Chapter 5: June 1997 ER-2 Flight Measurements

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Preface

Within our current understanding of the atmospheric ionizing radiation, the ER-2 flight package was designed to provide a complete characterization of the physical fields and evaluate various dosimetric techniques for routine monitoring. A flight plan was developed to sample the full dynamic range of the atmospheric environment especially at altitudes relevant to the development of the High Speed Civil Transport. The flight of the instruments occurred in June of 1997 where predictive models indicated a maximum in the high altitude radiation environment occurring approximately nine months after the minimum in the solar sunspot cycle. The flights originated at Moffett field at the Ames Research Center on ER-2 aircraft designated as 706. The equipment was shipped mid-May 1997 for unpacking and checkout, size fitting, systems functional test, and preflight testing on aircraft power with flight readiness achieved on May 30, 1997. The equipment was qualified on its first engineering flight on June 2, 1997 and the subsequent science gathering flights followed during the period of June 5 – 15, 1997. Herein we give an account of the flight operations.

Introduction

The NASA Earth Resources (ER)-2 is a civilian version of the Air Force's TR-2 aerial reconnaissance aircraft. Both of these aircraft are the direct descendents of the old Lockheed U-2 which carried cameras on spy missions starting in the mid 1950s. The AIR/ER-2 flights were launched from Moffett Field, CA, and were precisely flown by the pilots along coordinates provided by the AIR Project as discussed in Chapter 4. The operations of the ER-2 aircraft were conducted under the management of the High Altitude Missions Branch at the Ames Research Center.

The AIR Project is an international collaboration devised by scientists at the NASA Langley Research Center and the DOE Environmental Measurements Laboratory with more than 12 domestic and foreign laboratories to make measurements and calculations of the stratospheric radiation field due to galactic cosmic rays. The first series of ER-2 flights for the AIR Measurement Project were successfully completed on schedule at the peak of the galactic cosmic radiation in June 1997.

The measurement part of the AIR Project involved placing 15 instruments on multiple flights of the NASA ER-2 aircraft. The instrument layout is shown in Figure 1. Payload integration of the international instrument array with the ER-2 was done by Langley Research Center and Lockheed Skunk works personnel in a very short time and on a constrained budget and fixed launch window. The first series of flights took place June 2-15, 1997 from the NASA Ames Research Center in California, covering altitudes from 52,000 to 70,000 feet and latitudes from 18 to 60 degrees N. The six flights are listed in Table 1. Data from these measurements are being used to benchmark an improved Langley model of the radiation environment which can be used to calculate radiation exposures that will be incurred in future high-speed civil transport (HSCT) commercial operations.

May 15-June 15, 1997 *AIR* Missions Plan: Sortie Definitions

All flights originate from Moffett Field, CA, the home base of the NASA ER-2 aircraft. The priority order of flights could change due to unexpected delays and the fixed June 15, 1997 end date for the campaign. The science flights in order of priority are 2,3,6,7,8,4 and 5.

<u>Flight 1:</u> This will be approximately a two-hour engineering-flight required by the ER-2 operations office with pilot's choice of flight path (assumed to be a racetrack around the home base). The aim is to check aircraft operational characteristics, and all aircraft and experimental instrumentation to assure everything is operating satisfactorily prior to the acquisition of science measurements.

> **Abort Criteria:** Red light condition - Computer is not recording measurement data. Turn switch off, wait two minutes and then turn switch back on. If red light is still on, repeat off/on procedure once more. If red light persists, return to base.
>
> **Success criteria:** All systems go for measurements.

<u>Flight 2:</u> This will be approximately a **six & one-half hour** flight on prescribed northern and easterly headings and return to home base over the reverse flight path. In the vicinity of Wine Glass (lat 38 deg 30 min N, long 117 deg W) maintain the current, standard-climb altitude (assumed to be about 63,000 ft) for about 20 minutes and then climb back to an altitude at which climb at constant Mach number can be attained along the prescribed easterly heading,. In the vicinity east of Amarillo, Texas (lat 34 deg 39 min N, long 100 deg.W), execute a 180 degree turn and descend to 52,000 feet at about 500 feet per minute (slow descent). Maintain 52,000 feet for 10 minutes and then climb to maximum altitude along the prescribed flight path repeating the ground track on the return to Wine Glass. Before returning to Wine Glass descend to the same altitude as on the outbound leg over Wine Glass (assumed to be 63,000 ft) and maintain that altitude for about 20 minutes. The aim for this flight is to determine if radiation measurements are being affected by the shielding characteristics of on-board aviation fuel, determine consistency of instrument readings, and take science data as a function of altitude along a constant-radiation, geomagnetic latitude line.

