

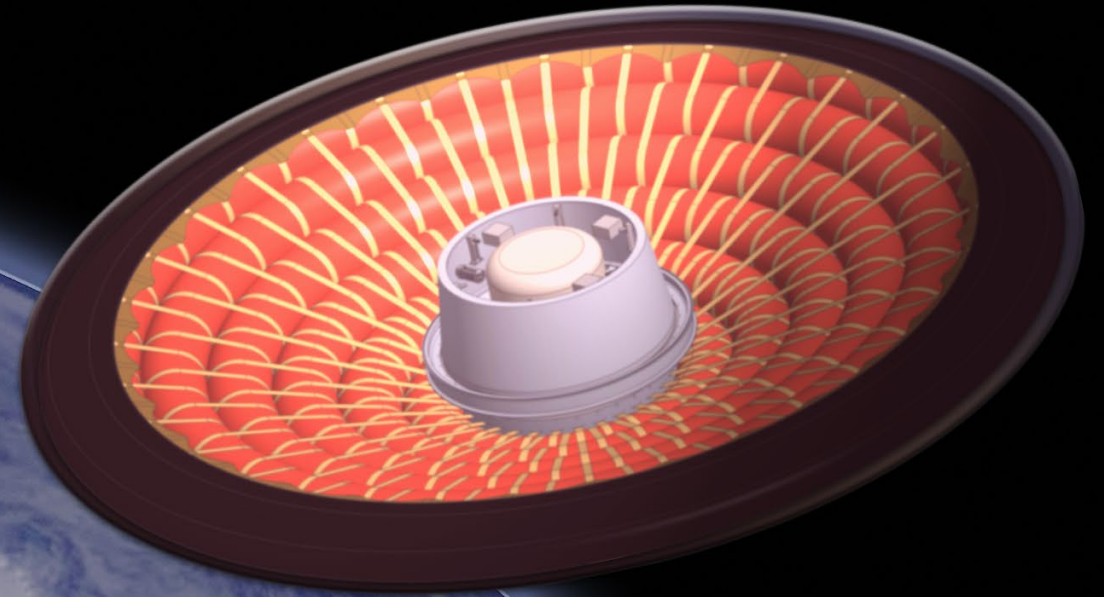


Low-Earth Orbit Flight Test
of an Inflatable Decelerator

National Aeronautics and
Space Administration



Preliminary Design, Testing, and Performance of the LOFTID Navigation System



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Low Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID)



Hypersonic Inflatable Aerodynamic Decelerator (HIAD) is a deployable aeroshell which can be stowed for launch and cruise, then deployed to decelerate payloads at destinations with atmospheres.

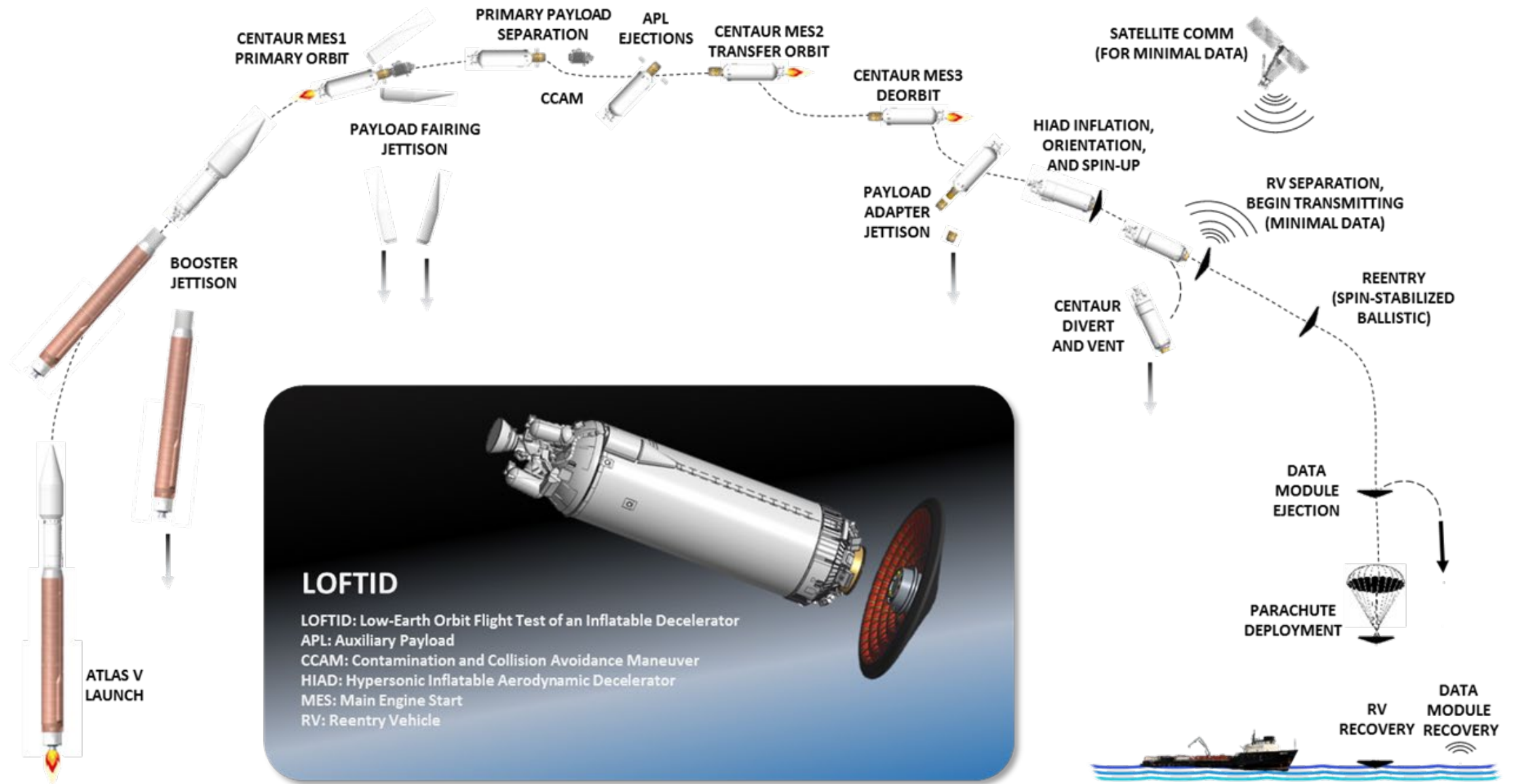
LOFTID Objective: Orbital entry (7-11km/s) of HIAD based reentry vehicle (RV) to demonstrate inflatable aeroshell for NASA heavy down-mass missions, and commercial applications.

The HIAD RV is designed to be flown as a secondary payload on an Atlas V launch vehicle delivering its primary payload to low Earth orbit.

The flight will test HIAD technology at a scale and entry conditions relevant to Earth and Mars mission infusion opportunities.



Concept of Operation





Navigation System Overview and Objectives



- **The LOFTID re-entry vehicle is an uncontrolled payload**
 - No in-flight guidance or control system
- **Objectives of Navigation System**
 - Estimate in real time the attitude, rotation rate, position, and velocity of the RV
 - Provide data that will be sent back via the real time beacon for real-time monitoring
 - Enable post-flight analysis if the real time beacon and on board storage are not recovered
- **Design Goal**
 - Re-use analysis, algorithms, and code from other projects to minimize the development time
 - Provide flight testing of common navigation library
- **Intention to maximize use of available facilities to minimize the integration and testing time**



Design Constraints



- **LOFTID RV is not powered on until all the other payloads have been released**
- **Unable to accept commands or state updates from the launch vehicle upper stage**
- **These constraints make the navigation system unable to initialize prior to the flight or receive an updated navigation state before being released by the upper stage**
- **Shape of the vehicle is also limited due to being a secondary payload; this shape minimizes the surface area exposed**
 - This limits the ability to use a second GPS antenna for attitude
- **Spin stabilization prevents the use of most star trackers**
- **Aeroshell material prevents the use of magnetometers**



