Explanatory Appendix to the Kepler Project call for white papers :
Kepler 2-Wheel Pointing Control

Using the initial Ball Aerospace 2-wheel pointing study discussed in the call for white papers, we herein present a further discussion of the pointing ability we believe can be achieved with the Kepler spacecraft. The X,Y,Z coordinate system discussed here is detailed in a figure shown in the call for white papers. Note that pointing the spacecraft in non-optimal directions may cost more in terms of operational complexity and/or fuel usage, but is possible. An example is given for a pointing to the nominal Kepler field of view

For a repurposed Kepler mission, limited to pointing control attainable with 2 reaction wheels and thrusters, the following performance can be assumed:

1. With the reaction wheels remaining, pointing of the telescope boresight can be attained at any allowable point on the celestial sphere (limited by power and thermal constraints) to a precision limited by the star trackers' ability to determine the spacecraft attitude, ~15-30 arcseconds (reduceable through calibration).

2. Momentum injection through thruster firings allows stabilization of the telescope boresight (spacecraft X axis), with precision and duration dependent on selected attitude and fuel usage.

3. The reaction wheels can maintain pointing for 4 days while absorbing solar torque momentum in the Y & Z axes. This establishes a 4-day cycle for managing wheel momentum, although more frequent management is allowable.

4. Momentum in the X axis must be absorbed through spacecraft roll. Low drift about the boresight limits the sun to the XY-plane.

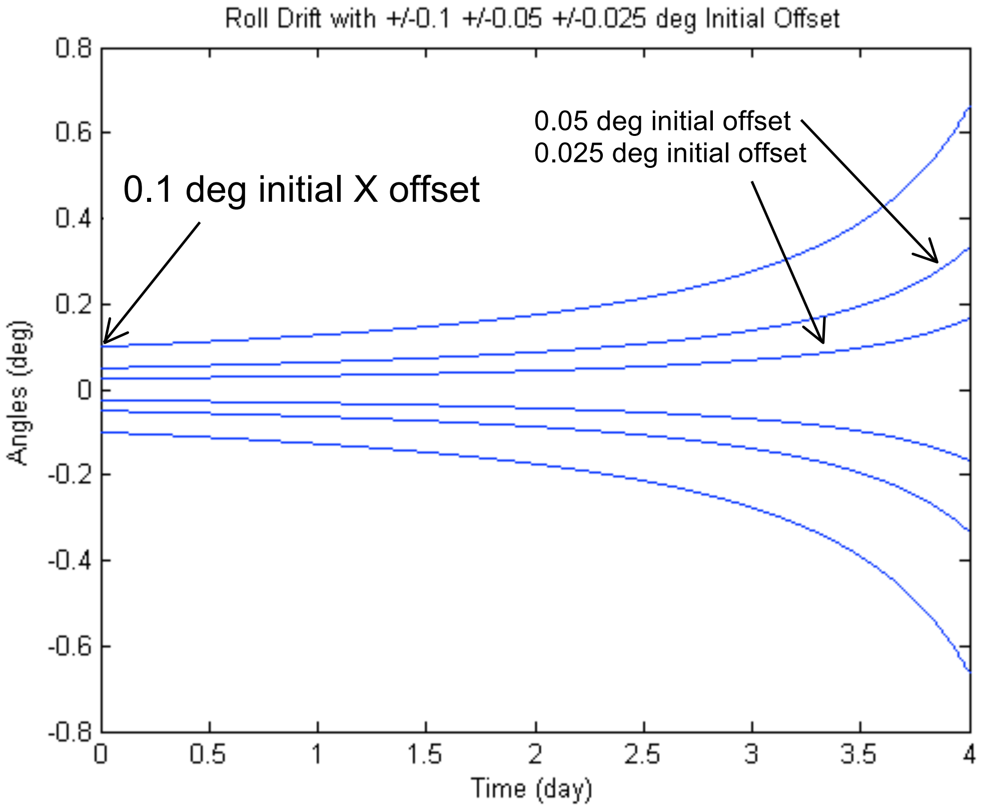
5. Maximum pointing stability is achieved when the spacecraft is pointed in the velocity- or anti-velocity-vectors, where the sun remains in the XY-plane throughout the 4-day period.

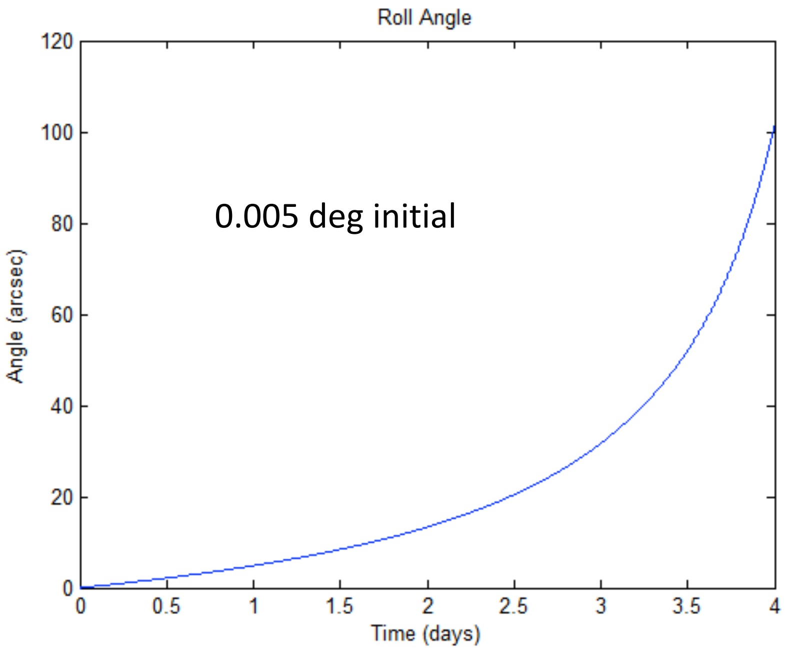
Initial assessments provide the following pointing performance estimates for various pointing attitudes. Performance at other attitudes may be inferred from these examples.

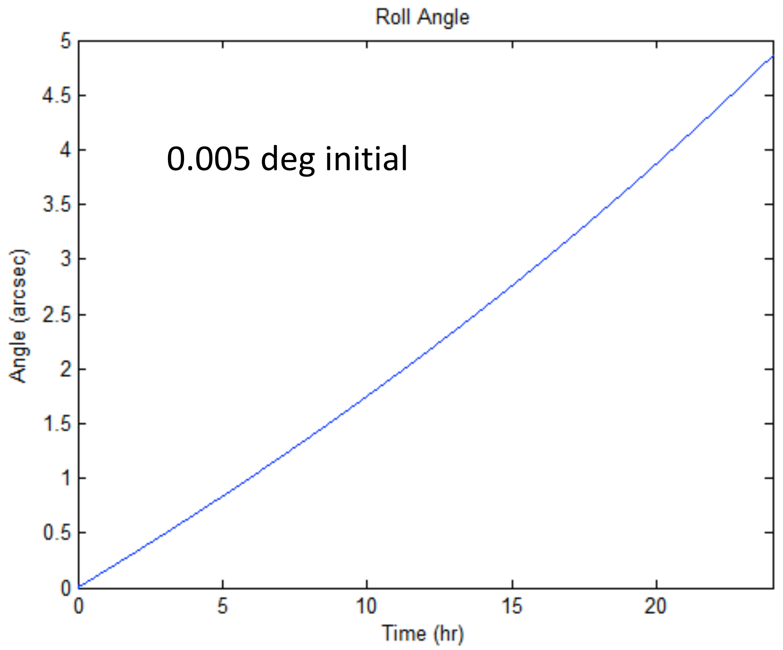
A. <u>Pointing along the velocity vector</u>

   Because the sun remains virtually in the XY-plane throughout the 4-day interval, boresight drift is impacted by the initial imperfection in boresight alignment to zero-out X-axis torques. The following plots show

how the drift varies with initial offset error. Initial offsets can be assumed to be arbitrarily small, limited by the precision of the star trackers. If boresight drift must be controlled more tightly, the initial attitude can be reset more frequently.

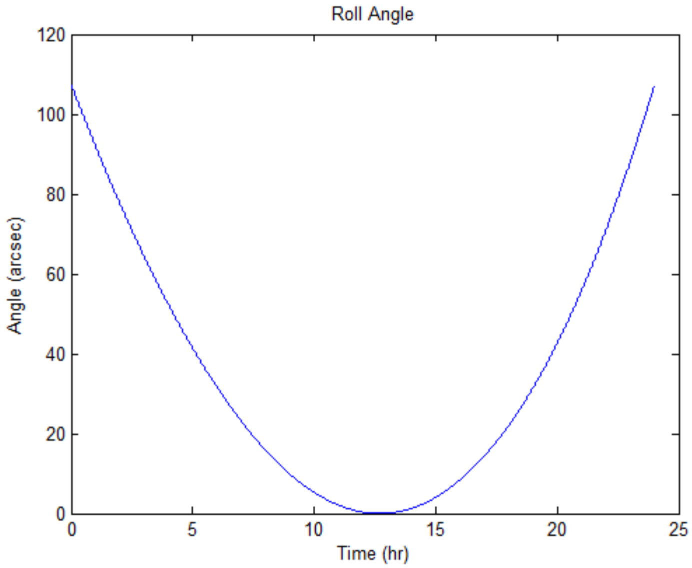


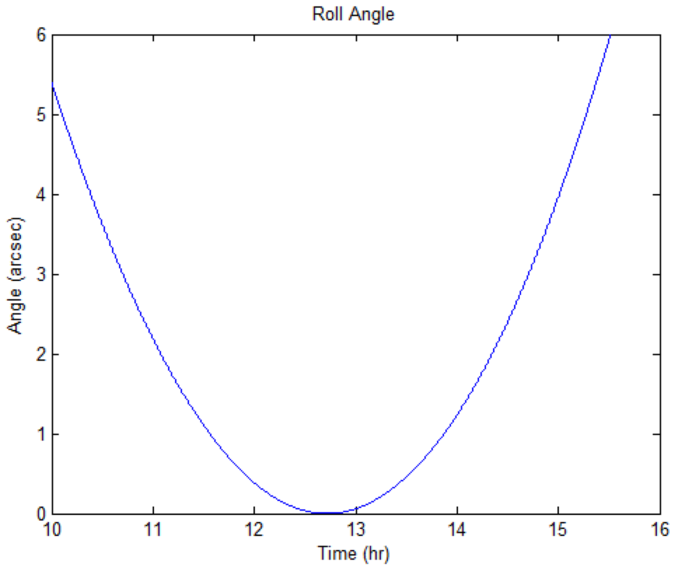




B. Pointing perpendicular to the orbit plane

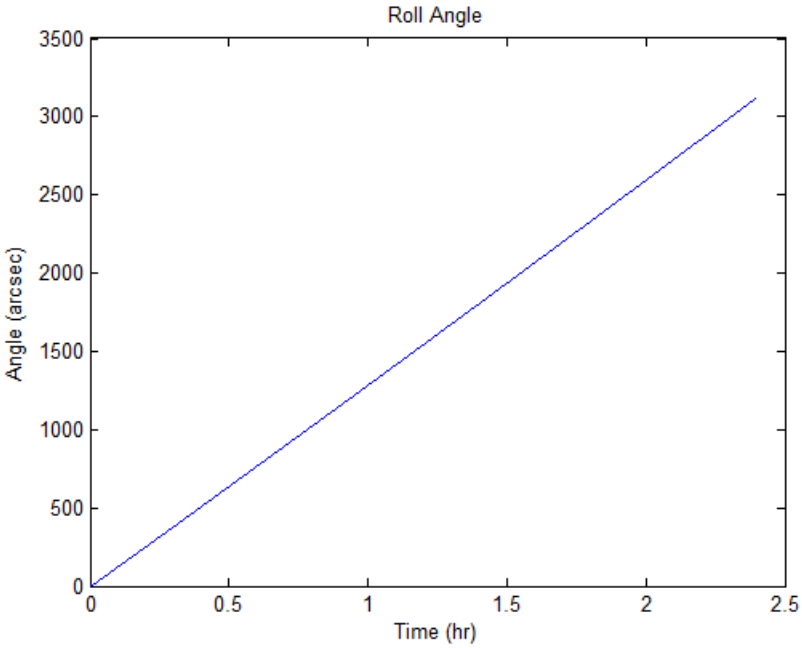
The sun is near the XY-plane but has an apparent motion of approximately 1 degree per day due to spacecraft orbital motion. The following plots show how the boresight drift varies over time.





C. <u>Pointing at nominal science attitude with worst sun (beginning of season)</u>

The sun is well off the XY-plane and has an apparent motion of approximately 1 degree per day due to spacecraft orbital motion. The following plot shows how the boresight drift varies over time.



Example: Observing the nominal Kepler FOV

The nominal Kepler observing approach used 4 93-day pointing attitudes. With 2 wheels, the nominal Kepler FOV can be approximated by the perpendicular to orbital plane case (the system is relatively insensitive to the sun being offset in the Z-axis). With an initial boresight offset biased such that the sun sweeps across the balance point, the Kepler FOV can be observed using 371 1-day pointing attitudes with the boresight error limited to approximately two arcminute.

It may be assumed that pointing performance for any of the attitudes discussed here may be sustained for 2-4 years, depending on the degree of precision pointing required.