> **Abort Criteria:** Constant red light condition after two restart attempts - Computer is not recording measurement data.
>
> **Success criteria:** Seventy percent of instruments functioning and sufficient data as required to determine any possible effects from aviation fuel shielding.

<u>Flight 3:</u> This will be approximately an **eight hour** flight on prescribed northern, western and southern headings. In the vicinity east of Fort Nelson, CANADA (lat 58 deg, 30 min N, lon- 1 18 deg, W), execute a turn to the west and descend to 52,000 feet at a descent rate of about 750 feet per minute (moderately slow descent rate). Maintain 52,000 feet for about 5 minutes and then climb at constant Mach number. In the vicinity west of Fort Nelson (lat 60 deg, 30 min N, lon 60 deg 30 min W) execute a turn to the south and climb to cruise altitude and return to home base. The aim is to obtain radiation measurements as a function of geomagnetic latitude to as far north as possible with an altitude excursion along a constant-radiation, geomagnetic latitude line at the extreme northern latitude location.

Abort Criteria: Constant red light condition after two restart attempts - Computer is not recording measurement data.

Success criteria: Seventy percent of instruments functioning and data acquired.

<u>Flight 4:</u> This will be an engineering flight of approximately **three hours** after instrumentation additions with pilot's choice of flight path (assumed to a racetrack around home base). If this flight is combined with flight 5 on the same day there should be a 12hour interval between the flights which would dictate that flight 4 should be launched about 10:00 am. After engineering flight objectives are obtained for flight 4, continue to acquire science data by climbing to maximum altitude and hold for about 10 minutes. Initiate descent about 12:00 noon and descend at about 500 feet per minute (slow rate) to 52,000 feet and then continue descent at the standard rate of descent to landing. The aim of this flight is to acquire daylight data for comparison with night time data to determine diurnal variation of radiation.

Abort Criteria: Constant red light condition after two restart attempts Computer is not recording measurement data.

Success criteria: All systems go for measurements.

<u>Flight 5:</u> This will be approximately a **three hour** flight after dark (with take-off after about 10:00 PM) with a flight path similar to Flight 4 (assumed to be a race track around the home base). Climb to maximum altitude, cruise for about 30 minutes and hold a constant altitude for about 10 minutes. Initiate descent at 12:00 midnight and descend at about 500 feet per minute (slow rate) to 52,000 feet and then continue descent at the standard rate of descent to landing. The aim of this flight is to acquire night-time data for comparison with daylight data to determine diurnal variation of radiation.

Abort Criteria: Constant red light condition after two restart attempts - Computer is not recording measurement data.

Success criteria: Seventy percent of instruments functioning and data acquired.

<u>Flight 6:</u> This will be approximately a **six & one-half hour** flight on a prescribed southerly heading, over the North Pacific ocean. At the position Latitude 17 deg N, lon 127 deg 28 min W, execute a 180 degree turn and return to base. The aim of the mission is to obtain radiation measurements as a function of geomagnetic latitude to as far south as reasonably possible. An altitude variation at the extreme south was not attempted since less than on percent variation is expected and there is a danger of flame out.

Abort Criteria: Constant red light condition after two restart attempts - Computer is not recording measurement data.

Success criteria: Seventy percent of instruments functioning and data acquired.

Flight 7: This will be approximately a **six and one-half hour** flight on prescribed northern, western, and southern headings. In the vicinity of Edmonton, CANADA (lat 53 deg 43 min N, lon 1 19 deg 48 min W), execute a turn to the west and descend to 52,000 feet at a descent rate of about 750 feet per minute (moderately slow descent). Maintain 52,000 feet for about 5 minutes. In the vicinity east of Fort St. John, Canada (lat 56 deg 33 min N, lon 125 deg W), execute a turn to the south and return to base climbing to the highest altitude. The aim is to obtain radiation measurements as a function of geomagnetic latitude to as far north as possible with altitude excursions along a constant radiation, geomagnetic latitude line near Edmonton, CANADA.

> **Abort Criteria:** Constant red light condition after two restart attempts - Computer is not recording measurement data.
>
> **Success criteria:** Seventy percent of instruments functioning and data acquired.

Flight 8: This is a repeat of flight #6. The aim of this flight is to check data measurement repeatability.

> **Abort Criteria:** Constant red light condition after two restart attempts - Computer is not recording measurement data.
>
> **Success criteria:** Seventy percent of instruments functioning and data acquired.

The total flight hours for these missions is 42 hours. We currently are budgeted for 46 hours. The 4 extra hours is held as reserve in case we need additional engineering flights for unknown reasons.

