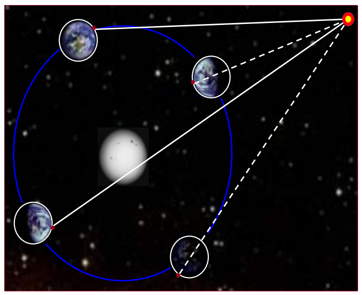
Gravity Probe B Orbit Determination

Paul Shestople, Hunt Small

Motivation

Gravity Probe B requires detailed knowledge of position and velocity of the vehicle:

- Initialization and On-Orbit Checkout Phase: Potential orbit trim operations
- Science Phase: Support of relativity measurements



Requirements

Real time and post processed position and velocity requirements:

	Real Time	Post Processed
Position (rms)	100 m	25 m
Velocity (rms)	1 m/s	7.5 cm/s

Specifications flow down from relativity measurement requirements

Hardware & Modifications

Redundant Trimble Tans Vector III GPS Receivers provided primary position and velocity information.

Trimble TANS Vector III GPS Receiver

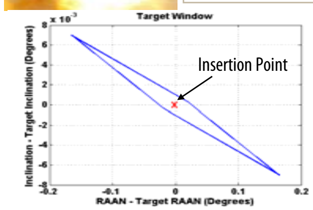
Hardware, software modified by Stanford University and Lockheed for space mission [1].

Satellite Laser Ranging (SLR) provided backup method of orbit determination [2].

GPS Hardware also used for time transfer [3].

Launch

Because Mission Orbital Parameters are sensitive to initial orbit position, GP-B required stringent orbit insertion tolerance, including a 1 second launch window. As can be observed in the plot below, the insertion was a Bull's Eye!



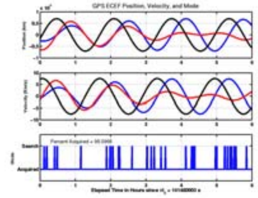
On-Orbit Performance: Hardware

GPS Hardware performance exceeded mission requirements

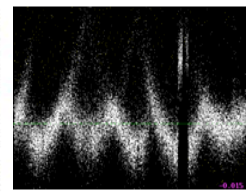
- GPS Hardware Output ~100 million Position, Velocity, Time (PVT)
- Minimal hardware issues were easily fixed

Satellite Laser Ranging performance

- More than 1850 laser solutions obtained, an average of 5 per day.
- While too sparse and ill-conditioned to provide accurate orbit determination solutions, Satellite Laser Ranging does allow independent verification of GPS Orbit Determination Results [2].

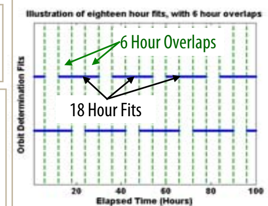


6 hours of on-orbit GPS Data



Laser returns off the GP-B Retroreflector

Orbit Determination Process

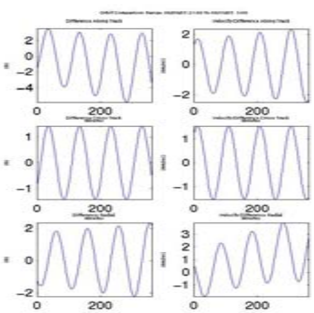


Eighteen hours of GPS data (12 Orbits) centered at noon and midnight UTC, are used to produce one orbit solution using the commercial orbit determination software, MicroCosm. Overlaps between successive solutions are used for consistency and comparison analysis.

MicroCosm Setting Highlights

- Force Modeling includes
  - 50x50 GGM02C Geo-potential Model
  - Luni-Solar Gravitational Model
  - Earth-tide Gravitational Model
  - 2 sinusoid parameters
  - 3 polynomial parameters
  - Atmospheric Drag NOT modeled while drag free
  - Radiation Pressure NOT modeled while drag free
- MicroCosm developed by Van Martin Systems, Inc

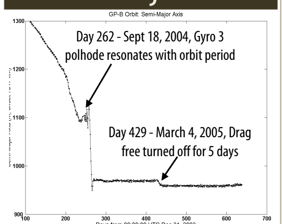
Real Time GPS Results



Typical comparison of six hour overlaps between subsequent orbit solutions.

Overlap Comparison	Along Track	Cross Track	Radial
Position (m)	10	4	5
Velocity (mm/s)	4.5	4	6

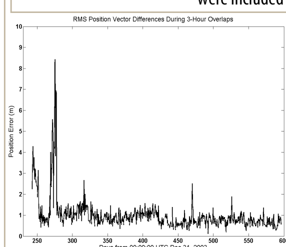
Semi-Major Axis



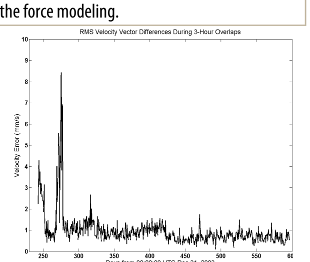
While in drag free mode, the mean semi-major axis oscillated at the difference between the polhode and orbital frequencies. The above plot shows that the history was relatively stable except for two jumps. Around day 262, the increasing polhode frequency of the proof mass (Gyro 3) became equal to and then exceeded the orbital frequency. The corresponding oscillations of the mean semi-major axis then passed through a resonance, leading to an abrupt altitude decrease of about 140 m. The oscillations persisted until the proof mass was changed to Gyro 1, on day 268. On March 4-8, 2005 (days 429-434) the drag-free control was turned off for 5 days, resulting in a decrease of the semi-major axis by 9 m.

Post Processing the Entire Mission

During the science data collection phase, two types of non-gravitational perturbing accelerations were observed in the orbital motion. Both acted along the satellite roll axis (Satellite roll averages out any satellite body-fixed accelerations transverse to the roll axis). One perturbing acceleration was nearly constant each day, and gradually increased over time. The other was nearly sinusoidal and oscillated at the frequency of the polhode motion of the gyroscope used as the proof mass. Polhode motion is a periodic motion of the gyroscope spin axis moving in the gyroscope body-fixed frame due to the difference of principal moments of inertia. The effects of sinusoidal and polynomial terms in the direction of the satellite roll axis were included in the force modeling.



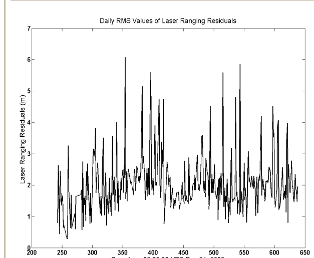
RMS Position Vector Differences



RMS Velocity Vector Differences

Laser Ranging

As an independent verification, laser ranging residuals were compared to GP-B orbit solutions. The plot below shows that the residuals are at the level of 2.2 m (RMS). The laser ranging measurements were not filtered except to discard outliers with residuals greater than 30 m, nor corrected for the 1.75 m offset between the laser reflector and the mass center of the GP-B satellite.



Laser Ranging Residuals Referenced to GPS-Based Orbit Solutions

Conclusions

- Gravity Probe B used GPS equipment to calculate vehicle Position, Velocity, and Time solutions
- Gravity Probe B GPS hardware meet and exceeded mission specifications
- MicroCosm, a commercial orbit determination software package, was used to fit the GPS data
- Ground processing of the GPS data produced solutions which satisfied mission requirements
- Satellite Laser Ranging was successfully used to verify GPS based Orbit Determination solutions

References

1. P. Shestople, et al, "Gravity Probe B GPS Receivers." ION-GPS 04, Long Beach, Ca, Sept 2004
2. G. Hanuschak, et al, "Gravity Probe B GPS Orbit Determination with Verification by Satellite Laser Ranging" ION-GPS 05, Long Beach, CA, 2005
3. J. Li, et al, "Time Transfer between UTC and Local Vehicle Time for the Gravity Probe B Relativity Mission." Proceedings of Annual Meeting of Institute of Navigation, pp.560-570, 2004.
4. J. Li, et al, "On-Orbit Performance of Gravity Probe B Drag-Free Translation Control and Orbit Determination." COSPAR 2006, Beijing China, July 2006

W. W. Hansen Experimental Physics Laboratory • Stanford University, Stanford, CA 94305-4085 • http://einstein.stanford.edu

This research supported by NASA on contract NAS8-39225