



Updated Kalman Filter to Provide Best Estimated Trajectory of Morpheus

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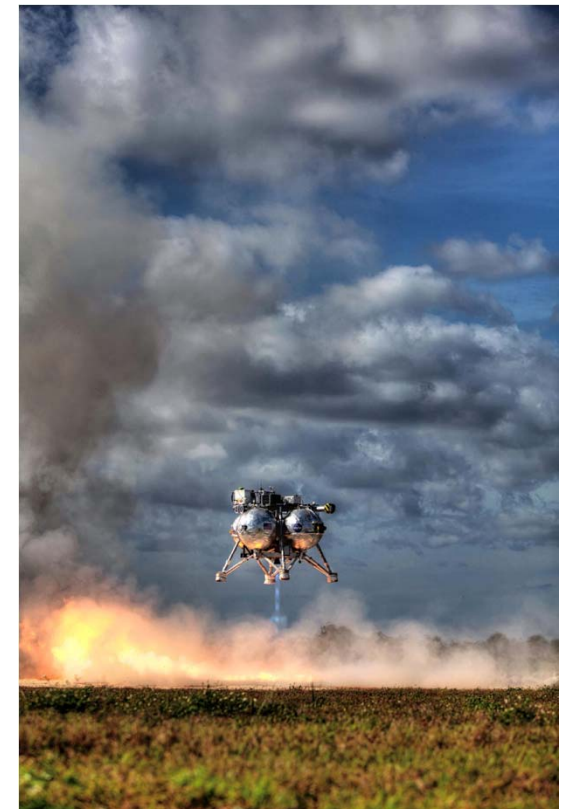
May 6, 2014



Background - Morpheus



- Vertical Test Bed (VTB) for spacecraft technologies
- 46 test flights since 2011
 - Johnson Space Center (Tether)
 - Kennedy Space Center Shuttle Landing Facility (Tether/Freeflight)
- Provides testing platform for:
 - LOx/Methane Engine/RCS (“green” propellant)
 - Lean Development Practices
 - GN&C Algorithms/Sensors
 - Autonomous Landing and Hazard Avoidance Technology (ALHAT)
 - Primary payload