Results of the June 1997 Campaign

Flight #1 (N97-104, Engineering Test)

The first flight was an Ames/Lockheed-required two hour duration engineering flight. The Ames flight number was N97-104. Its purpose was to verify compatibility of the instrument array with all of the ER-2 systems, including aircraft flight handling. All instruments in the array were fully operational, and gathered data during the flight, except as noted below. The pilot reported no interference with ER-2 systems, and the instrument array was certified by Ames/Lockheed for flying on the ER-2. The flight ground track is shown in Figure 2 and consisted of a race track path around Ames. Figure 3 shows the altitude profile.

Ten of the fourteen EML detectors functioned properly during the flight. Post flight review of the EML data showed that the high voltage power supplies for four detectors cut off during the flight: in the nose bonner sphere #2 and in the Q-bay bonner sphere #9, bonner sphere #10, and the ion chamber. Science data from these detectors ended when the high voltage was lost. Two of the EML detector cutoffs were caused by a leak in the pressure containers surrounding the detectors. Faulty pressure fittings on these containers were found and replaced. All of the EML pressure containers functioned properly for the remainder of the flights. The other 2 EML detector cutoffs were the continuation of a intermittent problem discovered earlier during all-up system operation, and was not resolved.

After this flight, the JSC Particle Telescope flight data was retrieved from the unit and sent to JSC for analysis. They reported back that the unit was not reading data from 8 of the 10 detector channels, effectively making its data useless. A quick look inside the unit revealed a malfunctioning connector, but fixing it did not cure the problem. Because of budgetary and time constraints, JSC elected not to fix the problem at that time. The Particle Telescope was left in place on the ER-2 rack, and operated on subsequent flights, but did not produce meaningful data.

The ER-2 system that records the high altitude (above 10 km) ambient pressure also failed during this flight, making it impossible to read both the high altitude pressure and the low altitude pressure at the same time. The pressure readings at high altitude were considered most important, so the system was configured to record only the high altitude ambient pressure for subsequent flights. In spite of a few issues concerning a few detectors and the altimeter, the overall mission reached the threshold of success as defined in the planning document.

Flight #2 (N97-105, Easterly)

The second flight was to be a six and one-half hour flight on a prescribed northern and easterly path and return over the reverse path. Leaving Moffett Field the craft headed on a northerly path to the vicinity of Wine Glass (38^{o} 30"N, 117^{o} W) and then followed an easterly line of constant magnetic latitude to Amarillo, Texas. The altitude continuously increased as the ER-2 "cruise climbed" until Wine Glass where a constant altitude was maintained for 20 minutes. Normal cruise climb then resumed to Amarillo. An altitude dip was performed shortly after turnaround. After turnaround, the pilot retraced the previous path back to Ames. Just before leaving the constant magnetic latitude path, the pilot descended to match his altitude at the same location during the outward bound leg. He held this altitude for 20 minutes to allow a comparison of the measured data at two distinct fuel loads at the identical locations in the radiation fields. The Ames flight number was N97-105. All instruments in the array were fully operational, and gathered data during the flight, except as noted below. The flight ground track is shown in Figure 4 where a storm over northern New Mexico was avoided. Figure 5 shows the altitude profile.

Twelve of the fourteen EML detectors functioned properly during this flight. Post flight review of the EML data showed that again the high voltage power supplies for two detectors were cut off by the computer system: bonner sphere #2 in the nose and bonner sphere #10 in the Q-bay. Science data from these detectors ended when the high voltage was shut off. The detector shutdowns were again caused by the same problem that showed up on the previous flights, and was not yet resolved.

The JSC Particle Telescope was operated, and the flight data was left onboard the unit.

Flight #3 (N97-106, North-1):

The third flight path headed north as far north as the ER-2 could fly in an extended 8 hour mission, turned west along a constant geomagnetic latitude line, and then returned directly to Ames. An altitude dip was executed along a constant magnetic latitude line at the northern extremity of the path. The Ames flight number was N97-106. All instruments in the array were fully operational, and gathered data during the flight, except as noted below. The flight ground track is shown in Figure 6. Figure 7 shows the altitude profile.

Eleven of the fourteen EML detectors functioned properly during this flight. Post flight review of the EML data showed that the high voltage power supplies for three detectors cut out during the flight: bonner sphere #2 in the nose; bonner sphere #10 in the Q-bay; and bonner sphere #12 in the right superpod. Science data from these detectors ended when the high voltage was lost. The three detector cutoffs were the continuation of the same problem that showed up on the previous flights, and was not yet resolved.

