Fundamentals of Astrodynamics and Applications 2^{nd} Ed

Errata

Auguts 10, 2003

This listing is an on-going document of clarifications and corrections encountered in the book. I appreciate any comments and questions you find. You may reach me at:

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I categorize the listings as corrections, or as clarifications.

Introduction.

Page xvi, 4th para **: Clarification :** The phrase should read "standardization and documentation" in two places.

Page xvii, Next to last para **: Correction :** "Curriculums" should be "curricula". "Form" should be "from".

Page xvii, Last para **: Clarification :** "All 10,000 satellites" should be "10,000 objects".

Page xviii, 1st para **: Correction :** "tired" should be "tried".

Page xviii, 3rd para **: Clarification :** First sentence, "For academic ..." should be deleted.

Page xviii, 4th para **: Clarification :** "chapter they are cited in" should be "chapter in which they are cited".

Page xx, last sentence**: Clarification :** "!" should be ":".

Chapter 1.

Page 3, 5th para **: Clarification :** Change "Mars and didn't observe" to "Mars and didn't accommodate."

Page 4, 2nd para **: Clarification :** Change "the original science of astrology" to "ancient astrology", and later, "represent the data" to "represent the data adequately."

Page 8, 1st sentence of the quote **: Correction :** The sentences should include "filed" in "things filed past her"

Page 23, Next to last para **: Clarification :** "adequate and even necessary" should changed to "the defining statements".

Page 24, 2nd para : **Correction :** Change "the internal quantity" to "the integral quantity".

Page 27, Last para : **Correction :** Change "[Eq. (C-7)]" to "[Eq. (C-5)]".

Page 32, Middle para : **Correction :** Change "trajectory equation [Eq. (1-23)]" to "trajectory equation [Eq. (1-24)]".

Page 38, Eqtn before Eq 1-40 : **Correction :** Add "m_i" to the middle term.

Page 39, Footnote **: Correction :** The footnote is confusing, adds nothing to the discussion, and should be deleted.

Page 40, 1st para **: Correction :** “Sundmann” should be “Sundman”.

Page 41, 1st sentence **: Clarification :** Insert “the” before “common practice”, and insert “we have” at the end of the sentence. It should also be pointed out that, although it’s commonly called the mass ratio, μ_* is *not* actually the mass ratio; $\mu_*/(1 - \mu_*)$ is.

Page 42, Eqtn 1-44**: Correction :** Delete $\mu_*(1 - \mu_*)$.

Page 45, After figure 1-18: **Clarification :** Add the following paragraph after the figure. “I’ve taken the notation of Szebehely (1967) and Kaplan (1976) in placing L_2 between the two bodies. Other notations place L_1 between the bodies.

Page 47, Last sentence in problem 6 **: Correction :** Change “question 9” to “question 8”.

Chapter 2.

Page 53, Last para. **Clarification:** Change the conversion from rad/tu to “(14)(2π)(86400) = 0.001 018 109 rad/sec”.

Page 68, Eqtn 2-43**: Correction :** The equation number should be on the following equation.

Page 79, Algorithm 4 **: Clarification :** The side bar lines are not lined up.

Page 91, Footnote**: Clarification :** Change the footnote to read:

We can also adopt a matrix notation and write the update in Eq. (2-57) as a state vector of position and velocity vectors, and with Φ_s as a matrix containing *scalar* 3×3 matrices (See Sec. C.3) of the f and g values,

$$\bar{X}_{k+1} = \begin{bmatrix} f & g \\ \dot{f} & \dot{g} \end{bmatrix} \bar{X}_k = \Phi_s \bar{X}_k$$

The Φ_s matrix is called the ***state-transition matrix*** because it moves the state through time. Be aware that Φ_s will not propagate the state errors that we’ll discuss in Chapter 10. I’ll use the “s” subscript to differentiate the two.

Page 93, Eqtn above 2-65 **: Correction :** The ydot term should not be negative.

Page 94, Last equation **: Correction :** The unnumbered Taylor series expansion of r should be

$$\vec{r}(\tau) = \vec{r}(0) + \dot{\vec{r}}(0)\tau + \frac{\ddot{\vec{r}}(0)\tau^2}{2!} + \frac{\dddot{\vec{r}}(0)\tau^3}{3!} + \dots$$

Page 107, 2nd para **: Clarification :** Change the first sentence to “The ***right ascension of the ascending node***, Ω, RAAN, or simply the ***node”***. Insert the following footnote concerning the RAAN: “The term ***longitude of the ascending node*** is often used, but remember that it is measured from the vernal equinox, not Greenwich. If longitude is intended, an ECEF frame must be used."

