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A Geometric Model of a V-Slit Sun Sensor Correcting for Spacecraft Wobble

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Abstract

A V-Slit sun sensor is body-mounted on a spin-stabilized spacecraft. During injection from a parking or transfer orbit to some final orbit, the spacecraft may not be dynamically balanced. This may result in wobble about the spacecraft spin axis as the spin axis may not be aligned with the spacecraft axis of symmetry. While the widely used models in *Spacecraft Attitude Determination and Control* edited by Wertz correct for separation, elevation, and azimuthal mounting biases, spacecraft wobble is not taken into consideration. A geometric approach is used to develop a method for measurement of the sun angle which corrects for the magnitude and phase of spacecraft wobble. The algorithm was implemented using a set standard mathematical routines for spherical geometry on a unit sphere.

1 Introduction

Spin-stabilized spacecraft will exhibit wobble or coning if the principal axes of the vehicle are not aligned with the body axes. This condition exists for some dual spin spacecraft when they are in an all-spun condition before the platform is despun. For vehicles that use integral propulsion to achieve operational orbit, attitude determination while in an all-spun condition can be important, since the attitude determination accuracy will determine the accuracy of the direction of the integral propulsion injection maneuvers.

For our problem the principal axes are well known in the vehicle body system; all that remains is to model the sensors taking vehicle coning into account. The sensors include a V-slit sun sensor and an infrared body mounted horizon sensor measuring earth chord. We will discuss the development of a V-slit sun sensor model accounting for vehicle coning.

2 V-Slit Sun Sensor Model

We wish to produce a model that generates predicted sun sensor measurements given an orbital position, an attitude, and the location of the principal axes in body coordinates. This is what many attitude determination processes require.

We start with the discussion of V-slit sensors in Wertz[1]. The model developed in Wertz is not intended to take vehicle coning into account, but the development does provide the insight required to find a model that does account for coning. **Figure 1** shows the geometry of V-slit sensor with no coning. As seen from the vehicle body coordinate system, the sun will describe a small circle of radius β. That is, the sun describes a small circle about the spin axis of the vehicle as seen from the vehicle body coordinate system.

To develop the V-slit sensor model accounting for a coning vehicle, observe that the small circle that describes the sun motion is no longer centered at the pole of the figure; it is centered about the spin axis of the vehicle, just as in the case without coning. The only difference is that the spin axis is no longer the body z axis. This is shown in **Figure 2.** In Figure 2 P is the spin axis of the vehicle, S_1 is the sun-slit 1 intersection, and S_2 is the sun-slit 2 intersection. The rotation angle, S_1PS_2 is the desired sensor prediction.

To calculate S_1PS_2 the points S_1 and S_2 must first be found. Then the rotation angle S_1PS_2 can be calculated. This task is simple if the analyst's software toolkit includes routines for finding the intersections of small circles and routines for finding rotation angles. The intersections of the sun small circle with the two great circles that define the V-slit fields of view are the

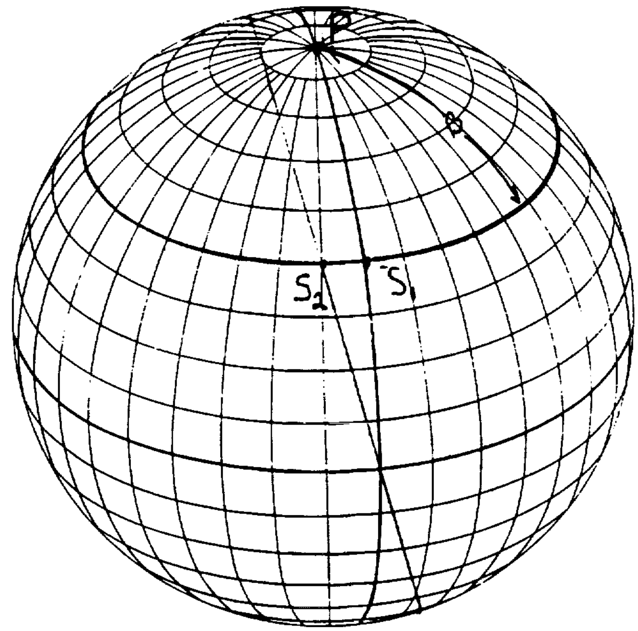

Figure 1 V-Slit Sun Sensor Geometry with No Wobble

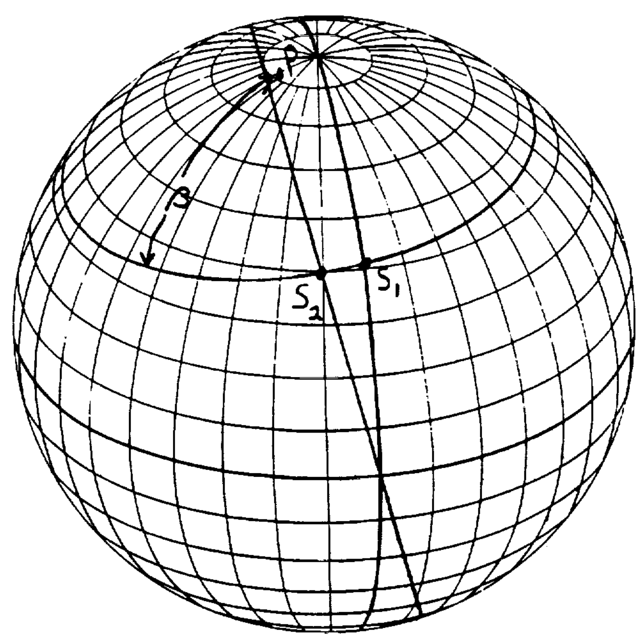

Figure 2 V-Slit Sun Sensor Geometry with Vehicle Wobble

points S_1 and S_2. The rotation angle from first slit crossing to the second slit crossing about the axis of rotation is the rotation angle S_1PS_2, the predicted sensor measurement.

This approach to modeling the V-slit sensor also makes dealing with slit misalignments quite easy, since the slit alignments are described by the location of the poles of the great circles that describe the slit fields of view. Inclusion of slit alignment biases reduces to simple changes to the coordinates describing the poles of the slit great circles. The resulting FORTRAN code is shown in **Figure 3**.

3 Results

Figure 4 compares the predictions of the coning and non-coning V-slit models. The x-axis shows the azimuth of the principal axis in the body coordinate system (the vertical slit of the V-slit sensor is assumed to be at azimuth 0°). The cases shown are for a 3° coning angle; the different lines show different β angles. The size of the model error increases for the extreme elevation angles. Since injection scenarios can involve extreme sun angles, this increases the desirability of using the more sophisticated model.

4 Conclusions

Inclusion of coning effects in V-slit sensor predictions produces a marked improvement in the model accuracy. The adjustment to the V-slit model developed in Wertz is simple and intuitive. Model development is simplified when software utilities for finding rotation angles and intersections of small circles are a part of the analysis environment.

5 References

1. Wertz, James R. (Editor), Spacecraft Attitude Determination and Control, Norwell, MA, Kluwer Academic Publishers, 1978, pp. 217-221.

```
function vslit(ra1,dec1,rad1,ra2,dec2,rad2,beta,wobble,phi)

c ra1, dec1        right asc. and declination of slit #1 pole
c rad1             radius of the small circle that describes slit #1
c ra2, dec2        right asc. and declination of slit #2 pole
c rad2             radius of the small circle that describes slit #2
c beta             sun angle measured from axis of rotation
c wobble           coning magnitude (deg)
c phi              coning phase (deg)

      real*8 ra1,dec1,rad1,ra2,dec2,rad2,beta,wobble,phi,vslit
      real*8 sun(3),sens1(3),sens2(3)
      real*8 vecout1(3),vecout2(3),usens1(3),usens2(3)
      real*8 cross1(3),cross2(3)
      real*8 rad,dang,rotang
      integer flag

c RADECV forms a vector from a right ascension, declination, and magnitude
      call radecv(rad(ra1),rad(dec1),1.d0,sens1)
      call radecv(rad(ra2),rad(dec2),1.d0,sens2)
      call radecv(rad(phi),rad(90.0d0-wobble),1.0d0,sun)

c CONES8 finds the intersections of two small circles
c DANG finds the included angle between two vectors
      call cones8(sens1,rad(rad1),sun,rad(beta),flag,vecout1,vecout2)
      call radecv(rad(ra1-90),rad(dec1),1.0d0,usens1)
      if(dang(usens1,vecout1).gt.dang(usens1,vecout2)) then
         call dup(vecout2,cross1)
      else
         call dup(vecout1,cross1)
      endif

      call cones8(sens2,rad(rad2),sun,rad(beta),flag,vecout1,vecout2)
      call radecv(rad(ra2-90),rad(dec2),1.0d0,usens2)
      if(dang(usens2,vecout1).gt.dang(usens2,vecout2)) then
        call dup(vecout2,cross2)
      else
        call dup(vecout1,cross2)
      endif

c ROTANG finds the rotation angle from vector1 to vector2 about vector3
      vslit = rotang(cross2,cross1,sun)

      return
      end
```