Flight #4 (N97-107, South-1):

The fourth flight path was south, following a path nearly perpendicular to the geomagnetic latitude lines down to about 18° latitude, and then back along the same path to Ames. The Ames flight number was N97-107. The ER-2 was allowed to cruise climb in altitude the entire flight. All instruments in the array were fully operational, and gathered data during the flight. The flight ground track is shown in Figure 8. Figure 9 shows the altitude profile.

All of the EML detectors functioned properly during this flight. Software changes installed prior to this flight apparently stopped the high voltage shutdown problem.

The JSC Particle Telescope was operated again, and the flight data was left onboard the unit.

Flight #5 (N97-108, North-2):

The fifth flight path was essentially a repeat of the first northerly flight. The outbound and return legs were shortened to allow a 6.5 hour flight time. An altitude dip was again executed during the westerly, constant geomagnetic latitude at the northern extreme. The Ames flight number was N97-108. All instruments in the array were fully operational, and gathered data during the flight, except as noted below. The flight ground track is shown in Figure 10. Figure 11 shows the altitude profile.

All of the EML detectors functioned properly during this flight. The JSC Particle Telescope was operated, and the flight data was left onboard the unit.

Flight #6 (N97-109, South-2):

The sixth flight path was a repeat of the first southerly flight #4. The Ames flight number was N97-109. All instruments in the array were fully operational, and gathered data during the flight. The flight ground track is shown in Figure 12. Figure 13 shows the altitude profile.

All of the EML detectors functioned properly during this flight. The JSC Particle Telescope was operated, and the flight data was left onboard the unit.

Postmortem

The loss of high voltage on the early flights was software/hardware interaction problem and change in software parameters allowed reliable operation in successive flights. The JSC telescope ran without fault although some of the data failed to record rendering the data unusable. The inability to down load data without disassembling the device would have allowed the determination of the continued problem and a possible fix between flights. The DOSTEL instrument operated properly, but analysis of the flight data months after the flight series has shown an interference on some of the data. The source of the interference appears to be an ER-2 navigation transmitter (TACAN). Although the DOSTEL data shows noise in a middle spectral range the spectrum can still be constructed by interpolation with a loss in accuracy. The BGO and plastic scintillation counters were never completely integrated into the system and data from them was not obtained. The NaI scintillation counter did obtain data and although noise appears in the lower spectral channels the real data range appears not to have been effected.

Conclusions:

In spite of the low funding and the fast track to meet the June 1997 flight date, the overall performance of the flight package was well over the threshold required for success and the flight team received an award for the “Outstanding planning, coordination and implementation of a complex Atmospheric Ionizing Radiation ER-2 flight measurements campaign in support of the Environmental Impact element of the HSR Program.” Members of the team are listed in an appendix at the end of these proceedings.

Table 1 - *AIR* flights at Ames - June, 1997

Flight Designation	Date	Duration	AIR Flight No.	Ames Flight No.	Start Time	End Time
Engineering	6/2/97	2 hrs	101	N97104	20:00 GMT	22:00 GMT
East	6/5/97	6.5 hrs	102	N97105	16:00 GMT	22:33 GMT
North 1	6/8/97	8 hrs	103	N97106	16:00 GMT	23:47 GMT
South 1	6/11/97	6.5 hrs	104	N97107	16:00 GMT	22:30 GMT
North 2	6/13/97	6.5 hrs	105	N97108	16:00 GMT	22:37 GMT
South 2	6/15/97	6.5 hrs	106	N97109	18:00 GMT	00:24 GMT