Navigation Hardware Overview



- **Due to the design constraints, the hardware of the navigation system only includes an Inertial Measurement Unit (IMU) and a GPS receiver**
- **The hardware was selected to maximize flight heritage and to limit the required environmental testing**
- **Inertial Measurement Unit: Northrop Grumman LN200**
 - Three fiber optic gyroscopes
 - Three accelerometers
 - Space flight heritage on similar vehicles
- **GPS Receiver**
 - JAVAD TR-G2T
 - Space flight heritage on similar vehicles



Software Design



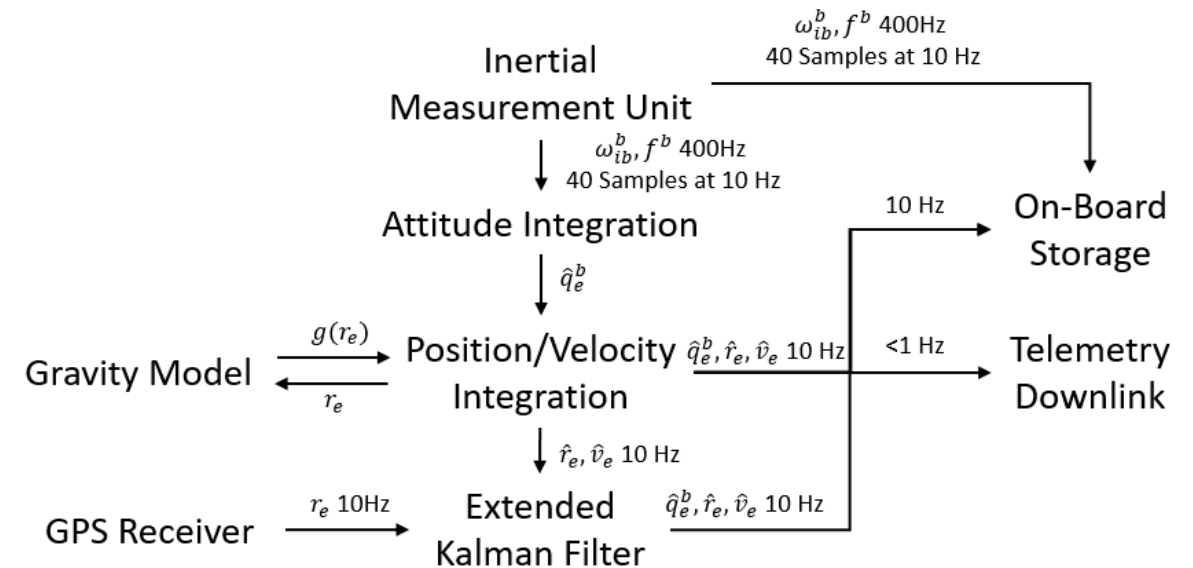
- The LOFTID flight software utilizes the Core Flight System (cFS) architecture
- The navigation system is implemented as a relatively standalone application to simplify integration and testing
- Three main applications: IMU, GPS, and Navigation
- IMU app receives data from the IMU, buffers the data, and outputs the 400 Hz data at 10 Hz
- GPS app receives data from the GPS receiver and outputs at 10 Hz
- Navigation app runs at 10 Hz, processes any measurement available from the IMU or GPS apps, and sends out the navigated state



Inertial Navigation and Kalman Filter



- Navigation app runs at 10 Hz, and receives 40 IMU measurements, and any GPS measurements
- On each IMU sample, the navigation app performs attitude integration, then position/velocity integration
- A first order geopotential is used to minimize computation time
- If there is a GPS measurement, the Extended Kalman Filter (EKF) runs to process the GPS measurement once all IMU measurements are processed
- The output from the 10 Hz navigation app is stored in on-board memory
- The telemetry downlink sends the latest navigated state each time it runs



