CHAPTER 5

STRATOSPHERIC BALLOON FLIGHT AND AEROSOL RETRIVALS

# 5.1 Stratospheric Balloon Flight

After the completion of the ALI system tests on August 18, 2014 the instrument was transported to Timmins, Ontario and preparation were underwent for the balloon launch from August 25, 2014 until September 19, 2014. During this balloon campaign there were seven balloon launches with ALI being a part of the seventh balloon. The flight of ALI took place on September 20, 2014.

## 5.1.1 Preflight Preparations

The Canadian Space Agency (CSA) balloon launch facility in Timmins, Ontario located at the Victor M. Power Airport (48.47oN 81.33oW). ALI arrived at the base on August 25, 2014 with a launch window from September 8 to 14, 2014. In between the arrival of ALI and the balloon launch, ALI had to be verified to have survived transportation, a seal within the CCD needed to be removed, thermal insulation needed to be added, and finally ALI needed to be integrated onto the Centre National d'Etudes Spatiales (CNES) CARMEN-2 gondola.

ALI was unpacked and set up on a test bench at the launch facility. A visual inspection occurred to verify that no obvious damage occurred to the instrument during transportation. Once completed, ALI was connected to its electronics and power boxes and ALI was powered on. A ground station computer was used to connect to ALI and preform a system check, including verification that of automated startup, telemetry connection was established, that the system powered on correctly with no error and that the science operation program functioned. With this test it was verified that no functional problems occurred to the device during transportation, all temperature and voltage sensors, GPS module, and CCD camera were reporting valid diagnostic values.

Once the ALI system was verified to be operational an imaging check was performed to check that no optical components suffered damage or slippage during transportation. An EIA 1956 resolution target was illuminated by a 250 W tungsten halogen light source and was imaged by ALI to verify the optical layout. The recorded images were very similar to the one taken in the laboratory before the leaving Saskatoon.

Following the successful test of ALI the final preparations were needed prior to beginning integration with CARMEN-2 were performed. First, the CCD used by ALI had a sealed chamber that was in a vacuum state designed to be at atmospheric pressure and would be required to be unsealed before the flight. The unsealing is done in order to not develop a strong pressure gradient between the CCD chamber and the low pressure of a 35 km environment causing permanent catastrophic damage to the CCD detector. At the launch facility ALI was taken to a semi-clean area to unseal the CCD chamber. A panel was removed on the side of the camera and the seal to be removed can be seen in Figure 5-1. The orange o-ring was removed with associated sealing components and the vacuum seal was broken. The chamber panel was replaced and ALI was moved back to the integration hall and another set of test resolution targets were taken to verify the correct operation of the ALI. All resolution target were similar with from the set before the chamber was unsealed expect there was approximately a 5% drop in counts which may have been caused by unsealing the chamber or a change in the lighting conditions of the resolution target.



**Figure 5-1:** Side of the QSI CCD with the panel that contains the vacuum seal opened. The orange o-ring seen in the cavity is removed from the chamber to open the vacuum seal to the camera's CCD chip.

The next step before ALI could be integrated was to add thermal in order to protect ALI from the thermal environment at approximately 35 km. The first thermal concern was the instrument falling to a temperature were the electronics were too cold to function. The instrument would have to be in complete darkness during the assent which would result in little to no solar heating. Furthermore, ALI will pass through the tropopause where temperatures can be as cold as -70oC. Insulation, in the form of foam, was added around the exterior of the instrument to give ALI thermal isolation from the cold environment. The second concern was once CARMEN-2 was at float altitude ALI would have to be able to survive the direct heating from the sun's radiation which could have overheating. The impact of the sun's energy was reduced on ALI by adding a thermal reflector to the outside of the thermal insulation which would reflect a portion of the incoming solar radiation away from ALI.

With the completion of the thermal management, ALI was ready to be mounted onto the CARMEN-2 gondola. ALI can be seen mounted on the CARMEN-2 gondola in Figure 5-2 and ALI used the power and communication subsystems of CARMEN-2. Testing was performed with collaboration from the CARME-2 team to check there were no issues between ALI and CARMEN-2’ systems. A problem was found in the communication module, named Siren, between ALI and the ground station computer. With as assistance from the CARMEN-2 team the correct Ethernet setting were determined and a correction to the ALI operation code was applied.

