ARLISS Data Logger Project

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For the last few years there has been continuing discussions regarding the increased number of student payloads that seemed to have been damaged while being deployed from ARLISS rockets. (ARLISS is an annual international launch event sponsored by AEROPAC. For more information see www.ARLISS.org.) Following the 2012 ARLISS event, a team was assembled to create a device that could be used to instrument the current fleet of AEROPAC ARLISS rockets and measure the forces that the rockets were inflicting upon their payloads. The team consisted of Jeff Stutzman, Grant Saviers, James Dougherty, Allen Palmer, James Prior, and myself. The ARLISS Data Logger that we created is a combination of hardware, firmware, data analysis software and web presentation software.

The objectives of the ARLISS Data Logger are to:

- Measure the forces to which student payloads are subjected while inside the rocket.
- Provide failure analysis data to help determine the causes of payload damage.
- Permit ARLISS Rocket designs to be improved to provide a more consistent and less stressful flight for their payloads.
- Help ARLISS Payload Teams to better understand the environment for which their payloads must be designed.

The ARLISS Data Logger is an electronics module that resides in the bottom bulkhead of the ARLISS payload carrier. Both the carrier internal payload compartment space and the carrier external dimensions were maintained so that these instrumented carriers were compatible with existing payloads and rockets. This made it possible to deploy the instrumented carriers widely across the fleet and collect sufficient data to begin to profile AEROPAC's ARLISS fleet.

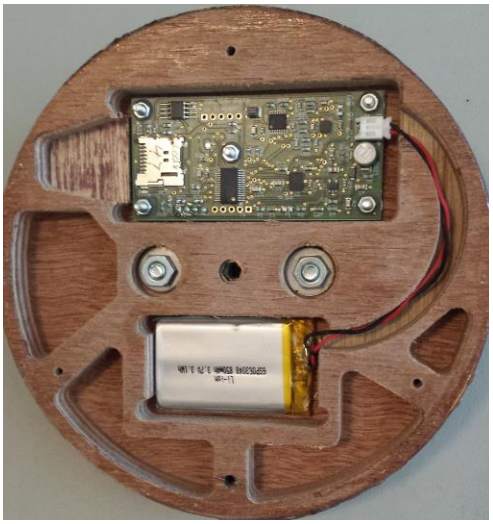

Figure 1: Logger mounted inside an instrumented carrier bulkhead (with the protective cover plate and carrier phenolic body tube removed). The AL-016 High Speed Data Logger and 850 mAh battery are visible.

Logger Sensors and Features

The Logger's sensors measure tri-axis acceleration forces, rotational movement, and detect the instant of payload deployment.

The Logger electronics module contains the below sensors and feature components:

- A STMicroelectronics LSM330DLC inertial module (IMU). The LSM330 has a 3D accelerometer that is configured to measure up to ±16 g and a 3D gyroscope that is configured to measure angular rates of up to ±2000 deg/sec.

- An Analog Devices ADXL377 3D accelerometer and amplifier/filter circuit that measure up to ±200 g. This sensor was installed to measure High-G events, such as ejection charge and collision shocks.

- A photo-transistor that monitors the light level inside the payload carrier and is used to detect the time at which the payload is deployed.

- A 16Mb high speed flash memory chip, which temporarily holds the most recent flight recording until it is copied to the MicroSD-card and verified.

- A SDHC MicroSD-card socket. The MicroSD-card is used to hold recorded flight data.

- A high performance PIC18 microcontroller able to sustain a 1.3 kHz data sample and record rate. (The entire sensor cluster is sampled about every 744 microseconds.)

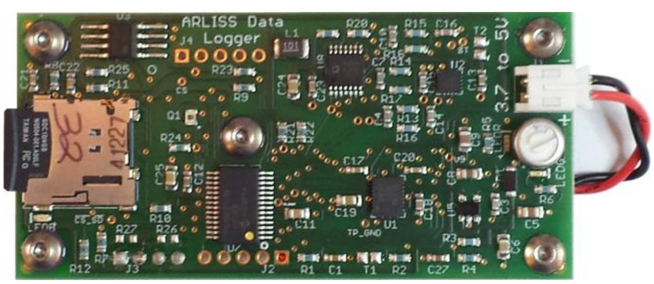

Figure 2: AL-016 ARLISS Data Logger

- Red, Green, and Blue LEDs that are used to communicate the Logger's activity and launch readiness status.

- A serial port that can be connected to a terminal (or terminal emulator). The serial port is used to perform Logger calibration.

Logger Use Scenario

At the beginning of the ARLISS Launch Event, instrumented payload carriers are distributed to fliers. Each Logger is loaded with a MicroSD-card, powered-on, and is ready for flight when the carrier is provided to the flier. Battery use is managed by the Logger and the Logger will remain powered-on for the entire multiday launch event. At rest, the Logger resides in a low power utilization state called "sleeping". While sleeping, a subset of the IMU accelerometers remain active and they will wake the Logger when movement is detected. Within 2 milliseconds of detected movement, the full sensor cluster is operational and the Logger is monitoring for launch. If 15 seconds elapse without a launch being detected, the Logger will resume sleeping. Assuming that the Logger will be allowed to sleep between flights, the ARLISS battery (850 mAh) is expected to last six days or more.

Just before the flier loads the payload carrier for flight, the flier can give the carrier a gentle shake (a nudge) and to make the Logger run a flight readiness and battery test. The result of this test will be blinked out using the Red and Green LEDs. If the Logger reports that it is ready for flight, the flier loads the payload and proceeds to fly the rocket. No special actions need be taken after a flight. The Logger will reset itself and be ready for another flight within 20 minutes of the previous launch. Each flight recording is a sequentially numbered file the MicroSD-card and the recording contains a date/time stamp to help identify the flight to which the file corresponds.

After the last flight of the event, the flier returns the instrumented carrier to an ARLISS coordinator. ARLISS coordinators match recorded data to flight cards. (ARLISS flight cards collect substantial amount of information from both the flier and the student team.) This data is fed into a post-processing program that analyzes the flights and generates a collection of web pages for the event's flights.

Eight instrumented carriers were distributed for the 2013 ARLISS event and 17 flights were recorded. The analysis of data from this event showed that the original +/-50 g accelerometer range and +/-500 degree/sec gyroscope range were not sufficient to capture the characteristics of the flights. We were surprised to find out that nearly all of the flights exceeded the +/-50 g accelerometer range.

A new version of the Logger was developed for the 2014 ARLISS event. At the 2014 event, fifteen instrumented carriers were distributed and 49 flights were recorded.
The processed flight data for the September 2014 ARLISS Event can be found at
www.rafresearch.com/arlissdatalogger/flightdata/ARLISS2014/index.xml .
This web page is the "Event Summary". It contains a summary of key flight characteristics and a link to the detailed data for each launch. Unfortunately, the payload damage status of several flights is unknown, because some payload teams did not fill out and submit this segment of the flight cards.

Flight Analysis

For ARLISS flights, the Data Loggers are set to record the first 45 seconds of the flight. Each of the sensors is sampled every 744 microseconds. (The gyroscopes supply data at about half this rate.) The high sample rate provides excellent resolution for examining the shocks and vibrations that are delivered to the payload. An example of the flight data can be seen by selecting any of the links on the event summary page. It's possible to view the sample by sample data in spreadsheet format by clicking on the "Flight.xls" link. Data post-processing software divides each flight into four windows, launch, coast, deployment, and recovery. The first three windows are analyzed, key results are extracted, and flight anomalies are reported.

Launch Window

The launch window is from first movement to motor burn-out. Figure 3 is an example of an acceleration chart generated from the data in this window. The “blue” series of the chart is acceleration in the vertical axis. (Clicking on any thumbnail chart on the web page displays a high resolution version of the chart.) Motor characteristics (thrust and impulse) are analyzed during this window.

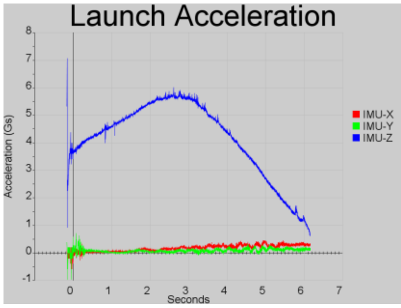

Figure 3

Deployment Window

The deployment window is the time interval from the firing of the first ejection charge until the payload deploys and deployment forces quiesce. For ARLISS flights, the first ejection charge is programmed to occur at apogee. This charge splits the rocket in two and deploys the main parachute(s). A second ejection charge, for payload deployment is programmed to occur six seconds later. This delay interval is to permit the main parachute to deploy and orient the payload compartment downward. (The payload carrier is located just behind the nosecone.)

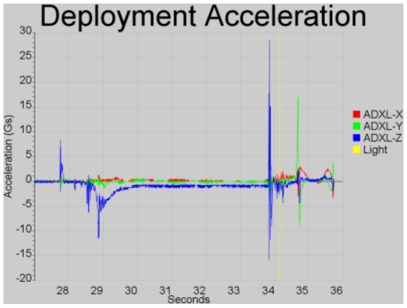

Figure 4

The payload is typically subjected to the highest magnitude shock forces during this window. This is due to close proximity of the ejection charge, the relatively low mass of the loaded payload carrier, and the breaking of the nosecone shear pins that are used to prevent premature deployment. This window is analyzed to determine the magnitude of the acceleration shocks and the time at which the payload becomes free of the carrier.

Results

Figure 5 shows an acceleration profile of a typical flight.

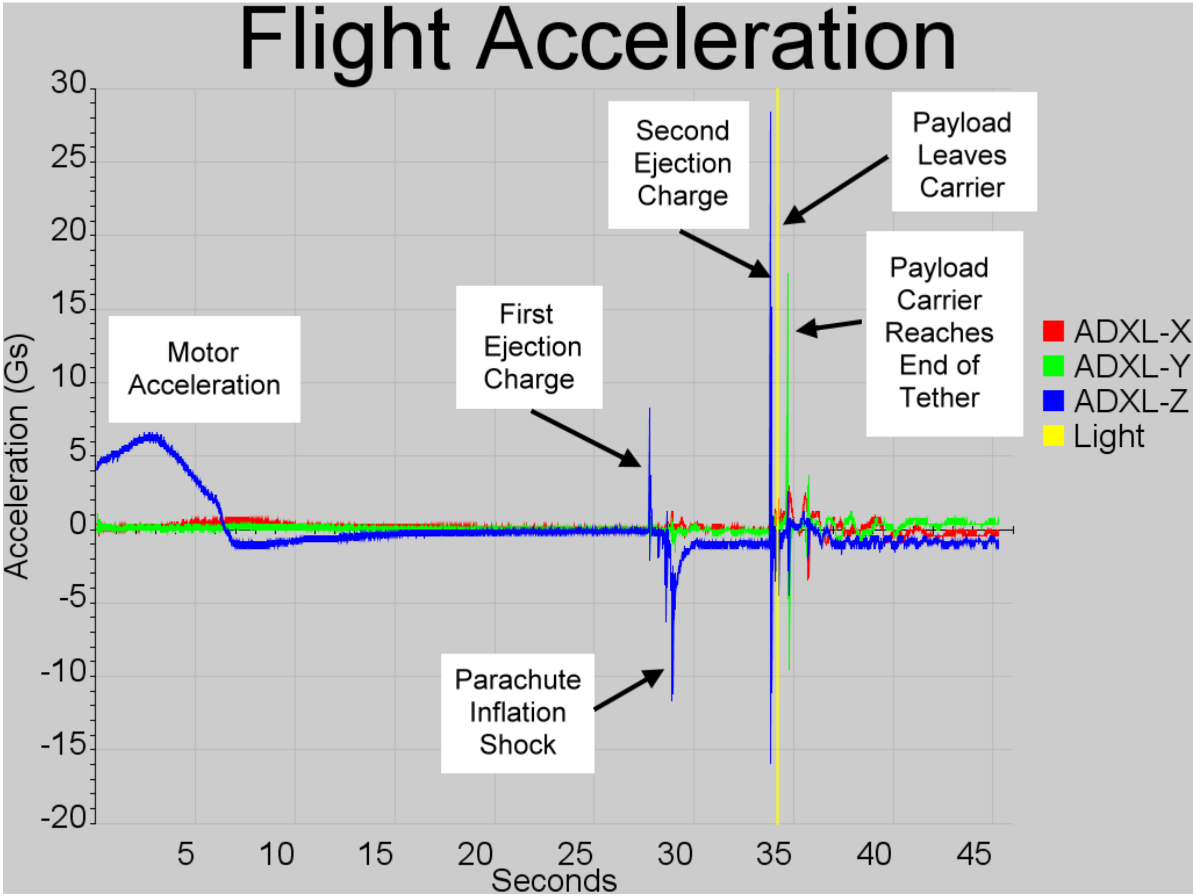

Figure 5. Normal ARLISS flight events.

