The MANTRA 2004 Campaign

POST-FLIGHT REPORT

Contract No. 9F007-033099/001/ST
Client Reference No. 9F007-3-3099
PWGSC File No. 007st.9F007-033099

Prepared by

Stella M L Melo (Deputy PI) and
Kimberly Strong (Principal Investigator)
Department of Physics, University of Toronto

with material provided by the
MANTRA 2004 Science Team

November 30, 2004

This Post-Flight Report provides a summary of the MANTRA 2004 field campaign including launch preparations, flights profile, instrument performance, assessments of the incidents that happened during the campaign and the results acquired, as required under the PWGSC Contract. Additional details can be found in the minutes of the 6 Quarterly MANTRA Meeting in Toronto last November 10.

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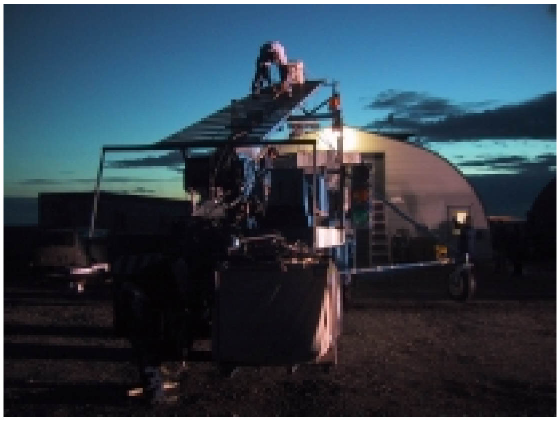


Courtesy of Tobias Kerzenmacher

1. Executive Summary

MANTRA is an ongoing project that has increased in complexity since the first campaign in 1998. Relevant scientific results have been achieved from all previous flights. One example is the use of the MANTRA dataset to assess the nitrogen budget in the Canadian Middle Atmospheric Model (CMAM), an activity that has contributed to improvements in the model. In terms of technology, the MANTRA project has developed a gondola pointing system that is innovative and is capable of providing solar pointing within 0.1 degree in elevation and 4 degrees in azimuth, a rather demanding specification. During the MANTRA 2004 campaign, this system was shown to achieve such specifications when controlling a payload of considerable mass (more than 600 kg of science instruments). The advantage is that it allows the flight of a complementary suite of instrument at once, with the ability to perform both solar pointing and limb scanning observations from the same platform. The science results are then broadened since all the instruments are truly co-located in time and space. Another achievement of the project was the development of a Canadian Fourier Transform Spectrometer that was demonstrated during this year campaign to be able to acquire high quality data from a balloon platform.

We conducted a very successful ground-based inter-instrument comparison campaign during MANTRA 2004, with the objective of assessing instrument performance and evaluating data processing routines and retrieval codes. The campaign included instruments under development, such as the York University AOTF spectrometer, and well-established instruments such as the SAOZ ground-based spectrometer which is a NDSC-certified instrument and the Brewer which is a reference instrument for ozone measurements. The ground-based measurements were conducted for the duration of the field campaign, expanding significantly the availability of data for satellite validation, one of the main scientific objectives of this year's campaign.

MANTRA 2004 plans included the launch of the main gondola using a 11.8-mcf balloon, one or maybe two launches of the SAOZ BrO instrument using a smaller balloon and, as for the previous campaigns, the launch of several ozonesondes throughout the campaign. CSA also authorized the acquisition of a spare balloon of the same size as for the main gondola (11.8 mcf) to be used in the case of problems in the first flight.

All the balloon instruments were tested and characterized in Toronto before the field campaign. Instruments new to the MANTRA project or instruments that had significantly changed from previous flight versions were vacuum and temperature tested to ensure that they met flight expectations. Mechanical and electrical integration was performed in Toronto. The Denver FTS and PARIS were both integrated in Vanscoy. The instruments were shipped to Vanscoy on July 29, arriving at the launch facility on August 3. The field campaign then began with the Brewer instrument being set up and put into operation on the roof of the main hangar.

Final instrument preparation and calibration began immediately after the arrival of the instruments in Vanscoy. Instrument preparations were performed in parallel with final gondola preparations and payload integration. A considerable amount of work was done to finalize the development of the main gondola pointing system.

Weather conditions in Vanscoy were a problem during this year's campaign. From the middle of August, the weather pattern changed towards a fall scenario with constant rains, strong winds, and mostly cloud-covered days. This imposed some difficulties and delays since sunlight was required for final calibration and alignment of some instruments such as the three FTSs.

The first flight of the main gondola was performed on September 1. The 11.8-mcf balloon was launched at 8:30 AM local time (14:30 UT) on Wednesday, September 1, 2004 under calm surface wind conditions. The humidity level was considered high but since the weather conditions had been very poor for a long time and there was no expectation of any improvements, we decided to proceed with the launch. The total mass of the gondola with instruments was ~1450 lb (658 kg). Payload command capability was lost shortly after launch and due to overheating the pointing system stopped working after sunset. The gondola then started spinning and the flight was aborted after sunset. Despite these incidents, some useful data like OH measurements, were acquired during the first flight. The first flight events are summarized in the table below:

LOCAL TIME (UTC – 6 hrs)	**MANTRA 2004 FLIGHT #1 SEQUENCE OF EVENTS**
8:30 AM, Sept. 1	Launch; sonde and radiometer measurements on ascent
8:56 AM	Telemetry monitors from the upper CIP (termination pack) failed
9:12 AM	Lost command capability (uplink). Pointing system in solar mode
11:30 AM	Payload at float altitude (37.185 km)
4:16 PM	Pointing system stopped working
8:40 PM	Sent signal to cut down payload

The payload was recovered and the failure assessment showed that the lost of command was caused by the receiver antenna centre connector, which was pulled away 2 mm from the SMA connector. Solutions were devised and implemented. Since we had the back-up balloon, a second flight was planned. The instruments were quickly refurbished and an identical payload was prepared for a second launch.

The weather conditions remained poor and the first available launch window was on September 14. The launch happened at 2:16 AM under calm winds conditions. At launch the termination pack (upper CIP) downlink failed. Shortly after launch both termination systems fired prematurely and the flight was terminated at 2:21 AM. The maximum altitude reached was 2.09 km. The payload was recovered immediately after the flight termination. A pre-assessment of the failures was made in the field but all the analyses were not conclusive. Causes for the premature flight termination could not be clearly identified. The science team therefore decided to terminate the campaign on September 15, with SIL to proceed with a detailed analysis of the events.

A total of 23 ozone profiles were successfully measured during the campaign using ECC sondes; these included one on the main payload, and one with the SAOZ BrO balloon. Each separate ozonesonde launch included a complete suite of PTU measurements and a GPS receiver was used to calculate upper air winds. Most of the ozonesondes flown during the campaign were recovered, refurbished and re-flown. The ozonesondes were prepared according to the new WMO recommendations, which produce results that are traceable to a UV reference ozone photometer and believed to be accurate to +-5% in ozone concentration. In addition to ozone profiles, the sondes recorded upper air data including pressure, temperature, humidity and wind speed and direction which were used to support both the science effort and flight planning for the heavy balloon launches. The profiles obtained consist of an excellent dataset for satellite validation. Since the Brewer instrument was continuously operating on site, a high quality time series of WMO ‘standard’ ozonesondes with co-incident total ozone measurement were acquired.

As a bonus, those data can be used to determine the residual of ozone above the altitude of the sondes. Those data will be used on the next in WMO SOP report.

A smaller balloon (Raven-300 (300,000 cubic feet) carrying the SAOZ BrO instrument and an ozonesonde was successfully launched on August 24 at 5:10 PM local time. The instruments operated perfectly and high quality vertical profiles of temperature, air density, winds, humidity, O_3, BrO, and NO_2 were acquired as planned: during ascent and during sunset. The data acquired have already been processed. BrO is an important species in the ozone destruction cycle and is difficult to measure from the ground. The MANTRA measurement is important for satellite validation due to the scarce number of available BrO profile measurements. Indeed, satellite validation activities (OSIRIS and SCIAMACHY) are already in progress, with the first results being presented at the 6th Quarterly Meeting in Toronto on November 10, and at the SCISAT-1 Science Meeting on November 16 at University of Waterloo.

Overall, if not complete, MANTRA 2004 produced a good dataset. Analyses are already in progress. Preliminary results, inlcuding comparisons between balloon profiles and ground-based retrievals for algorithm and instrument inter-comparison, O_3, NO_2, and BrO satellite validation, and model performance investigations, will be presented in the next AGU Fall meeting in San Francisco in December. Publication of the results in scientific literature is also being prepared.

Ballooning is a risky activity in itself. In order to improve the MANTRA rate of success, the Science Team's recommendations for future flights are:

1. For CSA to provide financial support for another flight to complete the original science objectives of the MANTRA project. The science payload is ready to fly and a proposal is being drafted for submission to CSA in January 2005.
2. To fly as nearly the same payload as is practical. All of the Canadian instruments will be available, and we will be consulting our international partners (University of Denver and the Service d'Aeronomie) regarding their ability to participate in another campaign.
3. For CSA to contract to SIL directly for flight support. CSA will manage the launch support contract, and CSA and SIL will keep the Science Team informed of activities and progress.
4. For CSA to request a list of equipment to be upgraded from SIL side in order to assure better performance in future flights. Some of the equipment SIL is using is now obsolete and could be replaced. We note that such a list was provided in the budget for the MANTRA 2004 flight at CSA's request and consisted of estimates of $72,600-$77,600 for short-term equipment requirements and $98,000-$105,000 for long-term equipment requirements at the Vanscoy Balloon Base.
5. During the field campaign, a significant number of people work together under a stressful situation. In order to optimize the flow of tasks in the field, alleviate stress, and avoid conflicts it is recommended that the team define and follow a clear management structure with a clear line of communication that specifies who should be discussing what with whom.
6. For all three FTSs to be included in the gondola to have independent "delta" sun-pointing systems, with each instrument pointing system tested and flight-approved before shipping to Vanscoy.
7. The SAOZ instrument should be provided with telemetry to allow checkout on the flightline.

8. The gondola pointing system has been developed and the technology has been transferred to SIL. However, the system still needs some improvements e.g., more temperature sensors, better sun shielding, and a better way of loading limbscan sequence tables. SIL should be able to implement such changes without difficulties. The Science Team can advise as required.
9. The field campaign for an August 2005 launch to start later than the 2004 campaign as the instruments and pointing system are in good shape. We will aim for a shorter campaign, more like those of 1998, 2000, and 2002.
10. The ground-based part of the campaign was very successful and we recommend it to be performed in the same way next year.
11. The SAOZ BrO flight using a separate balloon was successful and we recommend that it be part of the next campaign.

2. Science Objectives and Achievements

MANTRA 2004 is a balloon mission to study stratospheric composition, building on the experience gained during the MANTRA 1998, 2000, and 2002 balloon campaigns. It consists of a high-altitude balloon flight from Vanscoy, Saskatchewan (52°N, 107°W) and a set of smaller balloons flights and ground-based instruments providing complementary data. MANTRA 2004 is supported by the Canadian Space Agency (under the Second Small Payloads Program), the Meteorological Service of Canada, and NSERC (under the Collaborative Research Opportunities Program).

The scientific objectives are as follows:

(1) To fly a comprehensive suite of instruments in order to measure the vertical profiles of the key stratospheric species that control the mid-latitude ozone budget, particularly species in the NOy, Cly, Bry, and HOx chemical families, along with dynamical tracers and aerosols.

(2) To combine these measurements with those obtained from similar northern mid-latitude campaigns of the past 20 years, in order to quantify changes in the chemical balance of the stratosphere.

(3) To perform an intercomparison of multiple measurements of the same trace species made by different instruments, in order to resolve previously observed discrepancies and to assess the instruments' performance.

(4) To use balloon-borne and ground-based measurements for validation and ground-truthing of Canadian satellite missions (Odin with OSIRIS and SMR instruments, and SCISAT-1 with ACE-FTS, and MAESTRO instruments), and to participate in validation of other current satellite missions as SAGE III, ENVISAT (SCIAMACHY, MIPAS, GOMOS), and ADEOS II (ILAS II).

As part of the 2004 campaign, we conducted a ground-based inter-instrument comparison campaign with the objective of assessing instrument performance and evaluating data processing routines and retrieval codes. The campaign included instruments under development, such as the York University AOTF spectrometer, and well-established instruments such as the SAOZ ground-based spectrometer which is a NDSC (Network for the Detection of Stratospheric Change) certified instrument and the Brewer spectrophotometer which is a reference instrument for ozone measurements. The ground-based measurements extended throughout the campaign, significantly expanding opportunities for satellite validation. They also provide the opportunity to study day-to-day variability in the measured species.

During the first flight of the main gondola (September 1) the following instruments acquired useful science data:

- Ozonesonde on ascent (O_3, temperature, and pressure vertical profiles – data has been processed and is available for the science team);
- SPS-B1 and B2 (O_3 and NO_2 vertical profile, J values - no processing of the data done yet);
- MSC OH spectrometer (OH densities – data of very good quality, processing underway);

- MSC radiometers on ascent (HNO_3 vertical profile after retrieval indicates that the data are of very poor quality);
- MSC FTS. This instrument obtained two solar spectra during sunset. The data are of high quality demonstrating an excellent performance of this instrument. Concentrations of CO_2, O_3, CH_4, N_2O can be retrieved at the tangent height but vertical profiles can not be recovered.

As for the second flight (September 14), although all the instruments were tested positively before flight, due to the premature termination of the flight no science data was acquired.

A smaller balloon (Raven-300 (300,000 cubic feet) carrying the SAOZ BrO instrument and an ozonesonde was successfully launched on August 24 at 5:10 PM local time. The instruments operated perfectly and high quality vertical profiles of temperature, air density, winds, humidity, O_3, BrO, and NO_2 were acquired as planned: during ascent and during sunset. The flight was terminated at 9:30 PM and the instruments were recovered next morning. The data have already been processed and profiles are now available for the science team. Satellite validation activities (OSIRIS and SCIAMACHY) are already in progress with the first results being presented at the 6th Quarterly Meeting in Toronto on November 10, and at the SCISAT-1 Science Meeting on November 16 at University of Waterloo. Comparisons between balloon profiles and ground-based retrievals for algorithm and instrument inter-comparison have also started.

A total of 23 ozone profiles were successfully collected during the campaign from ECC sondes (see table below). This provides excellent data for satellite validation. Since the Brewer instrument was continuously operating on site, a high quality time series of WMO ‘standard’ ozonesondes with co-incident total ozone measurement were acquired. As a bonus, those data can be used to determine the residual of ozone above the altitude of the sondes. Jonathan Davies is planning to use those data in the next in WMO SOP report.

A summary of all the balloon flight data acquired during this year's MANTRA campaign is given in the table below.

First Flight: Main Gondola Instruments	**Date**	**Species**
Ozonesonde	Sept 1 ascent	O_3, T, winds, p
SPS-B1 and SPS-B2	Sept 1	O_3, NO_2, J-values (NO_2 and O^1D)
MAESTRO	Sept 1	Data too noisy due to lack of pointing during sunset
MSC Radiometers	Sept 1 ascent	HNO_3 – poor quality data
MSC OH	Sept 1	OH
AIR	No data	-
SAOZ	No data	-
MSC FTS	Sept 1 (2 spectra)	CO_2, O_3, CH_4, N_2O
DENVER FTS	Sept 1 (below 16.5 km)	Data too noisy
PARIS FTS	No data	-
SAOZ BrO Flight	August 24 (ascent and sunset)	**BrO, NO_2, O_3, p, T, winds, humidity**
Ozonesondes (independent flight)	From Aug 9 to Sept 13 (see sondes table below)	**O_3, p, T, winds, humidity**
Second Flight of Main Gondola	No measurements	**-**

Daily ground-based measurements were made by a ground-based SAOZ, a Brewer, a triple-grating DOAS spectrometer, an AOTF spectrometer, and SPS-G. Ground-based measurements were also obtained on a sporadic basis by some of the balloon instruments: MAESTRO-B, MSC FTS, and Denver FTS. O_3 and NO_2 total columns, colour index, and NO_2 slant columns densities measured with the SAOZ spectrometer are available for the Science Team (shown here in Figure 1). For the other ground-based instruments, data from specific days have been processed. Activities for the instrument inter-comparisons have started and preliminary results have been presented to the scientific community. A paper reporting on the ground-based, sondes, and SAOZ BrO balloon data is in preparation.

A summary of the ground-based data acquired during the MANTRA 2004 campaign is given in the table below.

Instruments	Date of Operation	Species
Brewer	Aug 3 – Sept 15	O_3, NO_2, SO_2
SPS-G	Aug 6 – Sept 15	O_3, NO_2
MAESTRO	Aug 20, 21, 24	O_3, NO_2, NO_3, BrO (?)
	(Sept?)	
SAOZ – GB	Aug 5 – 13	O_3, NO_2, O_4,
	Aug 16 – Sept 15	Colour Index
AOTF	Aug 10 – 21	O_3, NO_2
	Aug 25 – 28	
UV-Vis DOAS	Aug 6 – Sept 15	O_3, NO_2
MSC FTS	Aug 10-12, 19, 24, 27-28 Sept 3, 7, 14	HCl, O_3, N_2O, CH_4, H_2O, N_2, CO, HDO, OCS
DENVER FTS	Sporadic days	CFC-11, CFC-12, N_2O, CH_4, O_3, HNO_3, H_2O

The time series of O_3 and NO_2 measured by the ground-based SAOZ instrument during twilight is shown in the figure below.

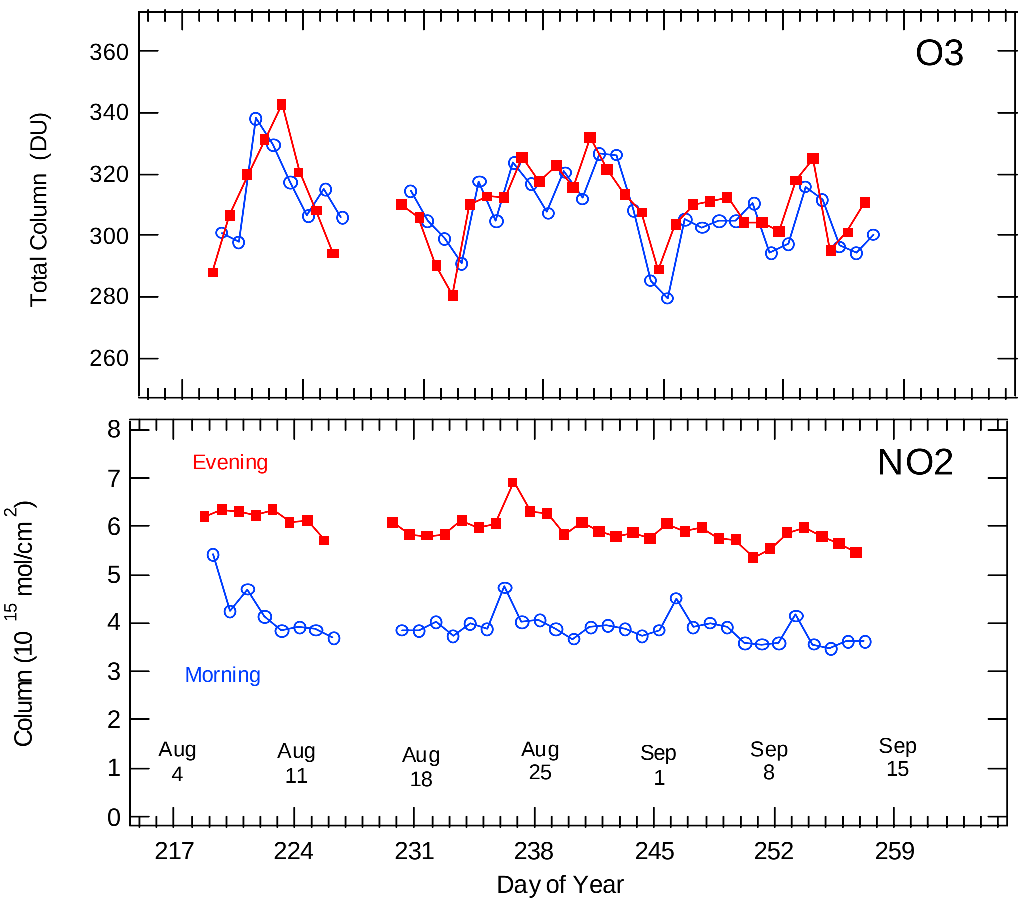


Figure 1: Time evolution in days of the ozone (top) and NO_2 (bottom) vertical column densities measured by the SAOZ ground-based spectrometer in Vanscoy during the MANTRA 2004 campaign. While ozone is variable between 280 and 340 DU, NO_2 was relatively stable with an average of 5.96 x 10^{15} molec.cm^{-2} in the evening and 3.96 x10^{15} molec.cm^{-2} in the morning. Data provided by Florence Goutail.

3. Balloon Flights

MANTRA 2004 plans included the launch of the main gondola using a 11.8-mcf balloon, one or maybe two launches of the SAOZ BrO instrument using a smaller balloon and, as for the previous campaigns, the launch of several ozonesondes throughout the campaign. CSA also authorized the acquisition of a spare balloon of the same size as for the main gondola (11.8 mcf) to be used in the case of problems in the first flight. Indeed there were problems with the first flight. In total, two 11.8 mcf balloons were launched with the same set of the instruments in the gondola, one 300,000 cubic feet balloon with the SAOZ BrO, and 21 smaller balloons with ozonesondes. Those activities are reported below.

3.1 Pre-Flight Preparation

The balloon instruments were tested and characterized in Toronto before the field campaign. Instruments new to the MANTRA project or instruments that had significantly changed from previous flight versions were vacuum and temperature tested to ensure that they met flight expectations. This was the case for MAESTRO, the two SPSs, MSC FTS, PARIS FTS, AIR, and the Pointing System. The tests were performed at University of Toronto, except for AIR, which was tested at MSC, from May to June prior to mechanical and electrical integration. No major problem was identified but those tests proved very useful to qualify the flight instruments. The report on the vacuum and temperature test performed on the Pointing System is included in Appendix B.

As was done for MANTRA 2002, a preliminary mechanical and electrical integration of the instruments onto the gondola was done in Toronto, rather than at Vanscoy. This was useful to identify problems that could then be corrected before going to Vanscoy and pointed towards the need for further tests of PARIS sun-tracker vibrations interference in the other instruments and therefore the need of options in case of detection of such interferences. SIL shipped the gondola to the University of Toronto in mid-June, where it remained until being returned to SIL on July 29.

A major activity in preparation for this year's campaign was the development of the gondola pointing system and the technology transfer to SIL. This activity, initially led by Prof. Ben Quine, was transferred to Prof. Jim Drummond in May. A considerable amount of the work had to be performed in Vanscoy, imposing some delay in achieving flight readiness. The required level of development was achieved and technology transfer to SIL was concluded.

All of the instruments from the University of Toronto, the Meteorological Service of Canada, University of Waterloo, and York University were packed up and sent by truck to the SIL launch facility on June 29. Most members of the MANTRA Science Team arrived in Saskatoon on August 3. A listing of MANTRA personnel, including those who were on site at Vanscoy, is provided in Appendix A. About 20 computers were set up, locally networked, and linked to the outside world on August 5. The status reports and photos were posted daily on the public MANTRA web site. Preliminary data products such as total column ozone and NO_2, and ozone and temperature vertical profiles, were also made available throughout the web page.

Final instrument preparation and calibration began immediately after the arrival of the instruments in Vanscoy. Instrument preparations were performed in parallel with final gondola preparations and payload integration. Scientific Instrumentation Limited was responsible for preparation of the gondola and support systems (command interface package, telemetry, STARS power distribution system, and battery packs). The 11.8 mcf primary balloon, a spare balloon of the same size, and the 7.6 mcf backup balloons were on site. Helium for the first main flight and for the ozonesondes and SAOZ BrO flight was supplied and was in place when the Science Team arrived on site. All instruments and telemetry were integrated on the gondola for all-up checks, electrical tests including external and battery power tests, RFI (radio frequency interference) tests, and balancing. A hole in the ceiling of the hangar was added allowing hanging tested to be done form inside using a crane outside. Such improvement proved to be very useful as the weather in Vanscoy during this year campaign was only poor with only feel sunny days. During the tests of the gondola pointing system four hanging testes were performed in Vanscoy.

Weather conditions in Vanscoy were a problem during this year's campaign. From the middle of August, the weather pattern changed towards a fall scenario with constant rains, strong winds, and mostly cloud-covered days. This imposed some difficulties and delays since sunlight was required for final calibration and alignment of some instruments such as the three FTSs.

3.2 – Winds Forecast

Plots of daily forecast balloon trajectories and surface and stratospheric winds were produced at by Yves Rochon at MSC using information from ECMWF objective analyses (up to 1 hPa) and wind data from the regular Vanscoy ozonesonde launches. This information was used to help in identifying turnaround and in flight planning, with data available from August 10 through September 14. In addition, surface wind forecasts were obtained regularly from the Calgary office of Environment Canada and were also used in ozonesonde and primary launch planning. Following is an example of the plots of the winds forecast for 24 of August.

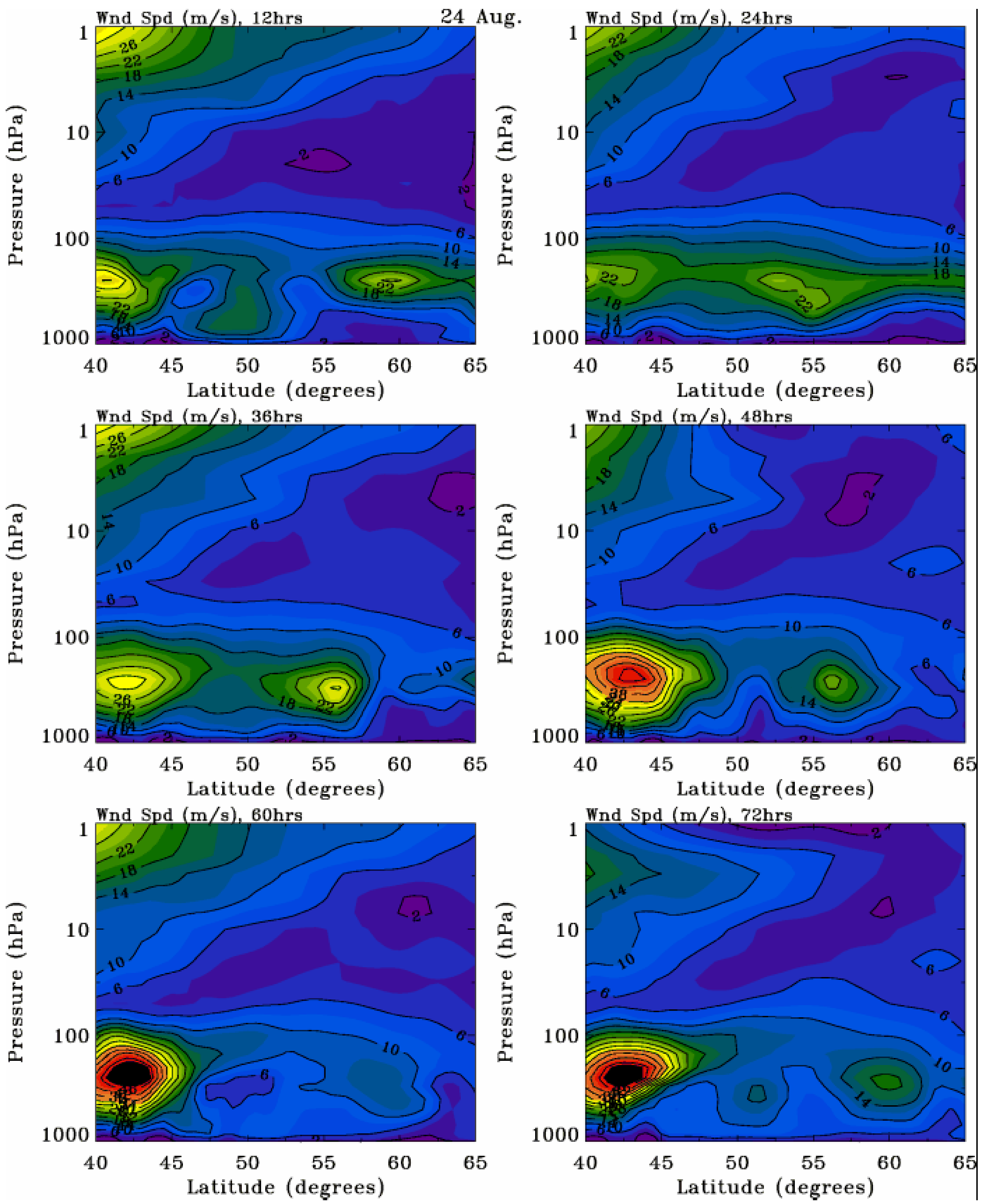
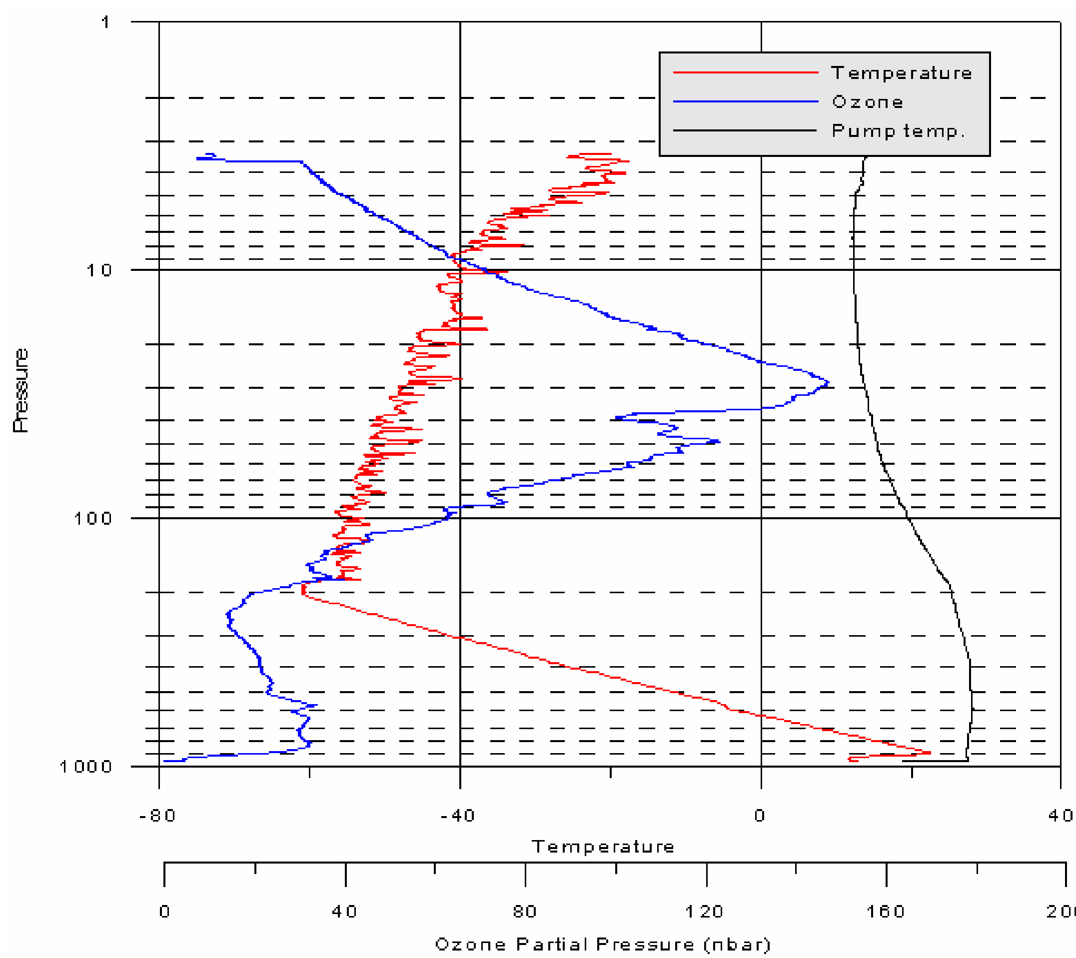


Figure 2: ECMWF winds forecast for 24 of August 2004 at Vanscoy.
Provided by Dr. Yves Rochon.

3.3 - Ozonesondes (with input from Jonathan Davies)

A total of 23 ozone profiles were successfully collected during the campaign from ECC sondes including one on the main payload, and one included to the SAOZ BrO balloon. Each separate ozone launch included a complete suite of PTU measurements and a GPS receiver was used to calculate upper air winds. Most of the ozonesondes flown during the campaign were recovered, refurbished and re-flown. The ozonesondes were prepared according to the new WMO recommendations, which produce results that are traceable to a UV reference ozone photometer and believed to be accurate to +-5% in ozone concentration. In addition to apparent ozone profiles the sondes recorded upper air data including pressure, temperature, humidity and wind speed and direction which were used to support both the science effort and flight planning for the heavy balloon launches.