Page 111, Para above Eq 2-91**: Correction :** Change "is the location of the satellite from periapsis; it's analogous to the true anomaly but not equal to it. The expression uses the mean anomaly, *M*, which we'll discuss later, " to "is the location of the satellite from the vernal equinox. The expression uses the mean anomaly, *M* (pgs 53-43).".

Page 115, Fig 2-19 **: Clarification :** Change the figure to show data starting in col 1, and add the ephemeris type field.

Page 116, Eq 2-97 : **Correction :** The f_r multiplier should be added to the COS(i) term in the denominator of the last two equations. In addition, the elements should include the additional notations (a_f, n, a_g, L, χ, ψ). The text should indicate for f_r that "It's +1 for all direct orbits, and –1 for nearly retrograde orbits."

Page 118, Eq 2-99 **: Correction :** Eq (2–99) is not correct. g_p and h_p have an extra term under the radical, and G_p and H_p do not need the minus sign in the front. Finally, g_p and H_p need a minus sign before the 2 in the radical.

$$
\begin{aligned}
g_p &= \sqrt{2(\sqrt{\mu a}(1-\sqrt{1-e^2}))}\,\text{COS}(\omega+\Omega)\\
h_p &= \sqrt{-2(\sqrt{\mu a(1-e^2)}(\text{COS}(i)-1))}\,\text{COS}(\Omega)\\
G_p &= \sqrt{2(\sqrt{\mu a}(1-\sqrt{1-e^2}))}\,\text{SIN}(\omega+\Omega)\\
H_p &= \sqrt{-2(\sqrt{\mu a(1-e^2)}(\text{COS}(i)-1))}\,\text{SIN}(\Omega)
\end{aligned}
$$

Page 125, Example problem 2-6 **: Correction :** The numerical values should use e = 0.83285 and ν = 92.335 throughout. The numerical results change as follows:

$$
\hat{r}_{PQW} = \begin{bmatrix} \dfrac{p\,\text{COS}(\nu)}{1+e\,\text{COS}(\nu)} \\ \dfrac{p\,\text{SIN}(\nu)}{1+e\,\text{COS}(\nu)} \\ 0 \end{bmatrix} = \begin{bmatrix} \dfrac{1.735\,27\,\text{COS}(92.335)^\circ}{1+0.832\,85\,\text{COS}(92.335)^\circ} \\ \dfrac{1.735\,27\,\text{SIN}(92.335)}{1+0.832\,85\,\text{COS}(92.335)^\circ} \\ 0 \end{bmatrix} = \begin{bmatrix} -0.073\,181\,9 \\ 1.794\,728\,1 \\ 0 \end{bmatrix} \text{ER}
$$

$$
\hat{v}_{PQW} = \begin{bmatrix} -\sqrt{\dfrac{\mu}{p}}\,\text{SIN}(\nu) \\ \sqrt{\dfrac{\mu}{p}}(e+\text{COS}(\nu)) \\ 0 \end{bmatrix} = \begin{bmatrix} -\sqrt{\dfrac{1}{1.735\,27}}\,\text{SIN}(92.335) \\ \sqrt{\dfrac{1}{1.735\,27}}(0.832\,85+\text{COS}(92.335)) \\ 0 \end{bmatrix} = \begin{bmatrix} -0.758\,500\,2 \\ 0.601\,313\,3 \\ 0 \end{bmatrix} \frac{\text{ER}}{\text{TU}}
$$

$$
\left[\frac{IJK}{PQW}\right] = \begin{bmatrix} -0.377\,860\,07 & 0.554\,641\,79 & -0.741\,346\,25 \\ -0.462\,525\,60 & 0.580\,556\,38 & 0.670\,092\,80 \\ 0.802\,054\,76 & 0.596\,092\,93 & 0.037\,166\,95 \end{bmatrix}
$$

the numbers carry through, and the final position and velocity vectors are:

$$= \begin{bmatrix} 1.023\,08 \\ 1.075\,79 \\ 1.011\,13 \end{bmatrix} \text{ER} = \begin{bmatrix} 6525.344 \\ 6861.535 \\ 6449.125 \end{bmatrix} \text{km} \qquad \textit{and} \qquad = \begin{bmatrix} 0.620\,12 \\ 0.69\,992 \\ -0.249\,92 \end{bmatrix} \text{ER/TU} = \begin{bmatrix} 4.902\,276 \\ 5.533\,124 \\ -1.975\,709 \end{bmatrix} \text{km/s}$$

Page 133, 1st equation **: Correction :** Should be (remove plus sign by r)

$$m = r_o r(1 + \cos(\Delta\nu))$$

Page 134, problem 1 **: Clarification :** Remove “Hint”. It’s a piece of information necessary to find the universal variable.