During the integration phase it should be noted that several instruments were also being verified with the CARMEN-2 systems for integration onto the gondola including four other Canadian instruments, including the OSRIS development model (*Kozun*, 2015; *Taylor*, 2015), and SHOW to measure water vapour.

The CNES gondola is an actively pointed gondola with azimuthal pointing precision better than 1’ with the use of an onboard star tracker. ALI was orientated so it would be maintained at 90o from the azimuthal direction of the sun, with an overall southern field of view during the mission.



**Figure 5-2:** The ALI instrument is mounted on board the CARMEN-2 gondola (top shelf on the right). ALI located next to SHOW, another Canadian instrument with collaboration between ABB, York University, and the University of Saskatchewan. ALI has its red tag cover over the optical entrance to protect the instrument from dust and other contaminates. Thermal insulation has been added to the instrument and during the flight sun side will be on the side of SHOW. Some of the reflective layer was blacked out to not cause additional stray light into SHOW optical path.

## 5.1.2 Balloon Flight

The flight plan for the CARMEN-2 gondola was once float altitude was reached and the sun had risen ALI, OSIRIS, and SHOW would perform their operational missions for the first four hours of the campaign. The operation objectives for ALI included a dark imaging suite for calibration purposes, and an aerosol imaging suite for aerosol measurements. A secondary goal was to test the sensitivity to aerosol of ALI with respect to SSA by recording images at various azimuth directions. After the end of the ALI mission, the instrument was to be powered off and other instruments on CARMEN-2 were to gather measurements.

The flight of CARMEN-2 was delayed past it launch window of September 8 to 14, 2014 due to poor weather conditions. On September 19, 2014 at 05:35 UTC (01:35 local time) ALI was launched as part of the Nimbus 7 mission from the CSA Timmins balloon launch facility. During the launch, the sky was clear with light winds allowing for a safe and uneventful launch. The ascent of the gondola occurred in darkness and reached its flight altitude of 36.5 km at 8:17 UTC. First light was observed by ALI at 9:39 UTC and spectral images were recorded until 14:42 UTC. ALI was powered off at 17:15 UTC.

A visualization of the flight path with major landmarks noted can be found in TODO:ADDREF. Temperature profiles for the ambient atmosphere and instrument are shown in TODO:ADDREF. The black curve is the ambient atmospheric temperature at the gondola altitude and location during the flight as obtained from ECMWF reanalysis (*Dee et al.*, 2011). The blue, green, and red are from temperature sensors onboard ALI located on the baffle, camera, and RF driver respectively. The baffle temperature sensor was attached just on the inside of the ALI right by the entrance aperture for the system and monitors the temperature at the front of the system. The camera sensor is attached to the back of the CCD camera and the RF driver sensors measures the surface temperature of the RF driver. ALI was thermally insulated to keep the system warm whereas the baffle temperature sensor is relatively uninsulated from the extreme cold of the tropopause. The effect of the cold tropopause can be seen on the gondola at approximately 6:00 UTC. The cooling effect can even be seen on the interiors CCD and RF driver sensors which are isolated from the exterior temperature. After, the internal temperature drop the system reaches an equilibrium temperature until the sun light rises and solar radiation comes into contact on the instrument at approximately 10:00 UTC at which point there is an increases in the systems temperature. The temperature of the system are kept within operating range with the aid of the reflective material during the flight.



Figure 5-3: (a) The GPS data from ALI during the Nimbus 7 mission generated via Google Earth. The colour of the line represents the absolute speed of the gondola during the mission. Important landmarks are noted on the image. The end of mission represents the end of the primary aerosol mission. No GPS data was collected from ALI after power down. The location of image 208 is the red label. (b) The temperature and altitude profiles from the Nimbus 7 flight. The time of image 208 is shown by the cyan vertical line and first light measured by ALI is occurs at the magenta vertical line.