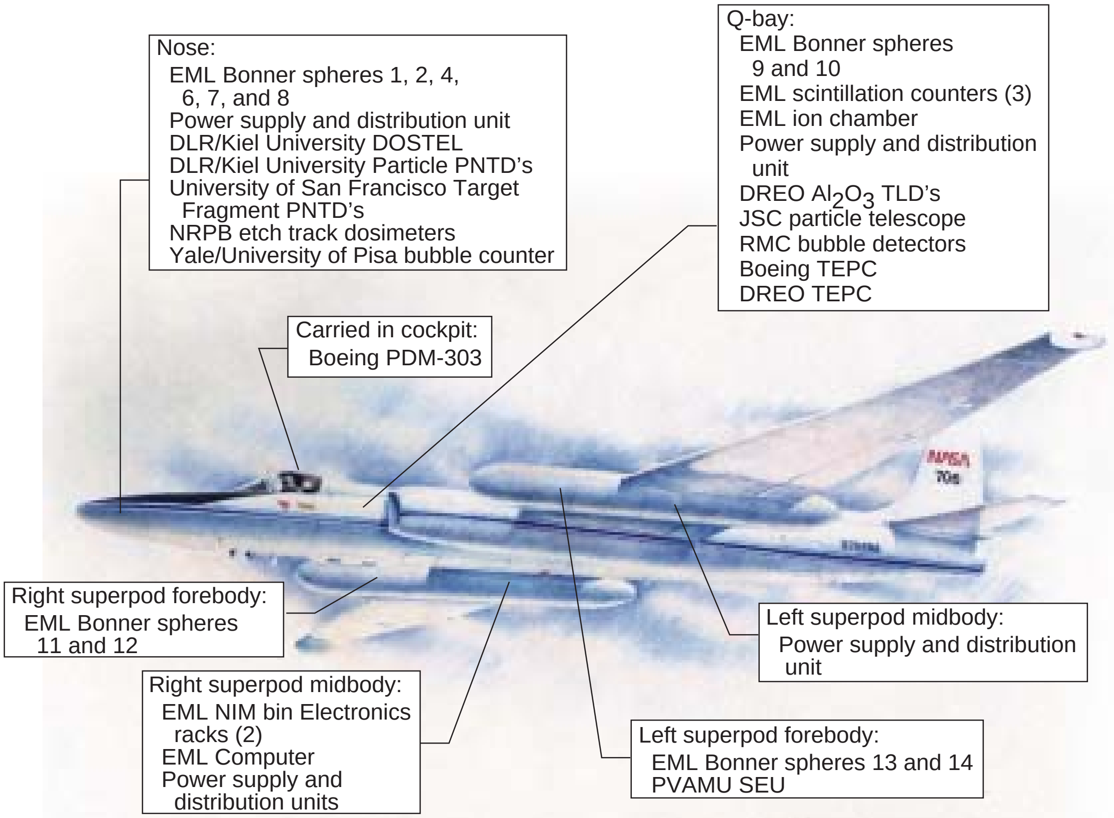

Figure 1.- Instrument Locations on the ER-2.

