Wallops/Virginia Tech FY07 Student Balloon Experiment

Science Report

Suitcase Name: Virginia Tech ARTEMIS

Suitcase S/N 04

Flight: HASP Flight, Ft. Sumner, N.M.
September, 2007

The Academic Research Team for the Establishment of a Lunar Magnetic Field Investigation System (ARTEMIS) flew a piggyback experiment in 2007. The basis of this piggyback experiment was to determine if the Moon's measured magnetic field can be accurately detected. The Virginia Tech team flew a data logger and power supply to autonomously collect data from a variety of sensors including: a magnetometer, a GPS receiver and an Inertial Measurement Unit (IMU). The magnetometer resided at the end of a fixed mechanical boom. The GPS receiver was used to track the motion of the system and provide ground coordinates for the corresponding magnetometer data. The IMU was used to measure the gondola's rotation rate during the balloon flight. All data was analyzed post-flight.

Payload Performance

The ARTEMIS experiment performed largely as expected with all sensors operating throughout the entire flight. The IMU provided velocity, acceleration and temperature data in the expected ranges. GPS data was recorded, matching the GPS data recorded separately by HASP. The only problem encountered during flight was in recording the magnetometer data. The data was in the expected ranges but occasionally was recorded in an incorrect format for unknown reasons. These errors did not corrupt the rest of the data, but did make post-processing much more difficult.

The mechanical boom did not break during flight and was considered by the integration crew to be over designed for its application. The foam insulation was a suitable design choice for keeping all sensors in optimal temperature ranges. Overall, the payload performed extremely well since data were collected from all sensors throughout the duration of the flight.

Problems Encountered

Several unexpected problems occurred throughout the duration of the ARTEMIS project. These include software design, thermal testing, and broken hardware. The software system was written by one person who was unable to travel to Wallops Flight Facility when the code was intended to be implemented for thermal testing. This caused the thermal testing date to slip entirely so that no thermal testing was accomplished in a test chamber before launch of the system. However, the team ran the system overnight to see how the temperature changed with time. A GPS receiver card was damaged during testing because of a misunderstanding in the amount of voltage necessary to power the unit. This problem was costly financially and in time. Fortunately, NASA Wallops Flight Facility was able to loan the ARTEMIS team another receiver.

Lessons Learned

The students involved in the ARTEMIS balloon mission picked up a variety of skills related to engineering and the manufacture of scientific experiments. Primarily these skills pertained to electrical wiring, computer coding, sensor communication, and data handling. On top of these skills, the ability to actually work on the project presented various expected and unexpected problems that gave important information on how to proceed with the next balloon project.

To improve later experiments the purchases need to be made farther in advance, sensors and other various equipment need to be available as soon as possible so that it can be tested and used to improve understanding. This improved understanding would help with the use of the sensors so the project can move more smoothly. Also getting the desired purchases sooner allows for more time to evaluate the system design and find if other equipment needs to be purchased. Other information gleamed from the building of the ARTEMIS project is that more time is always valuable, as well as getting as many members as possible on the team. The timeframe for the ARTEMIS project was very condensed and many parts of the project were rushed to meet deadlines. Additional time would allow for a greater understanding and a smoother assembly of the project. More students from various disciplines can improve understanding of all aspects of the project, as well as a more diverse interest in the various required tasks to get the project ready.

More thorough testing of the ARTEMIS project would have allowed for a more complete understanding of the system's capabilities and how the sensors would truly perform. In the ARTEMIS mission the inertial measurement unit was discovered to have a calibration error, the magnetometers should have been tested against ferrous components for interference, and other sensors needed more thorough testing before flight. This shows if any of the sensors has difficulty running for long periods of time or if the data can become corrupted from continuous use. On top of this, all sensors much be researched completely to prevent accidental damage due to errors such as inappropriate power settings, these errors can be very costly, both financially and to the team moral. One of the key parts of testing for the balloon mission would have been thermal testing, but this was not done due to time constraints and other factors. For any future balloon missions thermal testing is crucial to ensure accurate data, as well as survival of all the components. To actually perform thermal testing the experiment should be ready and working before traveling to perform testing.

Another part of the ARTEMIS mission that taught a lot about how the balloon missions works was integration. The ARTEMIS team approached integration with a "whatever works" attitude. This was not the best idea because a crucial part of the experiment was the boom, which needed to be mounted to the balloon gondola. The team learned that a more absolute integration plan is needed before traveling to integration to make sure everything goes smoothly and quickly. Some things had to be "finessed" at integration to make them work, and other parts needed to be assembled. For future missions everything must be working 100% before integration.

Finally the coding for the computer programs of the ARTEMIS mission were very crucial to its success. Many problems occurred because the code was made by one member of the team and being used by other members who did not have a complete understanding of how sensitive it was. For future projects the person who writes the code should be the one traveling with the code to use it. Also having post processing code written in advance would allow for the students to check if outputs from sensors are reasonable and optimize the code to gather the most useful data during flight.