The ozonesonde data obtained during the main gondola flight on September 1, 2004, is shown in the figure below (prepared by Jonathan Davies):



The ozonesonde flights are summarized in the table below (information provided by Jonathan Davies):

#	Date	Balloon	Payload	Altitude (km)	Status
1	9-Aug /11:00	TA-1200	Ozone sonde & GPS	Balloon train failure	Recovered
2	9-Aug /12:30	TA-1200	Ozone sonde & GPS	33	
3	11-Aug/10:00	TA-1200	Ozone sonde & GPS	32	recovered
4	13-Aug /22:00	TA-1200	Ozone sonde & GPS	33	Recovered
5	15-Aug /10:00	TA-1200	Ozone sonde & GPS	33	Recovered
6	17-Aug /10:00	Raven-141	Ozone sonde & GPS	41	Not recovered/GPS failure
7	19-Aug /10:00	TA-1200	Ozone sonde & GPS	32	Not recovered
8	21-Aug /10:00	Raven-141	Ozone sonde & GPS	38	Recovered
9	23-Aug /14:00	TA-1200	Ozone sonde & GPS	4	Rainy, balloon stalled between 6,000-12,000 f
10	24-Aug /14:00	Raven-141	Ozone sonde & GPS	36	Recovered
11	**24-Aug /18:05**	**Raven-300 (CV)**	**SAOZ, GPS**	**38**	**Recovered/ SAOZ BrO**
12	25-Aug /10:00	TA-1200	Ozone sonde only	33	Not recovered
13	26-Aug /10:00	TA-1200	Ozone sonde & GPS	34	Recovered
14	27-Aug /10:00	Raven-141	Ozone sonde & GPS	36	Not recovered
15	28-Aug /10:00	TA-1200	Ozone sonde & GPS	?	Partial data – not recovered
16	29-Aug /10:00	TA-1200	Ozone sonde & GPS	34	Not recovered
17	30-Aug /10:00	Raven-141	Ozone sonde & GPS	45	Not recovered/ GPS failure
18	31-Aug/17:30	Raven-141	Ozone sonde & GPS	38	Not recovered
19	**1-Sep/8:30**	**Raven 11800**	**Main gondola**	**37**	**First flight Main gondola**
20	4-Sep/16:00	Raven-141		41	Not recovered
21	6-Sep/16:00	Raven-141	Ozone sonde & GPS	32	Not recovered
22	8-Sept/16:00	Raven-141	Ozone sonde & GPS	35	Not recovered
23	11-Sept/19:00		Ozone sonde & GPS	35	Not recovered
24	**14-Sept/2:16**	**11.8 mcf**	**Main payload Second flight**	**-**	**Flight aborted**

Nomenclature:
- TA-1200: Latex rubber balloon 1200 gr,
- Raven-141: Plastic Raven balloon 141,000 cubic feet.

3.4 – SAOZ BrO Flight (material provided by Florence Goutail)

The French CNRS team was present during the MANTRA campaign with 2 balloon instruments, the standard SAOZ instrument (300-600 nm) and the enhanced UV version SAOZ-BrO (330-400nm). SAOZ and SAOZ-BrO instruments have been prepared in France. On the field, tests have been conducted to check the performances and verify that the setting of the spectrometers did not change during transportation. Both instruments were ready for flight on August 18, 2004.

The balloon forecast planning was the following:

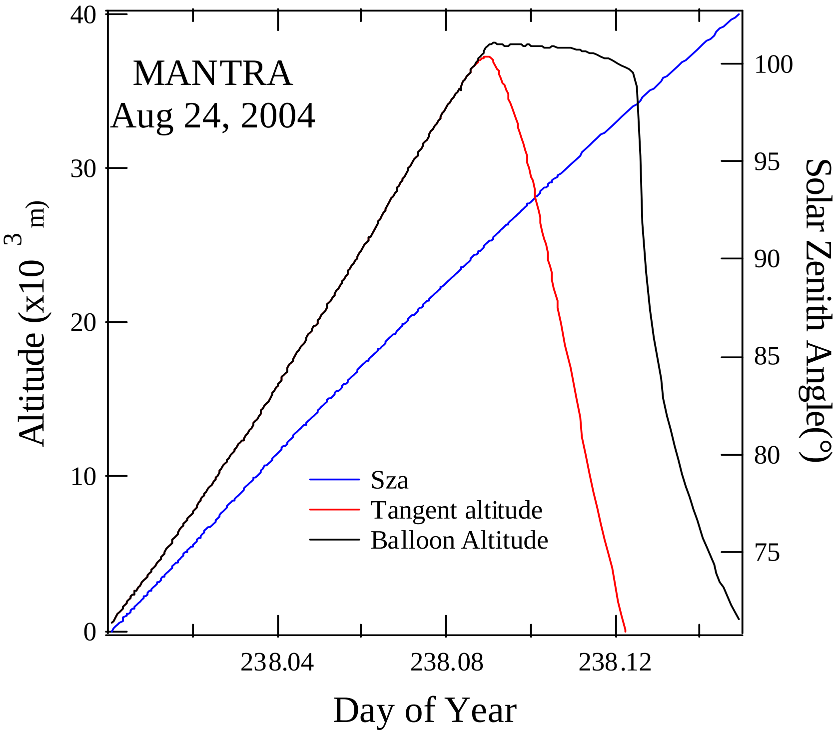
- One SAOZ-BrO flight on a separate balloon before the Main MANTRA flight.
- SAOZ NO2 on the Main payload.
- A second SAOZ-BrO flight while Main payload was in flight.

The SAOZ BrO instrument was launched in a 300,000 cubic feet balloon on August 24. Together was launched also an ozonesonde and a GPS. The exact time of launch has been calculated using temperature and wind forecast provided by Y. Rochon from Meteorological Service of Canada. The forecast was correct and the instrument reached float altitude just before sunset as it was planned. During the whole flight, the instrument has performed well and has been recovered on the following day in good shape. The flight details are:

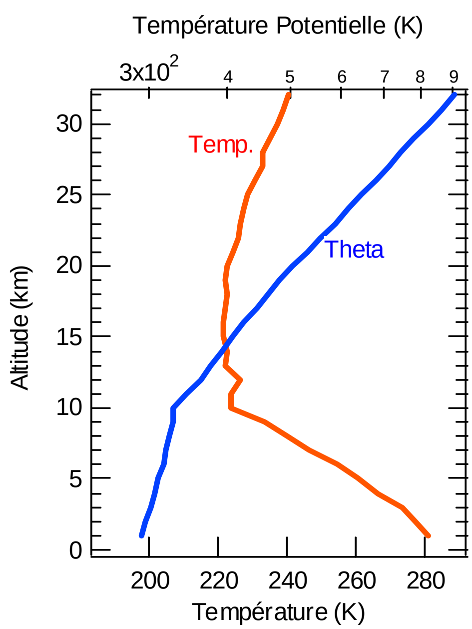
- Balloon released Aug 25 at 00:02 UT (18:02 local time)
- Balloon achieved 20 km altitude at 01:11 UT (19:11 local time) SZA =82
- Sunset start (alt 36200) 02:03 UT (20:03 loc) SZA =90
- Balloon achieve float altitude of 38100m at 02:10 UT (20:10 loc) SZA =91
- Tangent point of 20 km achieved at 02:33 UT (20:33 local time) SZA = 94.3
- End of occultation: 02:35 UT , SZA = 94.6
- Flight cut down: 02:59 UT, SZA = 98
- Landing: 03:34 UT

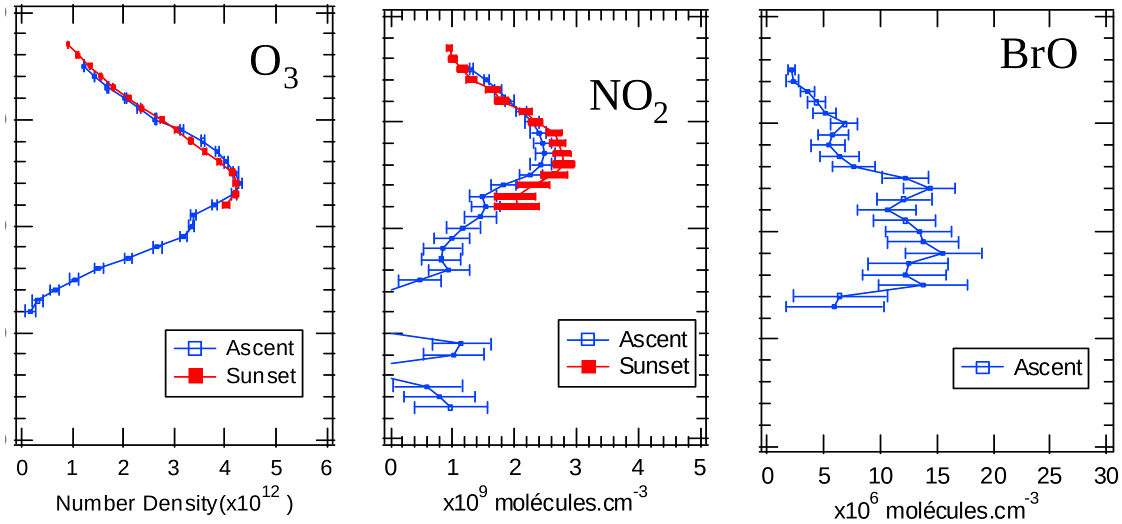
The instruments were recovered on the next morning and were all in excellent status. No refurbishment was needed to prepare for a second flight if weather conditions allow.

The flight profile is shown in the figure below:



The extracted quantities from the SAOZ BrO instruments are vertical profiles of atmospheric temperature, O3, NO2, and BrO. The data were processed in collaboration with Dr. Michel van Roozendael, IASB, Belgium, using WINDOAS, and the results are available for the science team and shown below:





3.5 – Main Gondola Flights

The field campaign at Vanscoy began with ground-based measurements starting on August 3 and sondes launching starting on August 9, continuing until September 15. The primary balloon was successfully launched at 8:30 am local time on September 1, 2004. Due to a series of incidents the flight had to be aborted. The payload was recovered in the next day and since the science objectives could not be achieved the instruments were refurbished and a second flight was attempted on September 14.

3.5.1 – First Flight: September 1

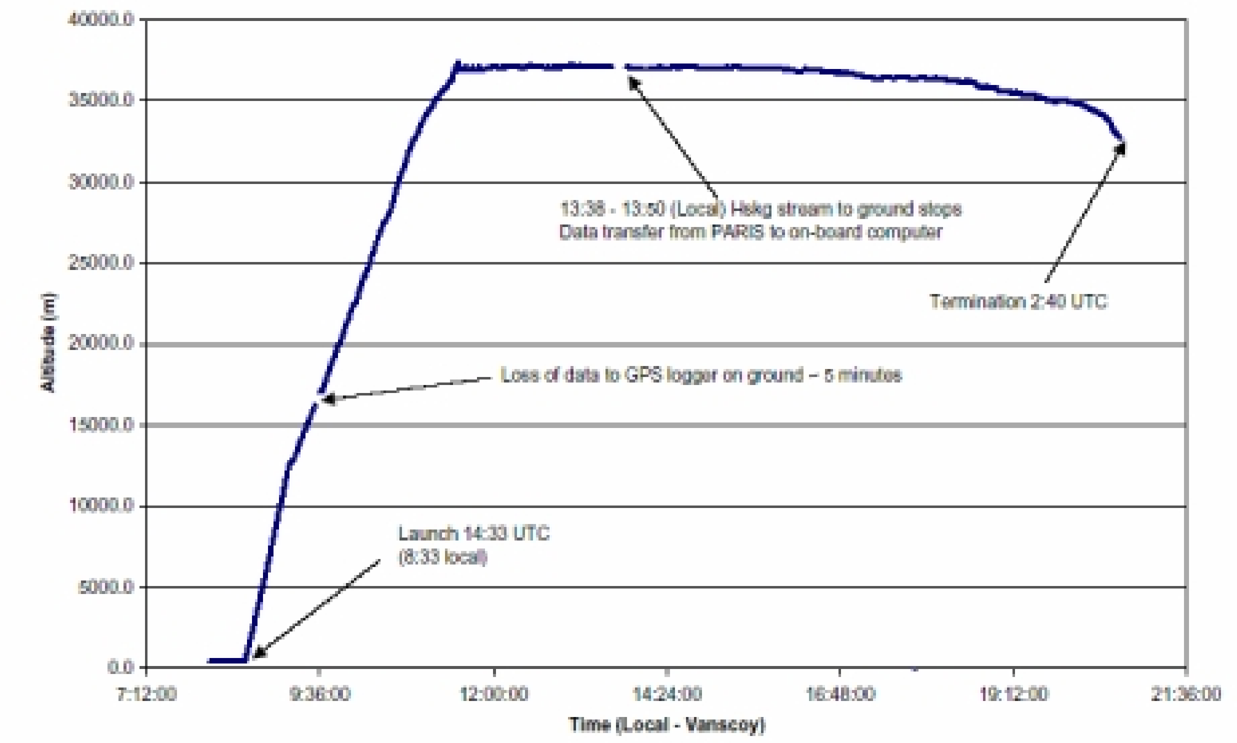
The 11.8-mcf balloon was launched at 8:30 AM local time (14:30 UT) on Wednesday, September 1, 2004 under calm surface wind conditions. The humidity level was considerably high, but since the weather conditions had been poor for a long time and there were no expectations of improvements we decided to proceed with the launch anyway. The total mass of the gondola with instruments was ~1450 lb (658 kg).

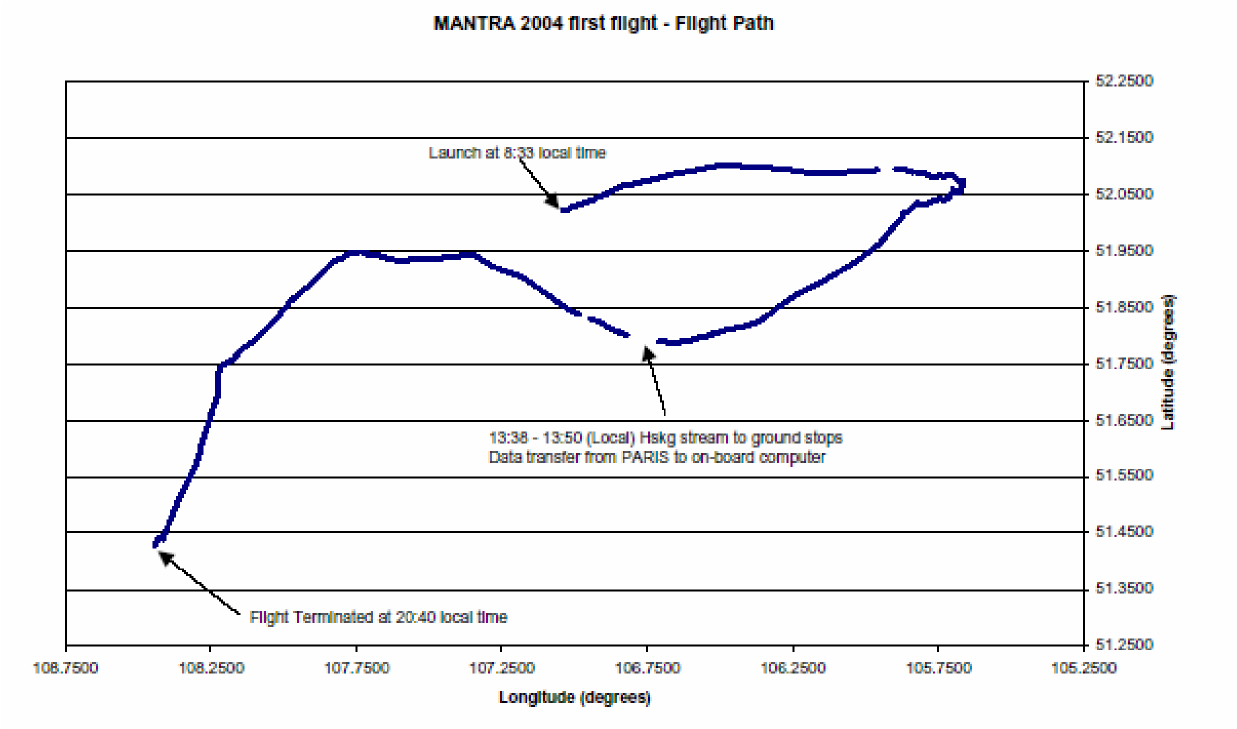
Members of the science and SIL launch teams arrived on station around 01:00 AM local time on September 1. Final indoor instrument telemetry checks were completed at 3:30 PM and the gondola was rolled out of the hangar shorter after. Science "go" was given at 6:30 AM after finishing command checkout from the launch site. Inflation of the balloon began at 6:45 AM and finished at around 7:40 AM. The table below summarizes the main flight activities and measurements during the balloon flight.

LOCAL TIME (UTC – 6 hrs)	**MANTRA 2004 FLIGHT SEQUENCE OF EVENTS**
8:30 AM, Sept. 1	launch; sonde and radiometer measurements on ascent
8:56 AM	telemetry monitors from the upper CIP (termination pack) failed
9:12 AM	Lost command capability (uplink). Pointing system in solar mode
11:30 AM	Payload at floating altitude (37.185 km)
4:16 PM	Pointing system stopped working
8:40 PM	sent signal to cut down payload

The launch at 8:30 AM local time (14:30 UT) went very smoothly. Because of the high humidity level the balloon disappeared in the fog shortly after launch. The balloon reached its maximum altitude of 37.185 km at around 11:30 AM. Command capability (uplink) to the gondola was lost at 9:12 AM when the balloon was at an altitude of 12.80 km and at a range of 46 km. An aircraft was sent to the area in an attempt to send commands from a loser range but this did not worked either. At 8:56 AM, at a range of 18 km and an altitude of 8.02 km, the telemetry monitors from the upper CIP (termination pack) failed and never returned. The pointing system was launched in solar mode and was performing very well. However, at 04:16 PM it overheated and stopped working. The gondola then started to spin. A decision was made to wait till for the twilight in the hope some useful data could still be acquired. The flight was then terminated at 8:40 PM local time. Detail reports on the pointing system and on the failure assessments were provided by SIL and are appended here.

The flight profile is shown in the figures below (provided by SIL using PARIS GPS data)





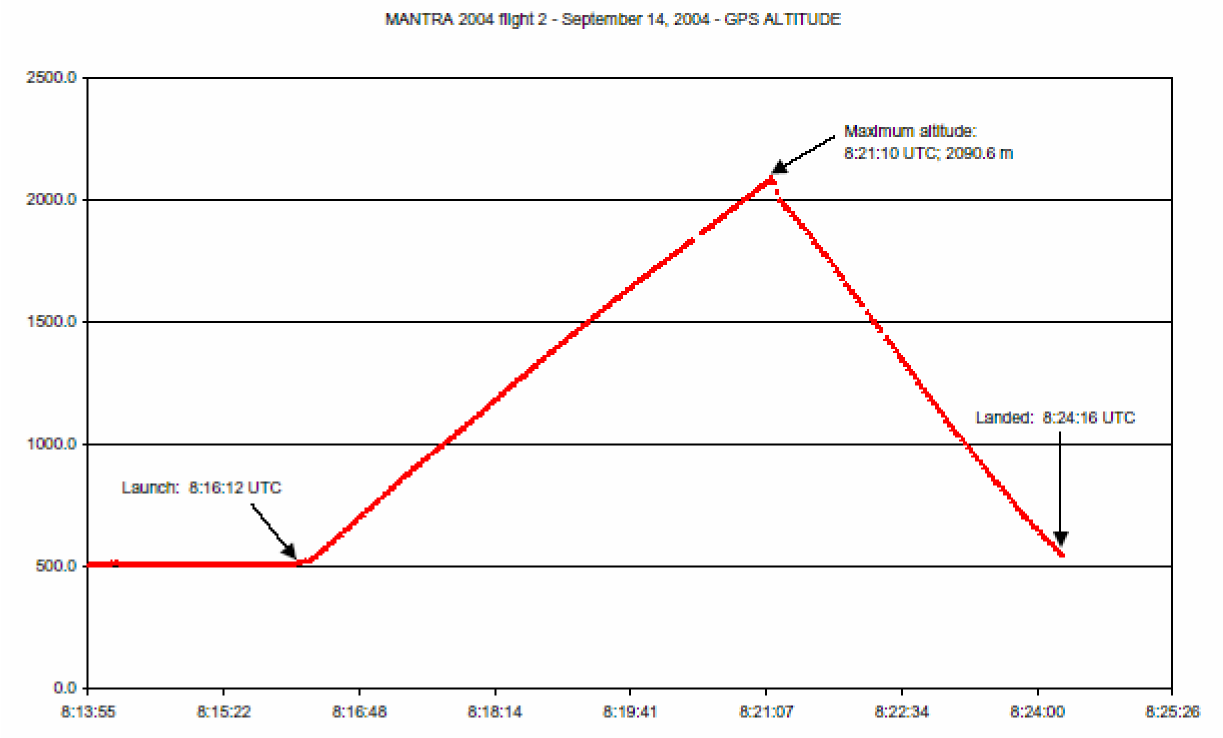
3.5.2 – Second Flight: September 14

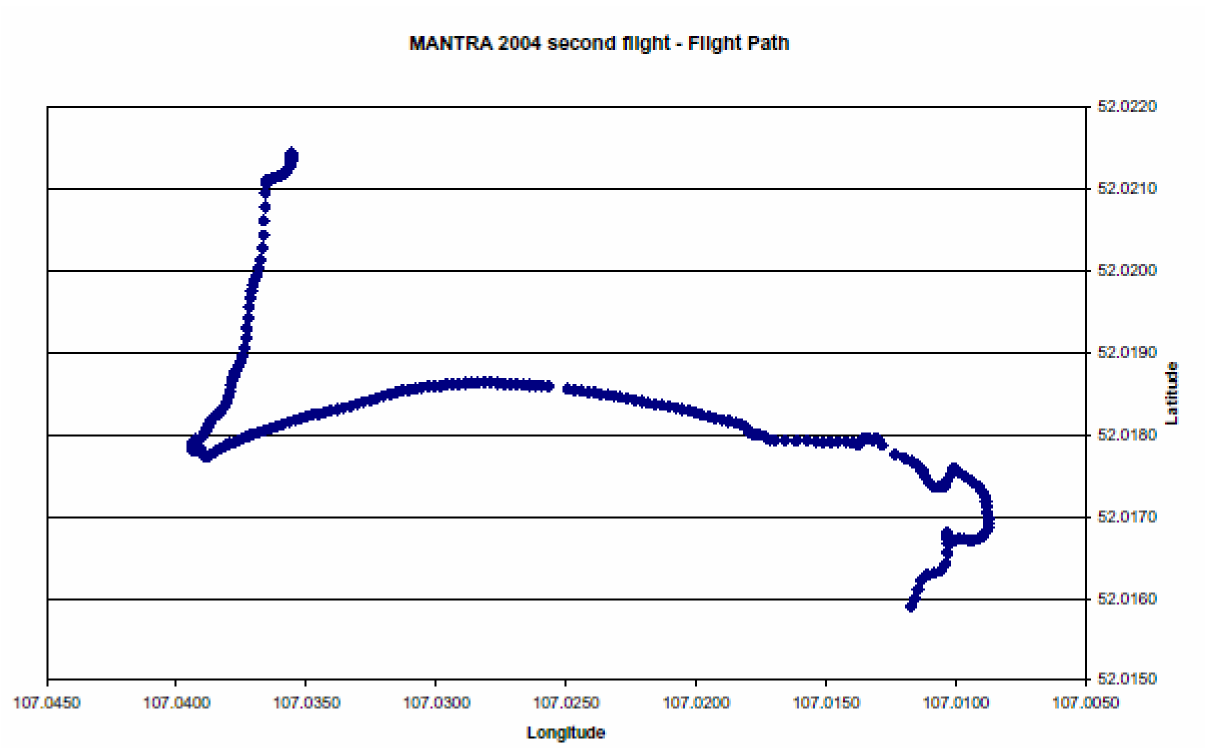
The main gondola was retrieved on September 2 and arrived in the hangar in the afternoon. The problems we had in the first flight were analysed and solutions were devised and implemented. A decision of launch a second balloon was then made. The instruments were quickly refurbished and an identical payload was prepared for a second launch.

We were then informed that due to problems with the provider, the helium available in the field was not enough. A new shipment of Helium arrived in the field on Saturday, September 11. The weather conditions were then very poor and the first available launch window was on September 14. The launch happened at 2:16 AM under calm winds conditions. At launch the termination pack (upper CIP) downlink failed. Shortly after launch both termination systems faired prematurely and the flight was terminated at 2:21 AM. The maximum altitude reached was 2.09 km. A separate report on failures assessment was provided by SIL and is appended at the end of this document.

The payload was recovered right after the flight termination. A pre-assessment of the failures was made in the field but all the analyses were non conclusive. Causes for the premature flight termination could not be clearly identified. Therefore, the team decided terminate the campaign on September 15 and proceed with a detail analysis of the events. All the instruments were packed next day and shipped back to Toronto on September 15. The science team left the field on September 16.

The second flight profile is shown in the figures below (provided by SIL using PARIS GPS data)


MANTRA 2004 flight 2 - September 14, 2004 - GPS ALTITUDE
Maximum altitude:
8:21:10 UTC; 2090.6 m
Landed: 8:24:16 UTC
Launch: 8:16:12 UTC
2500.0
2000.0
1500.0
1000.0
500.0
0.0
8:13:55
8:15:22
8:16:48
8:18:14
8:19:41
8:21:07
8:22:34
8:24:00
8:25:26


MANTRA 2004 second flight - Flight Path
52.0220
52.0210
52.0200
52.0190
52.0180
52.0170
52.0160
52.0150
Latitude
107.0450
107.0400
107.0350
107.0300
107.0250
107.0200
107.0150
107.0100
107.0050
Longitude

4. Balloon Instrument Reports

4.1 Pointing Control System (with input from Jim Drummond)

The gondola pointing system had to be extensively tuned during the flight preparation at Vanscoy. It was found that the best way of doing this was to “hang” the payload from a crane with a temporary flight train extending through the roof of the hangar. This kept the wind off of the payload and permitted some significant testing. A total of four hanging tests were performed of progressively increasing fidelity.

Other things that had to be achieved were the writing of the limb scan tables and an attempt at the scheduler. This latter was abandoned due to time constraints.

The pointing system performed adequately during the first flight. Elevation was extremely good, azimuth less so for the following reasons: It was intended that the system should be “tuned” at altitude, but with the loss of commanding this was not possible. However the system was (fortunately) turned on early in the flight and performed reasonably using the default parameters set during the hanging tests above despite the total loss of commanding.

The pointing system failed about five hours after float when temperatures inside the electronics box were well above the expected values. This is attributed to some issues with the insulation of the box – the box should not be insulated, but the sun should be shielded from the box.

For the second flight the pointing system did not have a chance to operate and so no data were collected.

A detail report on the development and performance of the gondola pointing system was provided by SIL and is appended at the end of this document.

4.2 MSC Emission Radiometers (with input from Matt Toohey)

Two emission radiometers were once again included on the MANTRA 2004 payload. Prior to shipment to Vanscoy, preparatory work focused on MX-36, the instrument that failed in 2002. The detector in this instrument was found to have failed, and was replaced with a scavenged detector from another radiometer, which necessitated also the transfer and testing of another preamplifier circuit. After reassembly and insulation, the instruments were shipped in working condition.

Blackbody tests in Vanscoy confirmed the instruments’ working condition. They were integrated onto the payload without complication and experienced no problems in the RFI tests, besides data transmission problems common to all instruments.

Both instruments collected data during the ascent of the September 1 flight. Anomalous encoder position values for the circular filter were collected during the entire session for both instruments; a problem that has not been seen before and is likely due to the build up of ice in the instrument due to the humid conditions at launch time. This fault was addressed for the second flight by sealing the electronics cavity more securely and the fabrication of a gas input valve, used to purge the electronics cavity with dry N_2 gas during the cryogenic fill procedure. This remediation appeared to be successful during the second flight. The utility of the data from the September 1 flight is currently being addressed through initial analysis.

4.3 MSC SunPhotoSpectrometers SPS-B1 and SPS-B2 (with input from Clive Midwinter)

SPS-B1 Occultation

The B1 instrument is on the pointing system and acquired the sun about 15 minutes after launch. There will be a good possibility to get NO2 (and less important O3) profiles on the ascent. The instrument continued to acquire data during the day and that can be used to extract a zero airmass spectrum. No data of any value was retrieved after the pointing system stopped acquiring the sun. The elevation was pointing too high during sunset and only indications of a slow rotation were observed.

SPS-B2 J-values

The SPS-B2 doesn't require pointing so the data collected will include J-values for J_{NO2} and J_{O1D}. These will include an ascent profile and observations throughout the day as the sun sets.

4.4 MSC MAESTRO-B (with input from Tobias Kerzenmacher)

The Maestro-G, used in Eureka before, was successfully vacuum tested for the Mantra 2004 campaign where it was employed both as a ground based instrument and as one of the primary instruments on the payload. Before employment on the ground the Maestro underwent testing and line shape and lamp calibrations. In order to increase the signal to noise ratio a freezer was used to cool the Maestro down, which led to excellent ground-based data during the pre-flight period up to the 23 August 2004. For the flight, tables with instructions on what kind of MAESTRO measurements to take were written and could be changed from the ground. We installed a neutral density filter so that the integration times used in those tables did not get too short for direct sun measurements. The instrument was aligned so that it was pointing to the sun. The Maestro has 2 channels, one UV and one visible channel. At the RFI test we noticed that there was noise on the UV channel of the instrument. This noise was very small and did not prevent us to get useful data, but for a future flight we need to consider earthing issues of the instrument. During the flight data was collected until the flight was terminated. After 2 hours into the flight the UV channel did not report any data anymore, but we can use the visible channel for the analysis after that point. Had we had communication to the instrument, a simple reset would have solved the problem with the UV channel. When the payload lost the sun pointing, we did not collect any useful data anymore.

The Maestro worked successfully during the whole campaign. The occurred problems were not serious and could be dealt with in the field without disruption. The data collected during the flight will allow us to get profiles of ozone for the ascent of the balloon. The ground based data collected with the maestro are excellent for the intercomparison of the various instruments employed since a totally different method is used to derive the chemical species and preliminary results show that these various methods lead to simian results.

4.5 University of Denver Fourier Transform Spectrometer (with input from Pierre Fogal)

The University of Denver Fourier Transform Spectrometer (FTS) arrived at Vanscoy far from its projected state of readiness. This was due to the very late arrival of funding from NASA headquarters. A great deal of effort by the DU team was invested into creating flight software and debugging flight computer hardware issues while at Vanscoy. By late August the software and hardware were declared flight ready. "All Up" tests showed all systems to be working nominally. However, pre-flight checks showed the computer to be inoperable, and it was determined that the power supply had failed. It was replaced with a spare. This also led to flash disk corruption, which was corrected on the flight line prior to launch. The nominal 28 V battery pack was measured at approximately 31 V, and this was the likely cause of the problem.

During the first flight, a failure in the scan drive electronics lead to a halt in the data collection. At approximately the same time, telecommand capability was lost and so we were unable to attempt to rectify the situation. Data was collected from approximately 4 km to approximately 16 km on ascent. The data is somewhat compromised by the presence of water-ice mixture present on external mirror surfaces. The water and ice mixture resulted when fog rolled over the launch site just before launch. After recovery it was determined that the optical encoding circuit that was used to determine scan length had developed a fault. When we were unable to determine which component had failed, we replaced the encoding system with a 555 timer circuit. At that time it was also determined that had we been able to send commands to the instrument it could have collected interferograms through the simple act of sending the command that switches the scan mechanism off, and then on after enough time had elapsed for a complete reverse-scan, forward-scan pair. After recovery, it was also determined that the scanning mechanism had incurred some damage on landing. As it was anticipated that the payload would have a quick (less than 1 week) turnaround for a second flight, we decided not to attempt a fix, but rather aligned the spectrometer to minimize the effects of the damage. The FTS was thus made ready for the second flight. It returned from the prematurely terminated second flight in relatively good condition.

4.6 MSC Fourier Transform Spectrometer (with input from Debra Wunch)

The main lessons learned from the 2002 launch of the MSC FTS (as described in the MANTRA 2002 Post-Flight Review) are as follows:

- Ensure that the MSC FTS is less dependent on the pointing system (especially in azimuth).
- Remove PCDA, the Bomem control software that is designed for manual ground-based work.
- Create more robust LabVIEW code to control the instrument.
- Embed housekeeping functionality into the main LabVIEW control code.
- Modify the detector mounts to include z-translation capability for the InSb detector.
- Devise a better method of solar alignment with the pointing system.

