER-2) aircraft as a high-altitude-flying long-range platform that is used to support Earth Science. Dryden's primary goal is to provide standard and specialty data products and equipment interfaces to our customers to achieve 100 percent mission success in support of their airborne facility systems. The ER-2 aircraft has been successfully utilized to conduct scientific studies of stratospheric and tropospheric chemistry, land-use mapping, disaster

assessment, preliminary testing and calibration and validation of satellite sensors.

The ER-2 aircraft can provide experimenters with a wide array of payload accommodations areas, with suitable environment equipped control, with the required electrical and mechanical interfaces. On a single flight, the ER-2 aircraft can carry over one ton of instruments to altitudes well above 65,000 feet mean sea level and outside 95 percent of the Earth's atmosphere. Missions may be flown out of the Dryden Flight Research Center or from remote bases worldwide, in order to meet research requirements. The combination of the range, endurance, altitude, payload power, payload volume and payload weight capabilities of the ER-2 aircraft is complemented by a trained maintenance and operations

team to provide an excellent and unique platform system to the science community and other customers.

The ER-2 aircraft facility takes advantage of NASA Dryden's high altitude, mission execution, and engineering expertise to increase success in meeting customer expectations and objectives. The ER-2 aircraft facility provides the customer with a cost-effective approach to flight-test to validate their sensors and/or enable data collection at high altitude.

4. REFERENCES

National Aeronautics and Space Administration, "ER-2 Airborne Laboratory Experimenter Handbook," 2002.