Science and Data Results

The morning of September 2, 2007, a high-altitude balloon carrying the ARTEMIS scientific package was prepared for flight and launched from Ft. Sumner, New Mexico. For 30 hours and the 19.5 hour duration of the balloon flight, ARTEMIS recorded data from a Systron MotionPak II Inertial Measurement Unit, a Magellan DG14 GPS receiver, and two Honeywell HMR2300 Three-Axis Magnetometers.

The IMU measured accelerations and rotation rates over three axes, as well as the internal temperature. Large variations in acceleration up to the maximum sensor measurement of 1.5g were recorded at the time of launch, flight termination, and impact (Figure 1). Large variation in rotation rate measurements occurred after launch when the balloon was ascending to flight altitude and after flight termination when the gondola was descending (Figure 2). The maximum rotation rate measured after launch was 15°/second and 40°/second after termination. The internal temperature sensor of the IMU recorded an initial temperature of 304 Kelvin, and temperature increased over four hours to 320 K before the balloon was launched (Figure 3). In flight temperature was measured to be 317 K to 320 K during the day, and upon nightfall the temperature decreased to 312 K. After impact, temperature increased to over 325 K by the final reading. After post-flight data analysis and testing, it was determined that the IMU was uncalibrated due to very slight but significant offsets in acceleration and rotation rate readings, and that the measured temperature data may be five to ten degrees higher than the actual temperatures experienced within the ARTEMIS scientific package. The temperature data is still useful for thermal analysis. Since attitude determination using the rotation rates requires integration of the data over the duration of the mission, the slight non-constant calibration error is magnified and any attitude determinations using this method are unreliable. Attitude determination is still possible using the acceleration data and the magnetometer data.

The GPS receiver returned latitude, longitude, altitude, time at this measurement, the true track over ground, speed over ground, vertical speed, the number of satellite vehicles used to the computation of position, and the dilution of precision. There were instances when position could not be measured properly due to a low space vehicle count (Figure 4) and this is reflected in a high dilution of precision or outright lack of data (Figure 5). Problems occurred during pre-launch, at launch, at termination, and at impact. Overall, there were few cases of unreliable position measurements, and the GPS data was determined to be reliable for most of the flight. In a comparison to data received from HASP and the known topography of the launch and impact sites, it appears that there is an approximate 25m underestimate in the measurement of altitude over the entire duration of the mission (Figure 6).[1]

The main purpose of ARTEMIS was to simulate and test the feasibility of mapping the magnetic field of the Moon by flying two magnetometers on a high altitude balloon. The first was attached to a boom away from the gondola and near a neodymium magnet, and the second magnetometer was located within the scientific package. The actual measurements are obtained once the magnetic field offsets due to the magnet and electromagnetic interference from the gondola are subtracted. In order to determine the reliability of the recorded magnetometer data, it is necessary to compare those values to a model of Earth's magnetic field. Using the International Geomagnetic Reference Field model, it is possible to determine the magnetic field at a given position on the Earth.[2] The data from the GPS were used as the position input for the magnetic field model, and the predicted and measured magnetic fields were compared. Once offset correction is applied to the magnetometer data, both the boom-mounted (Figure 7) and internal magnetometers (Figure 8) correlate with the predicted magnetic field.

It is possible to determine the attitude of the gondola by using two vectors with respect to the body frame, the gondola, and two vectors with respect to the inertial frame, the Earth. IMU acceleration data and magnetometer data are used as the body frame vectors, and vertical 1g acceleration due to gravity and the predicted magnetic field at a given position are used as the inertial frame vectors. The calculated attitude is given in terms of (3-2-1) Euler angles. Figure 9 plots the attitude of the body frame with respect to the inertial frame over time, with a range of ±180°. Figure 10 plots attitude of the body frame with respect to the inertial frame over time, but is “unwrapped” to correct phase angles.

References:

[1] Farr, T. G., et al., "The Shuttle Radar Topography Mission," *Reviews of Geophysics*, 45, RG2004, 2007.

[2] Maus, et al., "The 10th-Genereation International Geomagnetic Reference Field," *Geophysical Journal International*, Vol. 161, 2005, pp. 561-656.