These concerns were all addressed in preparation for the 2004 launch of the MSC FTS. The majority of time was spent on removing PCDA, which required eliminating the majority of the original electronics in the FTS. We then rebuilt the electronics and wiring system, using off-the-shelf components, and wrote control software in LabVIEW. The resulting instrument was 2/3 the weight and volume and consumed 2/3 the power. A sun seeker, which had been flown on previous balloon flights with a different FTS, was used to reduce our dependence on the main gondola pointing system.

After all the above changes, the ground-based data from the MSC FTS was excellent. Ground-based data was taken during at least 10 days of the MANTRA campaign, and as such, the MSC FTS will be able to participate in the MANTRA ground-based campaign.

During the first flight of MANTRA 2004, the MSC FTS performed extremely well. Since the software included an automated scheduler, the loss of uplink telemetry did not affect how the MSC FTS functioned. Unfortunately, three hours before sunset (the first measurement opportunity for the MSC FTS) the pointing system overheated and shut down. While we were significantly less dependent on the accuracy of the pointing system during this flight, we still depended on it functioning to within ±10° in azimuth. Once the pointing system shut down, the payload began to slowly rotate, and continued to do so throughout sunset.

Luckily, the rotation was slow enough that during the two minutes or so that the solar-pointing face of the gondola was facing the sun, the MSC FTS obtained two good-quality spectra from each of its detectors. This data is not enough to retrieve a profile of trace gas species – one would need more spectra of differing solar zenith angles to achieve this – however path amounts for certain species will be determined. This will not necessarily add to the science derived from the MANTRA 2004 balloon measurements, but it does prove that the MSC FTS works well, both on the balloon and on the ground.

Upon landing after the first launch, the MSC FTS took a hard sideways hit as the payload dropped on its feet and flipped over on its right side. This ripped out the shock mounts, tilted the entire optical system to around 30° to the vertical and cracked the welds in the new base plate. The optics were realigned and new shock mounts were ordered, delivered and installed on the base plate that had been flown in 2002 within a week.

After the second flight, the instrument was retrieved from the payload, a mechanical switch was fixed and it was taken outside and began recording data within a couple of hours.
The instrument is currently in the lab at U of T, and arrived home still in alignment after its trip back from Saskatchewan.

4.7 PARIS Fourier Transform Spectrometer (with input from Kaley Walker)

MANTRA 2004 was the first balloon mission that the Portable Atmospheric Research Interferometeric Spectrometer (PARIS-IR) took part in. Because of the issues with pointing and commanding, no atmospheric data was collected during the first flight (Sept. 1). These issues were resolved for the second flight (Sept. 14) but it did not last long enough to collect any data. Engineering data was collected during the first flight, which has been used to assess the thermal performance of the instrument and on-board computer. Also some ground-based measurements were recorded on August 13 while testing the Bomem-built suntracker.

The main issue for PARIS-IR during MANTRA 2004 was solar tracking. The Bomem-built suntracker was not allowed to fly because its motions caused perturbations in the MSC-FTS and DU FTS measurements. This meant that we had to use our backup plan: a mirror mounted on the gondola pointing system. This was augmented by a small azimuth tracker which provided the pointing accuracy (better than 0.15°) required for the PARIS measurements. Alignment of the azimuth tracker and PARIS proved to be challenging because it had to be done using the Sun and the pointing system. For the first flight, the solar alignment was very poor because there had not been enough clear sky before launch to verify the last set of adjustments. This was improved significantly for the second flight. The alignment had been completely redone and test measurements were made both at sunrise and throughout a day to verify the performance of the tracker.

A commanding issue was identified during the first flight, which prevented useful spectral data from being recorded. The path difference command has to be set after the interferometer has been turned on for the data to be recorded properly. This was not adequately tested before hand because of poor weather conditions - no spectra had been recorded with the autoscheduler batch file. This glitch could not be corrected during the flight because of the loss of the command uplink.

For future flights, a “stand alone” suntracker must be developed for PARIS-IR. This will allow the instrument to be more easily aligned (without needing the pointing system). Also PARIS can be removed from the gondola to make solar measurements whenever the weather permits without compromising its alignment. A more robust data downlink is required for the three FTS instruments. It should not require the uplink to be operational and thus will allow the data downlinking process to be automated.

4.8 MSC OH Spectrometer (with input from David Tarasick)

The spectrometer measures either sunlight or radiation from the sky (scattered sunlight). The observation direction for the sky radiation is 90 degrees from the sun in azimuth and just above the horizon in elevation (roughly at 2, 3, 5 & 8 degree elevations). The sky measurements are over the wavelength range 306-311nm and are done in two polarizations, ‘strong’ which maximizes the signal and ‘weak’ which is at 90 degrees to the ‘strong’ setting and for which the signal is considerably smaller, by as much as 50:1. The basis of this OH measurement method is that solar radiation scattered by OH molecules is only slightly polarized while the scattering by air molecules is very strongly polarized. The specific measurement comprises ten wavelength scans: four ‘weak’ scans followed by two ‘strong,’ then four ‘weak.’ The data in the strong scans are used to help isolate the OH radiation in the weak scans. Each set of ten scans (c 5 minutes in duration) yields one measurement of the OH radiation. The sets of ten scans are normally made in a sequence of eight sets with first increasing then decreasing elevations. Each sequence lasts for about one hour.

The optimum measurement schedule for the spectrometer on a Mantra flight would be for it to take sun spectra (294-314nm) during the ascent then, when higher than 25km, to do OH sequences interspersed with sun spectra. The best maximum altitude would be 40km. With this schedule and profile, the OH measurements would include the variation with height and solar elevation, and there would also be the by-product of accurate ozone profiles including especially the 30-40km region obtained for the sun spectra.

The Mantra2004 flight profile was good for the OH instrument, which worked well throughout the flight, compromised only by the lack of command from the ground and later by the loss of pointing. During the day, three full OH measurement sequences were successfully obtained from 37 km, as was later one set at an elevation of 1 degree just prior to sunset at a lower altitude. The total number of measurements was thus 25. These measurements nicely complement those from Mantra2002 which are in the final stages of analysis. The 2004 measurement may be better due to a slightly wider wavelength range.

The situation for ozone from the sun spectra is less important but, at this stage, promising. Excellent spectra were obtained during the float phase of the flight. Unfortunately, during the ascent the sun diffuser on the instrument was pointed at the horizon below the sun.

This was due to part of the default-rise program, intended to ensure that the instrument caught the sun as soon as it rose above the horizon. In the event, the launch was delayed and the sun was already more than 20 degrees above the horizon when the measurements started. Had the telemetry been functional, the program would have been changed so that the instrument precisely pointed the diffuser at the sun. However, the spectra can be corrected to some degree so that an ozone profile can be derived. In the early afternoon, the operating program changed automatically and thereafter the diffuser was pointed correctly.

In summary, the Mantra2004 flight was successful for the OH experiment. The value of this success, as is the case with most of the experiments, depends on the extent to which it can contribute to the suite of other measurements from the flight.

4.9 Service d'Aéronomie SAOZ Spectrometer (with input from Florence Goutail)

The French CNRS team was present during the MANTRA campaign with 2 balloon instruments, the standard SAOZ instrument (300-600 nm) and the enhanced UV version SAOZ-BrO (330-400nm). In parallel a ground-based SAOZ has been monitoring the stratosphere (O3 and NO2 vertical columns) from August 5 until September 15, 2004.

Instrument Preparation:

SAOZ and SAOZ-BrO instruments have been prepared in France. On the field, tests have been conducted to check the performances and verify that the setting of the spectrometers did not change during transportation. Both instruments were ready for flight on August 18, 2004.

First MANTRA Flight:

The standard SAOZ has been installed just above the Mantra gondola for the flight, which occurred on September 1, 2004 early in the morning. At 7:47 UT (that is 1:47 local) the instrument has been switched ON, a few hours before take off, tested and delivered to SIL. This early switch ON had been decided because of the location of the instrument on the crane, it was not easy to access to the SAOZ on the launch pad. As SAOZ was installed above the main payload, there was no telemetry available, and it was not possible to monitor the instrument before flight.

For an unknown reason, SAOZ stopped recording spectra at 13:50 UT (that is 7:50 local), about 40 minutes before take off. As there was no telemetry, we had no information of the problem. Possible reasons for such behaviour have been analysed but we did not find any: after recovery the batteries were still OK and the on-board computer was working correctly. The instrument has been intensively checked and tested and the anomaly has not been reproduced in the laboratory.

It seems that an "external" reason has blocked the on-board computer during the operations which were conducted on the launch pad before the flight (electromagnetic or radio interferences?). If the problem would have been known, it could have been solved by resetting the on-board computer. This could all be solved by having telemetry.

Second MANTRA Flight:

The standard SAOZ has been installed at the same location, just above the Mantra gondola for the flight, which occurred on September 14, 2004 early in the morning. The instrument was tested in the laboratory at 4:00 PM local tome. At 0:02 UT (that is 6:02 PM local) the instrument has been switched ON and delivered to SIL. At 1:02 UT (that is 7:02 PM local) the instrument was outside the hangar recording solar spectra. The instrument has recorded a few spectra after the balloon lift off.

Spectrum #	Time (UT)	Time (local)	Altitude (m)
847	8:14:25	2:14:25	519
848	8:16:12	2:16:12	862
849	8:17:59	2:17:59	1445
850	8:19:46	2:19:46	1915
851	8:21:33	2:21:33	1322
852	8:23:20	2:23:20	599
853	8:25:07	2:25:07	515

In the recorded data, spectrum and technical parameters, there is no signature of any problem, no interference, no burst, etc… After recovery of the whole payload, it has been noticed that a "funny" noise was coming from the SAOZ instrument. This noise has been identified in the laboratory after getting the instrument back to France. It was due to a small screw that had moved and was blocking the rotating disc. This problem probably occurred after touch down of the gondola. In any case, it has nothing to do with the failure of the main balloon.

5. Flight Incident Assessment and Recommendations

5.1 First Flight

During the first flight on September 1 the main problems that we had were related to flight support:

- Loss of command of the payload. Post-flight assessment revealed that the receiver antenna centre connector had pulled away 2 mm from the SMA connector. The solutions proposed by SIL are:

1 - A bulkhead connector to be added external to the CIP, which will enable this antenna to be easily changeable and be more visible should similar damage occur.

2 - Receiver testing with a reduced transmit signal will be included during pre-launch checks to ensure reception of the uplink for the full flight distance of the payload.

- Lost of termination pack monitor. At a distance of 18 km from the launch centre and an altitude of 8 km, the telemetry monitors from the upper CIP (termination pack) failed and never returned. Testing performed by SIL after the flight revealed proper operations of the link, however, it was noted that the Vaisala transmit power was lower than normal. The solution was to replace the transmitter.

Instrument anomalies:

- Both MSC radiometers did not perform properly during ascent. Anomalous encoder position values for the circular filter were collected during the entire session for both instruments. This problem had not been seen before and is likely due to the build up of ice in the instrument due to the humid conditions at launch time. This fault was addressed by sealing the electronics cavity more securely and the fabrication of a gas input valve, used to purge the electronics cavity with dry N2 gas during the cryogenic fill procedure. Although this remediation appeared to be successful during the second flight, the premature termination of the flight did not allowed proper data acquisition.

- The SAOZ instrument stopped recording data minutes before launch. This year SAOZ was installed just above the gondola. Because of the location of the instrument on the crane, it was very difficult to access SAOZ on the launch pad for tests just before launch. As SAOZ was installed above the main payload, there was no telemetry available, and it was not possible to monitor the instrument before flight. Post-flight inspections did not lead to any conclusive cause of the failure. SAOZ is a primary instrument so <u>the recommendation is for SAOZ to be provided with telemetry, at least up till launch, in the next MANTRA flights</u>.
- AIR instruments did not acquire data. Both instruments flew in manual mode, so with the loss of communication with the payload no commands could be send to start data acquisition. <u>The recommendation is for AIR to be launched in operational mode</u>.
- MAESTRO suffered from interference in the UV channel. However, the noise was very small and did not prevent us to get useful data, but <u>for a future flight we recommend that this be investigated and resolved</u>. 2 hours into the flight the UV channel finished to report data. This problem could almost certainly have been resolved by resetting the instrument had we had communication.
- The Denver FTS arrived at Vanscoy far from its projected state of readiness. A considerable amount of work was done in the field to prepare the instrument for flight. Pre-flight checks showed the computer to be inoperable, and it was determined that the power supply had failed. It was replaced with a spare. This also led to flash disk corruption that was corrected on the flight line prior to launch. These are not desirable scenarios. The Denver team reported problems in receiving funds from NASA preventing them from achieving the desirable instrument readiness level before flight. During the first flight, the instrument had a failure in the scan drive electronics leading to a halt in the data collection. The lack of command capability prevented any attempt to correct this situation. Data was collected from approximately 4 km to approximately 16 km on ascent. However, the data are somewhat compromised by the presence of a water-ice mixture on external mirror surfaces. The water and ice mixture resulted when fog rolled over the launch site just before launch. After recovery it was determined that the optical encoding circuit that was used to determine scan length had developed a fault. <u>The recommendation is to include this instrument in future flights only if flight readiness can be achieved prior to shipment to the field.</u>

5.2 Second Flight

All the instruments were refurbished and individually calibrated and successfully tested. The science payload was put together again and extensively tested before the re-flight of MANTRA. The balloon was launched successfully at 2:16 AM local time. Once again we had problems with launch support:

- At 2:21 AM local time the flight prematurely terminated.
- At launch, the termination pack (upper CIP) downlink failed.

An assessment of the failures after recovery of the payload was made in the field but nothing could be concluded in terms of the cause of the premature termination. Later, SIL made an extensive assessment of the problems. A detailed report was submitted (Appendix E) by SIL but there is still no clear determination of the cause of the premature termination of the second flight. The recommendation of the science team is that further investigations should proceed to the limit of what is reasonable. However, due to the lack of evidence, we recognize that a cause of the failure may not be clearly identified. Pages 17 and 18 of Appendix E include additional recommendations by SIL.

5.3 Future of MANTRA

MANTRA is an ongoing project that has increased in complexity since the first campaign in 1998. Relevant scientific results have been achieved from all previous flights. One example is the use of the MANTRA dataset to assess the nitrogen budget in the Canadian Middle Atmospheric Model (CMAM), an activity that has contributed to improvements in the model. In terms of technology, the MANTRA project has developed a gondola pointing system that is innovative and is capable of providing solar pointing within 0.1 degree in elevation and 4 degrees in azimuth, a rather demanding specification. During the MANTRA 2004 campaign, this system was shown to achieve such specifications when controlling a payload of considerable mass (more than 600 kg of science instruments). The advantage is that it allows the flight of a complementary suite of instrument at once, with the ability to perform both solar pointing and limb scanning observations from the same platform. The science results are then broadened since all the instruments are truly co-located in time and space. Therefore, the MANTRA science team sees this as an important project that should be continued.

Ballooning is a risky activity in itself. In order to improve the MANTRA rate of success, the Science Team's recommendations for future flights are:

1. For CSA to provide financial support for another flight to complete the original science objectives of the MANTRA project. The science payload is ready to fly and a proposal is being drafted for submission to CSA in January 2005.
2. To fly as nearly the same payload as is practical. All of the Canadian instruments will be available, and we will be consulting our international partners (University of Denver and the Service d'Aeronomie) regarding their ability to participate in another campaign.
3. For CSA to contract to SIL directly for flight support. CSA will manage the launch support contract, and CSA and SIL will keep the Science Team informed of activities and progress.
4. For CSA to request a list of equipment to be upgraded from SIL side in order to assure better performance in future flights. Some of the equipment SIL is using is now obsolete and could be replaced. We note that such a list was provided in the budget for the MANTRA 2004 flight at CSA's request and consisted of estimates of $72,600-$77,600 for short-term equipment requirements and $98,000-$105,000 for long-term equipment requirements at the Vanscoy Balloon Base.
5. During the field campaign, a significant number of people work together under a stressful situation. In order to optimize the flow of tasks in the field, alleviate stress, and avoid conflicts it is recommended that the team define and follow a clear management structure

with a clear line of communication that specifies who should be discussing what with whom.

6. For all three FTSs to be included in the gondola to have independent “delta” sun-pointing systems, with each instrument pointing system tested and flight-approved before shipping to Vanscoy.
7. The SAOZ instrument should be provided with telemetry to allow checkout on the flightline.
8. The gondola pointing system has been developed and the technology has been transferred to SIL. However, the system still needs some improvements e.g., more temperature sensors, better sun shielding, and a better way of loading limbscan sequence tables. SIL should be able to implement such changes without difficulties. The Science Team can advise as required.
9. The field campaign for an August 2005 launch to start later than the 2004 campaign as the instruments and pointing system are in good shape. We will aim for a shorter campaign, more like those of 1998, 2000, and 2002.
10. The ground-based part of the campaign was very successful and we recommend it to be performed in the same way next year.
11. The SAOZ BrO flight using a separate balloon was successful and we recommend that it be part of the next campaign.

6. Ground-Based Campaign

The MANTRA campaign also included a number of ground-based instruments operating in the field acquiring measurements in support of the main balloon flight. Some of the flight instruments were also operated on the ground occasionally while awaiting the flight opportunity. This year’s campaign included well-established instruments such as the Brewer to measure O_3 (WMO standard) and SAOZ (NDSC-certified) to measure NO_2, O_3, humidity, and colour index. Therefore, MANTRA offered a unique opportunity for instruments in development such as the York AOTF spectrometer, instruments that have been in operation but have not been part of instruments validation campaigns such as the U of T DOAS ground-based spectrometer, the ground-based SPS, and the MAESTRO-B. With such redundancy different instruments could be checked against each other and methodology of data processing could be tested and optimized. Such work started in the field and is continuing.

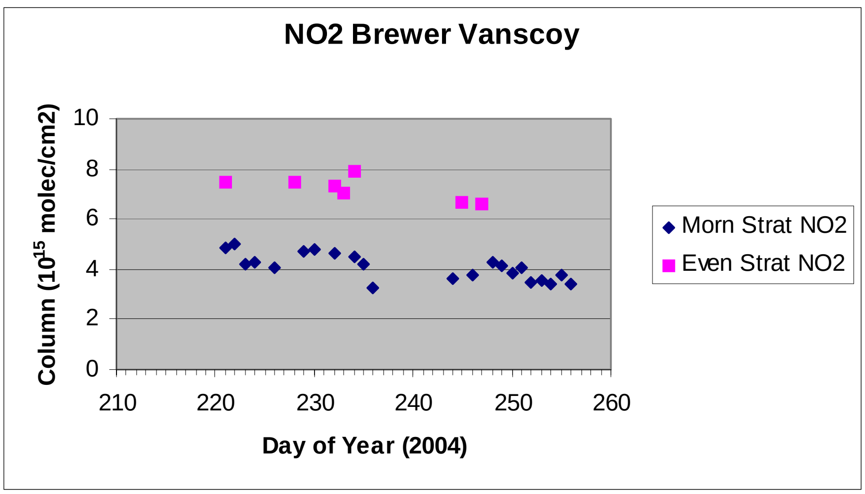
From the ground-based measurements, NO_2 vertical profiles can be retrieved and compared with satellite profiles. With about 43 days of measurements, the ground-based campaign extended the MANTRA dataset and significantly increased the number of overpasses with satellites. The dataset is now unique and invaluable for satellite validation, addressing one of the main scientific objectives. Work using MANTRA for ACE, ENVISAT, and OSIRIS validation has already started and a paper reporting on the dataset available is now in preparation.

6.1 MSC Brewer Spectrophotometer (with input from David Barton)

The Brewer instrument started operation in Vanscoy on August 3. Brewer is an instrument originally developed to measure atmospheric ozone and SO_2 using ultra-violet absorption spectroscopy between 290nm and 325 nm. It is now a standard instrument for ozone measurements, in operation in more than 38 countries. The Brewer Spectrophotometer is used in the Canadian stratospheric ozone and UV monitoring program, with 12 sites established in Canada that routinely collect and process data on a daily basis. The information derived from the Brewer network is used for ozone and UV Index forecasting, trend analysis and ongoing scientific research. Therefore, the data form the Brewer is invaluable for other instruments performance checks and for satellite validation activities.

A plot showing time evolution of ozone total columns from the Brewer measurements were published during the campaign at MANTRA web page and was updated in a daily bases.
During this year campaign the Brewer instrument sequence of measurements were modified in order to include recording of data that would also allow retrieve NO2 total columns during the occultations (sunrise and sunset). MANTRA provided then a unique opportunity to compare the Brewer NO2 data with 5 other instruments also measuring the same constituent. Such study is part of the Master thesis of David Barton (MSC).

The results obtained for NO_2 are shown in the figure below. Comparisons with results from other instruments are now in progress.



6.2 Ground-Based University of Toronto Grating Spectrometer (with input from Annemarie Fraser)

The University of Toronto ground-based UV-visible spectrometer acquired data from August 6 (Julian day 219) to September 15 (J-day 259). The data was obtained with the 600 g/mm grating and a slit width of 150 µm. The spectral resolution was 1.0 nm in the centre of the CCD chip based on line shape measurements made in Vanscoy. Spectra (345 – 550 nm) were acquired throughout the day for solar zenith angles approximately between 40^{o} and 93^{o} during both sunrise and sunset.

Shortly before the campaign began, the CCD detector of the instrument stopped working and could not be repaired in time for the campaign. The manufacturer of the instrument, JY Horiba, was able to provide a CCD on loan for the duration of the campaign. This replacement CCD was chosen based on availability and the ability to integrate with the existing instrument and software. The table below shows the important differences between the CCDs.

Property	*UofT CCD*	*Loaned CCD*
Size	2000x800 pixels 30 x 12 mm	1024x128 pixels 26.6 x 3.3 mm
Cooling	Thermo-electric, 250 K	Liquid nitrogen, 140 K
Illumination	Back	Front
Peak quantum efficiency	250 nm	700 nm
QE for 300-600nm	Approx. 60%	Approx. 10%

The liquid nitrogen cooling of the CCD was able to provide negligible dark current, however, the benefits of this seem to be outweighed by the low quantum efficiency of the detector in the spectral range of interest. The loaned CCD is more efficient towards the higher wavelengths, and as a result, the instrument appeared to be more sensitive to cloud cover than in the past. Although the data is noisy, it appears to be of the same quality as data recently recorded with the instrument (i.e. the Eureka 2004 campaign), and the retrieval of ozone and NO_2 slant and vertical columns is progressing.

A preliminary analysis of the acquired spectra was begun during the field campaign using the Differential Optical Absorption Spectroscopy (DOAS) technique. A daily reference spectrum was used, taken at local noon. The analysis bandwidth was 450-545 nm for ozone, and 405-450 nm for NO_2. Work is now being completed to finalize the analysis for these two gases. The next steps are to calculate the air mass factors (AMFs) from the ozonesondes flown during the campaign, select a common reference spectrum, re-analyse the spectra for slant column densities, and derive vertical column densities and NO_2 profiles.

6.3 Ground-Based CRESTech/York University AOTF Spectrometer (with input from Brian Solheim)

The York University AOTF instrument was refurbished for the MANTRA 2004 campaign by modifying the enclosure to make it more suitable for ground based observations, by adding an external cooling system and by upgrading the instrument operating software. This work was carried out in the CRESS Space Instrumentation Laboratory by a fourth year student, Jeff Levine. The modifications to the instrument enclosure and the operating software were completed as part of Jeff's fourth year extended laboratory project. This work was done as part of a course requirement and Jeff was not paid out of the MANTRA budget during this time.

During May and June, 2004, Jeff completed the upgrade to the cooling system, conducted field tests on the AOTF instrument and modified the analysis software to incorporate new ground based observing modes. Jeff then spent the month of August, on site in Vanscoy, running the AOTF during the MANTRA 2004 campaign. The instrument started collecting data on 5 August and ran until 2 September. Poor weather limited the number of good observations to evening sunset observations on August 10, 11, 12, 13, 15, 18, 19, 20, 25, 26, 28 and morning sunrise observations on August 12, 13, 14, 16, 17, 20, 21, 26, 27. The MANTRA project was charged for 3 months of Jeff's time and living expenses for Jeff while he was in Vanscoy. Brian Solheim was on site in Vanscoy for the last 2 weeks of August to support the main balloon launch and to assist with initial data analysis of the AOTF data. His travel expenses were covered by the MANTRA project.

6.4 SAOZ (with input from Florence Goutail)

A ground-based SAOZ instrument has been installed in Vanscoy as part of this year MANTRA campaign. The instrument operated throughout the whole campaign measuring the stratosphere (O3 and NO2 vertical columns) from August 5 until September 15, 2004 (Fig 1).

SAOZ is a French instrument certified by the Network for the Detection of Stratospheric Change (NDSC). NDSC is an international network of high-quality remote-sounding research stations and consists of more than 17 sites distributed in five primary stations (Arctic, Alpine, Hawaii, New Zealand, Antarctic) fully equipped with almost all the stratospheric observation remote techniques, called primary stations and about 20 secondary stations.

Complementary to the NDSC, 18 SAOZ and other NDSC-qualified UV-visible DOAS spectrometers constitute the so-called SAOZ/UV-visible DOAS network that monitor ozone and NO2 column amounts at a variety of sites in the world, from the Arctic to the Antarctic. The instruments operated at the NDSC and UV-visible DOAS stations regularly participate to blind instrument intercomparison campaigns in order to control their quality, to assess their accuracy, to examine their consistency with other types of instruments, and to certify them for use in the NDSC. SAOZ instrument has participated to the validation activities of the instruments: TOMS (Nimbus-7, Meteor-3, Earth Probe and ADEOS), GOME / ERS 2, and ILAS (ADEOS). More information about the SAOZ ground-based instrument can be found at: http://www.aerov.jussieu.fr/~fgoutail/

SAOZ will then be used as reference to assess the performance of the other ground-based spectrometers that operated during this year campaign. NO2 slant column densities measured with the SAOZ ground-based instrument will also be used to retrieve vertical profiles of NO2 to be used in satellite validation activities. Such activities have already started.

6.5 MSC SunPhotoSpectrometer SPS-G (with input from Clive Midwinter)

The SPS-G took part in the ground-based campaign. Data were collected from August 7 to August 15 for either a sunset or a sunrise observation and from August 16 to September 13 on a continuous basis. The periods missing during the first week were to accommodate calibrations and fitting into the freezer.

The species that will be looked at include O3, NO2, BrO, OClO and H2O. Preliminary analysis has occurred for most days to select the best days for detailed analysis and profile inversion. Analysis will emphasize the NO2 inter-comparison at first but the other species will be analyzed later.

7. Summary

Although there were a number of problems during the 2004 campaign, overall useful measurements were made. The pointing system performance in solar mode was demonstrated to meet the specifications and the MSC FTS was demonstrated to be a flight-ready instrument capable to acquire high quality data. Balloon profiles of NO_2 and BrO concentrations were acquired, 23 O_3 profiles were measured during the campaign using the new WMO standards, and

43 days of ground-based measurements are available to investigate instrument performance and for satellite validation.

Unfortunately the two main balloon flights failed, both due to launch support problems. The cause of the failure of the first flight was identified and we are confident that it can be avoided. As for the second flight, extensive tests were performed by SIL but none was conclusive and the cause of the premature firing of both termination devices is still obscure. However, it is clear that part of the equipment used by SIL for flight support should be replaced. This in itself will increase our level of confidence of having successful flights in the future.

Analysis of the MANTRA 2004 data is continuing and the First Data Workshop will be held on the second half of January at the University of Toronto. One of the four objectives of MANTRA 2004 was satellite validation. Although we do not have a complete dataset, the data collected during this year's campaign will be very useful for the accomplishment of this objective.

Appendix A – MANTRA 2004 Team Personnel

* indicates people who were on-site at Vanscoy for the field campaign.

From the Department of Physics, University of Toronto

- Kimberly Strong – Associate Professor, Principal Investigator
- *Stella M L Melo – Research Associate, Deputy PI
- * Jim Drummond – Professor, Co-Investigator
- Ted Shepherd – Professor, Co-Investigator
- * Tobias Kerzenmacher – Postdoctoral Fellow
- * Hongjiang Wu – Postdoctoral Fellow
- * Annemarie Fraser – Ph.D. Student
- * Caroline Nowlan – Ph.D. Student
- * Matt Toohey – Ph.D. Student
- * Debra Wunch – Ph.D. Student
- * Anne-Flore Bages – Undergraduate Research Assistant (France)
- * Chuan Li – Undergraduate Research Assistant (NSERC USRA)
- * Jennifer Walker – Undergraduate Research Assistant
- Paul Chen – Technical support
- * Clive Midwinter – Technical support
- Lana Tobiash – Program management and logistics support
- Mike Butler – Management support
- University of Toronto Physics Technical Services

From the ARQX Experimental Studies Division, Meteorological Service of Canada

- * Tom McElroy – Environment Canada Lead Scientist, Co-Investigator
- * David Barton
- * Jonathan Davies
- * Robert Hall
- Chris McLinden
- * Akira Ogyu
- Yves Rochon
- * David Tarasick
- * Aaron Ullberg
- * David Wardle

From York University

- * Brendan Quine – Associate Professor, Co-Investigator
- Jack McConnell – Co-Investigator
- * Brian Solheim – Co-Investigator
- * Stephen Brown – Research Associate
- * Michael Ilnicki – Undergraduate Research Assistant
- * Jeff Levine – Undergraduate Research Assistant

- Kirill Semeniuk – Research Associate

From the University of Waterloo
- Peter Bernath – Co-Investigator
- * Kaley Walker – Assistant Professor
- * Dejian Fu – Ph.D. Student
- * Ian Young - Undergraduate Assistant Research

From the University of Denver
- * Pierre Fogal – International Partner
- Frank Murcray – International Partner
- * John Olson

From the Service d'Aéronomie, CNRS
- * Florence Goutail – International Partner
- * Pierre François – Technical support

From Scientific Instrumentation Limited
Payload Support
- * Dale Sommerfeldt – Industrial Partner
- * Werner Ostwald
- * Kevin Nordstrom

Launch Support
- * Jack Dersch
- * Larry Cooper
- * Jeremy Gates
- * Garth Steel
- * John Butcher
- * Derek Kuzma
- * Dan Smith
- * Sheldon Sommerfeldt
- * Sean Cooper
- * Chad Cowles

From the Space Science Program, Canadian Space Agency
- * Ron Wilkinson – Project Manager
- * Robert Hum
- Réjean Michaud

Appendix B

TVAC Test of the Pointing System

TVAC Test of the Pointing System

June 30 – July 6, 2004

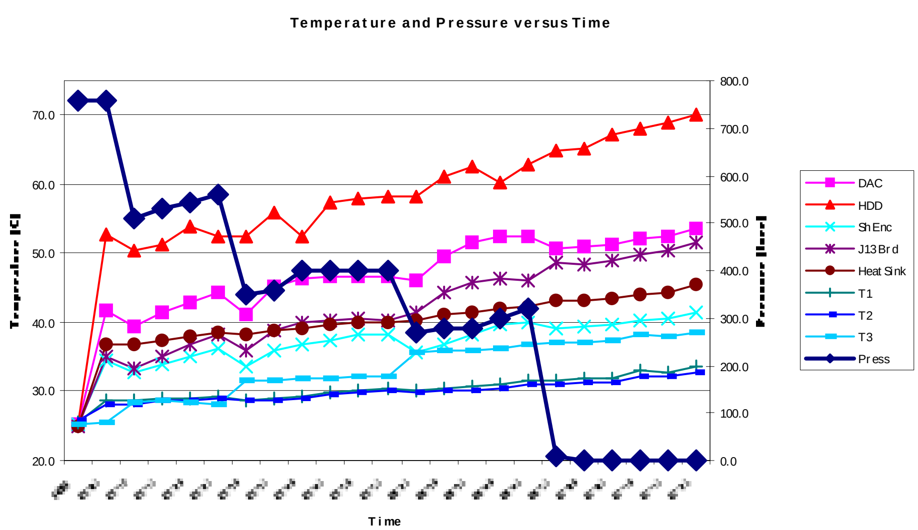
The Mantra pointing system was tested during the early summer to show its readiness for the Mantra 2004 balloon flight. It was put into the TVAC chamber at UofT to test it in a flight environment.

The pointing system was loaded to 900Kg to simulate the loading of the flight train. It was wrapped in copper tubing and cooled to temperatures expected in flight. Thermal couples were placed near the front of the electronics package so the electronics and the heat sinks were not disturbed. Three internal temperatures were also recorded.

Locations of the temperature monitors:

TC number	Position
4	J2.1 DAC
5	HDD
6	Shaft Encoder
7	J13 Board
9	Joint
12	CPU Heat Sink
T1	Internal Ambient
T2	External Housing
T3	Gyro Block

The TVAC tank was pumped down in stages to observe any signs of thermal runaway. The unit was left at one Torr for half an hour. Other than the hard drive, the temperatures showed signs of equilibrium that were within safety limits. The ambient temperature specification for hard drives is usually 70C, so a case of 70C should be within these limits.