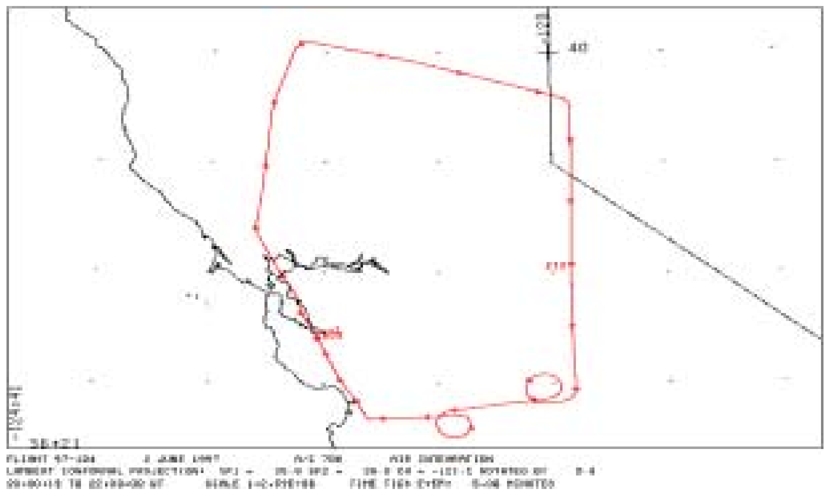

Figure 2 - Engineering Flight Ground Track

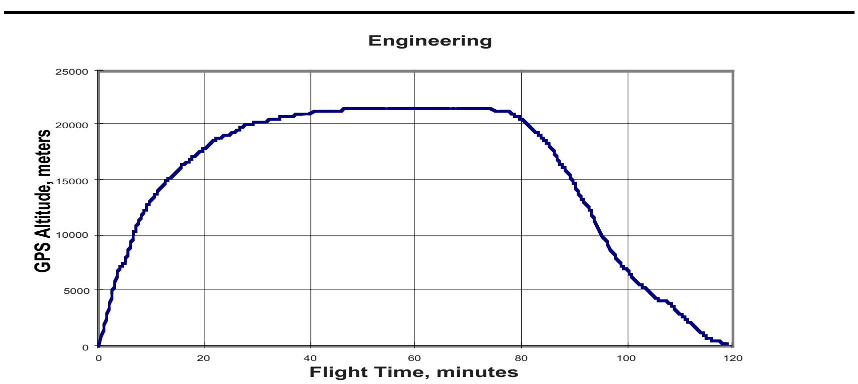

Figure 3 - Engineering Flight Altitude Profile

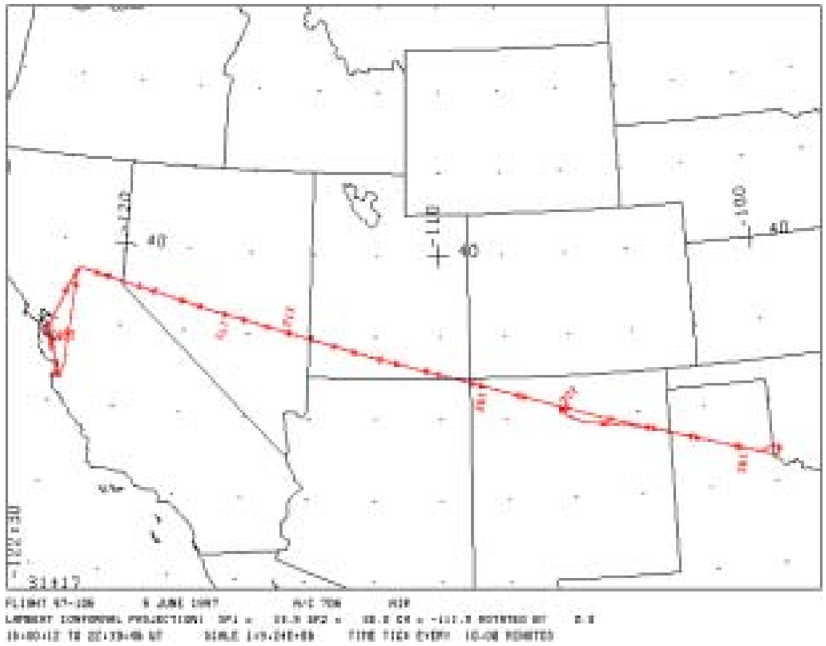

Figure 4 - East Flight Ground track

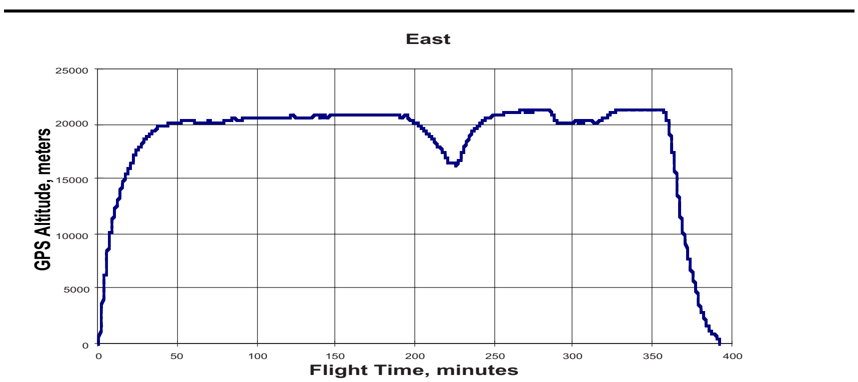

Figure 5 - East Flight Altitude Profile