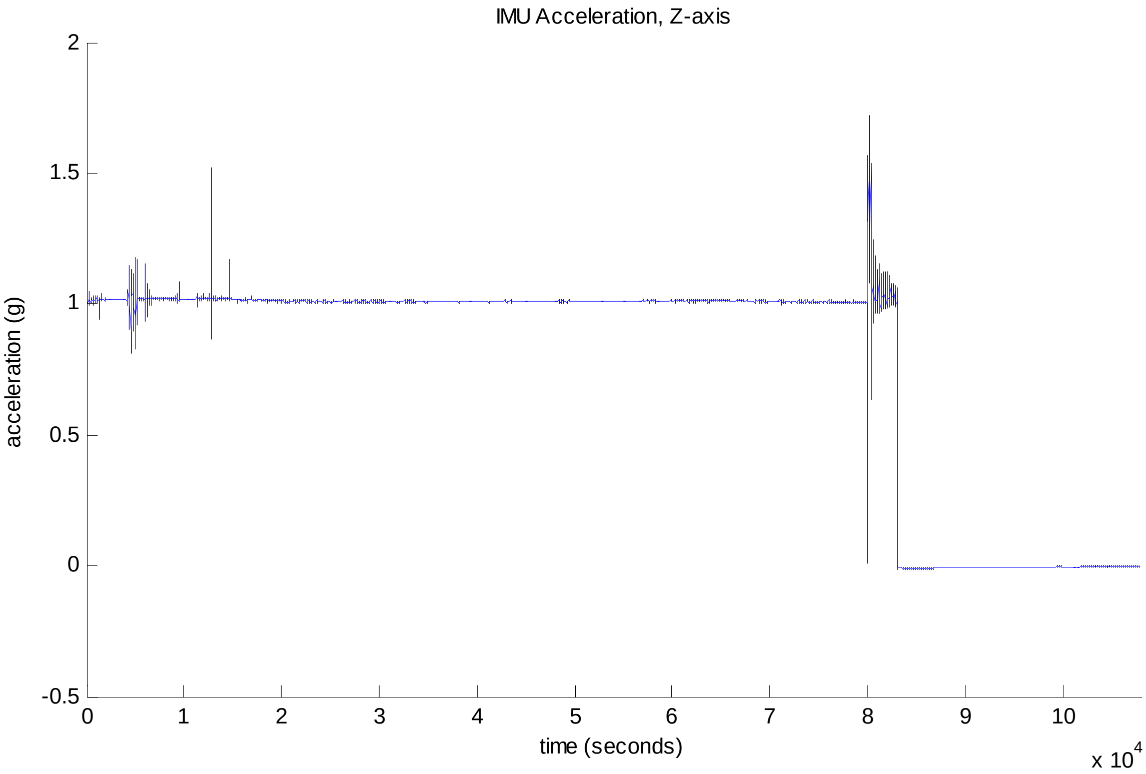

Figure 1. Acceleration measure by IMU along the Z-axis of the body frame.

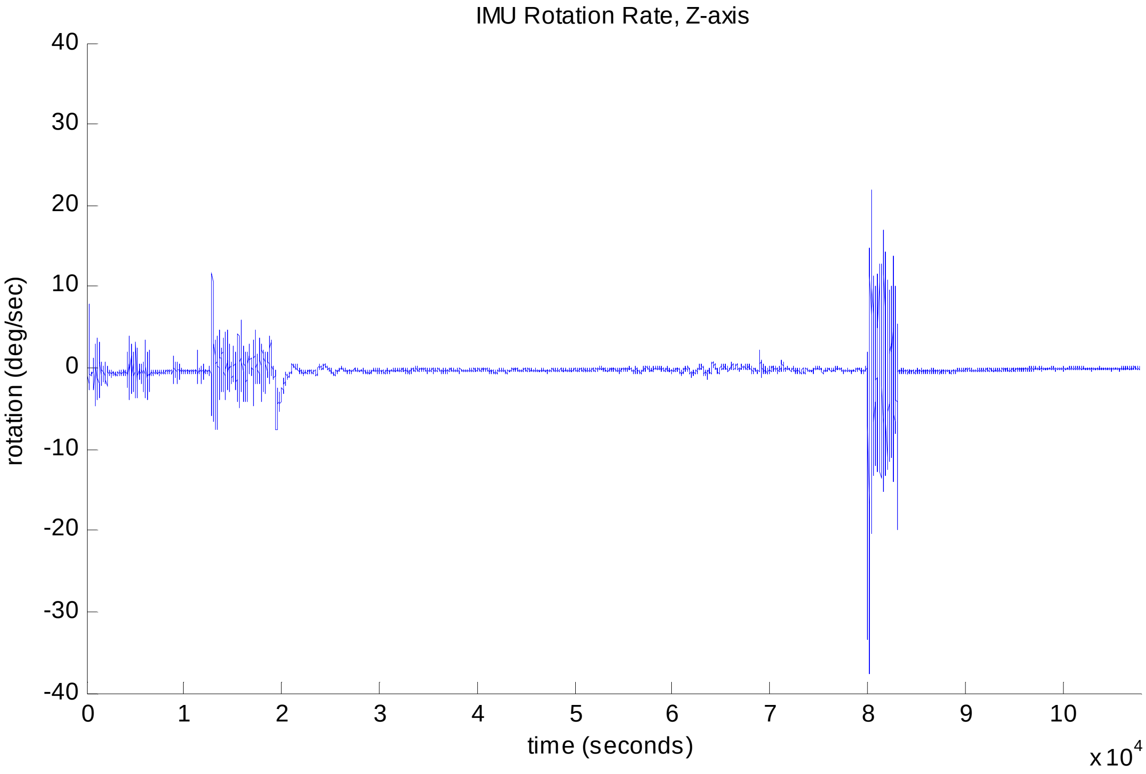

Figure 2. Rotation rate measured by the IMU about the Z-axis of the body frame. Note the offset from zero.

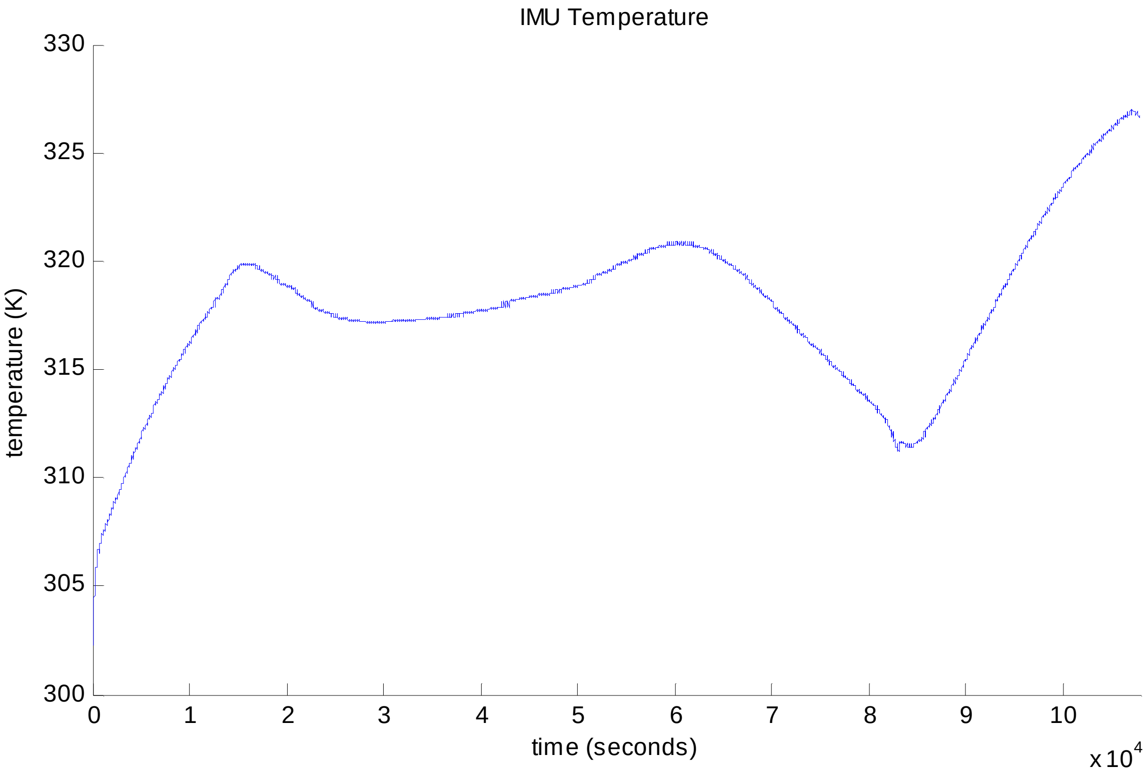

Figure 3. Temperature measured by the IMU.

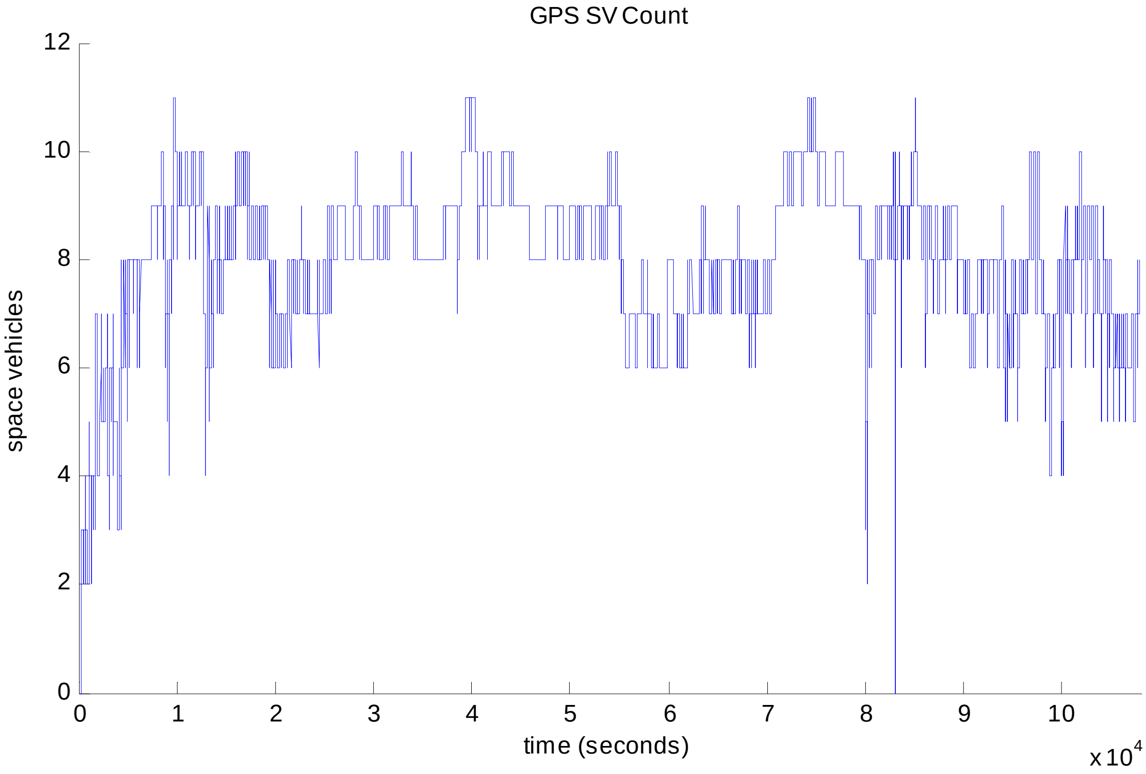

Figure 4. The number of satellite vehicles used by the GPS to calculate position.

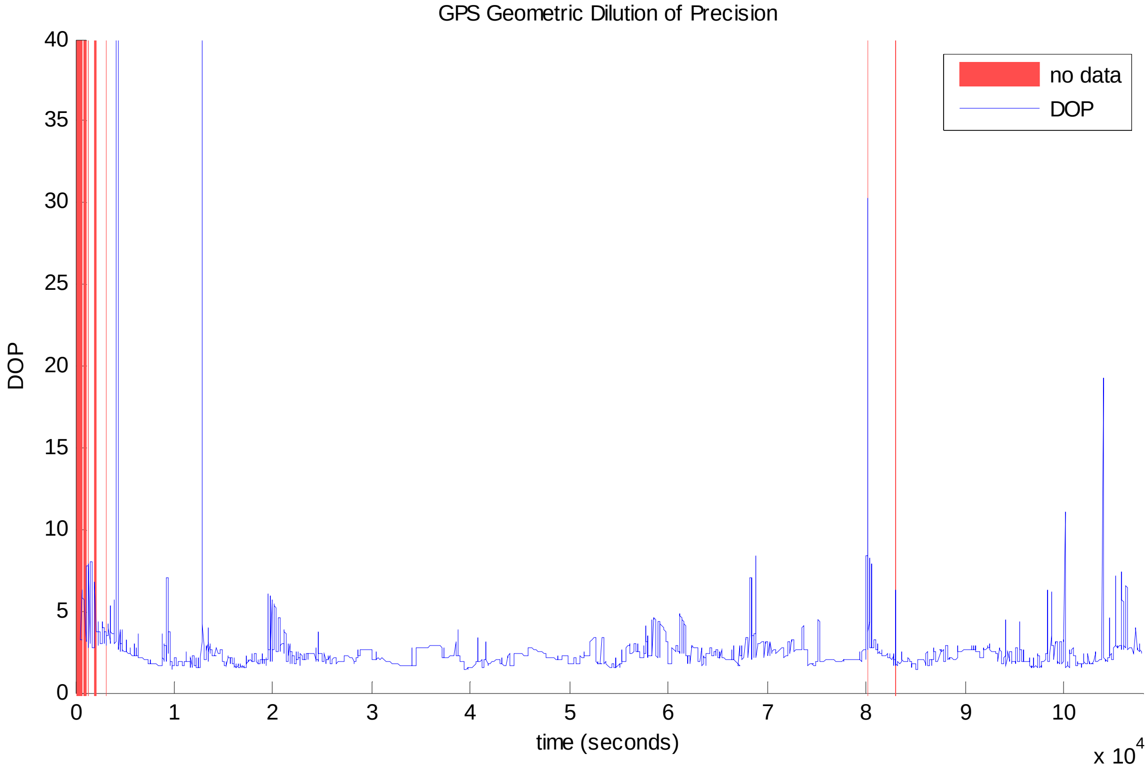

Figure 5. GPS Geometric Dilution of Precision and missing data points.

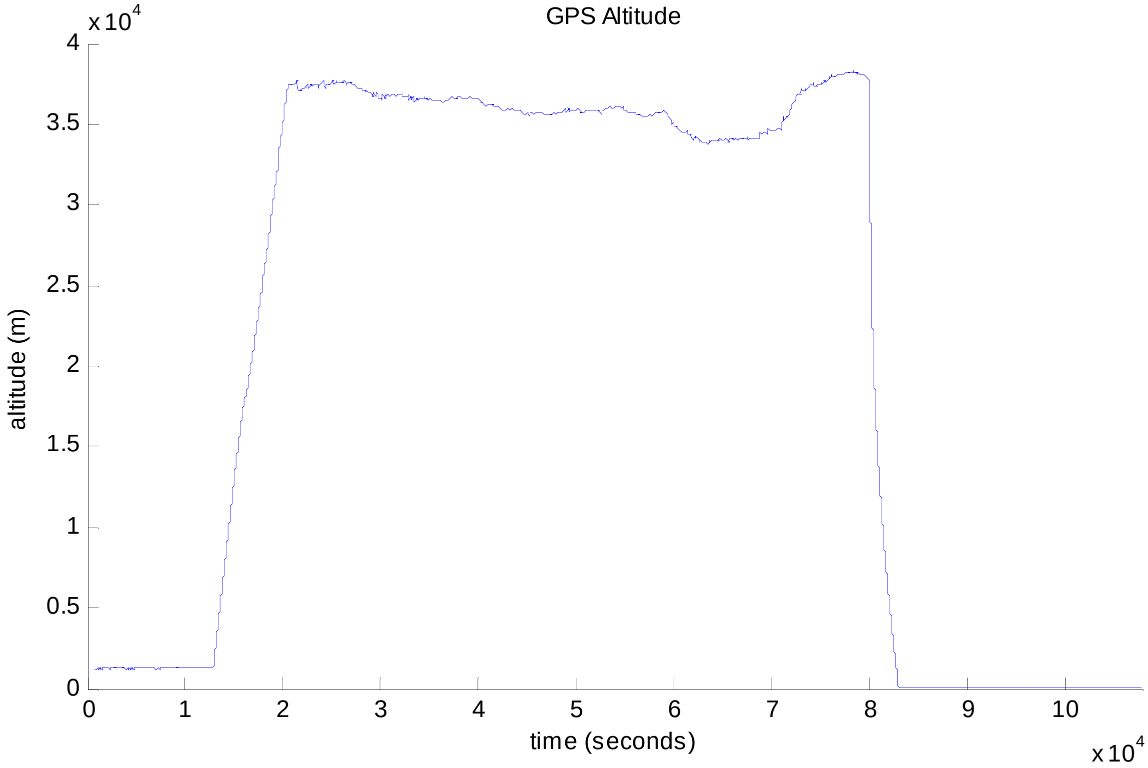

Figure 6. Altitude measured by GPS. Corrected for 25m underestimation of altitude.

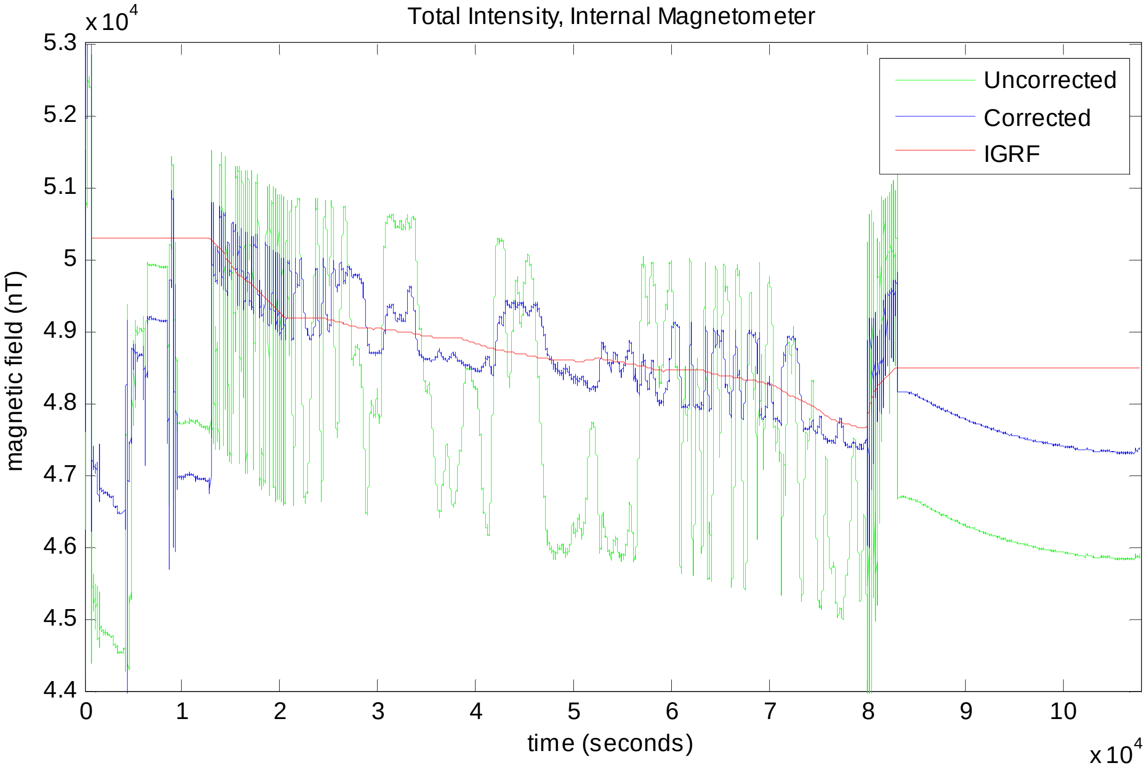

Figure 7. Total intensity of the magnetic field, measured by the internal magnetometer and compared to the IGRF model.

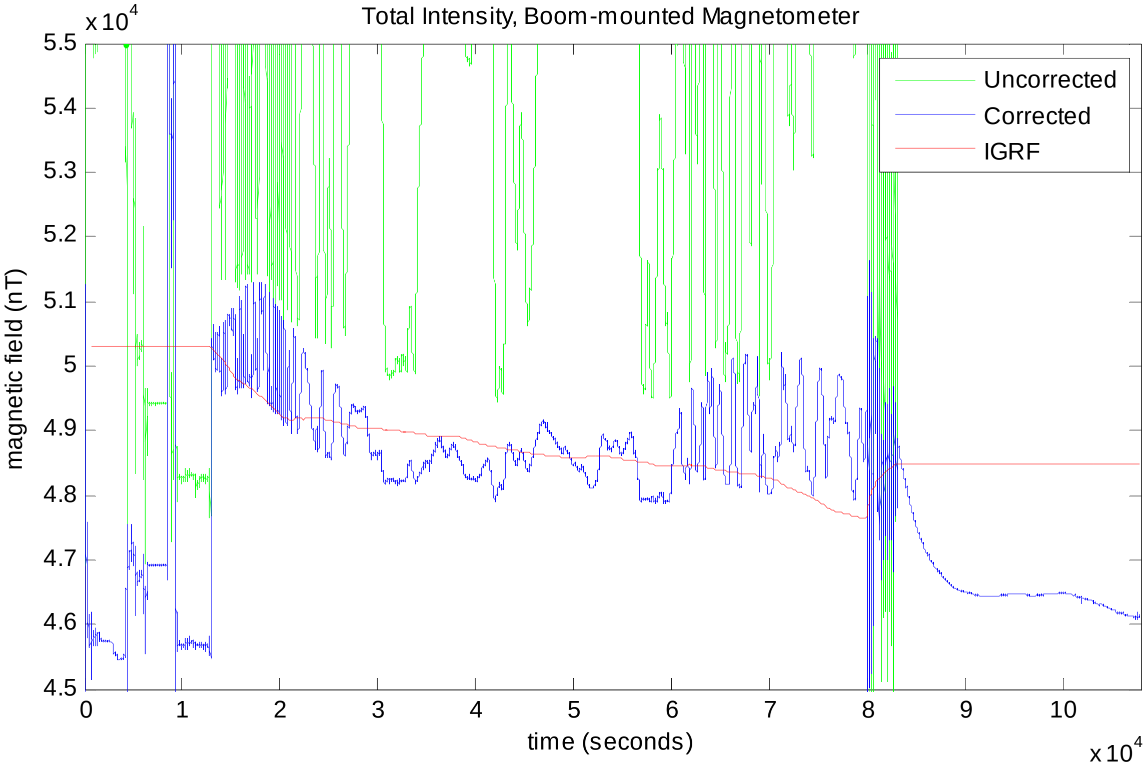

Figure 8. Total intensity of the magnetic field, measured by the boom-mounted magnetometer and compared to the IGRF model.

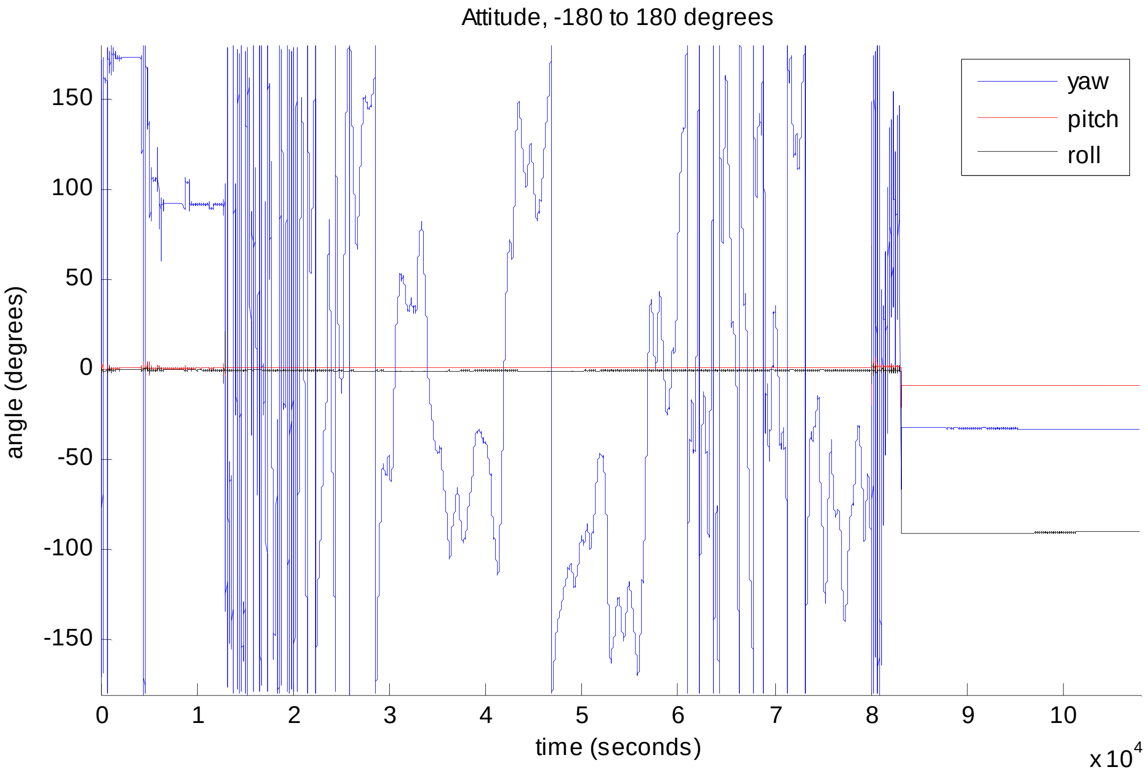

Figure 9. Attitude of body frame with respect to the inertial frame.

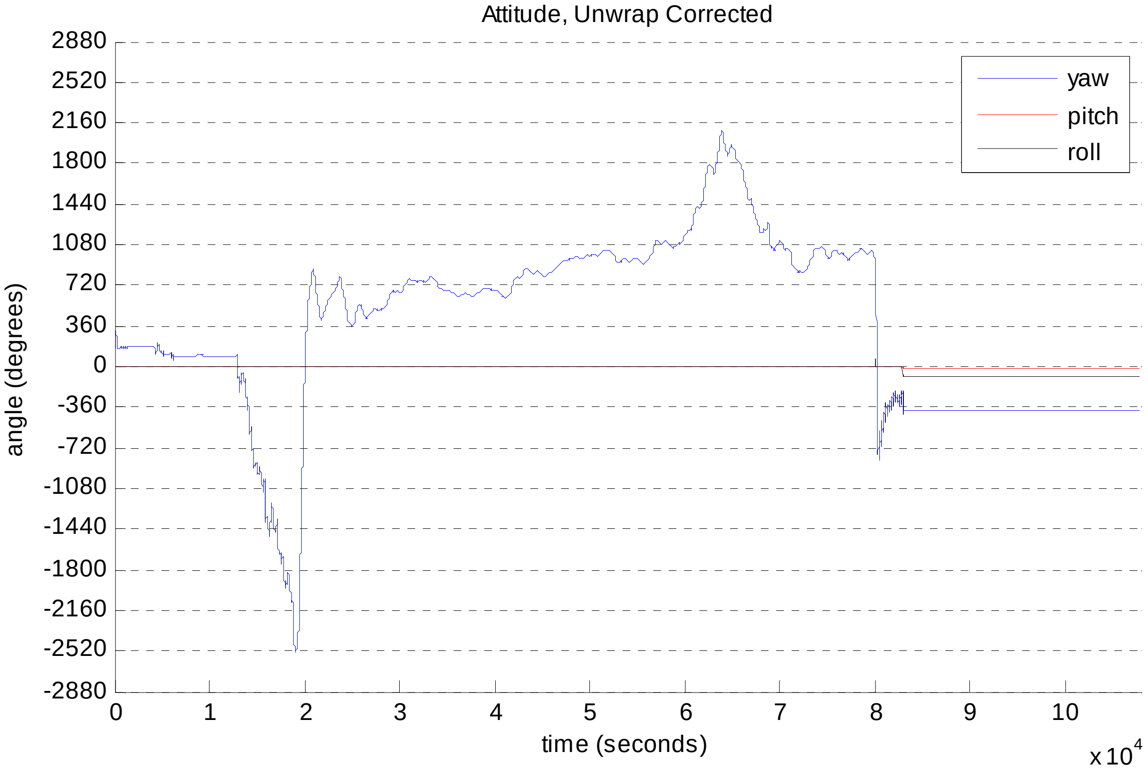

Figure 10. Attitude of body frame with respect to the inertial frame. Unwrapped to correct phase angles and better illustrate rotation.