The rest of the tests concentrated on the pointing system functionality as it was cooled. In the end, LN2 was circulated through the copper coils to cool the joint sufficiently. The joint operated at after cold soaking it at –40C in a vacuum.

The data outlining all the above tests are contained in the accompanying spreadsheet TVAC-PS.xls.

Recommendations

The pointing system performed within acceptable limits in the tests. However, there is a lot of excess heat generated by older electronics. The computer is 2000 vintage technology with external peripherals and boards. Newer computers, such as the EPIA along with compact flash drives, require much less power to operate and would significantly lower the pointing system temperature. A suitable one tested and flown for the MSC FTS and Paris is the Via EPIA CL600E. It requires a minimum of heatsinking and draws less than 20 watts. UofT has now developed a version of XPembedded that runs Labview from a CF card that can be used on that board.
Url: http://www.viaembedded.com/product/epia_cl_spec.jsp?motherboardId=181

Appendix C

SIL's Post-Flight Engineering Report

MANTRA 2004
POST FLIGHT ENGINEERING REPORT

TABLE OF CONTENTS

1 PART I

1.1 INTRODUCTION

This report summarizes the MANTRA payload flown twice in 2004. Data was collected only on the first flight, the second flight achieved an altitude of only 2,000m when it terminated.

1.2 PAYLOAD CONFIGURATION

The payload consists of 13 scientific instruments. There were three solar pointing Michelson Interferometers from the University of Denver, the University of Waterloo and MSC. The solar elevation table pointed two instruments in elevation, the MSC Maestro and the SPS. Other payload instruments included an MSC OH Spectrometer, two University of Toronto Radiometers, 180° from the sun, two York University spectrometers and one 90° and one 180° from the sun, an MSC Ozonesonde and a University of Toronto SPS B. Mounted above the payload in the flight train was the SAOZ.

1.2.1 Power System

Instruments were powered from either a common battery pack, or a pack dedicated specifically for the instrument. Power control was done in three different ways as outlined in Figure 1-3.

1.2.2 Power Distribution

Figure 4 outlines the measured and estimated power that each instrument and subsystem required.

1.2.3 Battery Configuration

Figure 5 outlines the battery packs used for the flights.

1.2.4 Uplink

The uplink data system was used by most instruments to do the in-flight control or changes to the in-flight configurations. The data stream received by the ground station from each instrument was multiplexed and relayed to the payload. The payload de-multiplexed the signal and directed it to each instrument as required (Figure 6).

1.2.5 Data Downlink

All instruments used this system to retrieve data in real time. Data was multiplexed, sent to the ground station, and de-multiplexed for each instrument. Following is a list of the baud rates:

STARS	1200
A/D Mux	1200
GPS	1200
Pointing	9600
SPS 1&2	9600
PARIS FTS	300
MSC FTS	300
Radiometer 1&2	1200
Maestro 1&2	9600
Ozonesonde	300
OH Spectrometer	9600
Air 1&2	9600

1.2.6 Analog Multiplex Signals

Monitors of many parameters were transmitted through this system. Graphs of temperature are attached as Figure 7, Location Figure 8 and Altitude Figure 9.

1.2.7 Downlink 2

Development of a "high speed data mutli-plexer" which would allow all of the payload data to be sent on one link was aborted due to speed and reliability problems. Further software design and testing would be required to make this system useable in the future. As a backup, a second link was added, as was used in previous flights.

This downlink was time shared by the three FTS instruments in order to allow each to send down their data stored onboard during high data collection time of the flight. The maximum data rate was 500K baud.

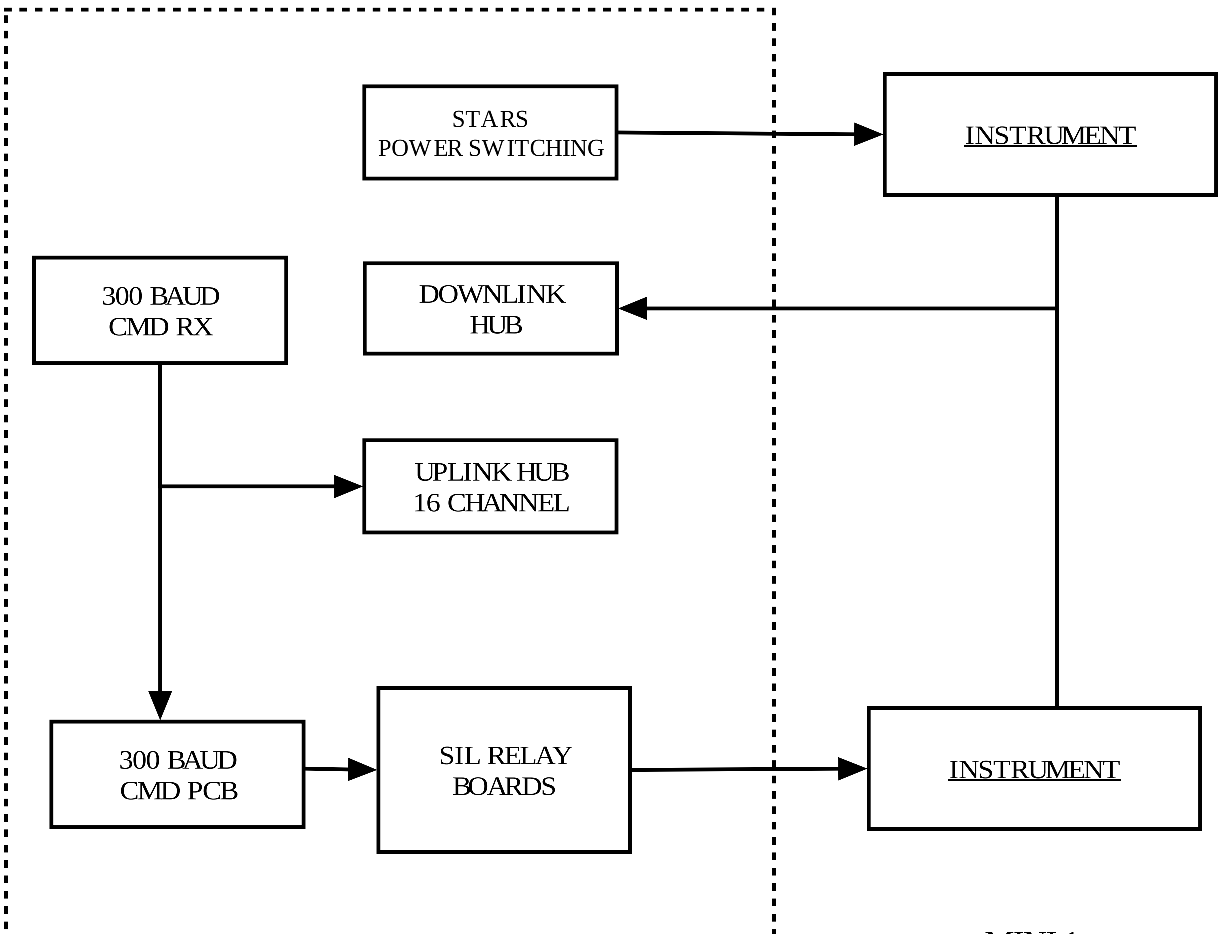
1.3 FLIGHT TRAIN

A diagram of the flight train components is attached as Figure 10.

1.3.1 Terminate Pack (Upper CIP)

This instrument package contains an uplink for valve, terminate and chute cutting commands and a 403 MHz downlink with monitor data.

POWER CONTROL (TYPE 1)



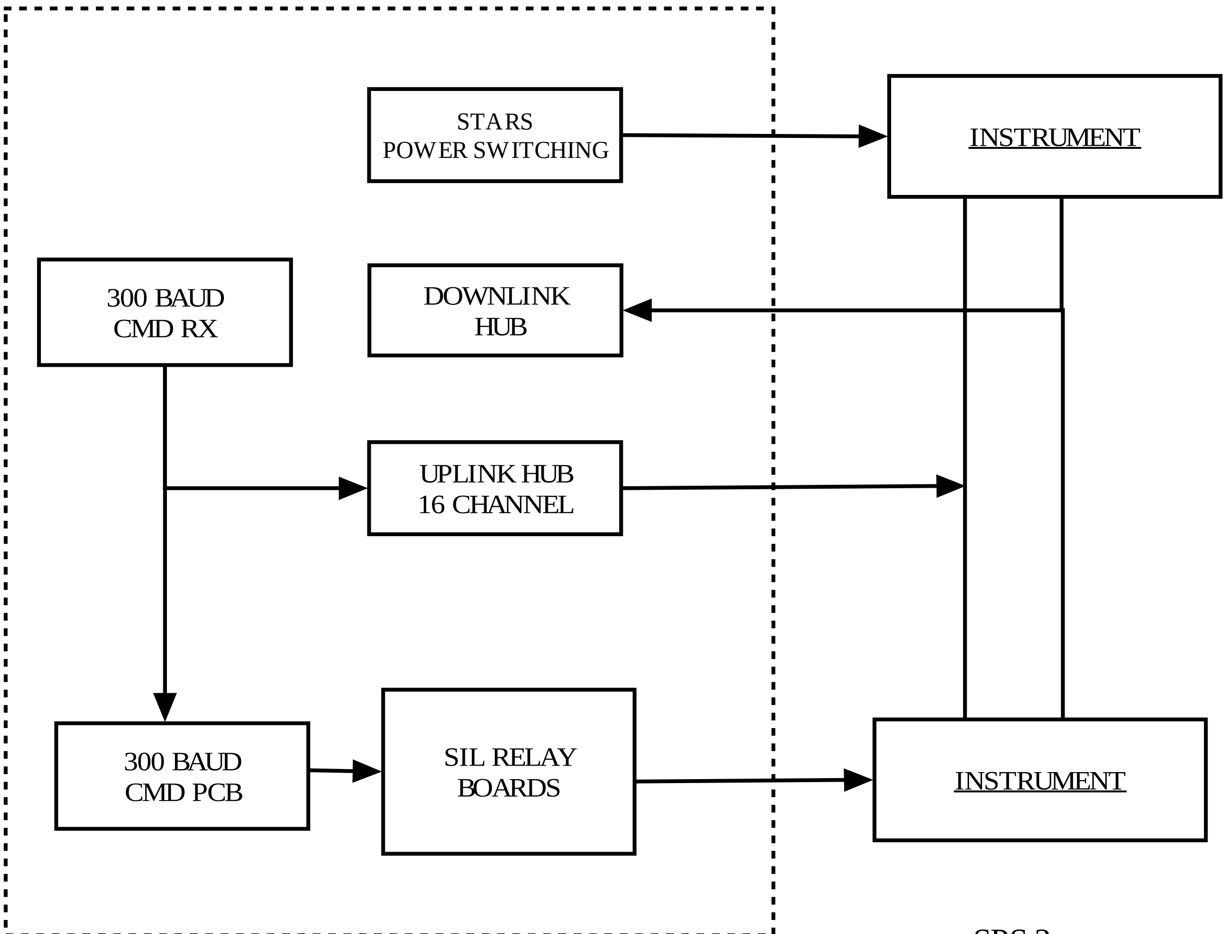
MINI 1
MINI 2
O3SONDE
GPS
SPS1

FOR THIS INSTRUMENT A SINGLE POWER ON/OFF COMMAND AND A SERIAL DOWNLINK IS REQUIRED.

N.B. SPS1 AND MAESTRO RECEIVE COMMANDS FROM THE POINTING SYSTEM

Figure 1

POWER CONTROL (TYPE 2)

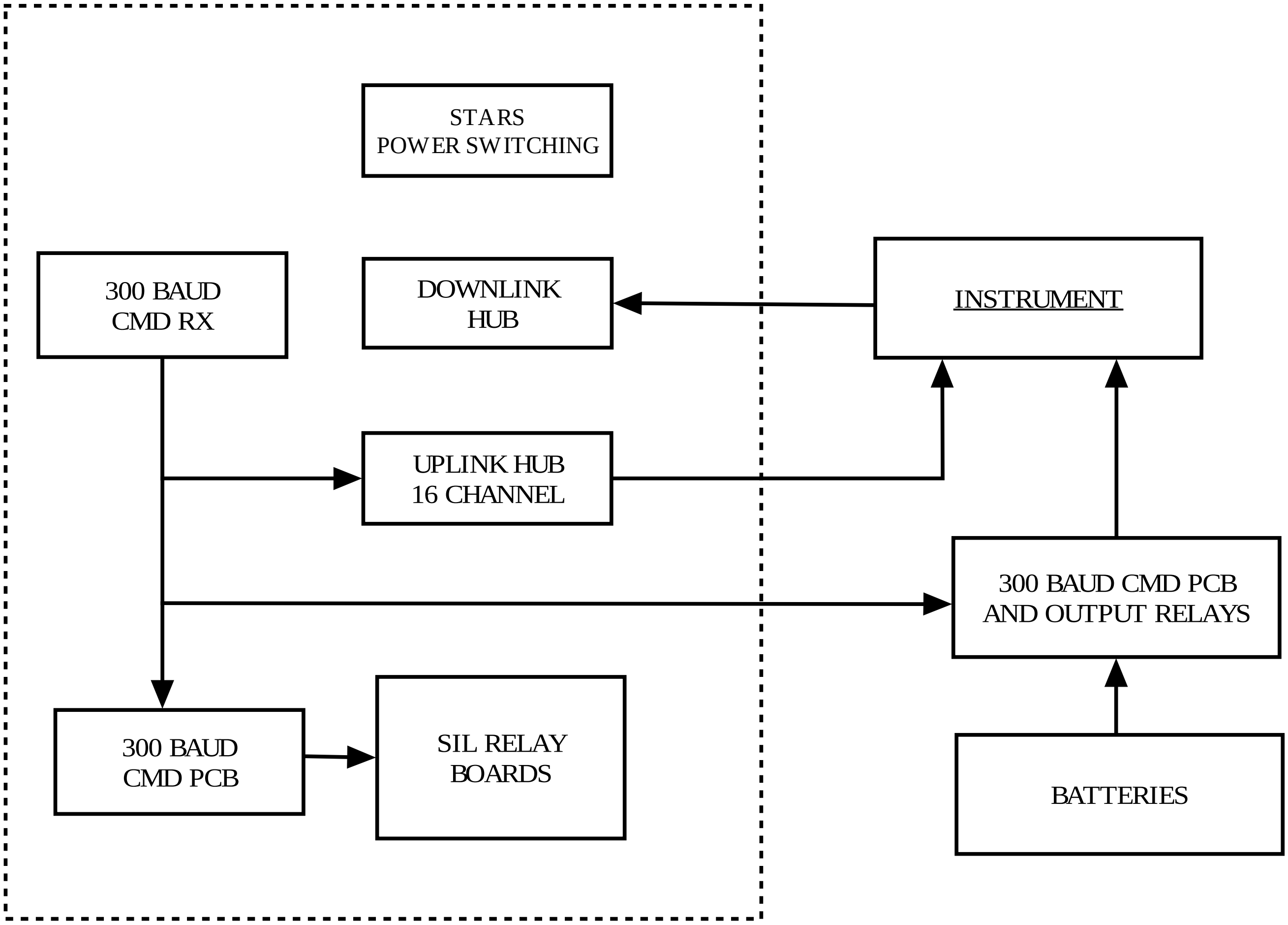


FOR THIS INSTRUMENT A SINGLE POWER ON/OFF COMMAND, A SERIAL DOWNLINK , AND A SERIAL UPLINK IS REQUIRED.

SPS 2
AIR
OH

Figure 2

POWER CONTROL (TYPE 3)



FOR THIS INSTRUMENT MULTIPLE ON/OFF COMMANDS,
A SERIAL DOWNLINK , AND A SERIAL UPLINK IS REQUIRED.

POINTING
DENVER FTS
MSC FTS
PARIS FTS

Figure 3

Power Distribution

Main CIP (28V Stars System)		I_{AVG}	I_{PK}	TIME	AHR
1.	Pointing	2.5	7.8	20	50
2.	SPS1	0.2	1.5	20	4
3.	SPS2	0.2	1.5	20	4
4.	MINIRAD 1	0.18	0.6	5	0.85
5.	MINIRAD 2	0.17	0.6	5	0.85
6.	OH Spectrometer	1.65	3.3	20	38
7.	Maestro	0.33	1.5	20	6.6
8.	Transmitter 1 & 2	1.6	2.4	22	35.2
9.	Video Tx	2.0	2.5	4	8.0
10.	Air 1 & 2	2.0	4.0	20	40
11.	CIP	0.3	0.3	22	6.6
12.	Ozonesonde	0.12	0.12	4	0.5
				Total	188
Main CIP (28V Stars System)		**I_{AVG}**	**I_{PK}**	**TIME**	**AHR**
1.	Pointing	3.0	4.0	20	60
2.	GPS	0.1	0.1	22	2.2
3.	Relays	0.2		20	4.0
4.	Receiver	0.1		22	2.2
5.	4 Decoder	0.4		22	8.8
6.	Transponder	0.5	0.5	7	3.5
				Total	80.7

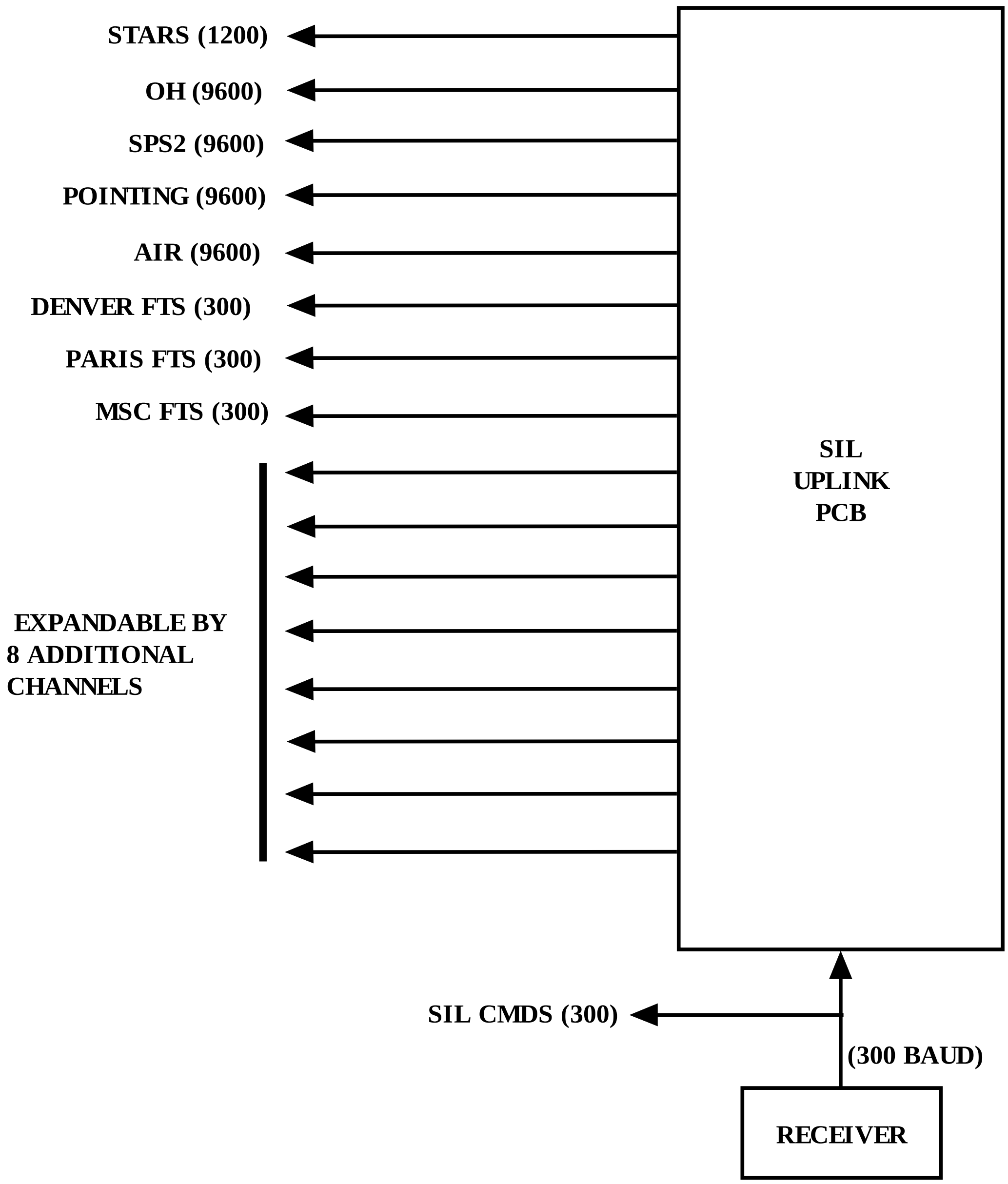
Figure 4

Battery Pack Configuration

	Pack	Description	Req'd Capacity (AHR)	Battery Pack
1.	Main CIP – 28v	28v @ 9.57A	268	8 x 35A Packs 280 AHR
2.	Main CIP – 15v	15v @ 1.5A	22.7	5 cells=35 AHR
3.	Upper CIP – 28v	28v @ 0.3A	7.5	11 cells=7.5 AHR
4.	Denver U FTS – 28v	28v @ 2.5A 10A Peak	80	3x35A Packs=105 AHR
5.	U of Waterloo PARIS – 28v	Instrument 2.2Ax10=22 Data 1.2Ax10=12 Heater 5.3Ax2=10.6	44.6	3x35A Packs=105 AHR
6.	MSC FTS – 28v	Heater 2.5x2=5A Data 1.5x10=15A Pre-launch & Ascent 3.8x4=15.2 2.4A Avg.	35.2	3x35A Packs=105 AHR

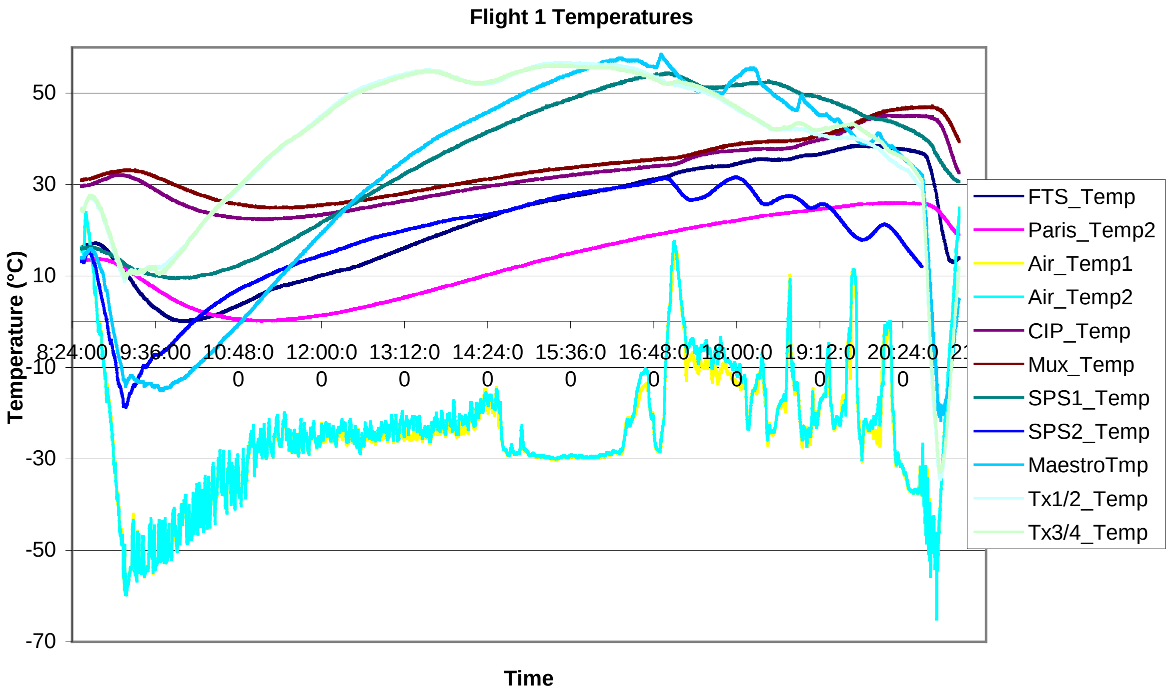
Figure 5

SERIAL DATA UPLINK (PAYLOAD)



Note: SPS2 and Maestro shared this link.

Figure 6



Flight 1 Temperatures
50
30
10
-10
-30
-50
-70
Temperature (°C)
8:24:00
9:36:00
10:48:0
0
12:00:0
0
13:12:0
0
14:24:0
0
15:36:0
0
16:48:0
0
18:00:0
0
19:12:0
0
20:24:0
0
Time
FTS_Temp
Paris_Temp2
Air_Temp1
Air_Temp2
CIP_Temp
Mux_Temp
SPS1_Temp
SPS2_Temp
MaestroTmp
Tx1/2_Temp
Tx3/4_Temp

Figure 7

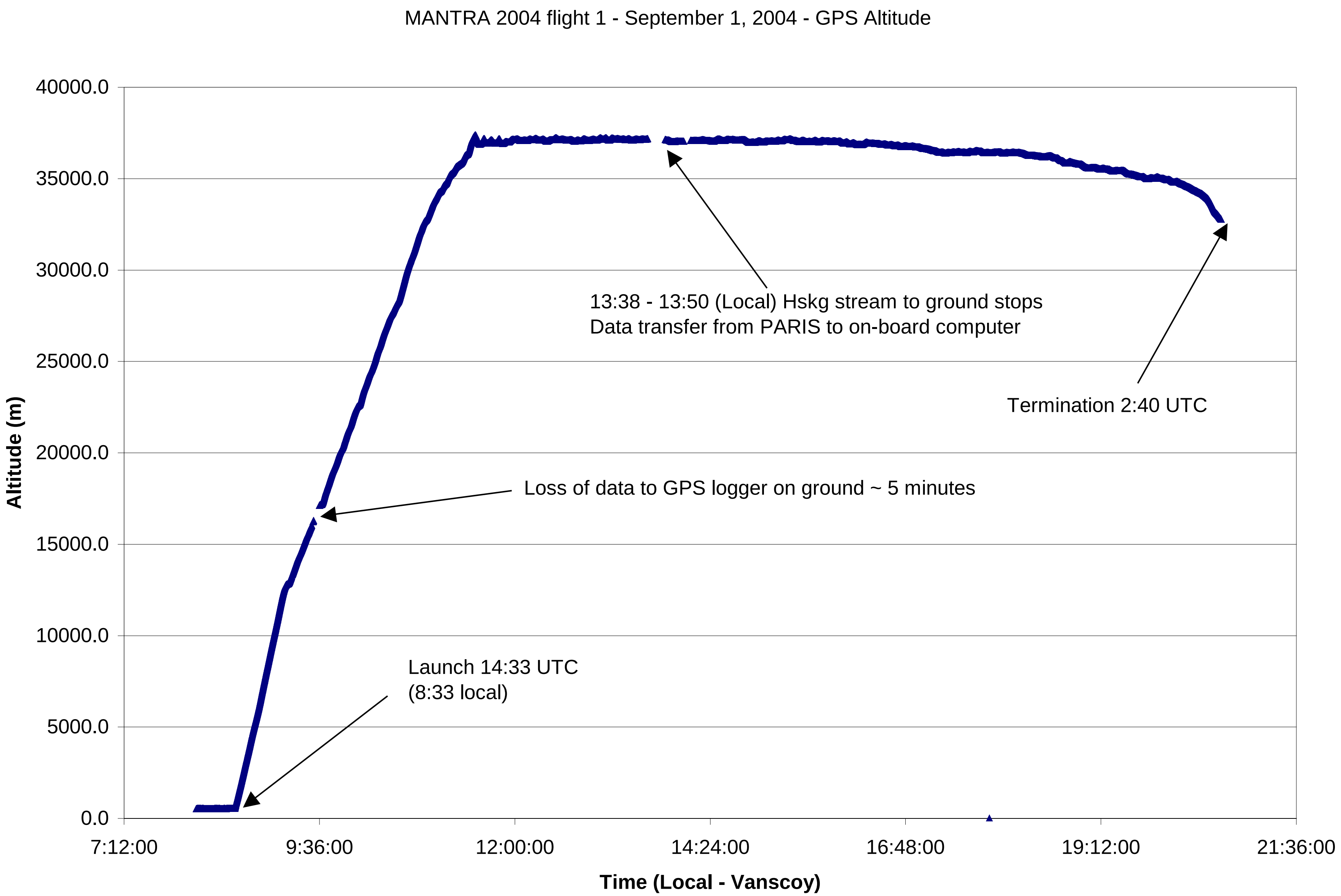

MANTRA 2004 flight 1 - September 1, 2004 - GPS Altitude
40000.0
35000.0
30000.0
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
Altitude (m)
7:12:00
9:36:00
12:00:00
14:24:00
16:48:00
19:12:00
21:36:00
Time (Local - Vanscoy)
13:38 - 13:50 (Local) Hskg stream to ground stops
Data transfer from PARIS to on-board computer
Termination 2:40 UTC
Loss of data to GPS logger on ground ~ 5 minutes
Launch 14:33 UTC
(8:33 local)

Figure 8

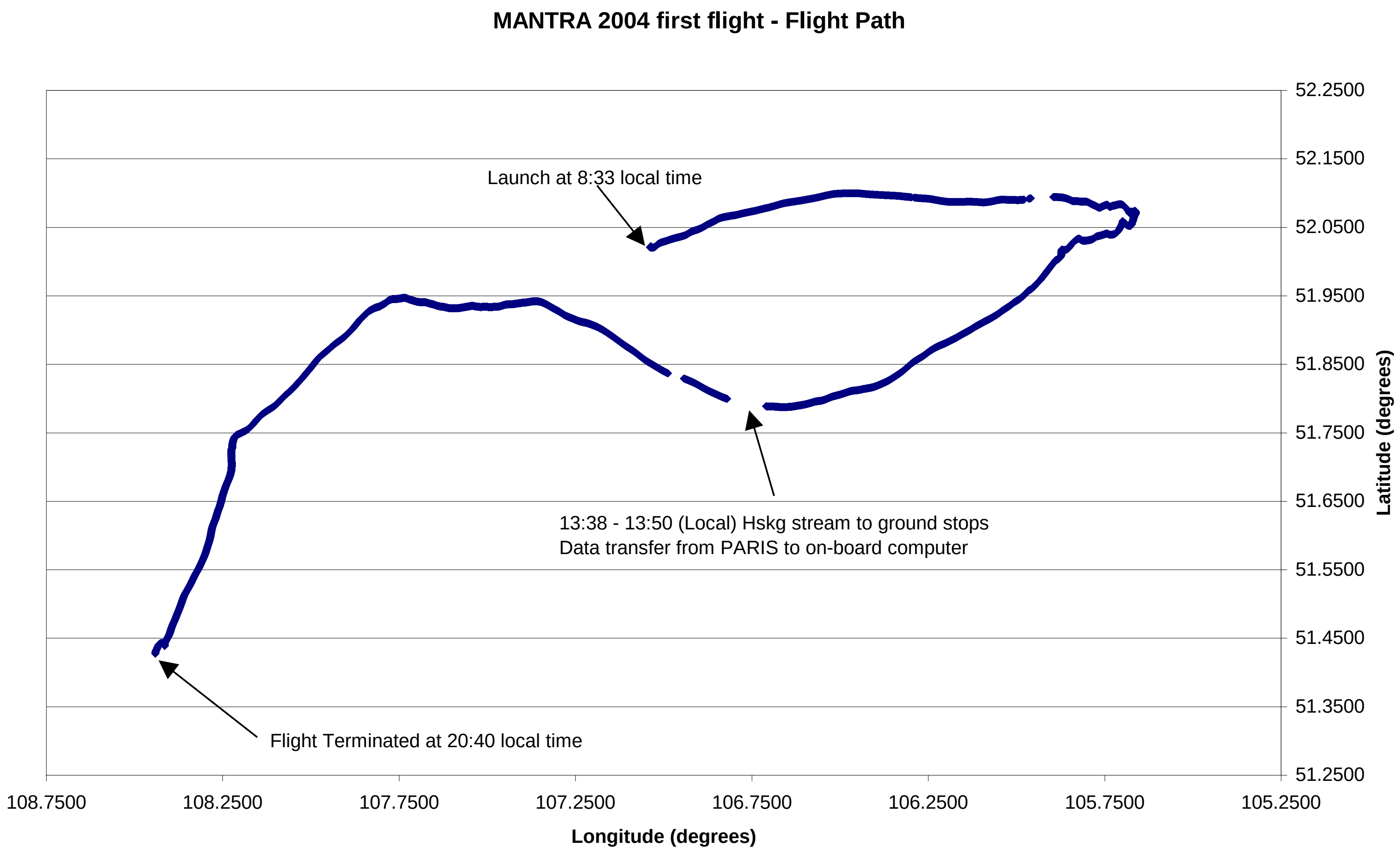
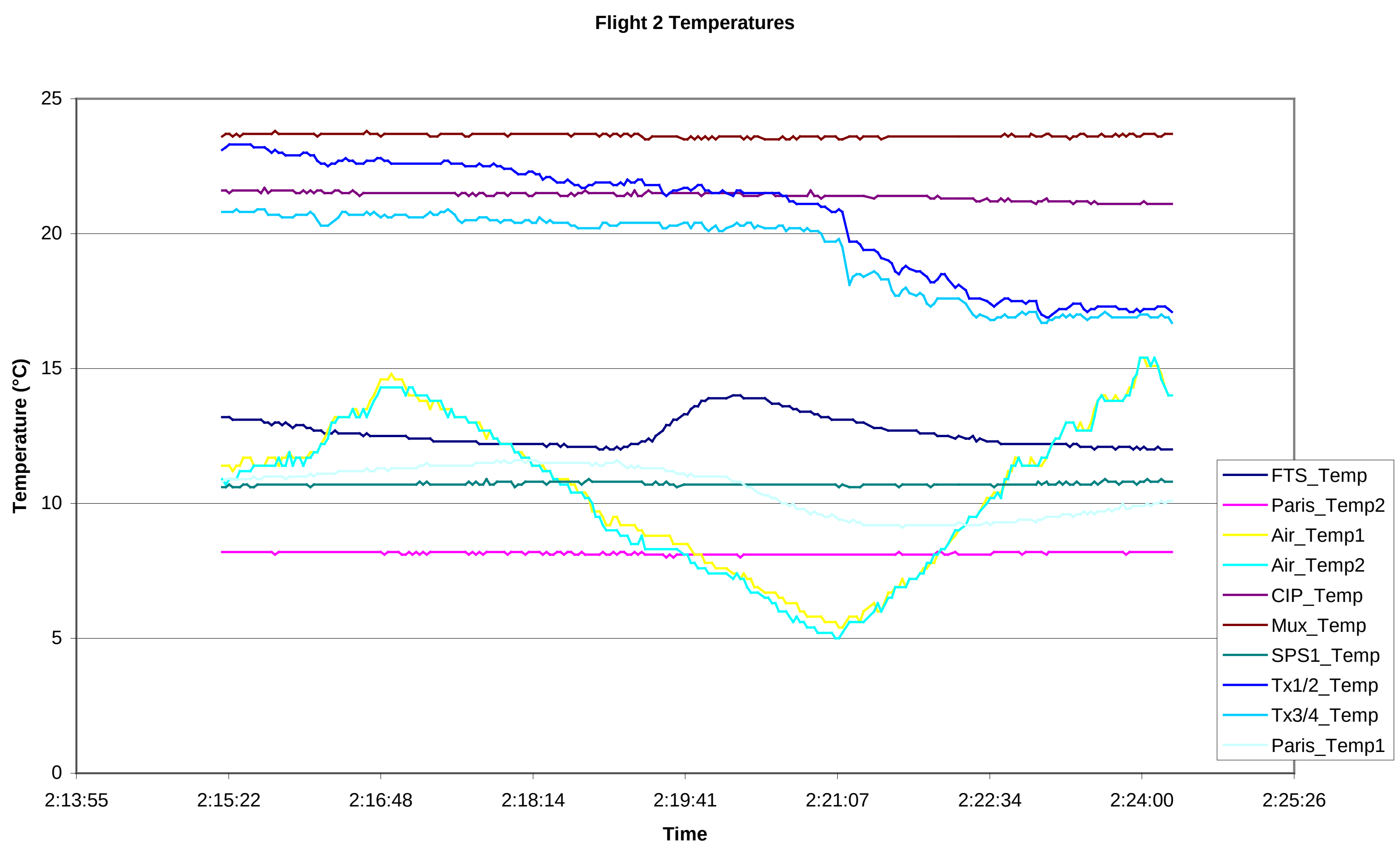

MANTRA 2004 first flight - Flight Path
Launch at 8:33 local time
13:38 - 13:50 (Local) Hskg stream to ground stops
Data transfer from PARIS to on-board computer
Flight Terminated at 20:40 local time
52.2500
52.1500
52.0500
51.9500
51.8500
51.7500
51.6500
51.5500
51.4500
51.3500
51.2500
Latitude (degrees)
108.7500
108.2500
107.7500
107.2500
106.7500
106.2500
105.7500
105.2500
Longitude (degrees)

Figure 9

This page is left blank intentionally.

