

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, 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 satellite damage.
- Permit ARLISS Rocket designs to be improved to provide a more consistent and less stressful flight for their payloads.
- Help ARLISS Satellite Teams to better understand the environment for which their satellites 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: Looking down inside an instrumented carrier with the protective cover plate removed. An ARLISS Data Logger (Version 1) and 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 ± 500 deg/sec. The LSM330 also contains a temperature sensor that measures temperature of the MEMS gyroscope in a range of -40 to +85 deg C. (The temperature sensor does not seem to measure accurately.)
- An Analog Devices ADXL377 3D accelerometer and amplifier/filter circuit that measure up to ± 50 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 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.

Figure 2: ARLISS Data Logger (Version 2)
Shown actual size.

- 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 flyers. Each Logger is powered-on, contains a MicroSD-card, and is ready for flight when the carrier is provided to the flyer. The 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 battery is expected to last six days or more.

Just before the flyer loads the payload carrier for flight, the flyer can give the carrier a gentle shake (a nudge) and to make it 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 flyer 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 flyer 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 flyer 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.

Flight Analysis

The processed flight data for the September 2013 ARLISS Event can be found at <http://www.arliss.org/data> Eight instrumented carriers were distributed for this event and 17 flights were recorded. 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 much of the flight card data for these launches was lost in a mini-tornado that ran through camp and sucked up a box of flight cards. Only some of this lost flight card data was able to be reconstructed.

For ARLISS flights, the Data Loggers are set to 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 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 for a flight is divided 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.

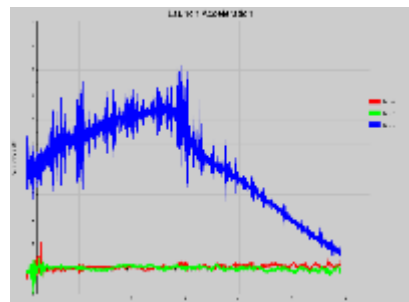


Figure 3

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.)

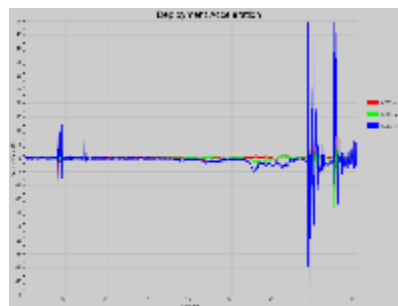


Figure 4

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.