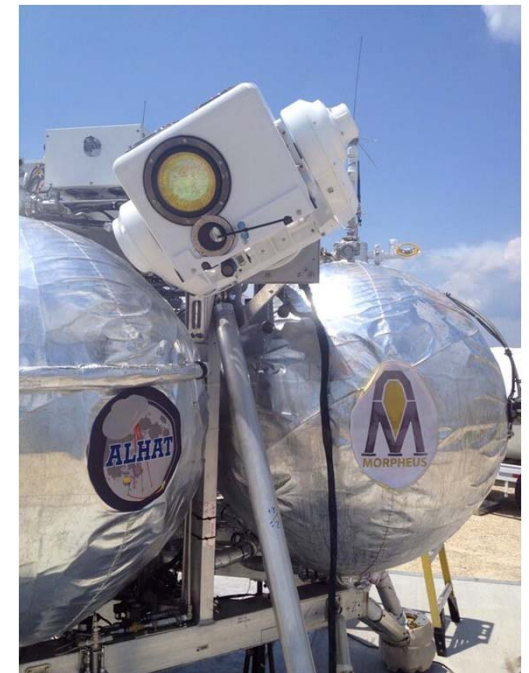




Background - ALHAT

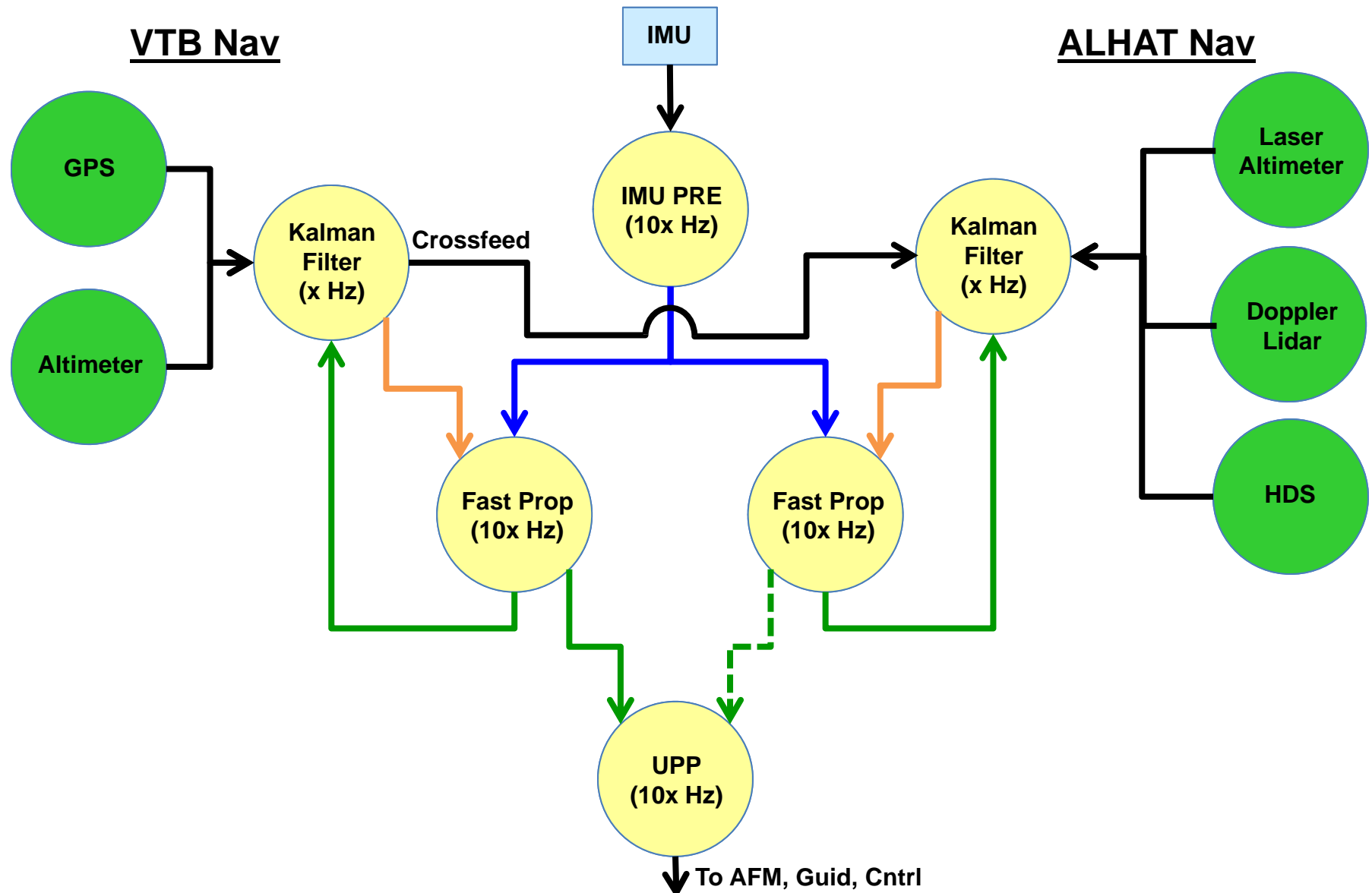


- Apollo 15 landed ~1 m from crater
 - Surface conditions difficult to judge
- Desire ability to land vehicle precisely
 - Any feasible surface condition
 - Any lighting condition
 - Autonomously
- ALHAT uses three sensors to accomplish this:
 - Laser Altimeter (altimetry)
 - Doppler LIDAR (altimetry/velocimetry)
 - Gimballed Flash LIDAR
 - Scans surface
 - Produces Digital Elevation Map (DEM)
 - Provides Hazard Relative Navigation (HRN)
- Testing Objective: TRL-6





Morpheus Navigation Architecture





Project Description



- Best Estimated Trajectory (BET) always came from VTB Nav
 - No external measurements, onboard nav state is best estimate
- ALHAT sensors integrated on vehicle in late March
- Project Statement: Modify the Kalman Filter in Morpheus Flight Software to process measurements from ALL the sensors
 - Additional information improves knowledge of the true trajectory
- Test solution from new Kalman Filter against existing solutions from VTB and ALHAT filter in simulation



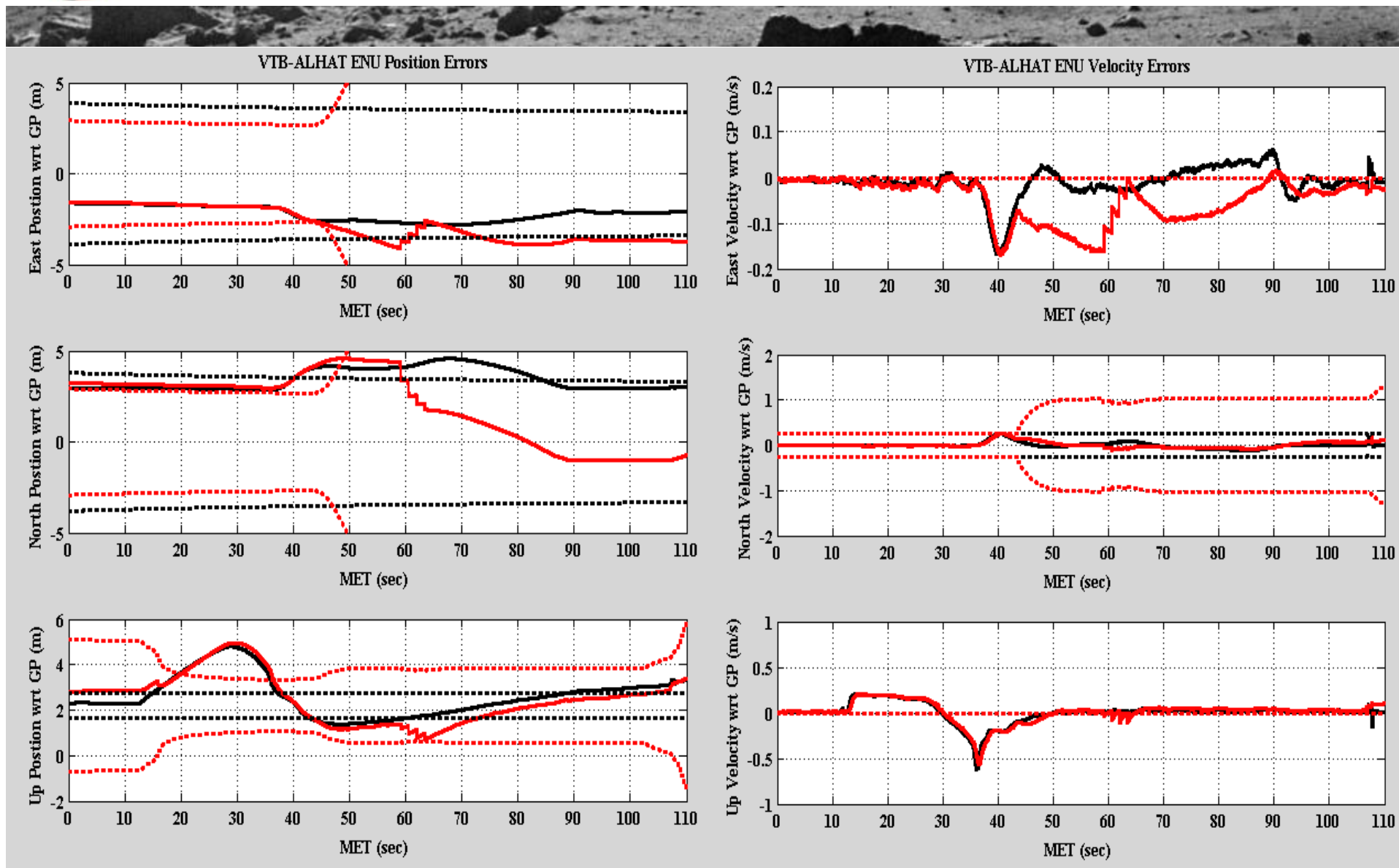
Project Methodology



- Existing Kalman Filter estimates 28 states
 - 3 Inertial position
 - 3 Inertial velocity
 - 3 Attitude
 - 6 IMU bias (gyro and accel)
 - 13 sensor bias (Exponentially Correlated Random Variables)
- Modify the Kalman Filter to handle additional 10 states
 - Reorganize the state vector to insert VTB sensor biases before ALHAT sensor biases, update the pointers so measurement update corrects proper states, regression test
 - Enables new Kalman Filter to run in place of VTB/ALHAT nav
 - Update VTB/ALHAT nav to handle changes (common code)
 - Run trajectory in 6-DOF simulation and compare results



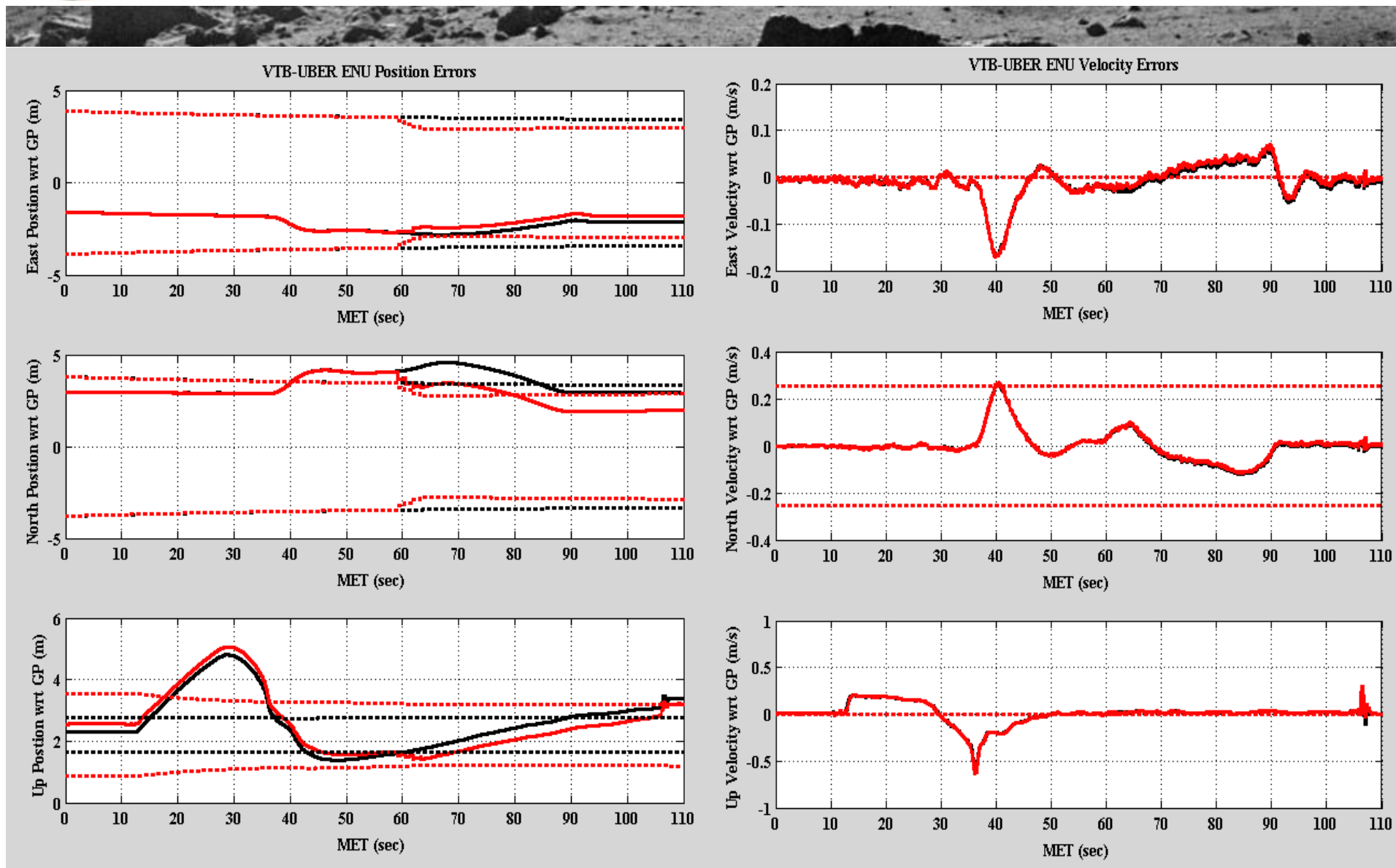
VTB vs. ALHAT ENU Nav Error w/ 3- σ Covariances



— = VTB Nav Error — = ALHAT Nav Error - - - = VTB Nav 3- σ Covariance - - - = ALHAT Nav 3- σ Covariance



VTB vs. UBER ENU Nav Error w/ 3- σ Covariances



— = VTB Nav Error — = UBER Nav Error - - - = VTB Nav 3- σ Covariance - - - = UBER Nav 3- σ Covariance



Future Work/Video



- Playback utility for flight data in development
 - Run actual data through new filter
- Apply smoother to filtered data to improve estimate
 - Rauch-Tung-Striebel Fixed Interval Smoother (Gelb)
- Freeflight 12 (4/30/2014) Video (2 min - time permitting):
 - <http://youtu.be/tmkPJUHYdRA>
 - ALHAT HDS correctly identified safe site 1.4 meters east of surveyed landing pad, provided landing site coordinates to Guidance
 - Next flight scheduled for 5/22/2014
- To follow along:
 - <http://morpheuslander.jsc.nasa.gov>
 - <https://twitter.com/morpheuslander>