ORION TWO LAUNCH SUMMARY

High Altitude Balloon project
Designed and executed by PWr Aerospace
Wroclaw University of Science and Technology

26.08.2017

Contents

Introduction

ORION is a high altitude balloon project developed by students of Wroclaw University of Science and Technology. Its main goal is to provide basic skills and knowledge needed to design big HAB projects in the future.

ORION TWO is, as the name suggests, second launch of our project, after partial failure of first mission in April 2017. The main goal of this flight was to test our electronics in flight and develop better launch procedures.

This document covers the design and post-flight analysis of ORION TWO mission, which launched 26.08.2017.

Mission summary

	Expected	Achieved
Altitude	28 – 31km	27 544m
Temperature outside	-50°C	-53.4°C
Temperature inside	10°C	3.7°C
Flight duration	1h 40min	2h 20min
Landing position relative to launch site	85km ENE	94km ENE

Onboard devices:

- ORION ONE communication unit
- ORION TWO data unit
- ORION TWO sensor unit
- 2x Xiaoyi 4k cameras
- Baofeng UV-5r
- Powerbank as additional camera power supply
- 2x ICR18650 battery as onboard computer power supply
- Vaisala RS41 radiosonde with custom software as backup location tracker

Notable time events:

Day of launch: 26.08.2017 (time zone UTC +2)

Start of launch preparations:	10:13
Launch:	11:52
Balloon burst:	13:17
Landing:	14:14
Payload pickup:	14:35

Launch position:	Wroclaw Sky Club Airfield, 51.2042 N, 16.9992 E
Landing position:	51.173190 N, 18.262702 E

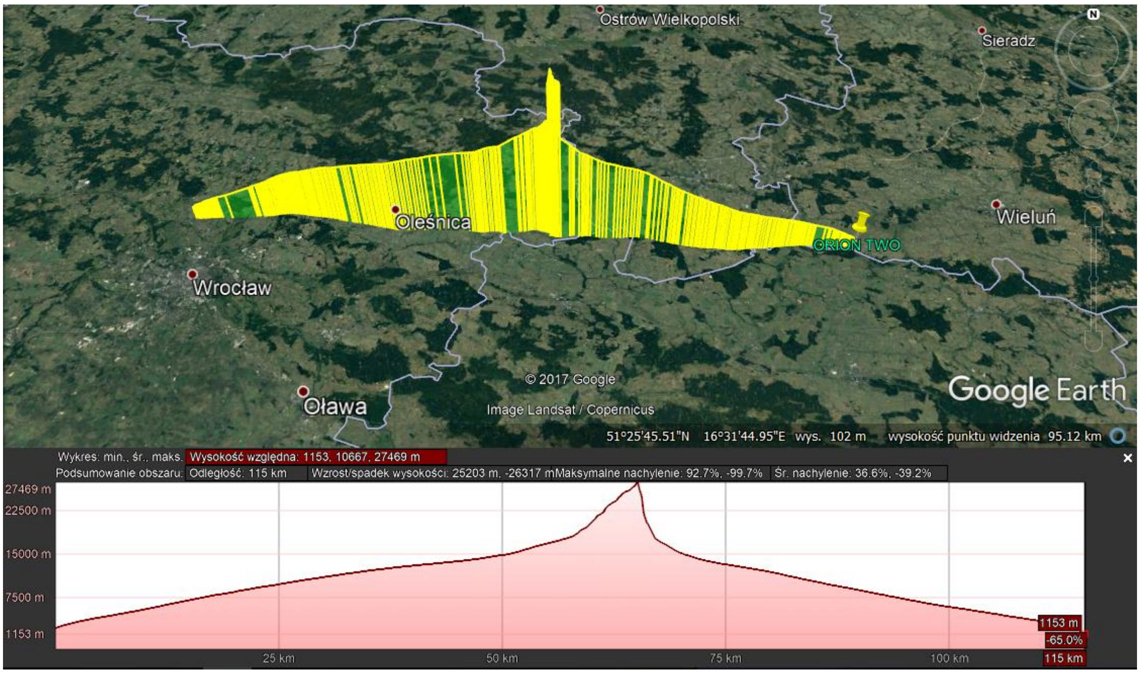
Balloon used:	Hwoyee 800g
Gas used:	Helium
Gas volume:	3.4 m^3
Parachute used:	Quest Aerospace 140cm
Payload mass:	1.5 kg