Figure 10



Flight 2 Temperatures
25
20
15
10
5
0
Temperature (°C)
2:13:55
2:15:22
2:16:48
2:18:14
2:19:41
2:21:07
2:22:34
2:24:00
2:25:26
Time
FTS_Temp
Paris_Temp2
Air_Temp1
Air_Temp2
CIP_Temp
Mux_Temp
SPS1_Temp
Tx1/2_Temp
Tx3/4_Temp
Paris_Temp1

Figure 11

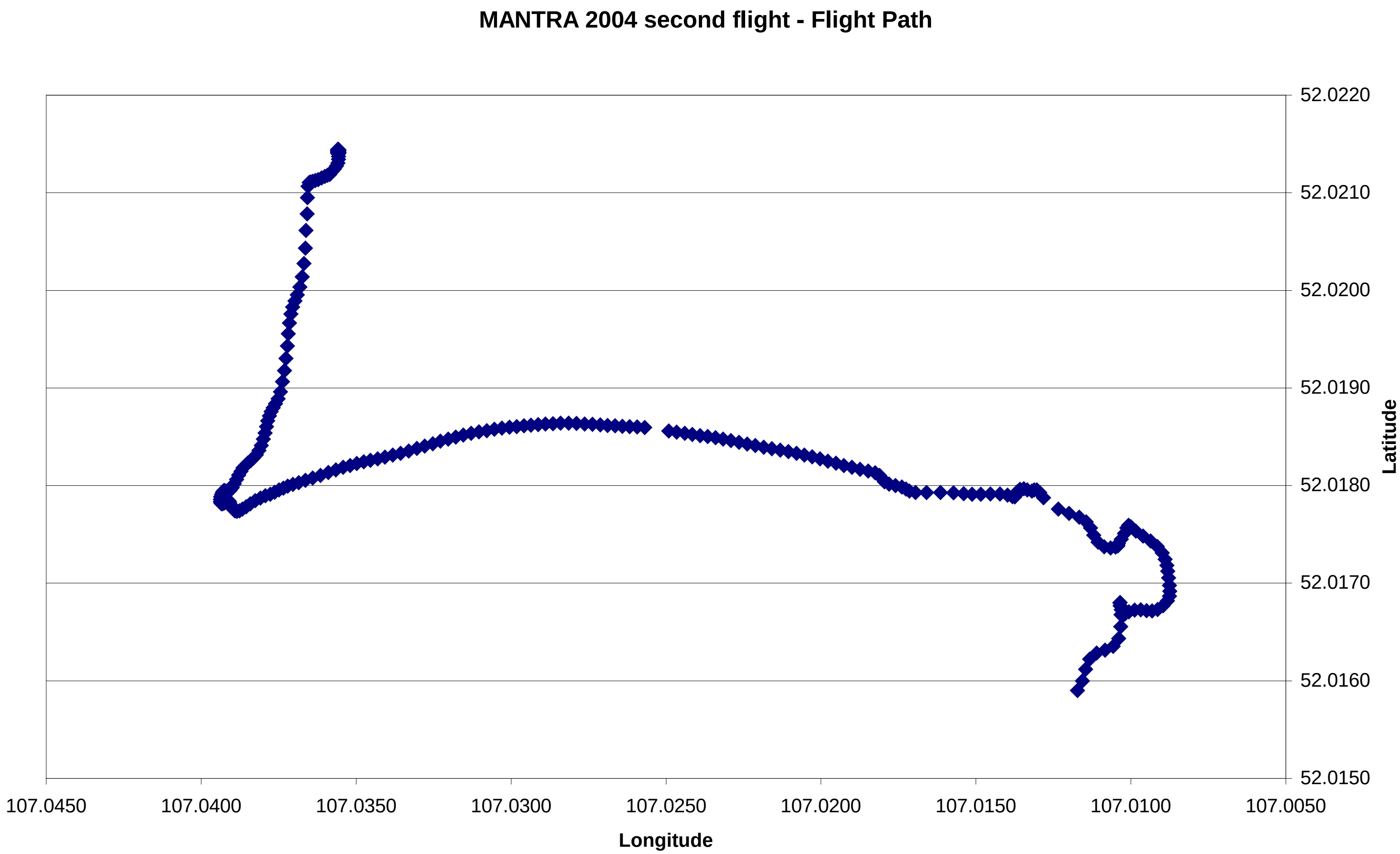

MANTRA 2004 second flight - Flight Path
52.0220
52.0210
52.0200
52.0190
52.0180
52.0170
52.0160
52.0150
Latitude
107.0450
107.0400
107.0350
107.0300
107.0250
107.0200
107.0150
107.0100
107.0050
Longitude

Figure 12

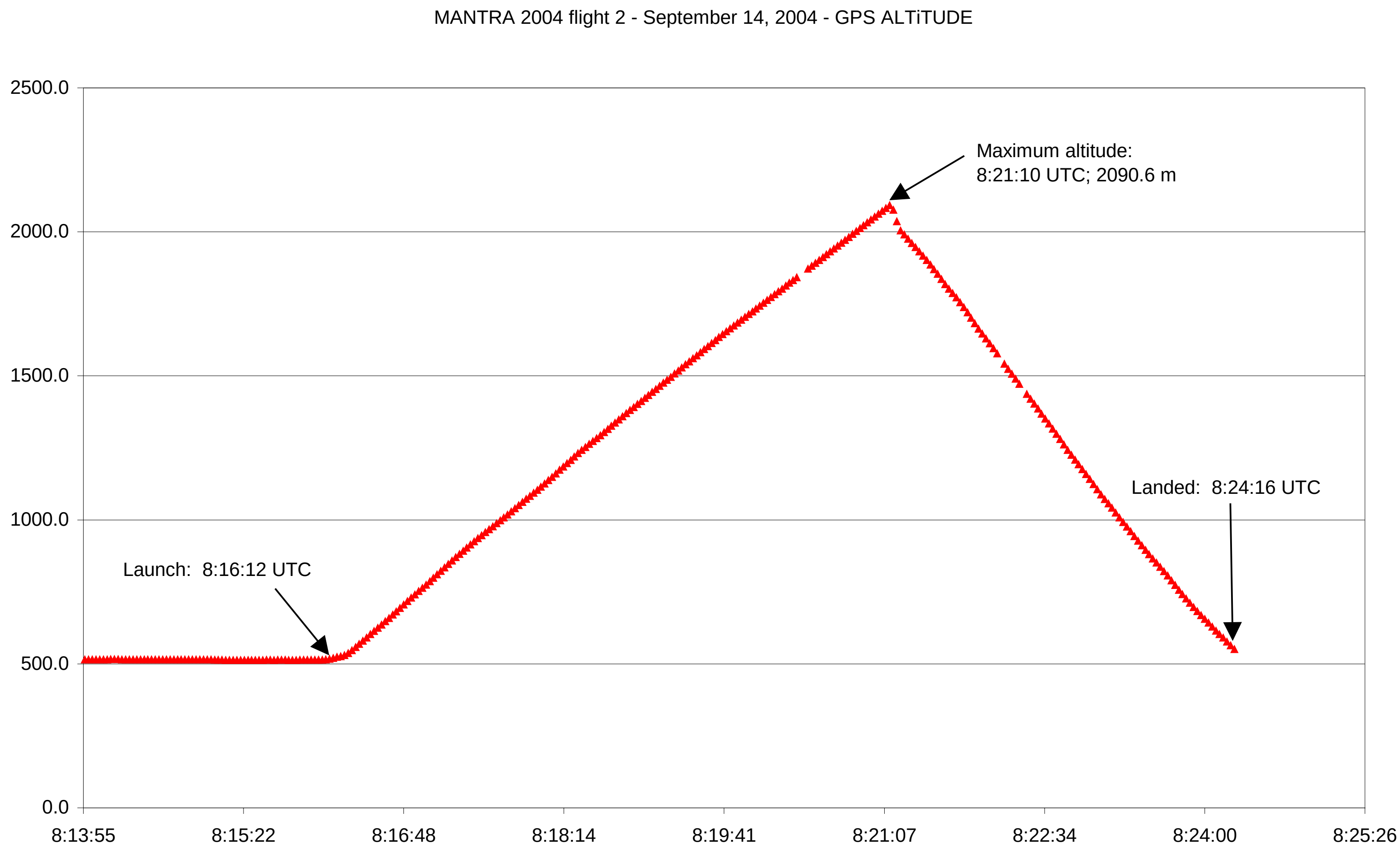

MANTRA 2004 flight 2 - September 14, 2004 - GPS ALTiTUDE
2500.0
2000.0
1500.0
1000.0
500.0
0.0
8:13:55
8:15:22
8:16:48
8:18:14
8:19:41
8:21:07
8:22:34
8:24:00
8:25:26
Maximum altitude:
8:21:10 UTC; 2090.6 m
Launch: 8:16:12 UTC
Landed: 8:24:16 UTC

Figure 13

2 PART II – Flight 1

2.1 GENERAL

Launch time:	04090114:33 UTC
Maximum Altitude:	37,350m (122,540 ft.)
Float Altitude:	37,185m (122,000 ft.)
Termination:	04090202:40Z
Position:	51°29.6’N, 108°26.3’W
Payload Landing:	04090203:15Z
Payload Position:	51°33.85’N, 108° 7.5’W
Balloon Position:	51°28.75’N, 108°18.5’W

2.2 PAYLOAD MONITORS

See Figure 7, 8, 9 for temperature, location and altitude. Specific voltage and current monitors are available upon request.

2.3 ANOMALIES

Two system failures were observed, the command (uplink) and the termination pack monitors.

2.3.1 Command (Uplink)

At 15:12Z, the uplink command system to the main gondola was lost. The balloon was at an altitude of 12,800m and a range of 46 Km. An aircraft was sent to the area in an attempt to send commands from a close range. None were received.

Post flight analysis of the hardware revealed that the receiver antenna centre conductor had pulled away 2 mm from the SMA connector of the receiver. The ground shield was intact. Testing proved that the receiver would get enough signal to operate at 46 Km range with the base station 25w radio and not with the 5w ratio used from the aircraft when it was 37 Km below the balloon. It was not determined when this damage occurred.

Solution: 1. A bulkhead connector will be added external to the CIP, which will enable this antenna to be easily changeable and be more visible should similar damage occur.

2. Receiver testing with a reduced transmit signal will be included during pre-launch checks to ensure reception of the uplink for the full flight distance of the payload.

Please note that prior to terminate, both PARIS and MSC FTS thought that their off commands went through. However, when the flight batteries were fully drained post flight, it was determined that both instruments drew their average power until recovery, then turned off.

2.3.2 Monitor Failure

At 14:56Z, range 18 Km and an altitude of 8,021m, the telemetry monitors from the upper CIP (termination pack) failed and never returned. Testing after the flight revealed proper operations of the link, however, it was noted that the Vaisala transmit power was lower than normal. The solution was to replace the transmitter (reference to flight 2 anomalies and solutions).

2.4 SOLAR POINTING

The system was launched in solar mode and because of the uplink failure, it remained there for the entire flight until it overheated and stopped. A separate detailed report has been done, entitled “Preliminary MK II Pointing System Analysis”, dated September 28, 2004.

3 PART III – Flight 2

3.1 GENERAL

Launch time:	04091408:16Z
Maximum Altitude:	2,090m
Termination:	04091408:21Z
Payload Landing:	04091408:24Z
Payload Position:	52.016°N, 107.01° W
Balloon Position:	100m east of the payload

3.2 PAYLOAD MONITORS

See Figure 11, 12, 13 for temperature, tracking and altitude data. Specific voltage and current monitors are available upon request.

3.3 ANOMALIES

At 8:21, the flight prematurely terminated. At launch, the termination pack (upper CIP) downlink failed. A separate detailed analysis and recommendations report will be issued to address these anomalies.

Appendix D

SIL's Post-Flight Report:
Preliminary MKII Pointing System Analysis

Post-Flight Report

The MANTRA 2004:

Preliminary MKII Pointing System Analysis

SCIENTIFIC INSTRUMENTATION LTD.

September 28, 2004

Post-Flight Report: MANTRA 2004-Preliminary the MKII Pointing System Analysis (draft)

Introduction

The pointing system for MANTRA should be capable of pointing a platform of optics at an inertial target from a pendulating platform which is suspended below a high-altitude balloon. It should also operate in both a solar mode, to observe solar absorption, and in a limb-scan mode, to make measurements of the earth's limb.

Early pointing systems for MANTRA employed the analog control technology, which met the requirements of then conventional solar modes. By 2000, the digital control technology, instead of the analog one, was implemented in the MKI pointing system, which was a combined solar and limb scanning system for scientific research of the MANTRA 2000 program. The MKI pointing system applied microprocessor controller, integrated sensors, and high-level icon-based software (Labview). In the 2000 flight, a pointing accuracy 0.1°(1σ) in elevation and 3.0°(1σ) in azimuth was obtained in both solar mode and in limb mode. A reaction wheel was used in the MKI pointing system to provide azimuth fine control in conjunction with the exiting top-mount torque motor in the 2002 flight. It was expected to obtain better performance than before, but it did not succeed in reaching that objective.

In 2003, SIL proposed to design and develop a new pointing system (model MKII) in order to meet the requirements of the MANTRA 2004 and to try to commercialize the pointing system. After the technical proposal was approved, the MKII pointing system was designed, developed, and tested by SIL up to and throughout the last flight, in order to obtain a better pointing accuracy in both elevation and azimuth than the MKI pointing system. Excluding the pointing accuracy, it was the first time that the requirement of dynamic characteristic of controller was particularly considered and successful in the design and development of the MKII pointing system, improving both its transient state response and steady state response.

There were two balloon flights in 2004 but only the first flight lasted more than 8 hours. The second flight failed shortly after the balloon was launched. The following discussion and analysis will focus on the first flight unless specified otherwise.

1.0 Review of the MKII Pointing System R&D

The development of the MKII pointing system commenced immediately after the approval of SIL's proposal for repackaging and commercializing the pointing system in 2003. In July of that year, SIL proposed a technical approach to do this work after having documented the hardware and software of the MKI pointing system. The MANTRA team approved this approach later in 2003.

According to this approach, main hardware redevelopment and redesign of the sub-system included the following:

1. A new high-speed multi-function DAQ (NI6036E) instead of two DAQs (NI6025E, NI-PC519) (COTS),
2. A new mother board (PCIMG P52-4046A) instead of the existing one (PCIMG PCI-7S-1) (COTS),
3. A 6-slot custom card cage with connector panel (SIL),
4. A new gear set with a new given ratio for the elevation drive system which would reduce any potential for damage to teeth(SIL),
5. A parallel port to the serial port converter for the zenith encoder (SIL),
6. Rewiring of cable harnesses (SIL),
7. Sun sensor conditioning circuitry (SIL),
8. Assembling and testing 3 interface boards (SIL),
9. Refurbishment of two torque motors (SIL),
10. Repairing and testing of back-up Pentium II single board computer (SIL),
11. A new anti-freeze precaution for top-mount torque motor,
12. A GARMIN GPS instead of sondes (SIL).

In addition, all subsystems were integrated and tested individually. The following special tests were conducted:

1. Sun sensor characteristic tests (SIL),
2. Gyro drift characteristic tests (SIL),
3. Torque motor characteristic tests (SIL),
4. Low temperature (below –20ºC) testing of the torque motor (SIL),
5. PID controller characteristic tests (SIL),
6. High temperature (@ constant 50ºC) tests of the pointing system excluding the torque motor (SIL),

7. Vacuum tests of the pointing system (U of T),
8. Solar mode tests with a simulated payload,
9. High Bay tests of the system (U of T),
10. Solar mode tests with simulated flight training suspended from a crane (MANTRA 2004 campaign, Vanscoy),
11. Limb mode tests with simulated flight training suspended from a crane (MANTRA 2004 campaign, Vanscoy),
12. RFI tests (MANTRA 2004 campaign, Vanscoy).

Software for the testing and the flights were developed and re-written. Table 1 shows several of these software versions with brief descriptions in both flight code and ground code. The development and design of the main VI included the following:

1. 2004 test code (SIL),
2. 2004 flight code ver 1.0 ~ 2004 flight code ver 12.0 (SIL),
3. 2004 ground code ver 1.0 ~ 2004 ground code ver 12.0 (each ground code includes three individual VI: ground code for command.vi, ground code for data.vi, display parameters.vi) (SIL),
4. Newly built auto-schedule table code (SIL),
5. Redisplay flight data code (SIL).

The Build auto-schedule table was revised but it was not used in two flights of this year. The redisplay flight code was also developed as an analysis tool. The development and design of the sub-Vi in flight code included the following:

1. New Initialization VIs of all sensors, actuator drivers, algorithms, and ports (SIL),
2. New reading VIs of all sensors, and ports (SIL),
3. New data conversion VIs of all raw data (including tilt sensor’s raw data, magnetometer’s raw data, gyro’s raw data, temperature and pressure sensor’s raw data, GPS’s raw data, and encoder raw data) (SIL),
4. New drive VIs of all actuators (including step motor, torque motor, and Kapton heater) (SIL),
5. New sun sensor data conversion VI (used in 2004 flight code VER1.0 ~ 2004 flight code VER4.0) (SIL),
6. New normalizing sun sensor data VI (used in 2004 flight code VER5.0 ~ 2004 flight code VER12.0) (SIL),

7. New PID control algorithms (solar azimuth control law, solar elevation control law, position control law, and velocity control law) with optional feedback for different control modes (SIL),
8. New gyro temperature control algorithm (SIL),
9. New control modes excluding the limb mode (SIL),
10. New command instrument VI (SIL),
11. New building event table VI for limb scan (Jim, U of T),
12. New auto command instrument procedure (Jim, U of T),
13. New command and data link procedure (SIL, Jim),
14. New transmitting package of data with new format (SIL),
15. New command receive and execute VI (with the original protocol) (SIL),
16. New automatic mode in the 2004 flight code V12.0 (not used in two flights of this year due to a lack of testing time) (SIL),
17. A new logging data in real time procedure (not used in two flights of this year for HDD's safety) (SIL).

The development and design of the sub-Vi in ground code included the following:

1. New pop menu window for commanding (SIL),
2. New command transmit VI with the original communication protocol under a new global variable.vi (SIL),
3. New packaged data (reducing one package of data from 115 bytes to 71 bytes without losing any useful information) receiving procedure with the new data format under new global variable.vi (SIL),
4. New data logging procedure with the new data format under new global variable.vi (SIL),
5. New status indicators, digital indicators, waveform charts and graphs with new data convert modular for operating and monitoring the MKII pointing system on the ground (SIL),
6. New PID term graph window (SIL).

It is necessary to point out that the main control loop (procedure) and the communication loop in the flight code now run at 10Hz instead of 4Hz of the MKI improving its dynamic response and correcting disturbance effectively. Other modulars, such as the reaction wheel, including its control algorithm and drive modular were not integrated into the system due to the lack of study time and budgetary constraints.

Table 1 Brief Version Description of Flight Code and Ground Code

Version	Name	Completion Date	Description
beta	2004 test code	Aug. 2003	All new data acquisition and process modules for new hardware
1	2004 test code	Jan 2004	Used for Vanscoy tests
2	2004 Flight Code ver2	April 2004	First draft of flight code
3	2004 Flight Code ver3	April 2004	Ben's mods
4	2004 Flight Code ver4	May 2004	Hi-bay Tests
5	2004 Flight Code ver5	June 2004	Implement normalized sun sensor
6	2004 Flight Code ver6	Aug. 10, 2004	Same as ver5 except sun sensor offset calibration and gain adjustment
7	2004 Flight Code ver7	Aug. 12, 2004	Same as ver6 except implementing GPS's data acquisition
8	2004 Flight Code ver8	Aug. 13, 2004	Same as ver7 except modifying azimuth PID control law and dividing sequence 0 (transmit data) into sequence 0 (preparing data) and sequence 1 (transmitting data)
9	2004 Flight Code ver9	Aug. 16, 2004	Same as ver8 except using azimuth control law in both solar mode and limb mode with Boolean switch and optional feedback for D-Term
10	2004 Flight Code ver10	Aug. 21, 2004	Same as ver9 except applying new command instrument modular developed by Jim
11	2004 Flight Code ver11	Aug. 28, 2004	Same as ver10 except modifying synchronization.vi in command

			case of downlink procedure and implementing a new sequence (sequence 0:Auto Command Instrument) in asynchronous control procedure. It was implemented in two flights of MANTRA 2004.
12	2004 Flight Code ver12	Sept. 8, 2004	Same as ver11 except implementing a new modular (execute automatic mode) in sequence 3 of asynchronous control procedure. It was to be applied in the second flight due to a lack time available for testing during the first flight.
3	2004 Ground Code ver3	April 2004	First draft of code
4	2004 Ground Code ver4	May 2004	Hi-bay Tests
5	2004 Ground Code ver5	June 2004	Implement normalized sun sensor
6	**2004 Ground Code for Data ver6; 2004 Ground Code for command ver6; Display Parameter ver6;**	Aug. 10, 2004	Ground Code is divided into three individual parts: Receiving Data, Pointing System Command and Display Parameters.
7	NA		
8	**2004 Ground Code for Data ver8; 2004 Ground Code for command ver8; Display Parameter ver8;**	Aug. 13, 2004	Same as ver6 except indicating the GPS information in the Display Parameter and removal of logging sonde data modular in the 2004 Ground Code for Data.
9	NA		
10	**2004 Ground Code for Data ver10; 2004 Ground Code**	Aug. 18 2004	Same as ver8 except graphing azimuth PID term and indicating parity check status of Pointing

	for command ver10; **Display Parameter ver10;**		System receiving command in the **2004** Ground Code for Data ver10; It was applied in the first flight of 2004 MANTRA.
11	**2004 Ground Code for Data ver11;** **2004 Ground Code for command ver11;** Display Parameter ver11; **Display Flight Data ver11(for analysis after flight);**	Aug. 13, 2004	Same as ver10 except rearranging graphic window, digital indicator, and Boolean status indicator in the **2004** Ground Code for Data ver11. It was applied in the second flight of 2004 MANTRA.
12	**2004 Ground Code for Data ver12;** **2004 Ground Code for command ver12;** Display Parameter ver12; **Display Flight Data ver12**	Sept. 8, 2004	Same as ver11 except implementation of automatic mode.

2.0 Preliminary the MKII Pointing System Analysis

Instrument Summary

In the first flight of 2004, the balloon was launched at around 8:36 (local time), September 1, 2004, Vanscoy. At approximately 9:13, the command link failed but the pointing system succeeded in engaging a solar mode with the angle velocity feedback. From this time on, the MKII pointing system operated in solar mode continuously until the last pointing system data was received at around 16:16. During this time the ground station of the MKII pointing system successfully collected approximately 50Mb of raw flight data.

A preliminary analysis of the data indicates that the MKII pointing system performed well with all sensors operational under the solar mode. It also demonstrated a pointing accuracy better than 0.05°(rms) in elevation and 0.8°(rms) in azimuth during the balloon drifting. Because no fine-tuning was conducted during the first flight, the dynamic performance of the MKII pointing system could not obtain its expected objective but this did not negatively affect other instruments in obtaining adequate data. Sunrise did not acquire due to launch time behind sunrise. Sunset did not acquire due to the computer malfunctioning as a result of overheating.

Flight Log

A rough log of the flight events in the first flight is as follows (time in local time):

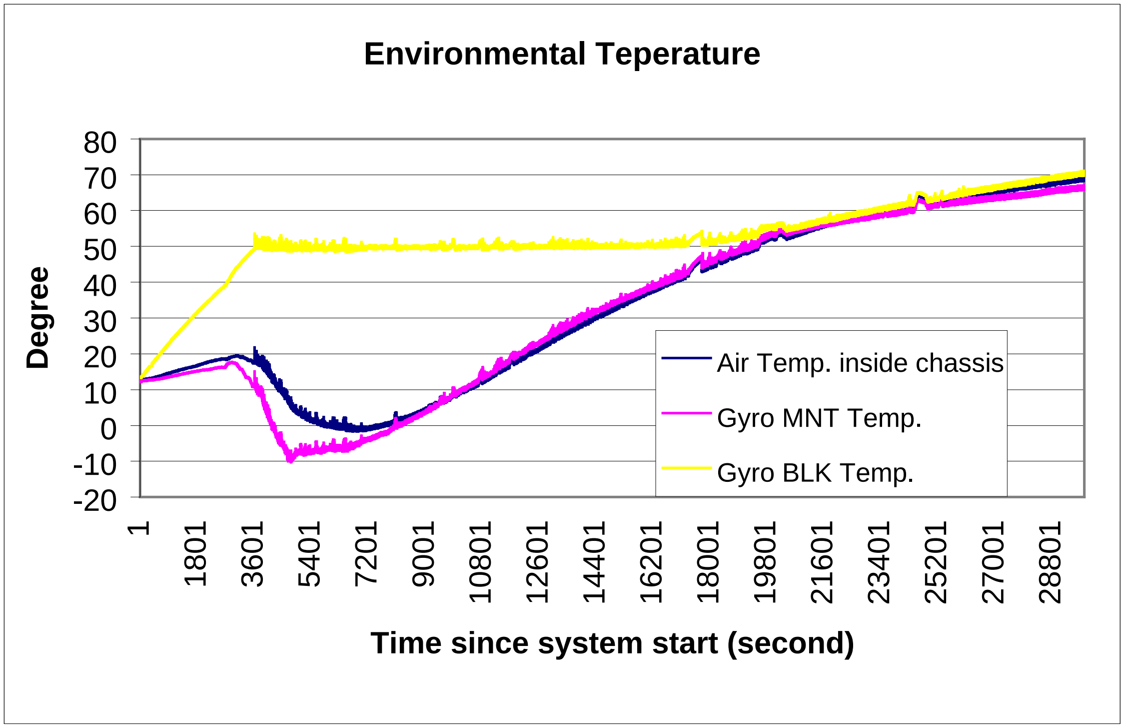
07:50	Switch on the pointing system.
07:52: 46	Receive the data of 2834 seconds before launch.
07:53	Update watchdog timer to 180 minutes.
07:54	Switch on gyro heater (set temp. to 50°C).
08:36	Launch.
08:52	Switch on step motor, amplifier A and B.
08:53	Switch on Solar Mode with sun sensor for D term, no V term.
08:55	Use raw rate azimuth gyro for D term without V term.
09:06	Use sun sensor for D term with V term.
09:09	Switch on V term with sun sensor for D term.

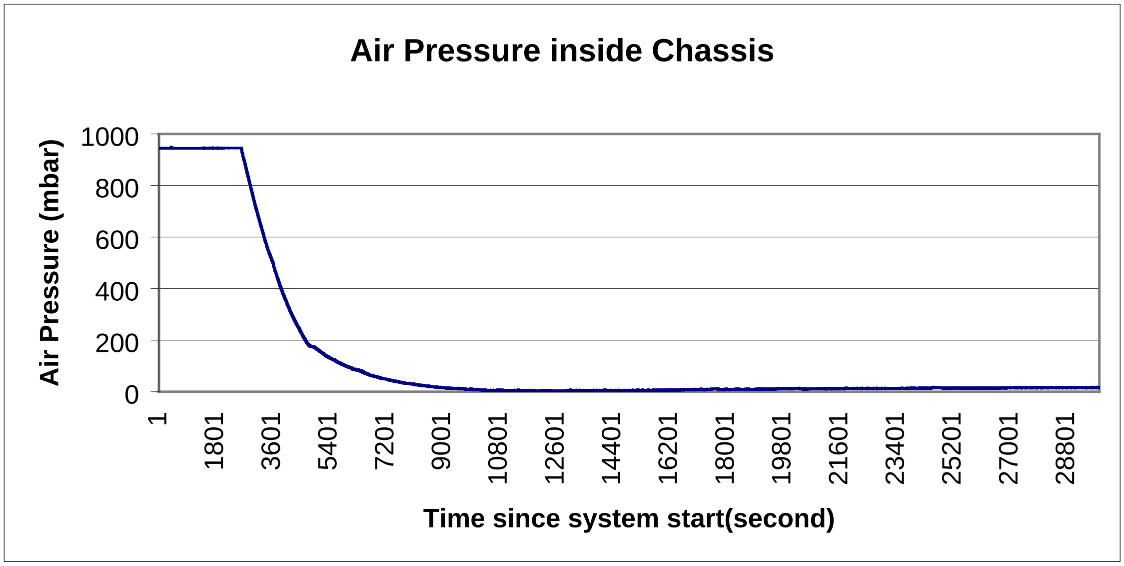
09:13	Did not succeed in modifying parameters due to command link failure
16:16:17	Last pointing system data received.