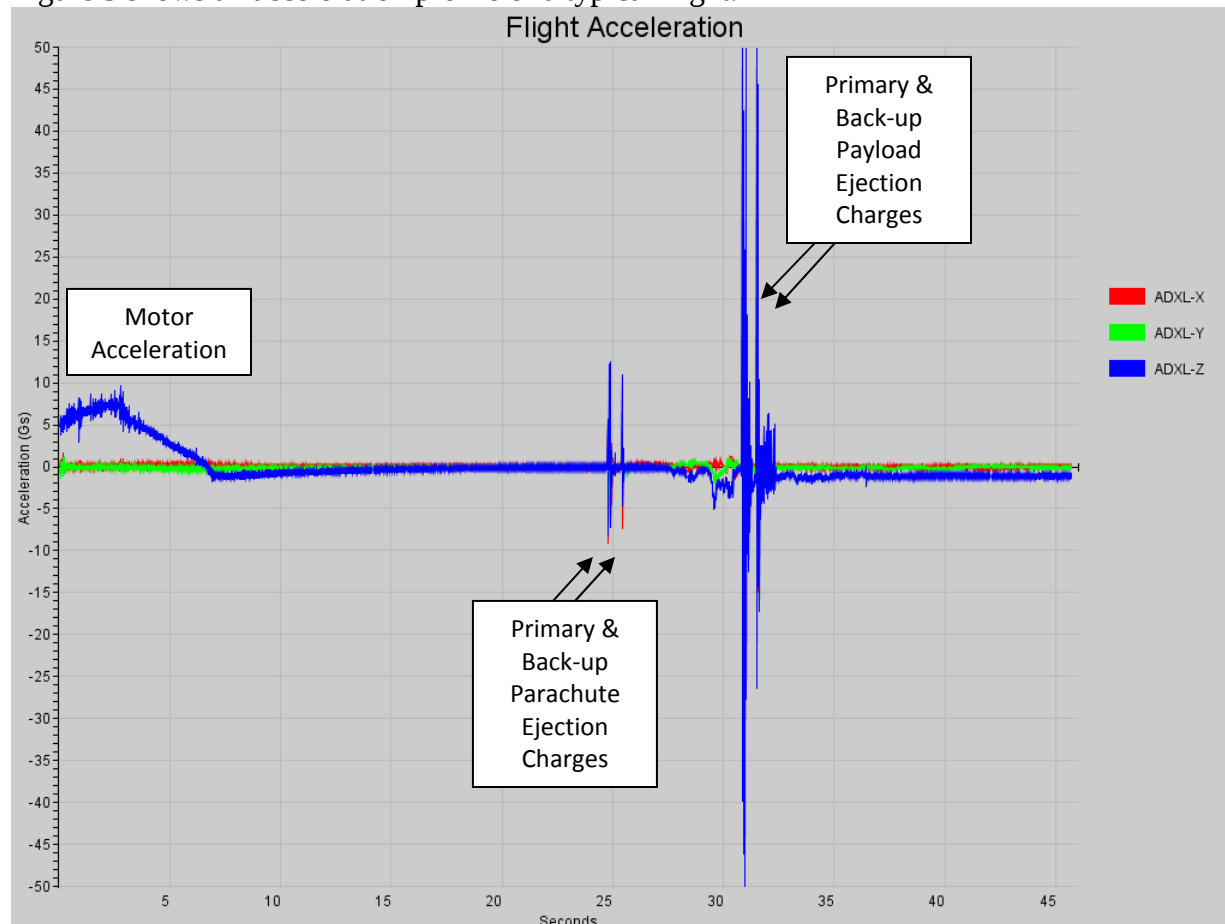


Figure 5

The most noticeable characteristic is the magnitude of the payload deployment shocks occurring at about 31 seconds into the flight. Since the Hi-G accelerometer circuit saturated at approximately 50 Gs, we do not know the real magnitude of these shocks. We had expected them to be no larger than 30 Gs.

Generally gyroscopic rates throughout the flight were well behaved, but external pods and

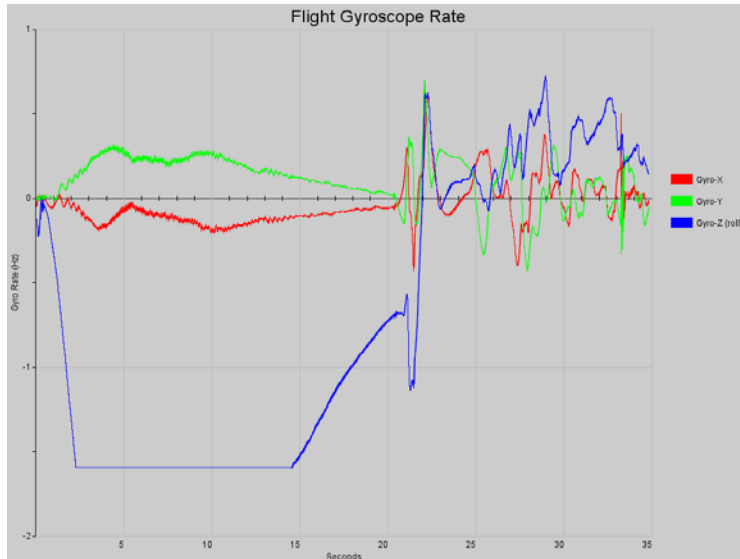


Figure 6

cameras did cause interesting roll and wobble. The roll (blue series) on this flight saturated the gyroscope sensor. Even the pitch and yaw (red and green series) gyroscopes show an interesting wobble.

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.

Another surprise was that the measured motor thrust and impulse were lower than expected. In previous ARLISS events, a significant number of flights performed a “wobble dance” just above the launch rail and/or exhibited significant wind-cocking. I didn’t observe as much of it this year. The weather/winds were very calm for most of the event and many of the launches occurred from a 20-foot rail rather than from the usual 10-foot rails. However, the measured initial thrust was less than 5 Gs for several flights. The motors were expected to deliver about 8 Gs of initial thrust. We don’t have an explanation for this difference. We are speculating that we may be losing significant thrust due to launch rail/button friction.

Conclusions

The data loggers succeeded in collecting a pool of data for ARLISS flyers to analyze. The mining of the pool of data has just begun. Our initial analysis indicates that...

- student payloads are being subjected to shocks that are larger than we expected
- rockets are leaving the rail at slower velocities than expected

Most importantly, the ARLISS Data Logger has provided a measurement capability that is expected to enable ARLISS flyers 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.