The most noticeable characteristic is the magnitude of the payload deployment shocks occurring at about 34 seconds into the flight. This rocket used a Rouse-Tech CD3 (CO_2) ejection charge for payload deployment, with a baffle between the CD3 and the payload carrier. It achieved one of the lowest payload deployment shocks. CD3 deployments were generally in the range of 20 to 50 g. Black powder deployment ejection shocks were generally in the range of 48 to 130 g.

The most violent payload ejection (174 g) was 2 grams of black powder placed very close to the payload carrier bulkhead (figure 6).

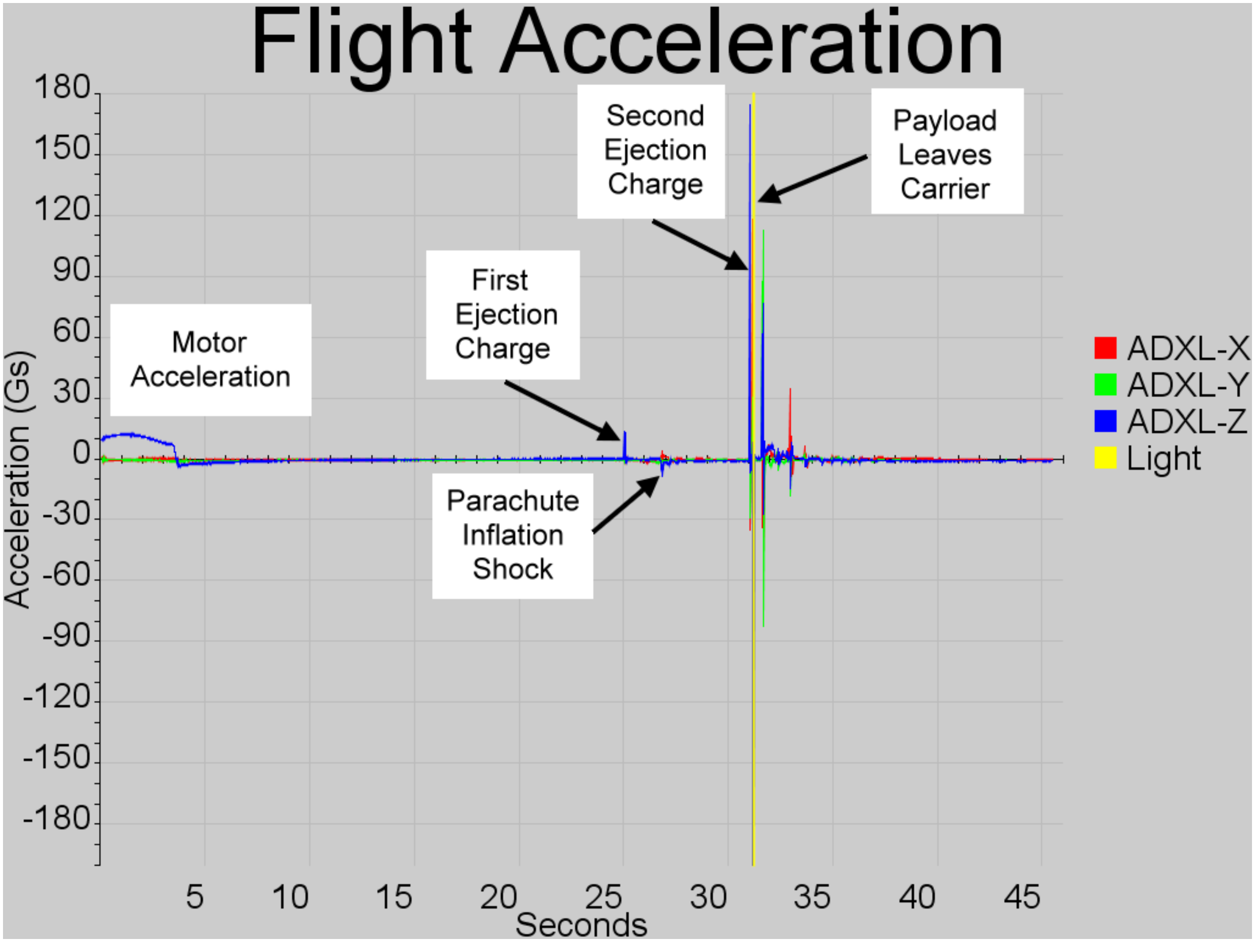

Figure 6. ARLISS flight events with a 174g BP deployment.

The proximity of the ejection charge to the payload carrier base is believed to be a major factor in the ejection shock delivered to the carrier. A small air gap seems to attenuate the shock significantly.

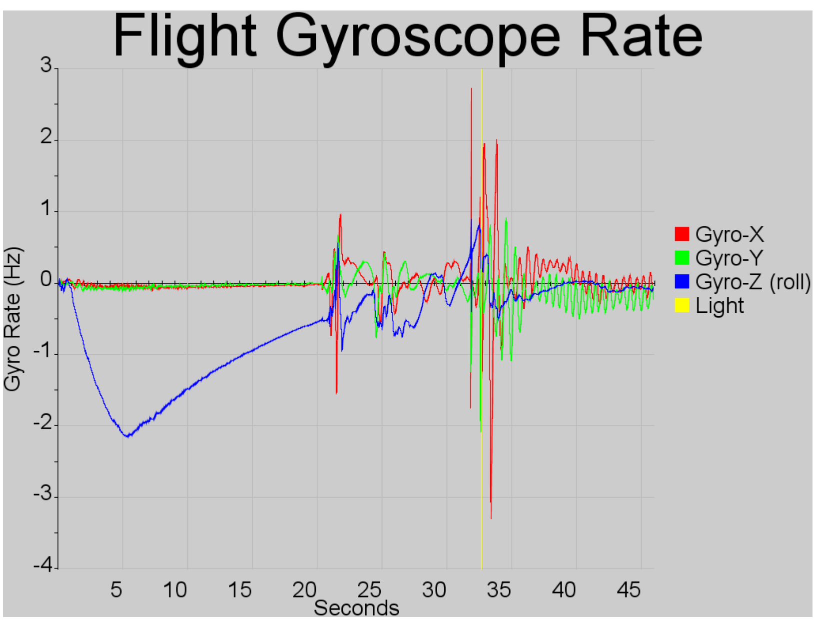

Figure 7. Gyro rates of a rocket with external pod.

Generally gyroscopic rates throughout the fleet were well behaved, but external pods and cameras did cause interesting roll and wobble. The roll (blue series) on this flight reached 756 dps. After the parachute deployed (22 sec) the gyro rates went crazy.

This rocket (Gumby) had an asymmetrical cross section profile due to an external pod.

Also typical of rockets with external pods and cameras was earlier occurrences of apogee, which was probably due to the additional drag.

Conclusions

The data loggers succeeded in collecting a large pool of data for ARLISS fliers to analyze. Our initial analysis indicates that student payloads are being subjected to acceleration shocks that are larger than we expected, but surprisingly, the huge acceleration spikes do not correlate strongly with payload damage data. This is believed to be because the duration of these shocks, and therefore the energy contained within them is small.

Further research uncovered that it is important to understand how the payload reacts to these shocks. More advanced analysis programs were developed to further analyze the raw data that was collected by the Loggers. These advanced analysis programs are the subject of part 2 of this article.

Most importantly, the AL-016 Data Logger has provided a measurement capability that is expected to enable ARLISS fliers to better understand what is occurring during the flights, to formulate experiments, and ultimately to improve our ability to provide a more consistent and less stressful flight for payloads.

More information on the AL-016 Rocket Data Logger is available at http://www.rafresearch.com/rocketdatalogger/ .