Launch weather conditions:

Temperature:	21°C
Barometric pressure:	1018 hPa
Wind direction:	SE
Wind speed:	4 m/s
Cloud layer:	2 octa
Visibility:	Very good
Precipitation:	None

Launch details

Flight path:



51°25'45.51"N 16°31'44.95"E wys. 102 m wysokość punktu widzenia 95.12 km

Wykres: min., śr., maks. Wysokość względna: 1153, 10667, 27469 m

Podsumowanie obszaru: Odległość: 115 km Wzrost/spadek wysokości: 25203 m, -26317 mMaksymalne nachylenie: 92.7%, -99.7% Śr. nachylenie: 36.6%, -39.2%

Flight path of ORION TWO balloon, plotted using data from APRS.fi, hence first and last positions were captured at the altitude well above 1000m

We launched during very favorable weather conditions, with mild SE wind and clear skies. At the beginning balloon went straight up with vertical speed of around 7m/s. At the altitude of 3 to 20km it hit strong east wind, which accelerated our balloon to around 90km/h. Above this level winds stabilized and again it went straight up, until burst at the level of 27 544m.

We used Hwoyee 800g balloon filled with helium. We used 20l helium tank, which gave us around 2.7kg of net lift, compared with 1.5kg mass of our payload.

The parachute we used was Quest Aerospace 140cm parachute. During descend it appeared that the size of this parachute was real overkill for this payload, and it slowed down to 3.4m/s, much slower than we expected. This led to longer descend time and longer distance travelled.

Communication unit

Our current project was supposed to examine the communication system with moving object using ISM Long Range radio bands. According to Polish Radiocommunication laws and the leading reliability the choice fell on UHF/VHF Bands. ORION TWO is a complex system based on ORION ONE communication main board and rebuilt Telemetry Data Unit.

Communication Protocol

After sort of analyzes of the various digital radio modulation modes and maintaining reliable radio communication with High Altitude Objects, our Team decided to use the VHF radio band (144-146MHz) for main communication solution. The advantage of choosing VHF band is existing Automatic Packet Reporting System (APRS) and open source project APRS.FI that uses HAM Radio station relays systems associated with APRS Protocol.

APRS (Automatic Packet Reporting System) is shortwave radio system based on AX.25 networking protocol allowing instant transmission about station position by broadcasting short-range radio packets containing for example telemetry payload. Data packets can be re-transmitted by other stations (relays) to increase coverage or to be mapped to the existing APRS.FI system. APRS protocol also allows the exchange of short messages (like as "SMS") between mobile and fixed stations.

APRS packets are short ASCII messages encapsulated in the AX.25 data link layer protocol frames. Data frames are broadcasted on a local (12.5 kHz bandwidth) channel with Audio Frequency Shift Keying (AFSK) modulation. The maximum baud rate of transmission for shortwave systems is 1200 bauds/symbols per second. AFSK modulation is a form of single-valued digital frequency modulation (BPSK). The Carrier Frequency depends on the region in which the frames are broadcasted. For the Europe and Asian parts of Russia this frequency is typically 144.800MHz (VHF band) and 433.800MHz (UHF band).

Radio wave propagation, coverage

The shortwave characteristics between VHF and UHF bands are similar. The "Line of Sight" visibility is the most prominent role in VHF band communications systems. These kinds of radio waves do not bend and do not follow the surface of the earth (compared to Long Wave and Medium Wave bands). For this reason, these bands allow communication "over the horizon" between stations, between mountain ranges up to 100-150 kilometers and even up to 400 kilometers with transmission from a balloon placed 30 km above the ground to the point at earth surface. SW bands are susceptible to refractions and diffractions on obstacles (such as buildings, trees) effectively limiting the range of transmission in urbanized areas (up to 5-15 km in communication between two stations). Shortwave are not very absorbed by water and oxygen in the atmosphere.