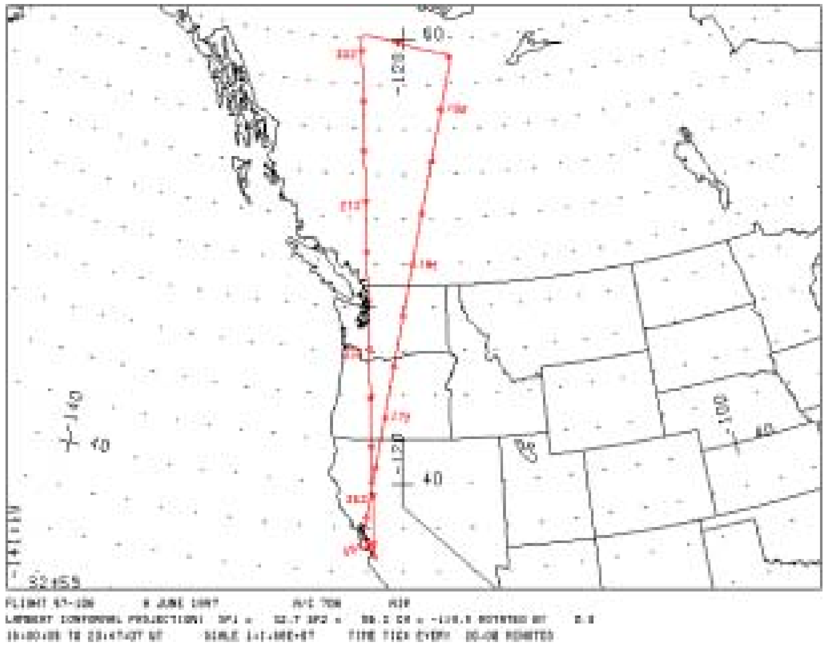

Figure 6 - North-1 Ground Track

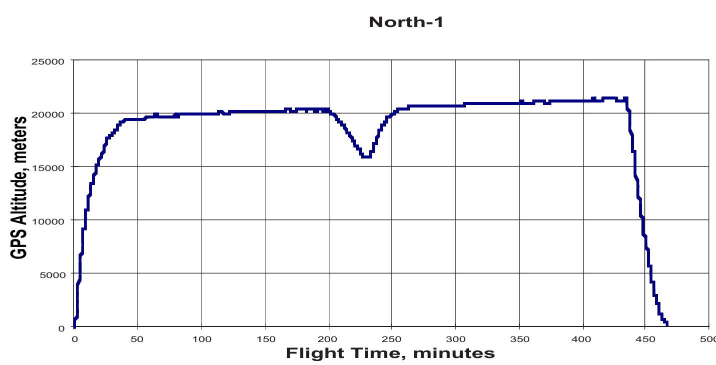

Figure 7 - North-1 Altitude Profile

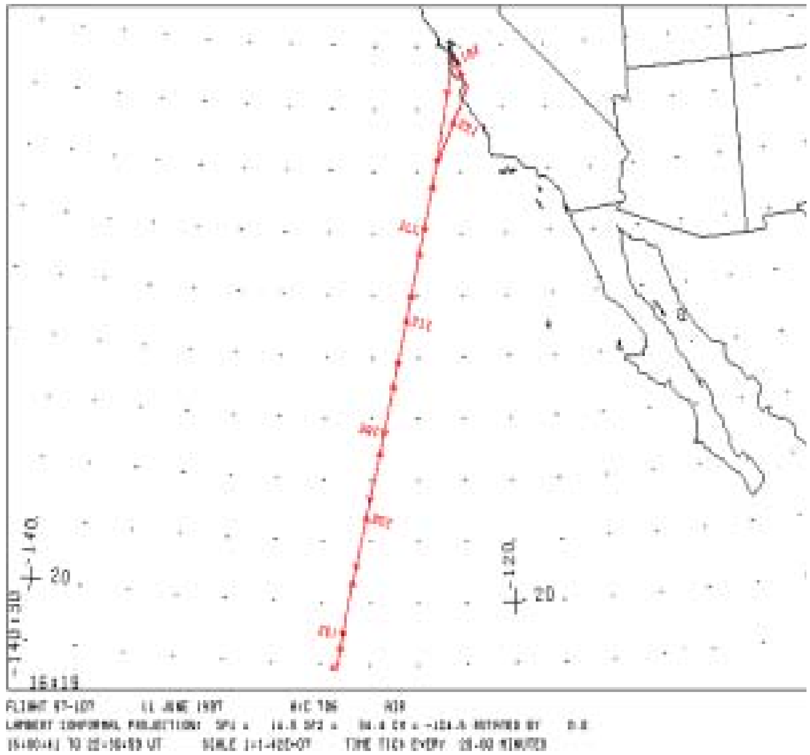

Figure 8 - South-1 Ground Track

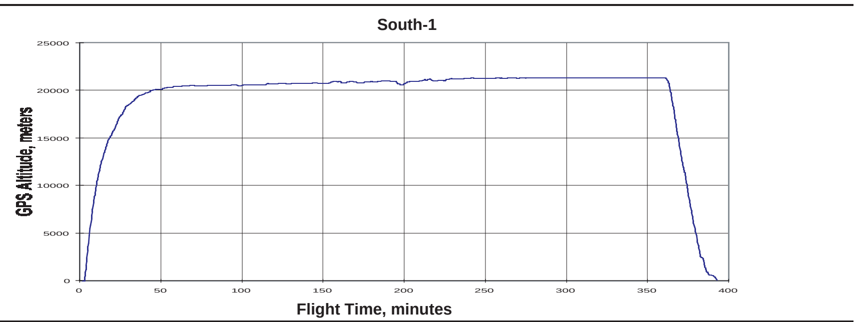

Figure 9 - South-1 Altitude Profile