Temperature and Pressure Data

At launch the pointing system was at 13°C, a small amount higher than the ambient air temperature. During the flight, the pointing system chassis (Gyro MNT Temp) ranged between -10°C (occurring at around 14000m height during ascent, 33 minutes after launch) and +67°C (7.5 hours after launch). The Gyro BLK temperature rose smoothly during the ascent and reached its set-point (50°C) at approximately 15 minutes after launch. The gyro heater held this set-point temperature until the pointing system chassis could no longer bring off the heat generated by the pointing system electronics, including the computer, DAQ card, DC/DC converter, gyro heater, and etc, four hours into the launch. This also demonstrated that the gyro heater performed well during the flight. Due to the loss of the command link, tracking the sun was run continuously and the pointing system chassis, without any sun shield, absorbed a great deal of heat from the sun. This caused the system's temperature to increase over the operational maximum temperature of 55°C 5 hours after the launch. When the system temperature rose to 68°C, 7.5 hours after the launch, the last pointing system data was received and then the computer apparently crashed due to the overheating.

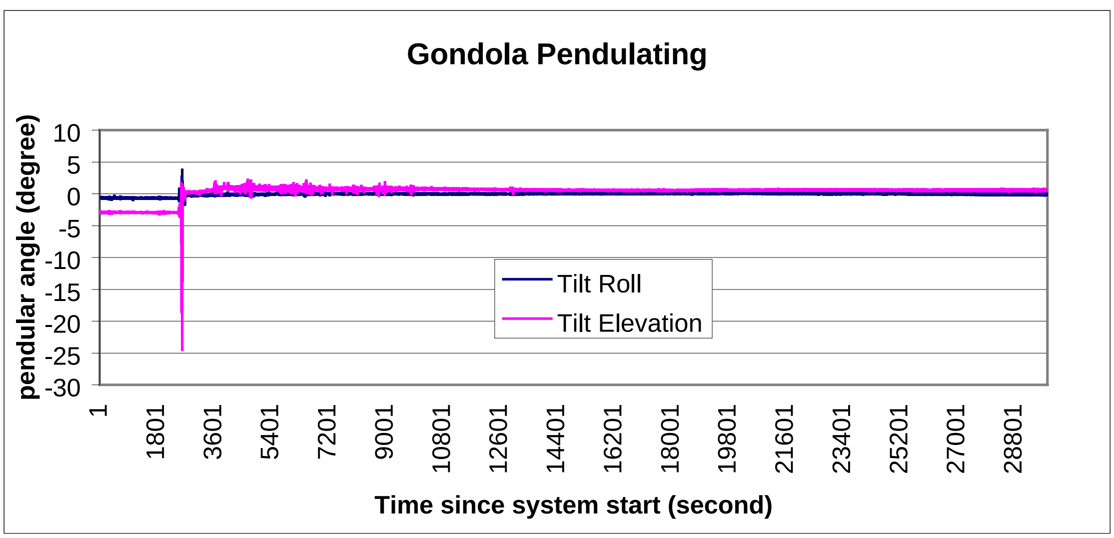
The pointing system carried three temperature sensors and one pressure sensor for measuring the air temperature and pressure. The temperature sensor, housed internally to the pointing system, recorded a low of -2°C (during the ascent) and a high of +68°C during the flight. The one pressure sensor, housed internally, performed well during the time of the flight. Because of high working temperatures, the pressure sensor performed improperly 4 hours after the launch. The two figures below show the three temperature measurements and the pressure measurement recorded by the system.


Environmental Teperature
Degree
80
70
60
50
40
30
20
10
0
-10
-20
1
1801
3601
5401
7201
9001
10801
12601
14401
16201
18001
19801
21601
23401
25201
27001
28801
Time since system start (second)
Air Temp. inside chassis
Gyro MNT Temp.
Gyro BLK Temp.


Air Pressure inside Chassis
Air Pressure (mbar)
1000
800
600
400
200
0
1
1801
3601
5401
7201
9001
10801
12601
14401
16201
18001
19801
21601
23401
25201
27001
28801
Time since system start(second)

Gondola Dynamic Data

The gondola dynamic was dominated by a complex pendulum motion of the flight train with pivot points at the base of balloon and at the top mount in the 2004 flight. This effect was particularly evident at launch, when the release of the gondola and balloon acted to drive this motion. Below figures show the gondola dynamic in both roll axis and pitch axis during the first flight. As there was little damping in the flight train, pendulation induced by launch took about 2.5 hours to damp. This pendulation was actually decreased to a correctable pendulum angle (below 0.05°) in the roll axis but still kept a visible one (around 0.2°) in the pitch axis by the time the balloon reached float altitude. At float altitude, wind shear forced acting on the balloon and vibration by the step motor's up-down motion acting on the gondola, also driving this pendulation in the pitch axis to induce oscillations in both azimuth and elevation. It was noticed that excluding the dynamic, there was an approximate 0.6° constant error angle in the pitch axis during float altitude. This constant error angle caused by an unbalance payload may have affected the dynamic response of both the azimuth and the elevation control loop.

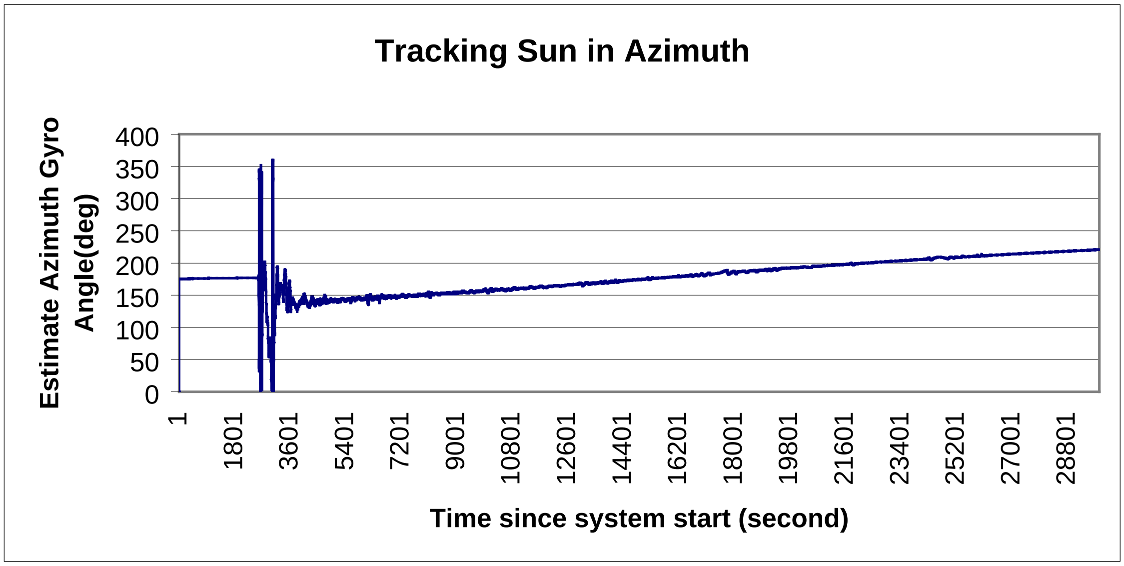


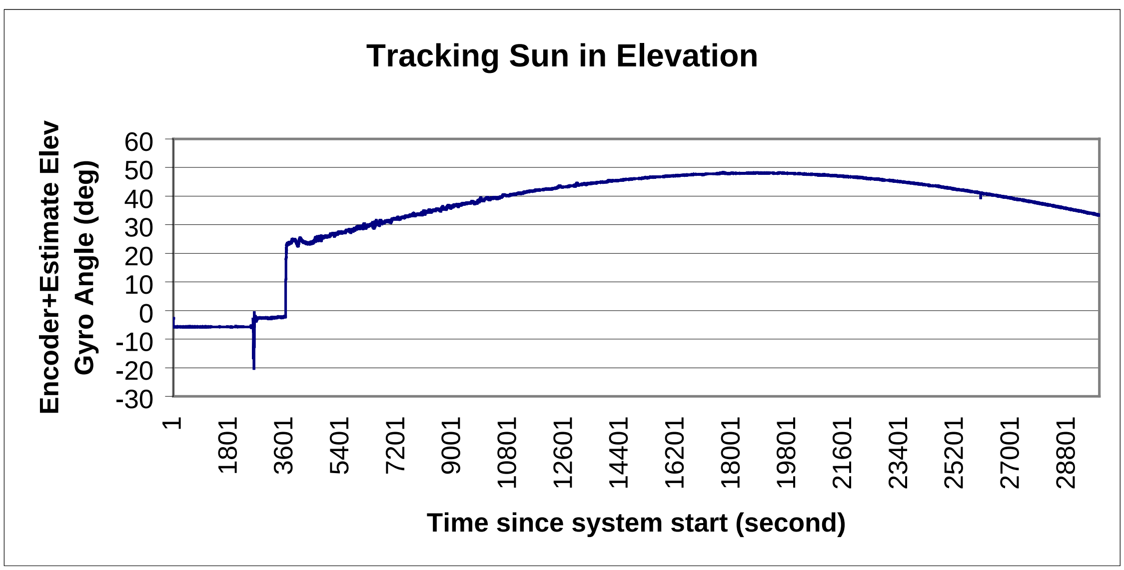
Solar Mode Data

The MKII pointing system was engaged to solar mode when the sun was acquired by the video camera during ascent (at around 5730m height 14.3 minutes after launch). Both the transient state response and the steady state response in the elevation control loop met the requirements during ascent. But the pointing system did not obtain the required transient response in the azimuth control loop due to a large pendulation. We made several attempts to improve its dynamic response by using different variations of the D-term in the azimuth PID without the velocity. Those attempts did not improve the transient response in the azimuth control loop. After velocity feedback was implemented in the azimuth PID, we tried to modify the torque motor's current limit from 5A to 7A but we did not succeed as the command link failed at approximately 9:13 (local time). The pointing system ran at the solar mode continuously with the sun sensor data for the D-term of the azimuth PID, velocity feedback, until the last pointing system data was received. At 16:16 (local time), the output of all temperature sensors inside the chassis were greater than 68°C and the pointing system's computer crashed, possibly due to overheating.

a. Tracking Sun Data

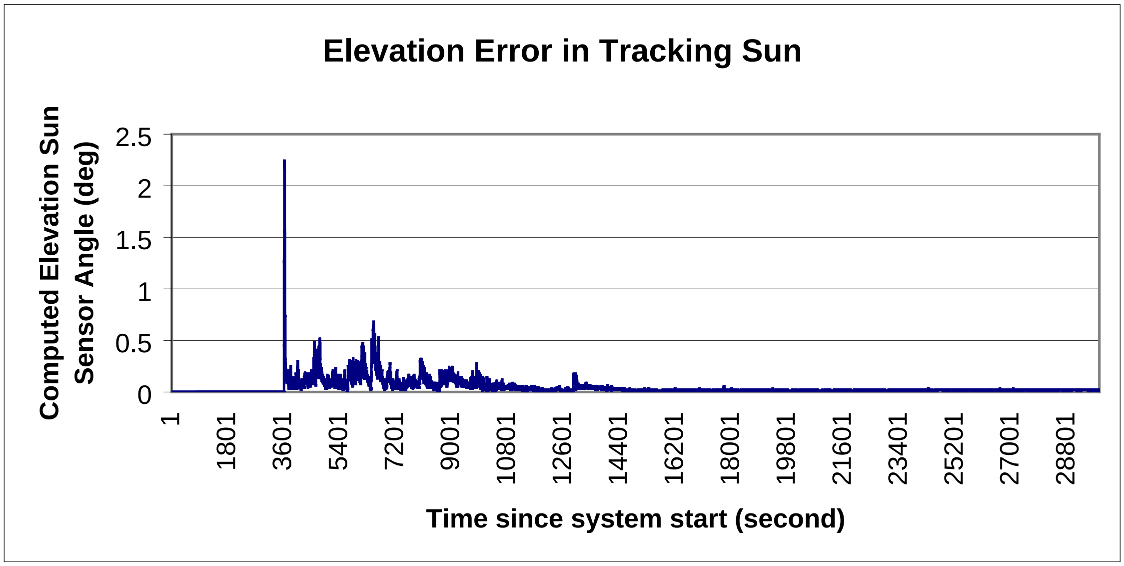
From 8:53, beginning solar mode, to 16:16, receiving the last pointing system's data, the pointing system continued to work in solar mode without any tuning. The following two figures reveal that the pointing system tracked the sun very well in both the azimuth and the elevation loop during the first flight.

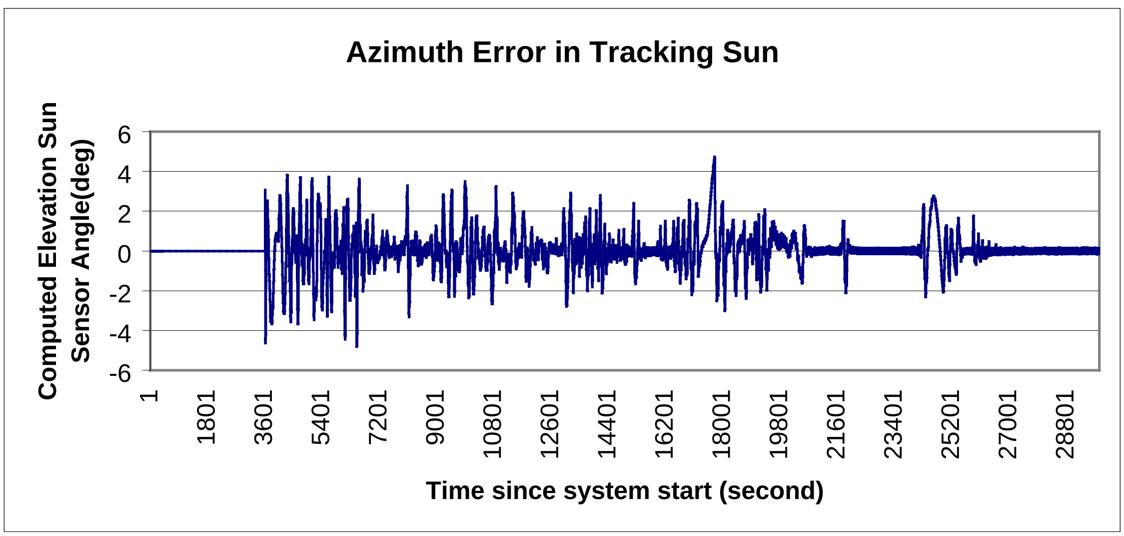




b. Tracking Error Data

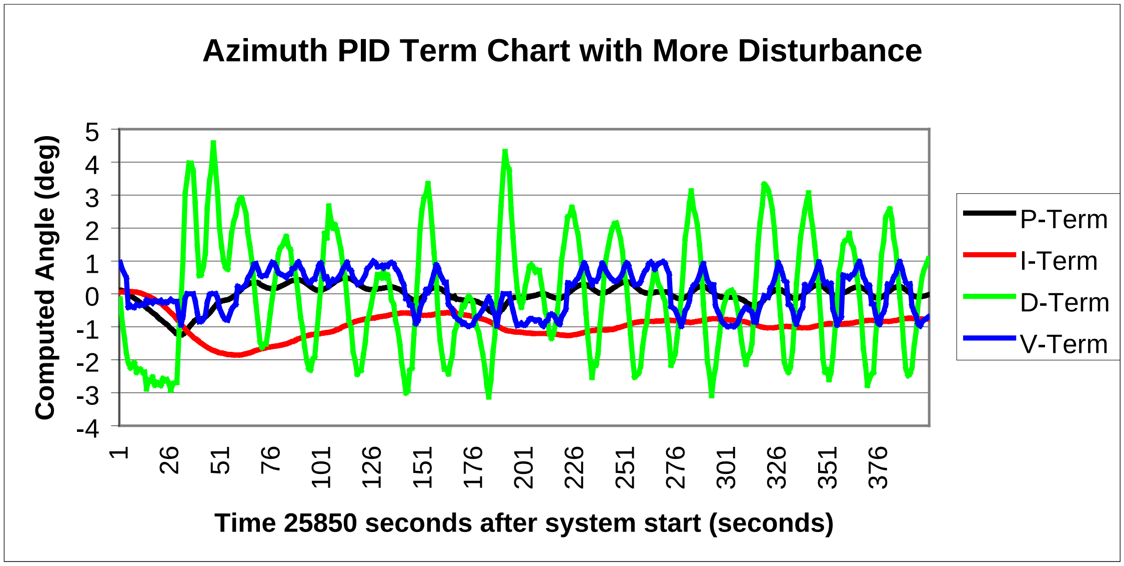
The sun was acquired at 8:52 (local time) and the pointing system was left in the sun mode until 16:16 (434 minutes in total). The pointing performance is indicated in the table 2. The next two figures show the calibrated sun sensor as offset from the pointing system line of sight (note that azimuth sun sensor has +10% gain error).

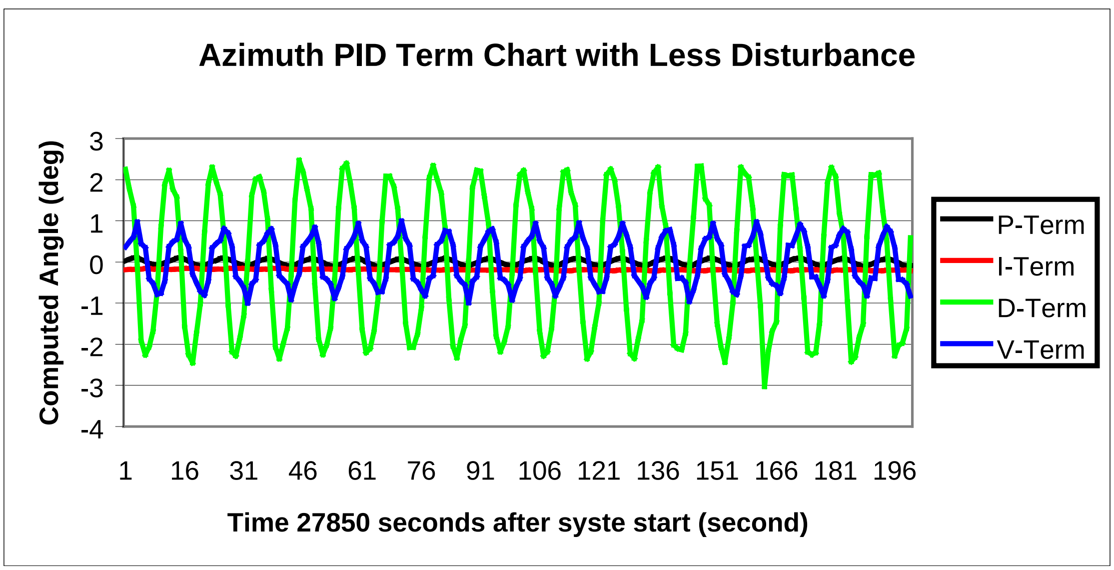




c. PID Term Data

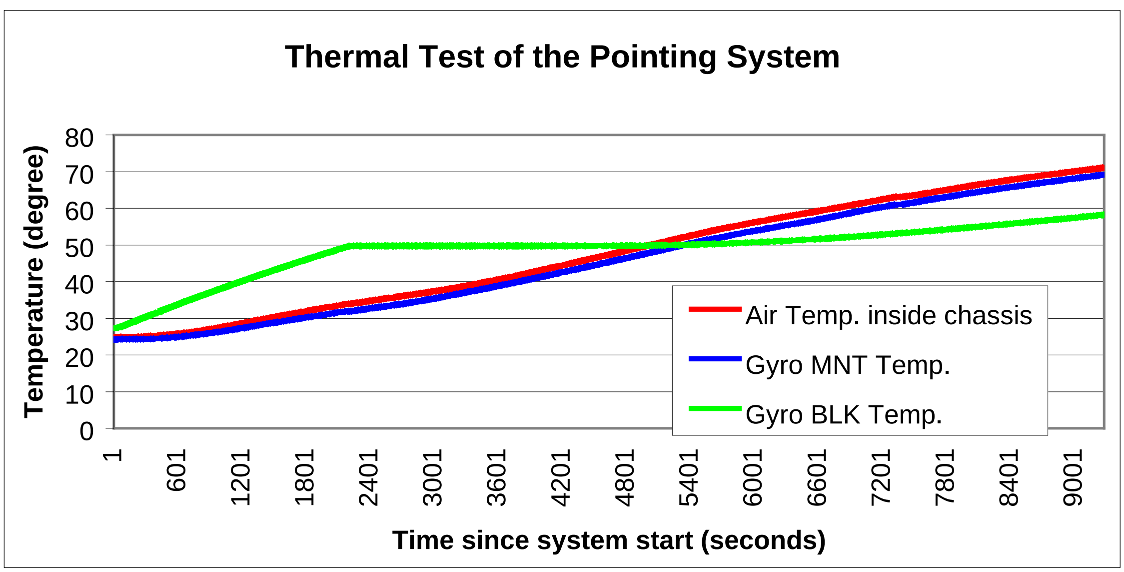
During the solar mode, the ground station also collected a large amount of data surrounding the azimuth PID controller in the pointing system. The following figures show the P-term, I-term, D-term, and V-term performance in two particular periods.





3.0 Summary and Recommendations

The pointing system, in common with other instrumentation, was operational during launch. The system was engaged in solar mode at 08:53 (local time). After fine-tuning azimuth PID controller was atempted and the command link failed, the pointing system was left in solar mode for the remainder of the first flight, with the velocity feedback and sun sensor for D-term succeeding until the last pointing data was received at around 16:16 (local time). At that time, the pointing system's computer in the payload crashed. The higher temperature around the single-board-computer (SBC), which was over 68ºC during the latter period of the first flight, may have caused the SBC crash. On October 20 in SIL, this assumption was proven through thermal testing of the pointing system, where the environmental temperatures of the first flight were simulated. The following figure shows SBC of the pointing system crashed again at around 69ºC. This test also indicated the best performance of the electronics including sensors, circuit boards, and cards of the pointing system at a range of 10ºC to 55ºC.



Our preliminary analysis indications:

● The MKII pointing system could run at a rate of 10Hz. In this new high rate, the system performed much better than the original system did under solar mode. The system could also obtain a pointing accuracy better than 0.05°(rms) in elevation and 0.8°(rms) in azimuth during the balloon float.

● All integrated electronics, including SBC, new analog/digital interface board, new high speed DAQ card, and the original serial card worked very well at a rate of 10Hz.

● All sensors, including solar azimuth sun sensor, solar elevation sun sensor, Limb azimuth sun sensor, tilt sensor, rate gyro, magnetometer, encoder, GPS, temperature sensors, and pressure sensors, all performed very well.

● The refurbished torque motor with anti-freeze precaution demonstrated that it still had proper performance for driving the payload and did not seize at all during the first flight. The Step motor performed very well too but its gearing could possibly be improved upon which may reduce vibrations.

● The Data link worked very well enabling the ground station to collect approximately 50Mb raw flight data in real-time. This extremely useful data was of great assistance in operating and monitoring the pointing system during flight and now are basic to analysis of the performance. Because other parts failed, the command link could not be proven, although it worked very well during ascent.

● The new flight codes were tested in this real flight and performed extremely well under solar mode. The rewritten ground code, with a more friendly windows and menu, performed very well too although the command link failed.

● The most sub vi and procedures of the new flight code had been proven out during the first flight. Those sub vi and procedures relative to conventional limb scan (fixed-orientation in azimuth by azimuth gyro feedback control) and new solar-limb scan (tracking sun in azimuth by a limb sun sensor) were not activated so their performance could not be evaluated and analyzed in this report though they were tested many times under ground-based simulations. It is necessary to mention that even in these simulations one of the key sub vi, event table handler.vi, could not ensure the system for automatic command of the instruments (SPS, Maestro A, Maestro B) according to scan table.

● The new normalizing sun sensor modular with the conditioning interface enabled independent intensifying of light but reduced its linear range.

Despite the linear range's tendency to be narrow, the pointing performance of the MKII pointing system, by using this new normalization, was much better than the original system which used conventional current-to-angle conversion without a conditioning circuit.

● The new elevation PID algorithm clearly met the pointing requirements. The new azimuth PID algorithm, with an optional angle velocity feedback, and different D-term sources, significantly improved the dynamic response of the azimuth control loop during solar mode. However, this fixed-value PID could not quickly and completely correct the disturbance torque generated by the flexible flight train.

● The Kalman estimator functioned properly at the new high sample rate although the estimated attitude angles of the pointing system were not used in the solar mode. It appeared very stable in both azimuth axis and elevation axis in this flight. Many tests on the ground, however, showed that estimated azimuth gyro angle depended deeply on the magnetometer's angle rather than on the azimuth gyro angle, delivered from the raw azimuth gyro rate.

● The new data link modular, with the new packet of data (reducing each packet of the flight data from 115 bytes to 71 bytes without losing any useful information), worked very well. The ground station collected approximately 50Mb of the raw flight data in real-time. The code for redisplaying the flight data had been developed for the post flight analysis. The newly written command link modular worked very well during launch but it lost an opportunity to test in a real long flight term and range, due to other part's failure in command link.

Pointing Performance

The elevation pointing definitely met the requirements of 0.1º(rms) in both transient state and steady state. Pointing performance in elevation was less than 0.03º(rms) during the entire float. In azimuth, the pointing system obtained a pointing accuracy of 0.20º(rms) during the last two hours. During the entire float, however, the pointing performance in azimuth was 0.80º(rms), which did not meet the specification goals in both the transient state and steady state. Table 2 calculates the pointing performance with varied start times.

Table 2 Pointing Performance (RMS)

Beginning Time	Computed Period (sec)	Elevation Error (rms)	Azimuth Error (rms)	Description
8:53 (3614)	26221	0.1º	1.02º	Beginning Solar Mode
9:53 (7214)	22621	0.05º	0.86º	1 hr after solar mode
10:53 (10814)	19021	0.023º	0.82º	2 hrs after solar mode
11:27 (12870)	16965	0.022º	0.80º	Beginning float altitude
11:53 (14414)	15421	0.017º	0.79º	3 hrs after solar mode
12:27 (16470)	13665	0.017º	0.81º	1 hr after float altitude
12:53 (18014)	11821	0.017º	0.65º	4 hrs after solar mode
13:27 (20070)	9785	0.017º	0.57º	2 hrs after float altitude
13:53 (21614)	8221	0.018º	0.35º	5 hrs after solar mode
14:27 (23670)	6165	0.019º	0.20º	3 hrs after float altitude
14:53 (25214)	4621	0.019º	0.18º	6 hrs after solar mode
15:27 (27270)	2565	0.020º	0.10º	4 hrs after float altitude

Experience and Lessons

Although the MKII pointing system performed much better than the original system in pointing performance under solar mode, a great deal of lessons were learned from the flight of MANTRA 2004 in preparation for future flights. A great deal of crucially valuable experience was gathered during these programs.

Experience gathered:

● The gondola requires approximately 2 hours to reach stability in the azimuth after the balloon reaches the desired float altitude. In elevation, the time required is much shorter. During ascent, any activating azimuth actuator operation may make the previously cited length of time.

● The main disturbance in azimuth for the pointing system is a disturbance torque caused by a relative spin motion between the gondola and the balloon. Because the flight train is extremely flexible, this relative spin motion will be transferred to the angular momentum to store in the flight train. The more motion occurs in one direction, the more energy will be stored in the flight train. The additional mass boom can make the period of this motion longer but cannot remove this motion. In elevation, the main disturbance arises from the combination of the pendulating payload and the vibration caused by all activated actuators in elevation. But this pendulum disturbance can be faded into an acceptable and correctable range at the float altitude.

● The fixed-value azimuth PID controller is not robust enough for correcting any torque disturbance caused by the flight train, however, the velocity feedback can significantly improve its dynamic response.

● The maximum working temperature, at which the pointing system with the thermal design can work well in, is 60ºC. As temperatures exceed this maximum working temperature, the performance of the pointing system is hindered.

● The refurbished torque motor with anti-freeze precaution works very well, but its current limit needs to be modified from 5A to 7A.

Lessons learned:

● An automatic mode is needed, including automatic seeking and tracking of the sun module, to be employed in case of a command link loss.

● Require a sensor (encoder, for instance) to monitor the relative spin motion between the rotator and the stator on the top mount motor (torque motor).
● Require an adaptive azimuth PID controller to correct the dynamic disturbance torque caused by the angular momentum stored in the flight train (especially in the parachute). Or an operation strategy dissipates this energy
● Require a sun shield to prevent the pointing system from overheating.
● Require a new event table handle vi ensuring automatic commanding of instruments without potential variable conflict in the limb mode.
● Requirement to widen the sun sensor linear range from ±5º to ±10º with more accurate gain (especially in azimuth sun sensor).
● Air temperature sensor and pressure sensor should be mounted outside the pointing system but remain in close proximity to it.

Recommendations

The MKII pointing system has a good beginning but has a long and arduous distance to go in its commercialization. We have made some recommendations for future MANTRA flights and for commercialization of the pointing system as below:
● Build a suspension test system to investigate and test a variety of control algorithms and technologies. This test system should be a torque motor, hanging from the top mount torque motor of the pointing system, which can simulate a motion of relative spin between the gondola and the flight train.
● Apply more advanced technology (adaptive PID controller, neural network, for instance) in the azimuth control loop to effectively correct the dynamic disturbance.
● Study a way to decouple the relative spin motion between the gondola and the flight train. SIL had proposed mounting a mechanical swivel between the additional mass boom and the flight train for decoupling this motion last year. We require more actions such as scientific calculation, and simulating tests on this idea.
● Study the use of a reaction wheel mounted on the flight train to stabilize the flight train in the inertial space, which should reduce the relative spin motion between the gondola and the flight train.
● Develop an automatic control mode for the case of a command link failure or for a lack of operational control. This mode should first download the balloon flight plan file in special text format to the pointing system through the command link. Then it should automatically translate this plan into an

executable command series. If watchdog or manual activate the automatic control mode, the pointing system will automatically execute these series of commands according to the flight plan.

● Rewrite the software codes related to the limb mode to ensure automatic command of the instruments.

● Study a new strap-down INS, which consists of 2 two-axis rate gyros, 2 accelerometers, 1 magnetometer, 1 tilt sensor, and 1 GPS with a new model and algorithm in both initial alignment and in attitude estimating to replace the current one. This new model and algorithm should be independent of the magnetometer readings during its normal work except during its initial alignment.

● Windows 2000 and relative Labview versions are recommended to be applied in the pointing system due to their increased reliability in real-time, multi-user, and multi-task applications of industry control than that of Windows 98.

● A more compact, lower consumption, higher speed SBC (SBC based on conduction cooled Pentium M technology, for instance) would prove better than the current one (full size, Pentium II).

Appendix E

SIL's Flight Two Failure Analysis Report

SCIENTIFIC INSTRUMENTATION LTD.
2233 HANSELMAN AVENUE
SASKATOON, SK
S7L 6A7
CANADA

DOCUMENT	:	**MANTRA 2004 FLIGHT TWO FAILURE ANALYSIS REPORT**
PROJECT NO.	:	7038

REV.	**APPROVALS**
01	Originated By: **DRAFT**
	Checked By:
	Approved By:
	Date: November 17, 2004

REV.	**DATE**	**APPROVAL**	**DCN**
02			
03			
04			

PROJECT	:	7038
REV. NO.	:	01
DATE	:	Nov. 17, 2004

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1. Introduction

This document presents the results of work done by SIL to investigate the balloon failure during the second flight of the Mantra 2004 campaign. Scientific Instrumentation Limited (SIL) was the launch contractor for the project, which was funded by the Canadian Space Agency (CSA). The scope of the work was to determine what caused the failure during flight and if there were any weak areas in the system design that could cause other failures.

This report is organized to deliver the following information: a brief background; an explanation of what failures occurred; a list of methods used for investigation; analysis of the results; the conclusions drawn; and recommendations for system improvement.

2. Mantra 2004 Flight System Description

2.1. Command System

At the Ground Station a command Hub PC accepts up to 16 channels of RS232 serial command streams at various baud rates and converts them to a 300-baud serial output stream. The output stream is encoded with a channel number and its baud rate so that the payload hub micro-controller can properly reproduce the data to its destination. The 300-baud output stream modulates a 138.54 MHz transmitter via an RS232-FSK converter. The transmitter can also be modulated with DTMF tones by using a keypad housed on the microphone.

