Using a MEMS Inertial Measurement Unit for Planetary Gravimetry. C. S. Lawson¹,², M. E. Evans³, P. B. Niles⁴, ¹Jacobs Technology-NASA Johnson Space Center (JSC), Houston, Tx.; ²Texas A&M University at Galveston, Galveston, Tx. (chandler.s.lawson@nasa.gov; elawson41@tamu.edu); ³NASA Johnson Space Center (JSC) Astromaterials Research and Exploration Science (ARES) (michael.e.evans@nasa.gov).

Introduction: Gravitational data taken from a planetary body can be used to infer densities and structures within the planet’s crust. While orbital surveys have been able to explore subsurface stratification and densities, surveys from the surface, or near-surface could study these characteristics at greater depths and increase the resolution of the data. Inertial measurement units (IMUs) have been traditionally used for navigation and attitude determination. In 1995, the first study using an IMU for gravimetry was carried out over the Rocky Mountains [1]. The use of IMUs for terrestrial gravimetry has since become more common and has proven to be an effective, low-cost alternative to traditional gravimeters with the main drawback being poor long-term stability due to instrument drift [2]. More recently, IMUs on the Curiosity rover were used to conduct a gravity survey of the rover’s traverse at Gale Crater. This marked the first gravity survey conducted on the surface of Mars and proved the feasibility of using IMUs for surface and near surface gravimetry [3]. The objectives of this project are to: 1) test a proof-of-concept instrument containing a micro-electromechanical systems (MEMS) IMU, and 2) develop proper gravity data reduction methods for planetary inertial gravimetry.

Instrument Background: The instrument, named HELIX, was developed by engineering students at Texas A&M University in College Station, Tx. HELIX is a balloon-mounted sensor package towed by a ground vehicle designed to collect airborne gravity data (see figure 1). The sensor package contains a low-drift IMU, GPS, rangefinder, and internal and external temperature sensors. The IMU is the tri-axial IMU-3030 manufactured by MEMSense.

Data Processing: Fixed bias, scale factor, and cross-axis misalignment errors are determined by performing a six-position static test where the positive and negative axes in each direction are aligned with the vertical gravity vector.

While flying, HELIX will experience turbulence and attitude instability. This can be compensated for by using a direction cosine matrix which rotates the IMU axes from the body reference frame into the inertial reference frame, where the gravity-sensitive z-axis is aligned with the gravity vector.

Temperature variations are strongly correlated to bias in MEMS accelerometers [4]. The internal temperature of the IMU, and environmental temperature must be considered when modelling this relationship. Multiple regression will be used to determine a thermal correction and will include a linear drift term.

Stochastic errors that occur during operation are highly nonlinear and must be estimated. The optimal system state estimator is the Kalman Filter [5]. An extended version called the Extended Kalman Filter (EKF) can be used to obtain estimates of gravity from a system containing stochastic errors. Gravity anomaly calculations can then be performed on the gravity estimates recovered from the EKF.

Test Site: The initial test site for HELIX will be the Hastings Salt Dome located south of Houston, Texas. Salt domes are diapirc structures that migrate upward through the subsurface due to density differences with the surrounding rock. This difference should provide an apparent gravity anomaly. The data collected with HELIX will then be compared to data taken from a survey of the site conducted using a CG-5 Scintrex gravimeter, and data from the Pan American Center for Earth and Environmental Studies [6].

Figure 1. HELIX flight test.
Summary: MEMS IMUs could represent a viable, low-cost alternative to traditional gravimeters. MEMS IMUs are durable in a range of varying environments making them suitable for planetary exploration. However, proper data reduction and calibration methods are required to obtain accuracies similar to traditional gravimeters. The goal of this project is to demonstrate the ability of a balloon-mounted IMU to detect subsurface structures.

References: