Gravity Probe B Attitude and Translation Control System (ATC)

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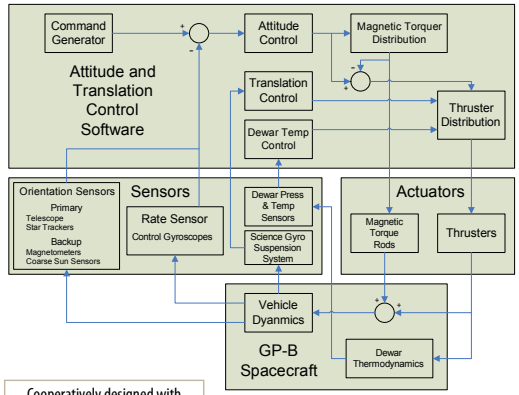
Abstract

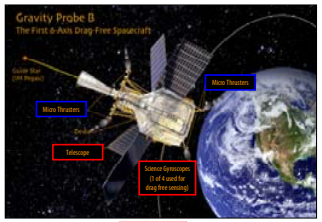
Gravity Probe B is the first space vehicle to provide active control of the vehicle's six degrees of freedom (DOF), three in translation and three in attitude. The Attitude and Translation Control (ATC) system uses helium boil-off gas from the cryogenic system as a propellant for 16 proportional cold gas thrusters to provide forces and torques on the vehicle. Common-mode operation controls the net flow rate from the dewar that is used, in turn, to control the liquid helium bath temperature. The pointing system controls the pointing of the guide star tracking telescope and maintains vehicle roll phase. The translation control system uses acceleration measurements from one science gyroscope's suspension system to null out the effects of external forces from the on-orbit environment. In this way, the vehicle is controlled to fly in a near-perfect gravitational orbit.

Block Diagram



Cooperatively designed with Lockheed Martin Corporation

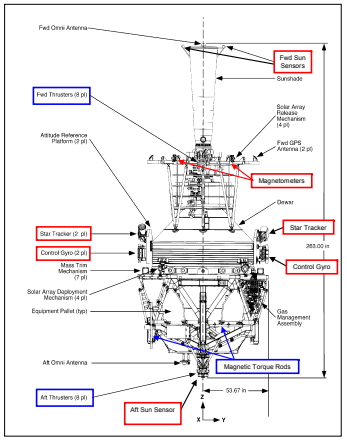
ATC System Hardware



Actuators

16 Proportional Micro Thrusters

The thrusters have a specific impulse of 130 s, and the vehicle has a nominal total mass flow rate of ~8 mg/s.



Telescope

Sensors

2 Control Gyroscopes

2 Star Trackers

Magnetometers

3 Coarse Sun Sensors

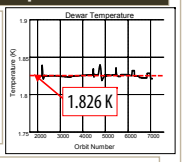
Dewar Pressure Sensor

Science Gyroscope

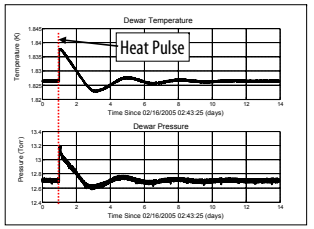
3 Magnetic Torque Rods

Dewar Temp Control

The ATC system maintains a constant dewar temperature of ~1.83 K by controlling the flow rate of helium boil-off from the dewar.

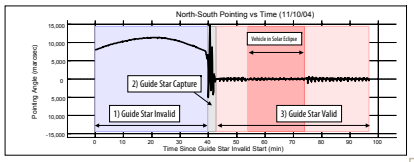


The temperature control behavior is observable during a heat pulse test (used to estimate the amount of helium remaining in the dewar).



Pitch/Yaw Pointing Control

Pointing Performance – One Orbit



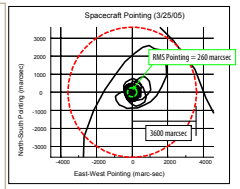
Nominal guide star capture times range from 30 to 90 seconds.

The attitude control goes through three different phases each orbit:

1) Guide Star Invalid – Guide star is blocked by Earth

2) Guide Star Capture – Guide star is re-centered in the telescope field of view

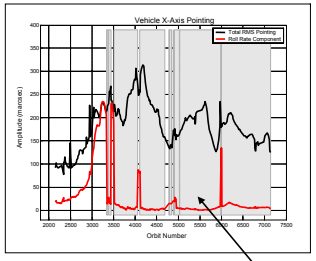
3) Guide Star Valid – Nominal telescope pointing



The RMS vehicle pointing is controlled to less than 320 marcsec (1.55 μrad).

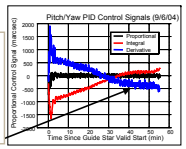
Orbit rate thermal distortion of the control gyro mounting platform is visible in the derivative signal. The integrator compensates for this component of the disturbance.

Pointing Performance - Science Mission



Shaded Regions = Notch Filter "On"

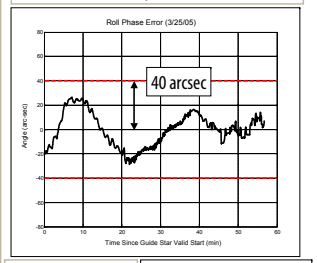
PID Controller Signals



It is important, for the science data analysis, to minimize the pointing signature at the roll rate frequency. A notch filter on the derivative signal is used to attenuate a roll rate disturbance resulting from the roll rate thermal motion of the control gyroscope mounting platform.

Roll Control

The control gyroscopes and star trackers are used to control the spacecraft roll angle to less than 40 arcsec at a constant roll period of 77.5 sec.

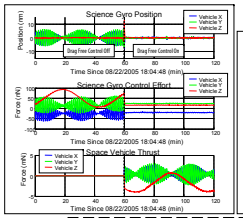


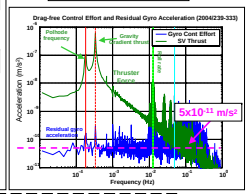
One star tracker, used to update the propagated roll phase, typically identifies two to six stars in the onboard catalog during one roll period.

Onboard Star Catalog Stars

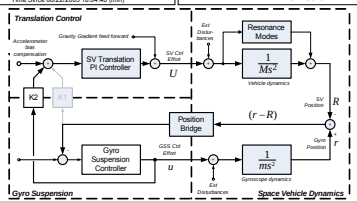
Drag Free Translation Control

The translation control system uses measurements from one science gyroscope's suspension system to control the vehicle's near-perfect gravitational orbit; transverse accelerations on the science gyroscopes are reduced to the 5×10^{-11} m/s² level.



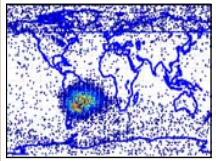


Drag Free Performance – Inertial Space



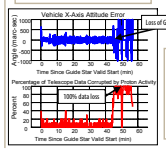
Proton Activity

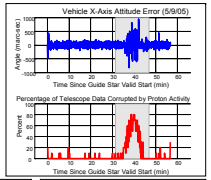
South Atlantic Anomaly (SAA)



A plot of the number of proton hits in the telescope electronics clearly draws out the shape of the South Atlantic Anomaly.

GP-B flies through the SAA at least three out of every fifteen orbits losing, at times, up to 80% of the telescope data to proton corruption.





Solar Flare – Jan 20, 2005

The solar flare that occurred on Jan 20, 2005 blinded the GP-B telescope causing the ATC system to lose lock on the guide star for several orbits.

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