At the payload main CIP the audio output of a 138.54 MHz receiver is fed to an FSK-TTL converter where the 300-baud stream enters the payload hub micro-controller and one of several SIL command decoders. The micro-controller generates the original command stream and delivers it to the proper destination. If the destination is an SIL command decoder then the payload hub micro-controller ignores the signal and the data stream includes addressing info to select the appropriate command decoder. Since the RF data uplink is at 300-baud and the original command stream can be as high as 9600-baud there will be some delay. Additional delays will occur since the command system is based on a first come first serve concept. The maximum length of a command string is 27 bytes and the byte protocol must be no parity, 8 data bits, 1 stop bit.

At the upper CIP the audio output of a second 138.54 MHz receiver is fed to a DTMF decoder and an FSK-TTL converter whose 300-baud output stream enters an SIL command decoder. The command decoder has 16 digital output lines, 8 of which are fed to a relay interface board. The relay interface board houses the drive circuitry to actuate the relays which in turn are used to perform various flight train functions like valving of helium, chute cutaway, and command terminate. To send a “command terminate” a password must be entered on the ground station computer. The output of the DTMF decoder directly drives a separate relay which in turn provides a second termination drive source (DTMF terminate). To send a “DTMF terminate” a unique timed sequence of four key presses need to be entered on the microphone keypad.

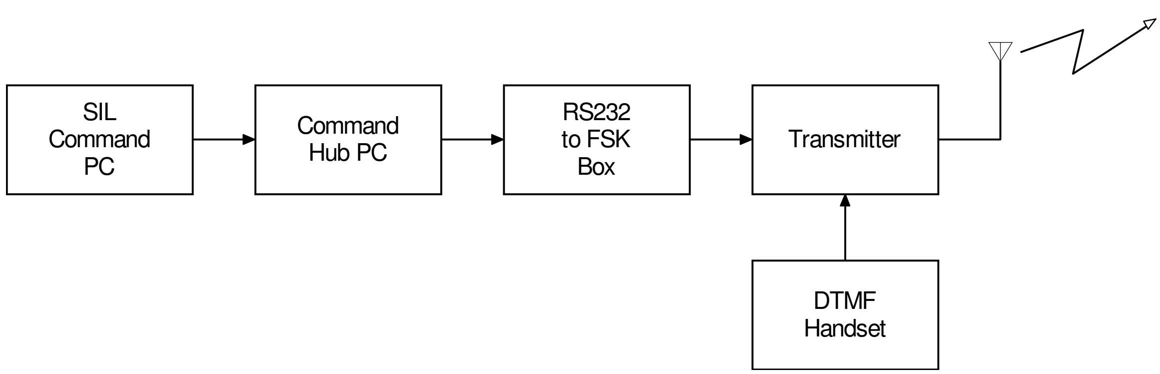


Figure 1 – Mantra 2004 Uplink Command System

2.2. Telemetry System

Various flight train monitors and meteorological (MET) data located at the upper CIP are transmitted to the ground using a modified Vaisala radiosonde operating in the 403 MHz frequency range. The RF output signal strength is less than 500mW. Flight train monitors include valve open/close status, terminate fired/ready status, upper CIP temperature, and battery voltages. The MET data consists of air temperature, air pressure and humidity.

At the payload there are two S-band (2.2 GHz) transmitters with an output power of either 2 or 5 watts, which are used to send all the SIL monitors and all of the science instrument data streams. In addition there is a third S-band transmitter with an output power of 10 watts, which is used to send signals from one of two video cameras.

2.3. Termination System

A termination fitting connects the bottom of the balloon to the top of the parachute. The fitting is held together by a 3/16 inch diameter steel cable. The fitting comes apart once the cable is cut by one of two explosive cable cutters. Each cutter has two inputs and for the second flight of Mantra 2004 one of the four inputs was not used. A monitor wire runs parallel to the termination cable and indicates when a cutter has fired by becoming open circuit.

When a termination command or DTMF command is received, the appropriate relay is actuated such that the pole (connected to +28V) gets connected to the normally open (N.O.) terminal. This places a voltage across one filament of a squib which will cause the cutter to fire. Additionally, a termination timer is set to countdown a specific number of hours and then output a voltage to fire a squib as a backup in the event of command loss.

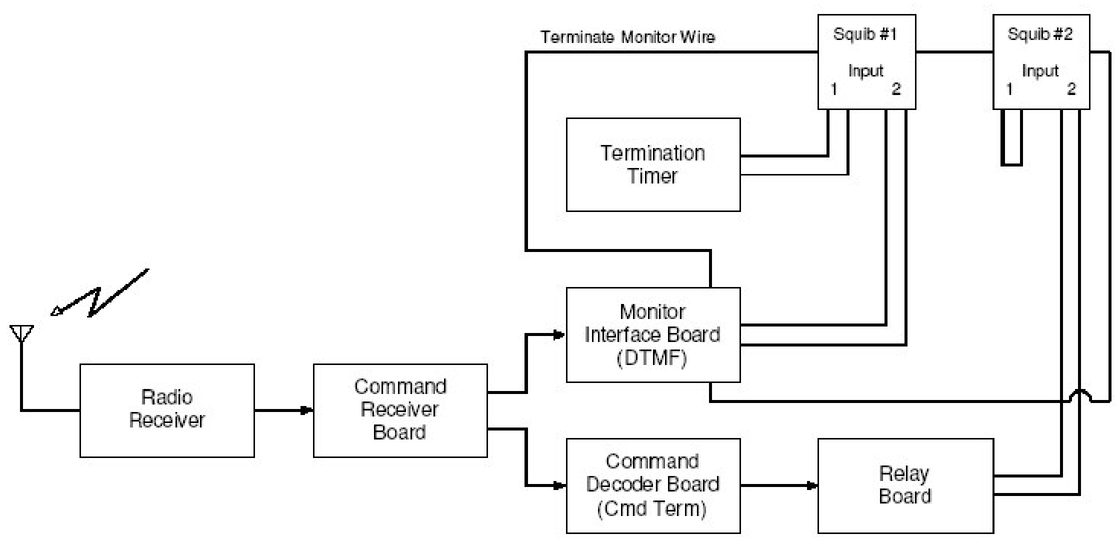


Figure 2 – Mantra 2004 Upper CIP Termination System

3. Flight Analysis

3.1. Flightpath (Key Events)

The important events, times and locations for the flight are listed here for quick reference.

3.1.1. Pre-flight Systems Checkout

SIL systems and Science instrument checkouts began at approximately 21:00 CST. The Science checks had to be restarted because the lead-acid batteries powering the payload had become depleted. The checkout was restarted under flight batteries and completed successfully.

3.1.2. Flightline Upper CIP Relay Failure

During the flightline upper CIP checkout, at approximately 22:21 CST (reference SIL cmdhub data, Section 7.4), the command terminate test failed. The proper behaviour for a command terminate is a one second pulsed 28V output from the upper CIP. However, after the command was sent the output remained at 28V indefinitely.

Power was removed from the upper CIP and it was brought back to the main building for further testing. The relay board was removed from the upper CIP and a short, due to a faulty relay, was found. After the relay was replaced there was no short on the board. The upper CIP was then tested inside the building before being taken back out to the flightline, where final checks were performed again.

3.1.3. Launch

Release of the balloon from the spool occurred at approximately 02:15:30 CST (video provided by Larry Cooper of the launch shows approximately 40 seconds between balloon release and launch).

Launch occurred at approximately 02:16:09 CST, location: 52° 1' 15.96" & 107° 2' 11.76" (interpolated using GPS data from Kaley Walker, Section 7.3).

3.1.4. Loss of Upper CIP Monitor Data

The last data packet was received at 02:16:23 CST (upper CIP monitor logfile, Section 7.7). Another packet was received at 02:42:06 CST, however the frame number associated with the data does not agree with the time it was received.

3.1.5. Termination

Termination occurred at approximately 02:21:10 CST, location: 52° 1' 5.52" & 107° 1' 9.48" (GPS data from Kaley Walker, Section 7.3).

3.1.6. Landing

The payload landing was interpolated at 02:24:20 CST, location: 52° 0' 57.24" & 107° 0' 42.12" using SIL GPS data (Section 7.5).

3.2. Initial Inspection of Recovered Payload

The payload was recovered the morning of the launch. Information from the recovery team was indicated the payload landed on all four crush pads then fell over onto the sun side. The parachute was laid in a direction west of the payload, and the balloon was approximately 150m east of payload.

The termination timer was found to be disconnected from the payload and located approximately 15m south of the top of the parachute. The timer was still running with 9 of 10 bars left on the display (confirmed to have been set for 20 hours). The timer output was measured as 0V. The termination timer was allowed to countdown, and the firing output confirmed (output measured 12V at the end of countdown).

Both explosive cable cutters were recovered and had been fired. The length of monitor wire seemed shorter than when installed. The squib resistances all measured open circuit (DTMF/term timer cutter model: 2801, serial: 2772-1; command terminate cutter model: 2802, serial: 2766-1).

The upper CIP was brought to the main building for some initial testing at approximately 04:15 CST. During transportation the battery pack was left connected. Both the command terminate and DTMF terminate outputs measured 0V. Command and DTMF termination tests were performed (both commands sent), the tests were successful.

3.3. Observations

On the launch date after premature termination had been confirmed, some information was given to SIL by Stella Melo. The graph given showed X-ray Flux as detected by a GOES Satellite (Figure 3) from the Space Environment Center in Boulder Colorado. The graph shows heightened electrical activity throughout the launch and recovery window. It is not known how widespread this activity was over the northern hemisphere.

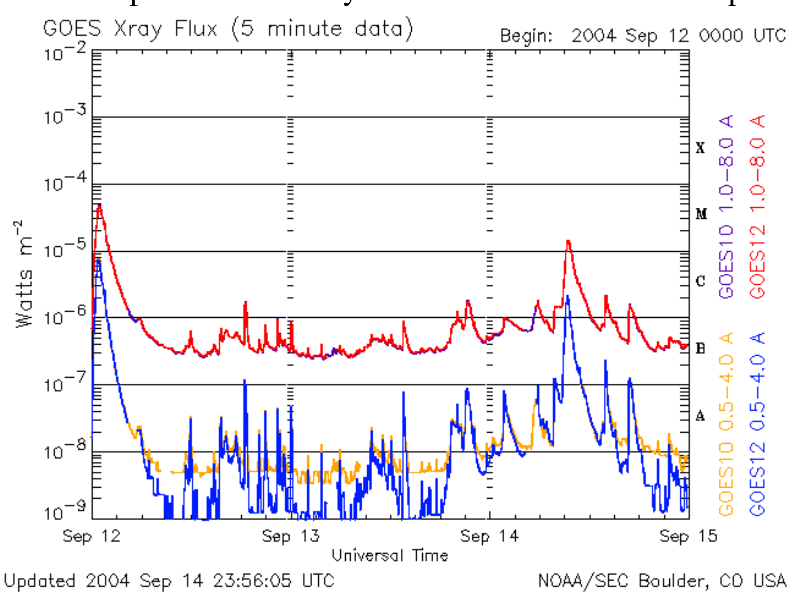


Figure 3 – SEC GOES Satellite X-ray Flux

Also of note is the fact that there were rain clouds in the area during the launch. Electrical activity accompanies rain and that could have been a contributing factor to the premature termination.

Post flight, SIL requested any information on unusual data received during the flight from the science teams involved in the launch. All responses received indicated there was no unusual activity on scientific instruments.

The SIL monitor data was also examined for unusual activity. At the time of termination, the current drawn by Minirad 1 dropped by approximately 450mA. A plot of the current versus time is shown in Figure 4.

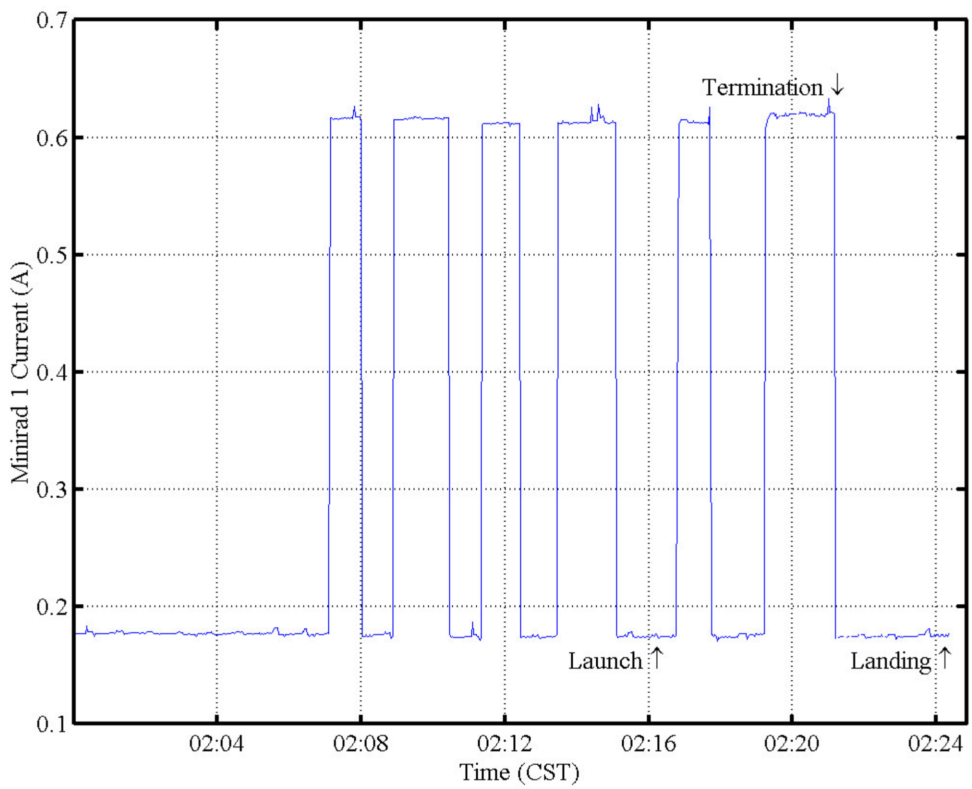


Figure 4 – Mantra 2004 (second flight) Minirad 1 Current vs Time

3.4. Graphical Flight Information

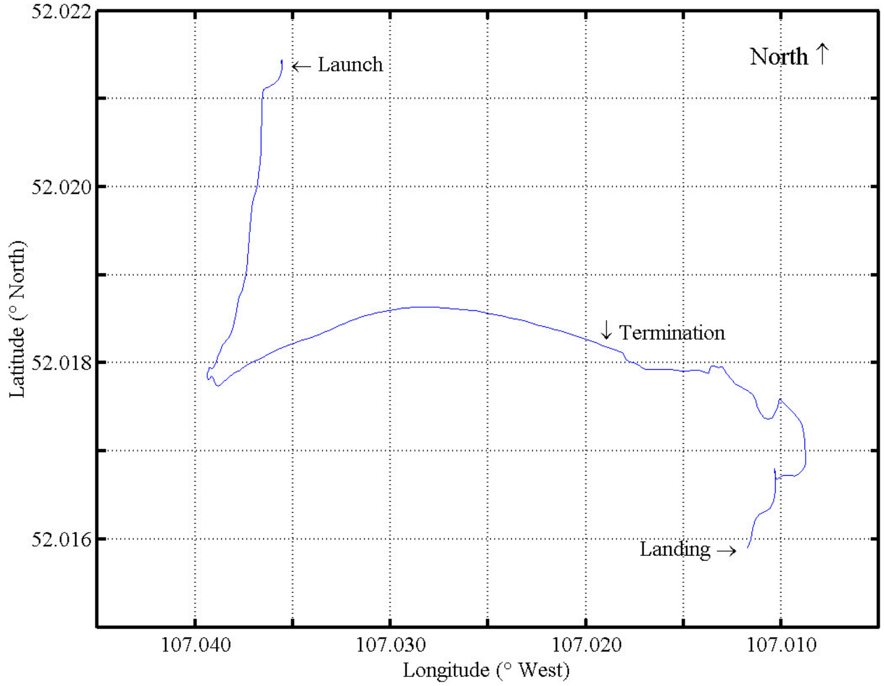


Figure 5 – Flight Path - Mantra 2004 (Second Flight)

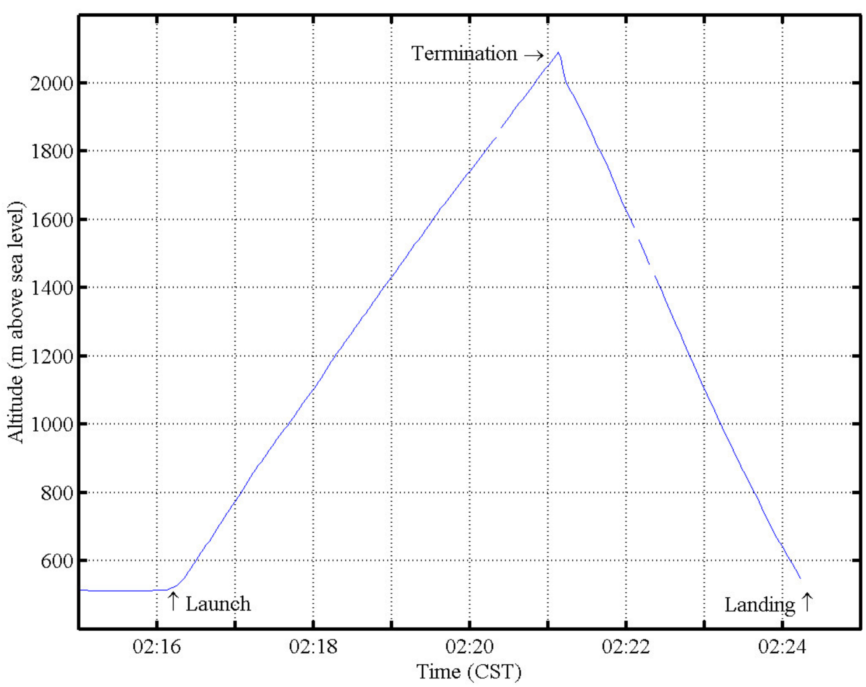


Figure 6 – Altitude Profile - Mantra 2004 (Second Flight)

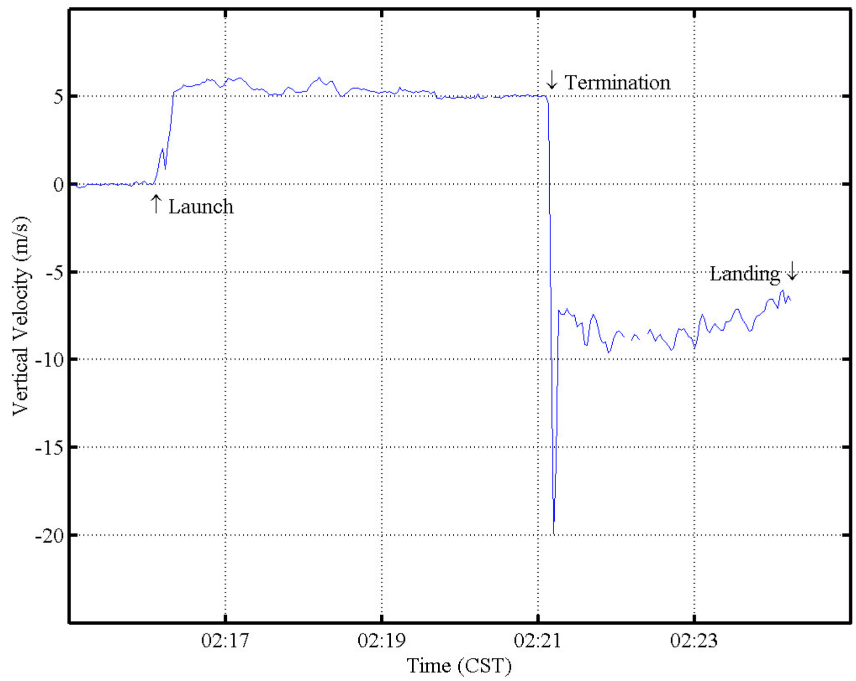


Figure 7 – Ascent Rate Profile - Mantra 2004 (Second Flight)

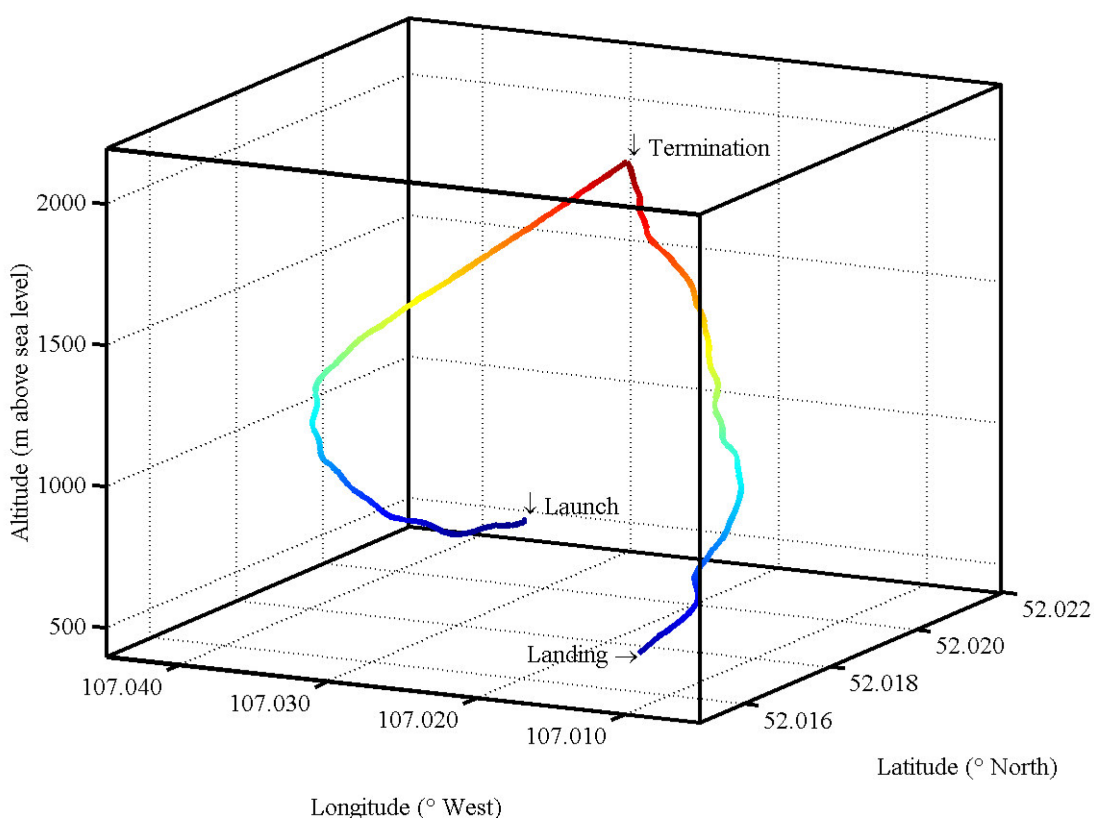


Figure 8 – 3D Flight Path - Mantra 2004 (Second Flight)

4. Failure Analysis

4.1. Description of Termination Failure

Approximately 5 minutes into the flight on October 14th premature termination occurred, which caused the payload to return to the ground via parachute. Initial inspection revealed no termination commands were sent, but both explosive cable cutters had been fired.

4.1.1. Possible Causes

Before the investigation began, a list of possible causes was put together. This list helped both by identifying what to look for during testing and by pointing out certain areas of the system that could be improved. The focus of the investigation was to eliminate these possible causes, leaving the most probable cause as a likely source of failure.

- Sending of unintentional termination commands;
- Steel Terminate cable was loose and fitting separated or cable broke apart;
- RFI-from S-band transmitters or other sources;
- Environmental electrical activity;
- ESD generated by the parachute/balloon or passing through a charged cloud;
- Upper CIP failure that caused premature cable cutter firing;
- Physical shock causing a momentary relay 'bounce".

4.2. Description of Upper CIP Monitor Failure

Approximately 15 seconds after the balloon was launched, upper CIP vaisala and monitor data ceased from being received. This behaviour was also noted during the first flight of 2004, a faulty vaisala transmitter was suspected and replaced before the second flight.

According to the log file of upper CIP monitor data there were 7 updates received after launch. However, the final update was received after the payload had landed, approximately 26 minutes after the previous update. Additionally, the frame number associated with the final update does not correlate with the time it was received. This may indicate data corruption of the final update received.

Also of note in the log file is the fact that the upper CIP 28V battery voltage monitor dropped from 29.00V to 26.05V at 2:15:42, approximately 30 seconds before launch. The 15V battery and CIP temperature monitors also changed by a proportional amount at the same time.

4.2.1. Possible Causes

There were a number of theorized sources for the upper CIP monitor data failure. The procedure to determine the most probable cause was the same method used to evaluate the termination failure. This list provided a direction for the investigation to take.

- Position of upper CIP in flight train;
- Antenna shielding by upper CIP enclosure;
- Lowered supply voltage;
- Did moisture get inside the upper CIP and cause a failure;
- Vaisala transmitter failure.

4.3. Testing Methodology

This section describes the methodology used by the failure analysis team to determine the cause of the premature termination and upper CIP failures. The areas and equipment investigated are listed along with the methods used.

4.3.1. Examination of Termination Fitting

The termination fitting consists of 4 main components: the balloon fitting; the payload fitting; the termination cable; and two explosive cable cutters (prime and backup). The two fittings were examined for physical damage. The termination cable was not found and could not be inspected.

Pacific Scientific Energetic Materials Co. (PS/EMC), the manufacturer of the cable cutters used to cut the termination cable, were contacted about the failure for any information they may have. Both devices were inspected to determine if each cut the termination cable and which of two inputs ignited each device.

4.3.2. Examination of Failed Relays

The first relay, K6, was removed from relay board 7 because the chute cutaway arm command did not function properly. This was found and repaired during the equipment refurbishment following the first flight. The second relay, K4, was removed from relay board 5 because of a flightline failure of the terminate command, described in Section 3.1.2. The DTMF and command terminate relays used for the second flight were also examined.

Functional testing using a load rated for the relays was performed and documented. The coil and contact resistances were also measured. The plastic shells were then carefully removed to allow a physical inspection of the mechanical components inside each relay. This included the coil, all contacts, and whether any loose conductive pieces were present that could cause a short.

4.3.3. Examination of LED Test Jig

A test jig was used on the flightline to show when a termination or DTMF command had been received by the upper CIP. The test jig was damaged during the flightline upper CIP relay failure, described in Section 3.1.2.

4.3.4. ESD & RFI Testing

The squibs were examined to determine how high a voltage is required to produce arcing internally to the device. Radio frequency interference (RFI) was introduced to the upper CIP and its effects on the termination relay controls lines documented.

4.3.5. Functional Upper CIP Testing

The upper CIP was connected to the flight cables and battery. Verification of proper monitor data and acceptable output voltages was then performed. Test commands were sent from the groundstation to the upper CIP, verification of command execution with zero crosstalk between adjacent command channels was done.

Additionally, the log of commands sent during the flight (including science commands) was played back to the upper CIP while the command and DTMF termination outputs were monitored.

4.3.6. Detailed Upper CIP Examination

After performing most of the other testing, the upper CIP was carefully removed from the enclosure for detailed examination. Photographs of the inspection were taken of conditions inside/outside the enclosure, the wiring and the electronics. The circuit boards were examined for defects and damage. The system wiring was inspected for bare sections, cut wires, damaged insulation and incorrect routing.

4.3.7. Physical Shock Testing

The upper CIP was dropped onto a foam pad from 3 feet in the air, from all six sides and the probable angled landing position. The output of both command and DTMF terminate relays were monitored using a two input latch test circuit (set to trigger and hold on a positive edge). After each release the latch was examined to see if the physical shock caused the relay to "bounce" and effectively output an undesired 28V.

4.3.8. Upper CIP Signal Strength Testing

With the upper CIP in various orientations, the received signal strength of the vaisala transmitter was monitored. This was done to determine if the physical position of the upper CIP affected the received signal quality. Another vaisala transmitter was also tested in similar positions for comparison of results.

4.4. Test Results

4.4.1. Examination of Termination Fitting

The parachute side termination fitting is a chromed piece of steel and showed no unusual markings that would indicate slipping of the termination cable. The balloon side termination fitting is made of brass and also showed signs of regular usage: traces of soil from landing and a small indentation from striking another object in the past.

A model 2801 squib was connected to both DTMF and term timer termination circuits. A model 2802 cutter was connected to the command terminate circuit and the two leads of the second bridgewire were connected together as it was not used. Both devices had been fired, however inspection of each guillotine and anvil show that only the model 2802 squib actually cut a steel cable.

It could not be determined which input ignited the model 2801 cutter (DTMF or term timer) as the bridgewires were destroyed when the device was set off. These results are consistent with the information given to SIL by PS/EMC, the manufacturer, about the typical condition of fired cutters.

4.4.2. Examination of Failed Relays

Functional testing of relays K4 and K6 showed they operated properly on the bench. The measured open and closed contact resistances were infinite and less than 1 Ω respectively for each pole on both relays. The coil resistances were measured at 269.6 Ω for K4 and 267.4 Ω for K6 which are nominal values.

The plastic protective case of each relay was removed and the metal contacts examined under a 30X magnification lens for evidence of damage. Both K4 and K6 showed heavy pitting on the pole and normally open contacts. This could cause intermittent operation of the device and was likely the result of the high instantaneous current drawn by firing a squib.

The relay used to fire the DTMF cutter was removed and inspected in a similar way. This relay is known to have fired a number of cutters on previous flights and under microscope showed damage to the pole and normally open contacts.

The command terminate relay from the flight was taken from a spare relay board to replace the damaged K4 on the night of the launch. The history of this relay is not known. There is evidence of a small black mark on one pole and normally open contact, which indicates it has likely fired a cutter.

4.4.3. Examination of LED Test Jig

The termination LED test jig was examined visually. The current limiting resistor was black and the plastic of the LED itself was melted. Damage from the relay failure rendered the device inoperative.

4.4.4. ESD & RFI Testing

The breakdown voltage of the fired squibs were investigated using a hypot tester. From information given to SIL by PS/EMC the likely form of ignition due to ESD on a squib is a spark internal to the device either from the case to a bridgewire or from one bridgewire to another.

Internally each Holex squib contains four circular metal pads arranged in a square, insulated from the metal case by ceramic. There are two nichrome bridgewires, one between the first pair of pads and another between the second set. Wires connected to each pad are present external to the device for connection to a firing mechanism.

The test set was connected between the case and one of the four contact wires of a squib and the voltage increased. For both squibs there was a wide variation in the results from each of the four wires to the case (eg. Current leakage at 50V, breakdown at 4300V, breakdown at 2400V, etc.) The deposits of spent propellant were thought to be affecting the test.

Using a model 2801 squib from a different flight that had been thoroughly cleaned and dried the test was repeated. There was no current leakage recorded, and breakdown was consistent at 2600V between the case and each of the four wires. Also, breakdown occurred when the voltage reached 3100V between the wires belonging to the two closest contacts. It should be noted that the breakdown voltage in air is 3MV/m and the distance between the bridgewire pads and case of the squib is approximately 1mm which is consistent with the testing results.

The hypot tester was then used with a live squib (the explosive part of the cable cutter) to see what voltage was required to fire. The positive lead was connected to the bridgewire and the ground lead to the case. The voltage was increased until the squib fired, at approximately 2800V.

A 2W radio was used to introduce RFI to the upper CIP while the command outputs were monitored. The lines from the command board to the relays have a nominal voltage of 0.05V when no command is sent and 5.05V when a command is sent. With the radio antenna 1cm from the wires at the relay board this voltage was 0.14V. That was the highest value recorded when moving the antenna around the upper CIP.

4.4.5. Functional Upper CIP Testing

The uplink command system and upper CIP were set up in flight configuration and the system was tested. All of the commands sent were executed properly by the upper CIP and no command crosstalk was observed. Specifically the termination commands (DTMF and command terminate) were tested 10 times each and the output of the upper CIP monitored. At no time did the output of one terminate subsystem energize when the command was sent for the other subsystem (i.e. No DTMF commands executed when the command terminate was sent).

Additionally, the log of all commands sent during the flight was used to play back each command to the upper CIP. The termination outputs were monitored throughout the playback and at no time was there a positive termination output (DTMF or command).

The transmitted monitor information was examined during testing and showed values consistent with the measured supply voltages and ambient temperature. It should be noted that the resistor divider circuit for the 28V battery voltage monitor on the monitor interface board is designed to show a maximum voltage of 29V. If a higher battery voltage is present, the monitor still shows 29V and not the correct voltage.

4.4.6. Detailed Upper CIP Examination

A detailed examination of the upper CIP was performed. There was no external damage found, some dirt and markings from the stubble from the landing area were present. Inside the enclosure, the battery was found to be free from the holding strap. Also, the FSK to TTL converter board was loosened from the adhesive pad that holds it in place. The DTMF decoder board was held onto the interface board by only one of the two nut/bolt pairs (the missing nut and bolt were not found inside the CIP).

There were no damaged or mis-routed wires found. All the boards were secure in their respective card guides and each connector was screwed in place. No loose debris was found inside the CIP enclosure. An inspection of each circuit board showed no damage or evidence of malfunction.