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During the mission, ALI ran in two primary operational science modes, a dark mode and a aerosol imaging mode. The first mode, the dark mode was primarily used during assent and intermittently between aerosol modes. During this mode the filtering of the AOTF is disabled, meaning with no RF signal being applied to the crystal, and as such the wavelength has no dependance on the images. Eight exposures are taken at with 0.05, 0.1, 0.5, 1, 2, 3, 5, 10 second exposure times with the camera shutter operating. The second operational mode was the aerosol mode and it records 13 measurements which each consisted of a pairs of images. A pair of images, one with the AOTF enabled and one disabled, were gathered for every 25~nm between 650 to 950~nm each measurement set took approximately 25~s to acquire. The exposure times were determined by making ground based measurements of all of the wavelengths in the aerosol mode at a variety of exposure times. This data was used to determine the value at which the well of the CCD well would be three quarters full on the ground. Then using the known geometry from the ground and assumed geometry from the balloon in combination with the SASKTRAN model, which will be discussed in \autoref{TODO:??} the balloon exposure times that were used during the flight were determine which was discussed in \autoref{sec:3.3:SystemTesting}. However during the flight it was determined that the calculated exposure times were not long enough and the CCD well was not receive enough incoming radiances so the exposure time curve was recalibrate during the flight using the image statics data that are send down in the house keeping. A comparison of the two exposure time curves with the percent increase can be seen in \autoref{fig:5.1:exposureTimeComparisons}. The percent increase is given by

\begin{equation}

\text{Percent Difference/,} = \frac{t\_{c}-t\_{u}}{t\_{c}}\*100\%

\end{equation}

where $t\_{c}$ is the exposure time for the original calibrated exposure times and $t\_{u}$ are the updated exposure times calculated from the flight. This difference is believe to be caused by the initial exposure time calibration curves being calculated with simulated scaler radiance since the SASKTRAN polarization module had not yet been completed development. The other two science modes used during the flight for water vapour and oxygen will not be discussed but their routines during flight as well as further details on the used routines can be found in \autoref{sec:B.2:ScienceModes}. % A unique feature of the AOTF is that the diffraction can be disabled to take an image with the filter disabled. These so called `dark images' allows capture of the stray light which are use in processing to accurately and easily remove stray light from the signal, as such a `dark image' was also gathered in between each filter acquisition for assist in the calibration of the measurements.

After the completion of the mission, ALI was powered off at 17:15 UTC after successfully gathering 216 aerosol images. The gondola continued its flight until 21:54 UTC, a 16 hour 19 minute flight, at which point it landed approximately 70~km from Amos, Quebec or approximately 250~km from the launch facility . CARMEN-2 was recovered by the balloon recovery team and was return to base on September 21, 2015. It was removed from the gondola, repacked and travelled back to Saskatoon, Saskatchewan were processing of the data occurred.

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During the mission, ALI operated in two primary acquisition modes, a calibration mode and an aerosol imaging mode. The first mode, the calibration mode, was primarily used during ascent when the gondola was in the darkness and intermittently between the aerosol mode during sunlit conditions. During this mode the filtering of the AOTF was not enabled and the system imaged essentially only dark current during the ascent in darkness and stray light during sunlit conditions. Eight exposures are taken in the calibration mode with 0.05, 0.1, 0.5, 1, 2, 3, 5, 10 second exposure times. The second operational mode, the aerosol mode, recorded measurements in a cycle that contained 13 pairs of images across the spectral range (650-950 nm every 25 nm), the pairs being a calibration image with the “AOTF-off” and an image of the limb. Each cycle took approximately 12 minutes with each measurement set taking approximately 45 seconds to acquire with exposure times varying between 0.5 to 6 seconds.

# 5.2 Limb Measurements

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# 5.3 Aerosol Retrievals

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## 5.3.1 Aerosol Extinction Retrieval Methodology

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## 5.3.2 Aerosol Extinction Retrievals

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## 5.3.3 Particle Size Retrieval Methodology

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## 5.3.4 A Sample Particle Size Retrival

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# 5.4 Results

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