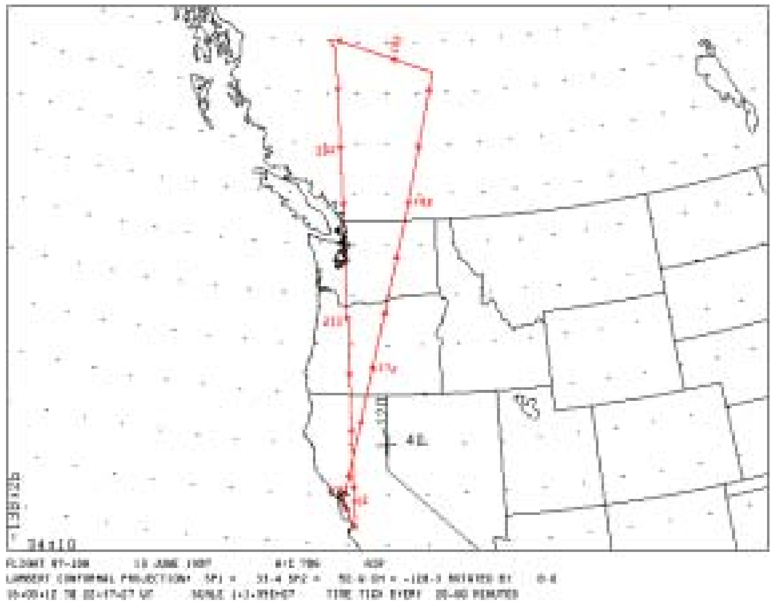

Figure 10 - North-2 Ground Track

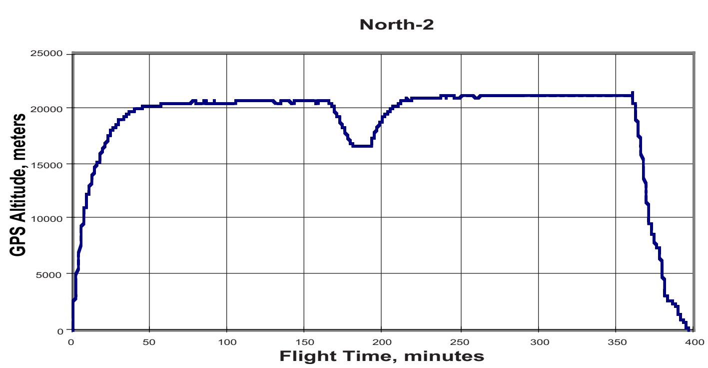

Figure 11 - North-2 Altitude Profile

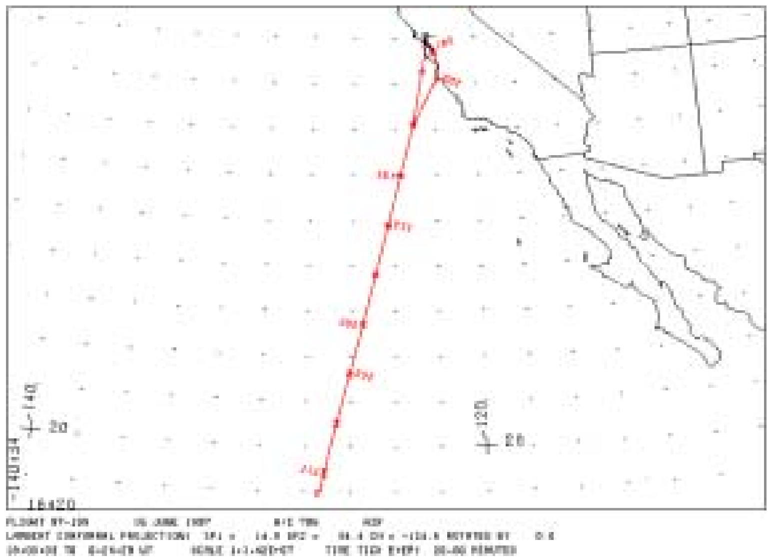

Figure 12 - South-2 Ground Track

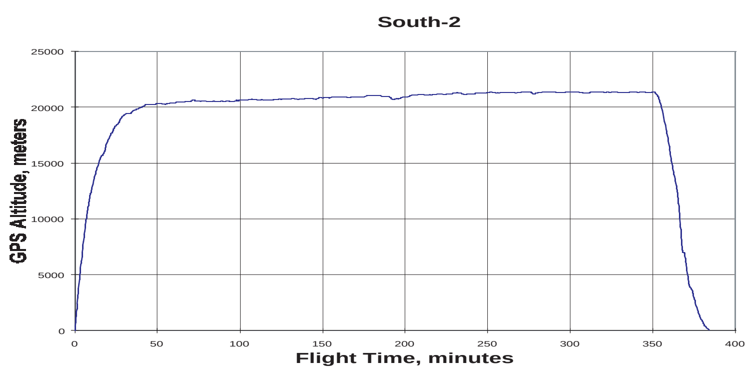

Figure 13 - South-2 Altitude Profile