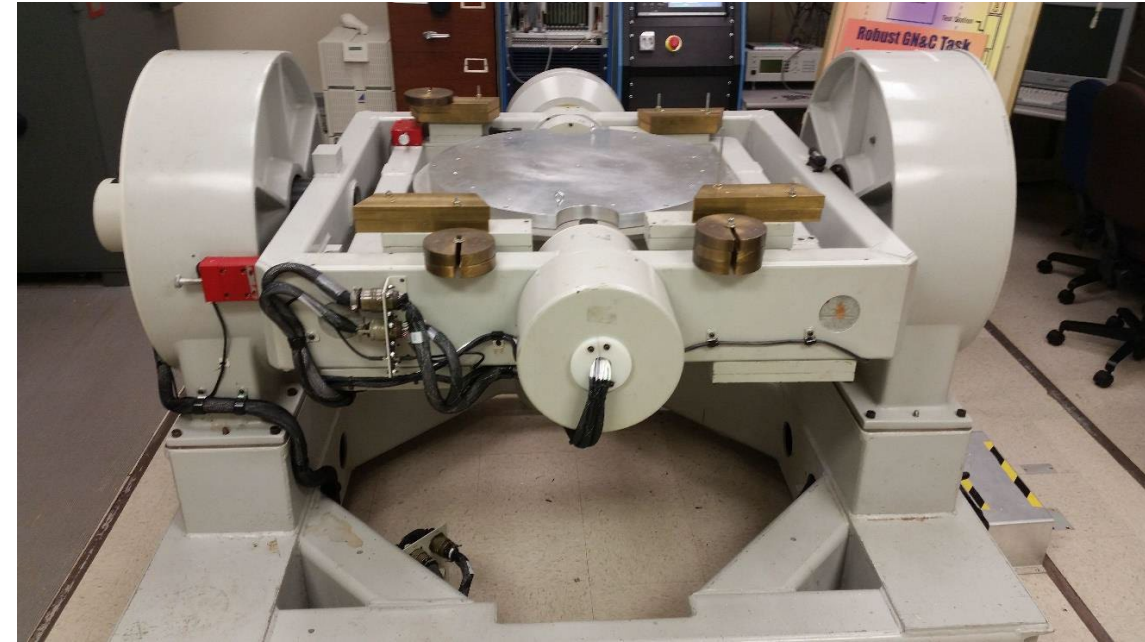


Initialization



- **Accurate navigation state initialization is one of the main challenges of the LFOTID navigation**
- **Currently, the plan is to use the estimated pre-flight initial state**
- **This initial state is loaded in the software on the order of weeks before the flight, and is not expected to be accurate**
- **Once the GPS records the first measurement, the navigation system will re-initialize the position and velocity states using the first measurement**
- **Options are being considered to update the attitude:**
 - Having a high covariance on the attitude, which will cause the attitude to update faster once the RV reaches the upper atmosphere and drag is higher than the IMU accelerometer error
 - Could re-initialize the attitude by assuming that the deceleration is opposite to the velocity, average over a set time

- Preliminary software testing occurred with a standalone cFS model which simulated the output of the IMU and GPS apps
- Further testing was conducted at the MSFC GN&C hardware laboratory
- This testing included mounting the LN200 to the three-axis rate table and simulating an expected flight rotation profile
- The flight computer was connected to the LN200 through slip rings to record and process the data in real time
- This allowed for efficient changes to the flight software as the need for changes appeared





Conclusions and Forward Work



- **A preliminary overview of the LOFTID navigation system is presented**
- **Demonstrated tailoring standard navigation algorithms to this specific mission**
- **Navigation hardware is mature**
- **Forward work**
 - Continued refinement as the vehicle progresses
 - Additional ground testing
 - Integration into the complete FSW stack
 - Post-flight reconstruction algorithm development
- **The design of the navigation system is expected to complete all requirements and operate successfully during the mission**



Questions?