For transmission with assumed 1 watt power of the transmitter we can expect a typical range within 200-300 kilometers from 20-30 kilometers above the ground and 15-25 kilometers after landing in rural environment but only 1-2 km after landing in high-urbanized areas. Limited range depends on the low power of the transmitted signal.

Terminal Node Controller

The module of the two-way radio communication located in balloon consists of:

- Radio transceiver – BAOFENG UV-5R Radiotelephone,

- Extended TNC modem based on the open MicroModem hardware project (MicroAPRS: unsigned.io/micromodem)
- ARM32 STM32F411RE based board for:
    - Payload data preparation,
    - Data load balancing,
    - Communication between peripherals,
    - GPS/GLONAAS control,
    - Reception, storage (buffer) of data frames
- GPS/GLONAAS Module – NEO-6M uBlox
- Power regulator module:
    - LDO/VDO positive voltage regulators,
    - 5V DC/ 3.3V DC logic power supply,
    - Lithium-Polymer 18650 Cells,
    - Analog to digital converters (for voltage status),
- Omni-Directional 3dBi VHF/UHF Band Antenna,
- Auxiliary IDC-6 connectors (USART1/ADC1/ISP/I^{2}C/SWD)*

**USART1 was used as main interface for ORION TWO telemetry board*

The Terminal Node Controller - MicroModem software for Microchip ATmega328p microcontroller was used in original form (unchanged).

Due to interferences that decreases TNC modem reliability – resulting in harmonic frequencies when transmitting in VHF band, both radio module and remaining components were covered with copper tape shielding. Copper is acting as a screen for radio waves.

In addition the GPS/GLONAAS output is detachable – based on IDC connectors. If necessary, the IDC connector can be used as auxiliary UART/TTL 9600 baud interface for other devices.

Due to differences between AVCC (analog power/voltage for use in TTL readings) in ATmega and STM microcontrollers was need to use a 8bit bi-directional voltage level translator based on Texas Instruments TXB0108 circuitry to provide stable UART/USART communication.

Terrestrial Radio Module

Thought the relays and digipeaters associated with the APRS.FI project, It is only possible to receive and display data on the map (via website) but without option to provide two way communication with balloon. For this reason, as well as to facilitate finding the balloon after landing, an additional radio module connected to Baofeng BF-F8+ receiver was used on one side and computer with APRS decoding software installed on the other.

The 'ground' module consists:

- Second ORION ONE main board as TNC modem with modified software to receive frames,
- TTL to USB converters attached to TNC board,
- Midland Diamond NR-770
- APRS/RTTY decoder software

The terrestrial receiving station was also equipped with an SDR (Software Defined Radio) receiver based on Realtek RTL2832U Controller. The purpose of the additional receiving station is to monitor sent frames and report failures during flight i.e. GPS module signal loss, errors of onboard computers, temperature alerts bypassing APRS.fi project receivers.

Software used in terrestrial station:

- Gqrx SDR (as receiver software),
- AFSK1200 Decoder,

Software used in project is distributed under the public GNU GPL license.

Communication unit details and schemas can be found in appendix

Data unit

Data unit computer designed for ORION ONE mission was completely redesigned for the purpose of second mission – we have switched from THT to SMD technology and integrated it with communication unit using Auxiliary IDC-6 connectors – data unit was plugged straight in the communication module, which eliminated the need to use cables, which could pick up noise from our radio.

The computer is based on ATmega644 microcontroller, and was designed to:

- Measure power supply voltage
- Reading data from sensors and storing it on SD card
- Send telemetry data to communication unit

Unit is powered using 3.3V supplied by communication unit, it has its own voltage regulator and filter. Microcontroller frequency is regulated by 16MHz quartz.

Sensors used:

- 4x DS18B20 thermometers
- MLX90614 infrared thermometer
- BMP180 digital barometer
- MPXM2202AS analog barometer
- LSM9DS0 accelerometer
- UV sensor
- PF panel

Most of them were installed on separate board, which was mounted outside the capsule to measure atmospheric properties. The outside board was connected to data unit using IDC cable. It also has set of LEDs to signalize status and health of data unit.

Outside board architecture can be divided into three main parts:

- Digital sensors segment
- Analog sensors segment
- LEDs segment

Digital sensors communicate with microcontroller using TWI or 1Wire bus. Diodes can be switched on and off using jumper. Analog sensors segment is powered by separate power line, which is connected to main power line using voltage. All analog sensors are connected to ADC converter, which also communicates with microcontroller using TWI bus.

Communication unit details and schemas can be found in appendix

Cameras

The flight was recorded by two cameras, Xiaoyi 4K Action, supplied by our partner, YI Technology. They both were placed horizontally on two distinct sides of capsule, looking at horizon. One was set to film Full HD 1080p 50fps movie, second was set to make photo time lapse with one 12mpx 4000x3000 pixels photo each 2 seconds.

Very wide camera field of view required us to file off quite big chunks of capsule Styrofoam to prevent blocking view. Also, very wide view angle created illusion of flat or even concave Earth on most photos.

Cameras were powered by their batteries, and also they were plugged to power bank with two charging slots. This allowed both cameras to constantly work until the end of flight.

Concave Earth

Flat Earth

Vaisala RS41

As the backup GPS tracker we used Vaisala RS41 radiosonde. This device is used by Institute Of Meteorology And Water Management to conduct daily atmosphere sounding and preparing weather forecasts. IMWM sends two of them daily, each one of them contains sheet of paper with information about their use and disposal for finder – IMWM does not require sending them back, as all information collected by radiosonde is transmitted to ground station during flight.

We managed to capture one of them in May 2017, and later reprogram it to use open ISM band instead of IMWM band. It was sending its position via APRS using MHz frequency and RTTY using MHz frequency.

More about Vaisala RS41 radiosonde can be found in producer datasheet:

http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/WEA-MET-RS41-Datasheet-B211321EN.pdf.

Capsule

We learned a lot after failure of our previous mission, where bad capsule design was a major factor. This time we tried totally different approach, and it went flawlessly. The capsule did so well, that its condition after flight allows it to be send again.

The capsule was made of extruded Styrofoam slabs glued together in the shape of cuboid of size 19x19x15cm. To reduce mass of glue we decided to join slabs using Mortise and Tenon Joint. This greatly increased join surface area and allowed us to use less glue. Using extruded Styrofoam as construction material worked great, as it's very easy to process and provides very good thermal isolation properties. This material is however fragile, so we decided to cover cords used in creating whole train using polymer tubes to prevent any kind of damage.

We took care of proper component placement, as we split them into sections. Cameras and their power supply were mounted together in one corner. Baofeng radio was placed in most distant corner from all electronic devices to prevent interferences and noise and add place for additional shielding if needed.

We left a lot of extra free space for easy access to each component. All of them were held in place with Velcro to allow possibility of easy replacement in any time. Cameras needed special treatment because we had to make sure they will not move at all during whole flight, so to keep them in place we used very strong tape instead.

Successes and failures

Successes:

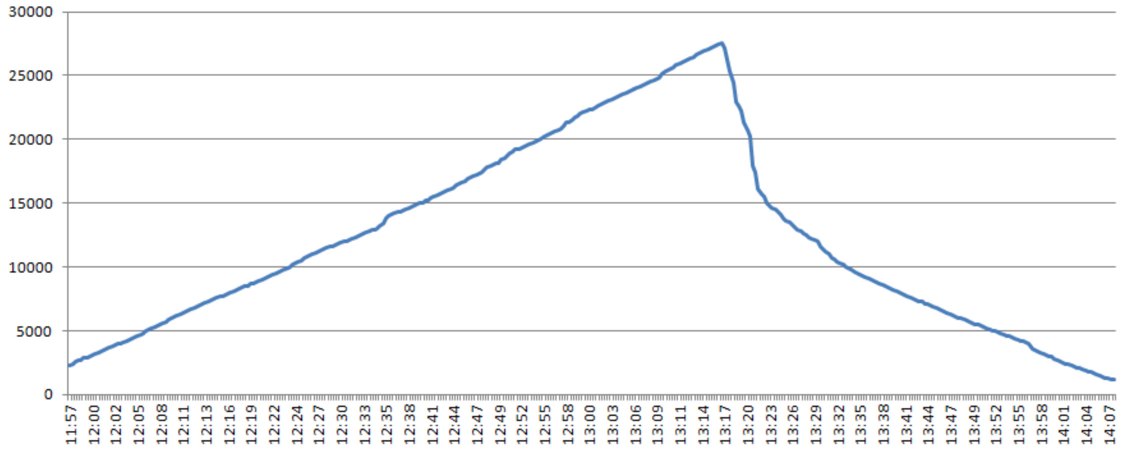
- Achieved desired altitude
- Successfully recorded over 7MB of raw sensors data
- Recorded 1h 31min of Full HD video
- Took 5210 12mpx photos
- Maintained constant connection with balloon and knew exact position during whole flight
- Picked up the capsule 20 minutes after landing

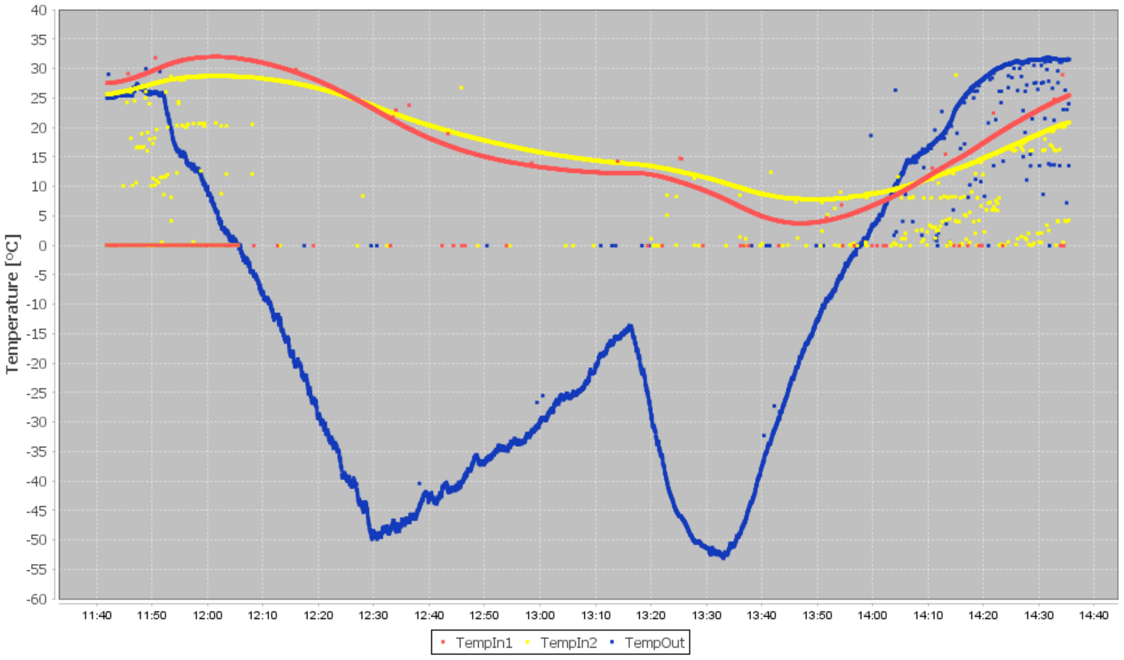
Failures:

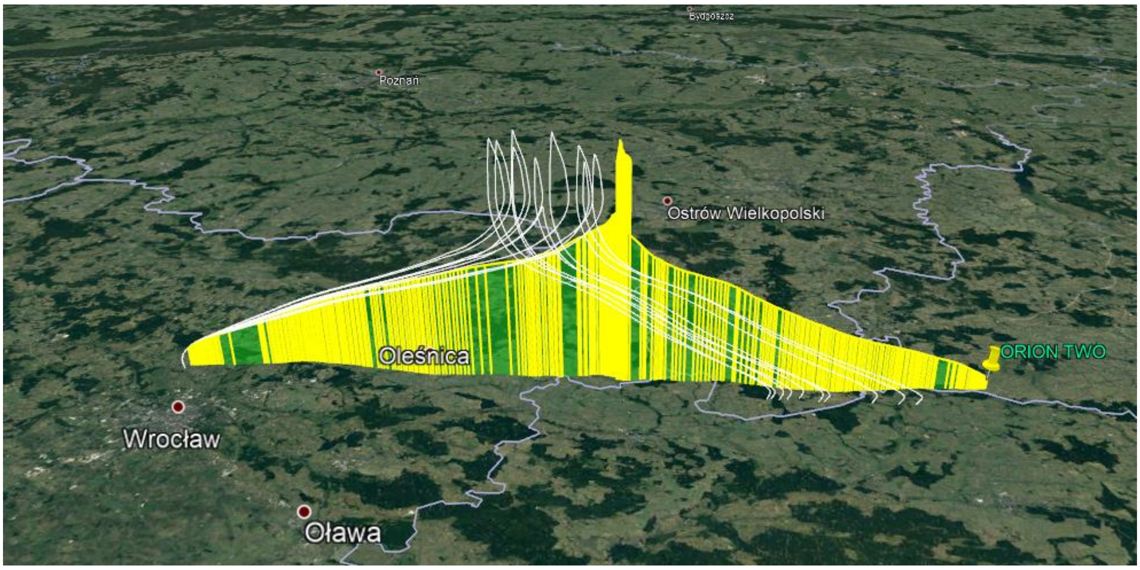
- Video recording camera ran out of free card space two minutes prior to balloon burst
- Unexpected behavior of communication unit, which stopped sending position and telemetry after surpassing 3km altitude, and restarted sending position below 1200m altitude, despite sending telemetry configuration as expected during whole flight. The reason of that behavior is not yet understood.
- Similar behavior was observed with our backup location tracker, reprogrammed Vaisala RS41, which was losing many of sent APRS frames. The last one captured by aprs.fi was sent at 12:54; although we were able to listen to it via SDR, sending more frames with correct telemetry and position. The reason may be failure of APRS digipeater, however this was not confirmed.
- UV sensor and FV panel data was considered useless, because of bad configuration of ADC converter. Voltage over 2.048 V caused buffer overflow in data unit microprocessor, which caused it to be interpreted in the same way as voltage of 0V. Lost bits caused this data to be irreversibly distorted and meaningless.

Registered data

As for the time of writing this article, not all sensor data was processed, thus the data presented below does not contain all data gathered during the mission.


ORION TWO Ascend profile


Temperature chart



Comparison of predictions (white line) and flight path - predictions calculated using University of Southampton ASTRA High Altitude Balloon Flight Planner - http://astra-planner.soton.ac.uk/

Afterword

This project could not become possible without support from our university – Wroclaw University of Science and Technology, and our supervisor - **Associate Professor Paweł Kabacik**.

Students most involved in project (alphabetical order):

- Michał Kosecki
- Grzegorz Kowalik
- Aleksander Kurczyk
- Maciej Marciniak
- Jakub Pal
- Artur Sawicki
- Łukasz Skwarszczow

We want to thank our sponsors and partners, who helped us to make this project successful, especially **TME Transfer Multisort Elektronik**, **YI Technologies** and **Wroclaw Sky Club.**