Figure 3 FORTRAN Code for V-slit Sun Sensor Model Accounting for Vehicle Wobble

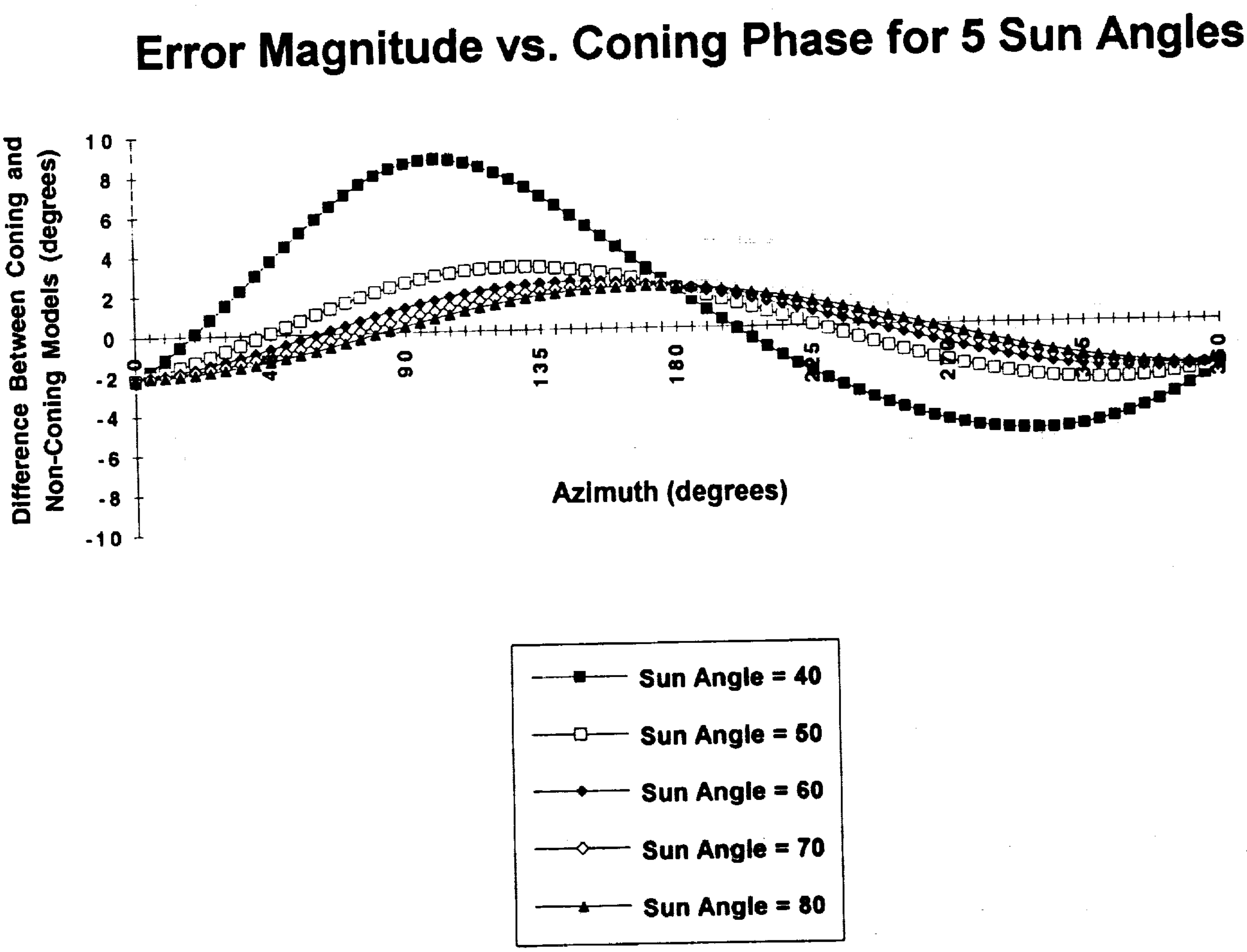

Figure 4 V-Slit Sun Sensor Model Predictions for Coning and Non-Coning Models