4.4.7. Physical Shock Testing

The relays used for termination were tested for accidental operation due to physical shock. A testing device was used to detect a momentary connection between the pole and normally open contacts of the relay while the relay was exposed to physical shocks in various orientations. The relay was tapped onto a hard surface and the 'bounce" behaviour was observed to occur in one main orientation.

When a force was applied on the top of the relay (the bottom being where the pins are), there was a reproducible momentary connection between relay contacts. The force was estimated to be approximately 10Gs. If the force was applied at a 45° angle on the end of the relay with coil contacts then the force required to cause a relay 'bounce" was slightly less.

Similar shock testing was performed on the termination timer, as it may experience a high force from the parachute side termination fitting at the time of termination. Force was applied to all sides of the timer both while inside its foam box and on the timer itself. The output was not observed to ‘bounce” as the relays did.

4.4.8. Upper CIP Signal Strength Testing

The upper CIP was placed 1m from a radio receiver with a whip antenna and the signal level shown was 20dB. Another vaisala was placed the same distance and the recorded signal level was 40dB.

The upper CIP was hung approximately 2m off the ground (at top of CIP) using the winch in the main building at the Vanscoy facility and the signal level was observed to be 8dB. When the chute cutaway fitting was connected, as in flight, the level did not change noticeably.

The upper CIP was then rotated in the vertical axis as the signal level was monitored. The maximum and minimum signal levels were 8dB and 4dB respectively. The maximum occurred when the steel support cables were on either side of the vaisala antenna when facing the receiving antenna. The minimum signal level resulted when the steel support cables were in front and behind the vaisala antenna when facing the receiver antenna, 90° to the maximum signal orientation.

The received signal started to suffer degradation when the CIP was turned approximately 30° away from the maximum signal position. As the CIP was raised higher off the ground this effect was more pronounced. At 2m in the air signal loss began at an angle of 15° and the minimum signal was reached when rotated only 50° from the maximum position.

The second vaisala was placed in the same position on the upper CIP, between the steel support cables, and the signal level on the radio receiver was observed to be 20dB lower than when positioned away from the CIP enclosure. It should be noted that a 20dB drop in signal level can cause a tenfold reduction in range due to free space attenuation in air.

4.5. Future Work

There are still some experiments SIL would like to perform to complete this investigation. Time is always an issue, but this failure analysis must be done as thoroughly as possible to prevent overlooking important information.

The effect of the main S-band transmitters as a source of RFI should be investigated. This would involve powering the transmitters and monitoring any induced voltage in flight cables or at crucial points inside the upper CIP.

Additionally, more work must be done to determine the level of electrostatic charge that can build up using the parachute and some of the balloon material. Perhaps an explosive cutter can be used in the experiment to demonstrate ESD can set of the devices.

5. Conclusions

The loss of upper CIP monitor data shortly after launch was related to the position of the vaisala transmitter in the flight train. Testing showed a significant signal loss when the upper CIP was rotated in the vertical axis to specific angles.

The voltage shift indicated by the upper CIP monitor data near launch time was likely due to a change in the A/D converter reference voltage as all monitor values changed by a proportional amount. However it is not known what could cause the reference voltage to change. Although the frame number did not correspond as expected with the time received, the final packet of monitor data from the upper CIP was probably valid because its information was correct (the data showed positive termination and the valve monitors were consistent with cables being unplugged due to separation from the balloon).

Premature termination of the second flight due to the command termination squib firing was likely the result of electro-static discharge. NASA has experienced similar NSBF failures in the past and come to the same conclusion. This is supported by the fact that after rigorous investigation, no sign of failure inside the upper CIP was found. Additionally, there is no evidence of a relationship between the flightline failure of the command termination relay and premature termination. The second squib could have been fired either by ESD or as a result of physical shock sustained by the upper CIP on landing.

The suspicious current change by Minirad 1 at the time of termination was likely part of a regular heater on/off pattern, which can be seen in Figure 4 on page 6.

6. Recommendations

Pursuant to this investigation, the following recommendations are made to prevent similar failures on future balloon flights. Suggested changes relevant to each failure, the upper CIP failure and the premature termination, are listed as well as a section on system improvements that will increase the overall reliability and effectiveness of the system.

6.1. Upper CIP Monitor Failure

There are two ways to prevent loss of the upper CIP monitor signal: place the vaisala transmitter in a different position; use a different method sending the monitor data such as a connection to the main CIP that allows transmitting the data using the main S-band transmitters. Other recommendations to improve the upper CIP are to:

- record serial numbers of each circuit board used for each flight;
- change conditioning circuits to allow wider input range (28V and 15V monitor);
- RTV all socketed ICs on boards to fix them in place;
- terminate the unused monitor channels properly with pull-up resistors.

6.2. Termination Failure

The recommendations to prevent premature termination are similar to those made by NASA as a result of NSBF failures. The incorporation of 10Ω bleeder resistors located at the explosive cutters will reduce the vulnerability to ESD. Additionally, the 30m shielded cables that connect the cutters to the termination electronics should be properly terminated to CIP ground. Any unused wires inside the shielded cables should be eliminated.

Secondly, all squib bridgewire terminals should be grounded when not in 'fire" mode (current system has one side of bridgewire connected to ground while the other is connected to the normally open terminal of a relay, which is at a floating potential). Care should also be taken to assess the launch conditions and be aware of the ESD risk level (is there rain or electrical activity in the launch vicinity).

6.3. System Improvements

Throughout the investigation a number of areas of the system design were noticed that could be improved. The following suggestions, if implemented, will increase system reliability and functionality:

- connect steel termination cable to top of chute securely on future flights;
- mechanism needed to prevent upper CIP from hitting the ground during launch;
- use an incandescent bulb to test squib firing circuits;
- use latching termination relays to aid in troubleshooting premature squib firing;
- conformal coat PCBs in main and upper CIPs (must vacuum test after coating);

- seal the main and upper CIPs to prevent moisture form getting inside;
- develop a procedure to flight qualify each subsystem;
- make contact with NSBF to exchange ballooning information;
- improve the safety training of personnel, specifically handling of squibs, balloon inflation and flightline procedures.

7. Appendices

7.1. SIL Monitor Data

See attached file SIL_AD_Monitors_Flight2.xls.

7.2. Pointing System GPS Data

See attached file Pointing_System_GPS_Flight2.xls.

7.3. GPS Data From Kaley Walker

See attached file KW_Flight2-GPS_Log.csv.

7.4. List of Commands Sent

[09-14-2004 02:10] (STARS)- Tx5 ON
[09-14-2004 02:10] (AIR)- 21
[09-14-2004 02:10] (AIR)- 24
[09-14-2004 02:17] (POINTNG)- CD 78 4D 42 00 00 09 00 00 13 F0
[09-14-2004 02:17] (POINTNG)- CD 78 4D 42 00 00 09 00 00 1F FC
[09-14-2004 02:18] (POINTNG)- CD 78 44 50 1C 7F FF 00 00 30 A3
[09-14-2004 02:19] (POINTNG)- CD 78 43 4D 00 00 00 00 00 00 D5
[09-14-2004 02:19] (STARS)- Tx5 OFF
[09-14-2004 02:20] (DENFTS)- 68 34 68
[09-14-2004 02:20] (DENFTS)- 34
[09-14-2004 02:25] (SILCMD)- 7.Balst_Open/Close_N ON
[09-14-2004 02:25] (STARS)- Tx1 OFF
[09-14-2004 02:25] (STARS)- Tx2 ON
[09-14-2004 02:25] (SILCMD)- 7.Balst_Open/Close_N OFF
[09-14-2004 02:34] (DENFTS)- 65 66
[09-14-2004 02:34] (DENFTS)- 65 66
[09-14-2004 02:34] (DENFTS)- 65 66 65
[09-14-2004 02:34] (DENFTS)- 66
[09-14-2004 02:34] (DENFTS)- 65 66 65 66
[09-14-2004 02:34] (MSCFTS)- 43 44 37 38 73 68 75 74 64 2E 66 69 6C 30 30 30 30 30 30 30 30 30 30 30 30 30 30 35
[09-14-2004 02:34] (DENFTS)- 65 66 65 66
[09-14-2004 02:34] (MSCFTS)- 53 48 55 54 44 E4
[09-14-2004 02:34] (DENFTS)- 65 66 65 66 65 66
[09-14-2004 02:34] (DENFTS)- 65 66
[09-14-2004 02:34] (DENFTS)- 65 66 65
[09-14-2004 02:34] (DENFTS)- 66
[09-14-2004 02:34] (PARFTS)- 43 6F 6D 6D 61 6E 64 3A EF EE EF EE 20 20 20 20
[09-14-2004 02:34] (PARFTS)- 20 20 31 31 20 31 20 36 4D 30 30 35 35 54 44 30 44 37 45 33 36 35 45 4F 43 3A FA FB
[09-14-2004 02:34] (PARFTS)- FC FD FE FF
[09-14-2004 02:35] (STARS)- Tx3 OFF
[09-14-2004 02:35] (MSCFTS)- 43 44 37 38 73 68 75 74 64 2E 66 69 6C 30 30 30 30
[09-14-2004 02:35] (STARS)- SPS1 OFF

[09-14-2004 02:35] (PARFTS)- 43 6F 6D 6D 61 6E 64 3A EF EE EF EE 20 20 20 20 20 20 31 32 20 31 20 36 4D 30 31 31
[09-14-2004 02:35] (MSCFTS)- 30 30 30 30 30 30 30 30 30 30 35 53 48 55 54 44 E4
[09-14-2004 02:35] (PARFTS)- 30 30 32 44 37 30 30 45 37 35 45 4F 43 3A FA FB FC FD FE FF
[09-14-2004 02:35] (STARS)- SPS2 OFF
[09-14-2004 02:35] (STARS)- Maestro OFF
[09-14-2004 02:35] (STARS)- Mini1 OFF
[09-14-2004 02:35] (STARS)- Mini2 OFF
[09-14-2004 02:36] (SILCMD)- 31.OH_Shutdown_____P ON
[09-14-2004 02:36] (SILCMD)- 31.OH_Shutdown_____P OFF
[09-14-2004 02:36] (MSCFTS)- 43 44 37 38 73 68 75 74 64 2E 66 69 6C 30 30 30 30
[09-14-2004 02:36] (MSCFTS)- 30 30 30 30 30 30 30 30 30 30 35 53 48 55 54 44 E4
[09-14-2004 02:36] (STARS)- MscSunTrakr OFF
[09-14-2004 02:36] (POINTNG)- CD 78 4D 42 00 00 09 00 00 11 EE
[09-14-2004 02:36] (SILCMD)- 13.MSC_INST_ON/OFF_N OFF
[09-14-2004 02:36] (SILCMD)- 12.MSC_COMP_ON/OFF_N OFF
[09-14-2004 02:36] (SILCMD)- 22.FTIR_SCAN_OFF___P ON
[09-14-2004 02:36] (SILCMD)- 22.FTIR_SCAN_OFF___P OFF
[09-14-2004 02:36] (SILCMD)- 26.FTIR_SEEKER_OFF_P ON
[09-14-2004 02:36] (MSCFTS)- 43 44 37 38 73 68 75 74 64 2E 66 69 6C 30 30 30 30 30 30 30 30 30 30 30 30 30 30 35
[09-14-2004 02:36] (SILCMD)- 26.FTIR_SEEKER_OFF_P OFF
[09-14-2004 02:36] (SILCMD)- 20.FTIR_LASER_OFF__P ON
[09-14-2004 02:36] (MSCFTS)- 53 48 55 54 44 E4
[09-14-2004 02:36] (SILCMD)- 20.FTIR_LASER_OFF__P OFF
[09-14-2004 02:36] (SILCMD)- 24.FTIR_COMP_OFF___P ON
[09-14-2004 02:36] (SILCMD)- 24.FTIR_COMP_OFF___P OFF
[09-14-2004 02:36] (POINTNG)- CD 78 4D 50 20 3F 80 00 00 30 F1
[09-14-2004 02:37] (SILCMD)- 54.SUN_TRACKER_OFF_P ON
[09-14-2004 02:37] (SILCMD)- 54.SUN_TRACKER_OFF_P OFF
[09-14-2004 02:37] (SILCMD)- 56.COMMAND_OFF_____P ON
[09-14-2004 02:37] (SILCMD)- 56.COMMAND_OFF_____P OFF
[09-14-2004 02:37] (SILCMD)- 52.PARIS_INST_OFF__P ON
[09-14-2004 02:37] (SILCMD)- 52.PARIS_INST_OFF__P OFF
[09-14-2004 02:37] (SILCMD)- 58.PARIS_COMP_OFF__P ON
[09-14-2004 02:37] (SILCMD)- 58.PARIS_COMP_OFF__P OFF
[09-14-2004 02:37] (SILCMD)- 33.Air_#1_ON/OFF___L OFF
[09-14-2004 02:37] (SILCMD)- 34.Air_#2_ON/OFF___L OFF
[09-14-2004 02:37] (SILCMD)- 46.O3_HEATER_______n OFF
[09-14-2004 02:38] (POINTNG)- CD 78 4D 50 20 3F 80 00 00 30 F1
[09-14-2004 02:38] (SILCMD)- 9.O3_INST_ON/OFF___L OFF
[09-14-2004 02:38] (SILCMD)- 50.PARIS_HEATER_OffP ON
[09-14-2004 02:38] (SILCMD)- 50.PARIS_HEATER_OffP OFF
[09-14-2004 02:38] (STARS)- OH OFF
[09-14-2004 02:39] (SILCMD)- 32.OH_(spare)_____vP ON
[09-14-2004 02:39] (SILCMD)- 32.OH_(spare)_____vP OFF
[09-14-2004 02:39] (STARS)- Pointing OFF
[09-14-2004 02:39] (SILCMD)- 3.Transpndr_ON/OFF_L OFF
[09-14-2004 02:39] (SILCMD)- 6.DataLogger_ON/OffN OFF
[09-14-2004 02:39] (SILCMD)- 84.VALVE__________vN ON
[09-14-2004 02:39] (DENFTS)- 03
[09-14-2004 02:40] (STARS)- Tx2 ON
[09-14-2004 02:40] (STARS)- Tx1 ON
[09-14-2004 02:40] (SILCMD)- 35.SIL_CAMERA_PWR__L OFF
[09-14-2004 02:41] (SILCMD)- 36.POINTING_CAM_PWRN OFF
[09-14-2004 02:41] (SILCMD)- 2.GPS_ON/OFF_______L OFF

7.5. SIL GPS Data

Time (GMT)	Alt (m)	Latitude	Longitude
8:14:28	515	52.02144	107.0356
8:14:35	515.2	52.02144	107.0356
8:14:42	515.5	52.02144	107.0356
8:14:49	515.5	52.02144	107.0356
8:14:56	515.7	52.02143	107.0356
8:15:03	515.9	52.02143	107.0356
8:15:10	516.4	52.02143	107.0356
8:15:17	515.7	52.02143	107.0356
8:15:24	516	52.02143	107.0356
8:15:31	515.8	52.02143	107.0356
8:15:38	516.1	52.0214	107.0356
8:15:45	516	52.02127	107.0357
8:15:52	515	52.02119	107.036
8:15:59	514	52.02114	107.0363
8:16:06	513.6	52.02112	107.0365
8:16:13	525.6	52.02069	107.0366
8:16:20	554.7	52.02009	107.0367
8:16:27	591.7	52.01983	107.037
8:16:34	630	52.01954	107.0372
8:16:41	668.2	52.01911	107.0373
8:16:48	708.3	52.01886	107.0376
8:16:55	747.6	52.01872	107.0378
8:17:02	787.4	52.01851	107.038
8:17:09	829.5	52.01833	107.0383
8:17:16	870.7	52.01823	107.0386
8:17:23	908.9	52.0181	107.0388
8:17:30	946.8	52.01797	107.039
8:17:37	982.5	52.01796	107.0392
8:17:44	1017.7	52.01795	107.0393
8:17:51	1056.3	52.01786	107.0394
8:17:58	1093.5	52.01783	107.0393
8:18:05	1130.2	52.01787	107.0392
8:18:12	1170.3	52.01784	107.0391
8:18:19	1210.9	52.01776	107.0389
8:18:26	1251.1	52.01781	107.0385
8:18:33	1288.2	52.01791	107.038
8:18:40	1326.5	52.01798	107.0375
8:18:47	1365	52.01804	107.0369
8:18:54	1402.4	52.01812	107.0361
8:19:01	1439.1	52.01821	107.0353
8:19:08	1476.2	52.01828	107.0345
8:19:15	1513	52.01834	107.0337
8:19:22	1550.3	52.01842	107.0328
8:19:29	1587.5	52.0185	107.0319
8:19:36	1624.8	52.01856	107.031
8:19:43	1660.2	52.0186	107.0302
8:19:50	1694.9	52.01863	107.0294
8:19:57	1729.9	52.01865	107.0285
8:20:04	1765	52.01864	107.0276
8:20:11	1799.6	52.01863	107.0268
8:20:18	1834	52.01861	107.026
8:20:25	1868.8	52.01857	107.0251
8:20:32	1903.7	52.01853	107.0242
8:20:39	1938.6	52.01848	107.0233
8:20:46	1973.9	52.01842	107.0224
8:20:53	2009.4	52.01837	107.0215
8:21:00	2044.7	52.01831	107.0206
8:21:07	2080.1	52.01823	107.0197
8:21:14	2038.8	52.01815	107.0188
8:21:21	1970.4	52.01808	107.0181
8:21:28	1919	52.01799	107.0176
8:21:35	1864.8	52.01792	107.0171
8:21:42	1804	52.01791	107.0157
8:21:49	1748.3	52.0179	107.0147
8:21:56	1683.6	52.01787	107.0138
8:22:03	1622.2	52.01794	107.0136
8:22:10	1561.2	52.01793	107.0133
8:22:17	1501.3	52.01794	107.013
8:22:24	1439.3	52.01775	107.0124
8:22:31	1379.2	52.0176	107.0114
8:22:38	1317.7	52.01737	107.0109
8:22:45	1253	52.01739	107.0104
8:22:52	1193.9	52.01745	107.0103
8:22:59	1134.3	52.01759	107.0101
8:23:06	1073.6	52.01742	107.0094
8:23:13	1017.8	52.01721	107.0089
8:23:20	961.2	52.01698	107.0088
8:23:27	904.6	52.01679	107.0089
8:23:34	851.8	52.01671	107.0095
8:23:41	799.6	52.01669	107.0102
8:23:48	743.1	52.01672	107.0103
8:23:55	691	52.01678	107.0103
8:24:02	644.8	52.01643	107.0104
8:24:09	598.2	52.01626	107.0112
8:24:16	552.9	52.0159	107.0117
8:24:23	515.2	52.01565	107.0125
8:24:30	512	52.01566	107.0125
8:24:37	512.1	52.01567	107.0125
8:24:44	512.4	52.01567	107.0125
8:24:51	513.2	52.01567	107.0125
8:24:58	513.1	52.01568	107.0125
8:25:05	514.9	52.01568	107.0125
8:25:12	515.6	52.01568	107.0125
8:25:19	516.5	52.01568	107.0125
8:25:26	517.5	52.01568	107.0125
8:25:33	516.8	52.01568	107.0125

7.6. STARS Data

PCAM Port->COM1: 1200,n,8,1 : September 14, 2004 at 01:35:37.

**************Configuration file: C:\My Documents\flt0201.str loaded*************** : September 14, 2004 at 01:35:37.
Tx1 On : September 14, 2004 at 01:51:30.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Count: 19389 --> : September 14, 2004 at 01:51:33.
Event Time: 19389 -->Tx1 On : September 14, 2004 at 01:51:33.
Event Time: 19389 -->Mini1 On : September 14, 2004 at 01:51:33.
Event Time: 19389 -->Mini2 On : September 14, 2004 at 01:51:33.
Event Time: 19389 -->Undefined button Pressed : September 14, 2004 at 01:51:33.
Tx5 On : September 14, 2004 at 01:52:06.
Event Time: 19425 -->Tx5 On : September 14, 2004 at 01:52:09.
Tx5 Off : September 14, 2004 at 01:52:24.
Event Time: 19443 -->Tx5 Off : September 14, 2004 at 01:52:27.
OH On : September 14, 2004 at 01:54:49.
Event Time: 19587 -->OH On : September 14, 2004 at 01:54:51.
Pointing On : September 14, 2004 at 01:55:37.
Event Time: 19636 -->Pointing On : September 14, 2004 at 01:55:40.
MscSunT On : September 14, 2004 at 01:55:42.
Event Time: 19640 -->MscSunT On : September 14, 2004 at 01:55:44.
SPS2 On : September 14, 2004 at 01:55:56.
Event Time: 19655 -->SPS2 On : September 14, 2004 at 01:55:59.
SPS1 On : September 14, 2004 at 01:56:37.
Event Time: 19696 -->SPS1 On : September 14, 2004 at 01:56:40.
Maestro On : September 14, 2004 at 01:56:42.
Event Time: 19700 -->Maestro On : September 14, 2004 at 01:56:44.
Tx3 On : September 14, 2004 at 02:00:16.
Event Time: 19914 -->Tx3 On : September 14, 2004 at 02:00:18.
Tx5 On : September 14, 2004 at 02:10:29.
Event Time: 20528 -->Tx5 On : September 14, 2004 at 02:10:32.
Tx5 Off : September 14, 2004 at 02:19:15.
Event Time: 21053 -->Tx5 Off : September 14, 2004 at 02:19:17.
Tx1 Off : September 14, 2004 at 02:25:21.
Tx2 On : September 14, 2004 at 02:25:22.

Tx3 Off : September 14, 2004 at 02:35:00.
SPS1 Off : September 14, 2004 at 02:35:12.
SPS2 Off : September 14, 2004 at 02:35:27.
Maestro Off : September 14, 2004 at 02:35:35.
Mini1 Off : September 14, 2004 at 02:35:44.
Mini2 Off : September 14, 2004 at 02:35:48.
MscSunT Off : September 14, 2004 at 02:36:21.
OH Off : September 14, 2004 at 02:38:25.
Pointing Off : September 14, 2004 at 02:39:14.

7.7. Upper CIP Monitor Data

Time	Frame	VALVE	VALVE	TERMINATE	CHUTE_CUTAWAY	VAISALA/MONITOR	BARO	BARO	COMMAND_VFY	28Vdc_BATTERY	15Vdc_BATTERY	CIP_TEMP
2:14:00.65	3299	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:01.64	3300	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:02.68	3301	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:03.67	3302	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:04.71	3303	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:05.70	3304	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:06.74	3305	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:07.73	3306	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:08.78	3307	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:09.77	3308	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:10.75	3309	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:11.80	3310	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:12.79	3311	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:13.83	3312	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:14.82	3313	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:15.86	3314	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:16.85	3315	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:17.89	3316	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:18.88	3317	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:19.87	3318	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:20.92	3319	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:21.90	3320	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:22.95	3321	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:23.94	3322	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:24.98	3323	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:25.97	3324	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:27.01	3325	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:28.00	3326	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:28.99	3327	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:30.03	3328	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:31.02	3329	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:32.07	3330	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:33.05	3331	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:34.10	3332	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:35.14	3333	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21

2:14:36.13	3334	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:37.17	3335	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:38.16	3336	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:39.21	3337	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:40.19	3338	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:41.18	3339	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:42.23	3340	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:43.22	3341	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:44.26	3342	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:45.25	3343	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:46.29	3344	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:47.28	3345	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:48.32	3346	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:49.31	3347	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:50.30	3348	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:51.34	3349	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:52.39	3350	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:53.38	3351	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:54.42	3352	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:55.41	3353	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:56.45	3354	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:57.44	3355	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:58.48	3356	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:14:59.47	3357	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:00.46	3358	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:01.51	3359	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:02.49	3360	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:03.54	3361	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:04.53	3362	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:05.57	3363	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:06.56	3364	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:07.60	3365	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:08.59	3366	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:09.58	3367	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:10.62	3368	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:11.61	3369	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:12.66	3370	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:13.64	3371	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:14.69	3372	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:15.68	3373	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:16.72	3374	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:17.71	3375	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:18.70	3376	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:19.74	3377	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:20.73	3378	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:21.77	3379	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:22.76	3380	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:23.81	3381	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21

2:15:24.79	3382	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:25.84	3383	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:26.83	3384	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:27.81	3385	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:28.86	3386	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:34.95	3392	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:35.94	3393	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:36.93	3394	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:37.98	3395	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	29	14.15	3.21
2:15:42.04	3399	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:15:43.03	3400	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:15:44.07	3401	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:15:45.06	3402	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:16:15.49	3432	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:16:16.48	3433	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:16:17.52	3434	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:16:18.51	3435	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:16:19.50	3436	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:16:23.56	3440	CLOSING	CLOSED	READY	READY	CLOSING	-	-	-	26.05	13.48	4.53
2:42:06.26	8035	OPEN	OPENING	FIRED	FIRED	OPEN	-	-	-	26.05	13.48	4.53

7.8. NASA Failure Summary

Reference:
http://lheawww.gsfc.nasa.gov/docs/balloon/BWG_Dec96/nock.html
http://lheawww.gsfc.nasa.gov/docs/balloon/freeman_ltr.html

January 22, 1997
TO: Distribution

FROM: 700/Chief Engineer

SUBJECT: Summary/Findings of Balloon Failure Oversight Committee

At the request of Mary Kicza, I submit this memo to formally close out the Balloon Failure Anomaly investigation. The text that follows is essentially a reprint of the "E" mail that I had issued to all of you on September 16, 1996.

After a long history of experiencing many balloon flight successes and one or two failures each year, the balloon program reliability record took a dramatic turn beginning in August, 1995, when a system failed abruptly in flight upon reaching float altitude. Although this was a qualification flight of a new balloon design, the failure was blamed on a possible balloon material or balloon manufacturing deficiency coupled with higher flight loading inherent in this non-heritage balloon design. This failure was followed by 5 additional inflight failures and 3 aborted flight attempts. It was this string of failures that forced a suspension of the balloon program.

Of the 3 aborted launch attempts, one was caused by a sudden shift of wind on the launch line while two were caused by spontaneous firings of the terminate system. With the absence of specific causal data to the contrary, the Wallops Flight Facility (WFF) review board concluded that the most likely cause of these terminate failures was static discharge. The oversight committee concurred that this was a reasonable conclusion based on a number of factors: (1) 8 unshielded 200 foot wires are routed from the terminate electronics box to the Holex termination device along the length of the collapsed parachute; (2) the nylon chute and the plastic balloon materials provide an excellent media for static charge build-up as the materials are dragged across an insulated material prior to launch; (3) the protective Holex bleeder resistor is located in the electronics box rather than adjacent to the Holex device; (4) the bleeder was found to have been open circuited in at least one of the two failures; and (5) probably of most importance was the fact that 4 of the 8 referenced wires were added to the flight configuration as a change in June '94 as telltale wires to report whether the cutter had in fact severed the restraining cable. This 4 wire cable is unshielded (as are the other 4 wires), 2 wires run right through the Holex device while 2 are unused and unterminated, and although many missions were flown successfully after the addition of these wires, it is certainly possible that these wires could provide a smoking gun for the static charge scenario given appropriate humidity and environmental conditions. Regarding these failures, the oversight committee recommended that four actions be taken prior to sanctioning a return to flight: (1) incorporate a 10 ohm bleeder protective resistor directly in the vicinity of the Holex device; (2) shield and terminate shields on 4-200 foot conductors that connect the Holex devices to the terminate electronics; (3) eliminate the telltale and unused wires entirely; and (4) select the best electronic packages available for the subsequent flights, and perform a detailed inspection of this hardware in the field prior to declaring a readiness for flight.

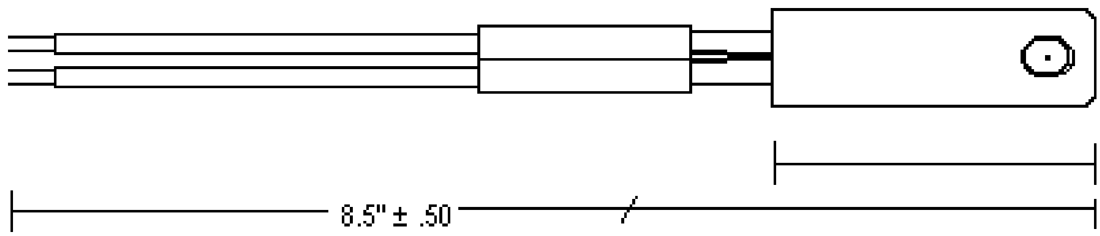
In addition to the aborted flights referenced above, 6 missions were prematurely terminated during the time frame in question. One failure was attributed to a faulty protective aneroid switch that fired the terminate circuitry prematurely. The failure analysis regarding this aneroid concluded that the current aneroid switches may contain solder balls and may be slow to operate. Accordingly, it was recommended that: all aneroid switches be radiographically examined for extraneous particles that may have been introduced during the lead soldering process; and if a slow operate time is not desired, then additional screening may be required. Finally, they concluded that the Honeywell "HM" series microswitch would be a better choice for this application because it is hermetically sealed and has bifurcated gold contacts which are not susceptible to oxide films. A second failure involved the bursting of a pressurized (rather than a zero pressure) balloon at altitude, and although this was an experimental balloon, it burst at approximately one half its calculated burst pressure. A third failure resulted when a flight system failed abruptly upon reaching float altitude. This was the qualification flight of a new balloon design referenced in my first paragraph, and the failure was blamed on a possible balloon manufacturing deficiency coupled with higher flight loads than would have been present in a heritage design in spite of the fact that 5 balloons of this new design had already flown successfully. Three additional failures involved the inability of balloons to reach or remain at proper altitude. Each of these failures was attributed to balloon imperfections or tears. And although it was not possible to link all of the failed balloons to build dates that corresponded to poor balloon plant quality audits, or to only one of two balloon producing facilities, all of the balloons in question were manufactured during the time frame that one facility was being purchased by the other. Although the people and processes supposedly remained constant during the months preceding and subsequent to announcements of the buyout and of management changes, employee anxieties may have affected balloon quality during that time period. To this end, the oversight committee recommended not flying balloons manufactured during this turbulent time, at least in the near term. It was also suggested that nights be resumed using smaller and traditionally reliable balloons at first. Furthermore, since the balloon material is quite fragile (0.8 mil thick), it was recognized that handling, and the flight line operation itself could also contribute to in flight failures. Consequently, the committee recommended that some of the "old timers" be asked to perform an audit of the balloon factory and to witness a number of upcoming balloon flights and report their observations and findings to WFF management and to the oversight committee.

Based on the data that had been made available to us, and pending implementation of the recommendations stated above, the oversight committee recommended the resumption of balloon flights on a limited basis until the reliability record of the past has been restored. The committee recognized the importance of Flight Safety for the crew and for the population in the vicinity of the balloon flights. For these reasons, we recommended that WFF select safe fly zones that would minimize overflying populated areas especially during balloon climb out. The concern for safety must be the primary consideration regarding the balloon flight, and it must be shown for every flight that safety has not been compromised.

H. Richard Freeman

7.9. Holex Cutter Datasheet

2800 Series Cutter



Part Number	Dia. A (± 0.005)	Dim B (± 0.035)	Dim. C Dia.	Mass (Oz)
2800	.375	1.490	#30 (.1285)	7/8
2801	.500	2.010	1/4 (.2500)	1
2802	.875	3.120	7/16 (.4375)	3-1/2
2803	1.125	3.500	9/16 (.5625)	6

DESCRIPTION

The 2800 Series of Cable Cutters are small, propellant actuated cutting devices. The unit is electrically initiated and a propellant charge drives a piston with a wedge-shaped knife through the cable, hose, or bolt located in the opening. The severance of the cable, tube, or bolt is clean and practically silent. The unit does not give off shrapnel in operation and may be fired without a cable or tube in the opening without danger of fragmentation. The cutters work over a temperature range of -60º Fto +200º Fand are designed to meet most military environmental specifications.

ELECTRICAL PROPERTIES	PERFORMANCE
Bridgewire Resistance: 0.66 Ω ± 0.08 Ω Leadwire-To-Case Resistance: 2 MegOhm min. at 500 VDC **FIRING CHARACTERISTICS** All Fire Current: 1.5 Amps Min. for 20 milliseconds Recommend All Fire Current: 5 Amps No Fire Current: 0.5 Amps Max.	The 5800 Series Cutter will cut the following cables: 2800 – 3/32 Dia. 7 x 7 Cres Cable per MIL-C-5424 2801 – 3/16 Dia. 7 x 19 Cres Cable per MIL-C-5424 2802 – 3/8 Dia. 7 x 19 Cres Cable per MIL-C-5424 2803 – 7/16 Dia. 7 x 19 Cres Cable per MIL-C-5424 ½ Dia. 6 x 19 Galv Steel Commercial Cable