Page 146, 1st sentence **: Clarification :** Add “For locations on the ellipsoid” at the beginning.

Page 154, 1st para **: Clarification :** Change “direction” to “angular location” in the first full sentence.

Page 157, 2nd para **: Clarification :** Add the following last sentence, The Earth-Moon barycenter is about 4671 km from the geocenter, in the direction of the Moon.

Page 158, bottom footnotes**: Clarification : Add “**I’ll use ECEF for generic references to the ITRF system.” Then change the footnote to read as follows:

The US DoD uses the WGS-84 terrestrial frame. It’s practically identical to the ITRF, but it’s realized through GPS observations. Because the positions of many fundamental stations in the WGS-84 solutions are not adjusted, but defined *a-priori* by their adopted ITRF positions, modern realizations of the WGS-84 frame are now closely aligned with the ITRF.

Confusion may exist because the ITRF system is frequently called the *Earth-Centered, Earth-Fixed* (ECEF) coordinate frame. The term “Earth-fixed” describes a terrestrial reference system whose net global orientation remains unchanged over time with respect to the crust of the Earth. However, imprecise use of this term invites confusion. For example, the US Air Force Space Command has historically reserved the term “*Earth-Fixed Greenwich* frame, EFG” for the (rotating) pseudo-body fixed frame (no polar motion), and used “*Earth-Centered Rotating*, ECR” to describe the Earth-fixed ITRF!

Chapter 3.

Page 162, 3rd para and Fig 3-15**: Clarification :** Change “The *S* axis points in the direction of the velocity vector” to “The *S* axis points in the direction of (but not necessarily parallel to) the velocity vector”. In Fig 3-15, the velocity vector arrow should be to the left of the S-axis.

Page 163, 2nd para **: Correction :** The definitions of pitch and yaw are switched; yaw is rotation about a vertical axis (like steering), so the axis is the radial vector, and pitch is pointing the nose up or down, so the axis is the angular momentum vector. Occurs two places each.

Page 164, Fig 3-16**: Clarification :** The NT-axes should be rotated so the N-axis is to the right of the radial direction.

Page 170, 2nd para**: Correction :** Change “We’ll derive” to “We have derived”.

Page 172-174, Sec 3.4.3**: Correction :** The references to IJK are ambiguous and should be changed to ECI (Inertial) except for the SEZ transformation, which should be deleted and replaced with

Transformations between SEZ and satellite body:

$$\vec{r}_{Body} = \text{ROT}3(Yaw)\text{ROT}1(Roll)\text{ROT}2(Pitch)\vec{r}_{SEZ} \qquad (3\text{-}3)$$

Page 173, 1st sentence **: Clarification :** Add: “Note that $\vec{\rho}$, $\dot{\vec{\rho}}$ are the slant range vectors from a site to the satellite.”

Page 174, 177, Sec 3.4.4**: Correction :** The reference to IJK should be ECEF to be more precise.

Page 178-179, Alg 13**: Correction :** Change “a = 1” to “a = R ”. Also reverse the inequalities on the IF statement.

Page 183, Eq 3-37 **: Correction :** The third term should be $2\lambda_{ecliptic}$, not $\lambda_{ecliptic}$.

Page 185, Middle Para. **Clarification:** Change the first two senteences to: For civilian timekeeping, we define ***local time***[1] as offsets from UTC. This creates time zones for particular regions.

Page 186-187, Julian Date Algorithms : **Clarification** : Add the note “use 61 seconds if the day contains a leap second” to the discussion.

Page 188, Sentence before Eq 3-40 **: Clarification :** Add “for J2000” before “is”.

Page 191, 2nd para **: Clarification :** Change “mean Sun and that sidereal time is equal to the hour angle” to “mean Sun and he defined sidereal time as the hour angle.” Also, delete the next sentence, “Thus, ...”

Page 191, 4th para **: Clarification :** Change “Some applications drop the cubed term because” to “Sometimes the last term is ignored because.”

Page 191, Last sentence **: Correction :** Delete the word “for”.

Page 192, Example problem **: Correction :** The Julian centuries, T_{UT1}, should be “ –0.073 647 919“ not “–0.073 648 186”.

Page 194, SI definition **: Clarification :** Add “at 0° K” at the end of the sentence.

Page 196, 1st para **: Clarification :** Change “Later, I’ll show” to “I’ve shown.”

Page 204, Alg 22 **: Clarification :** Change “Temp” to “τ.”

Page 208, top eqtn **: Correction :** The velocity term should include the cross product, and both vectors should be identified as *pef*, not *x*.

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1. Local time is sometimes abbreviated LST for Local Solar Time, however, this could be confused with Local Sidereal Time, so I’ll always use LT for local solar time.

$$\vec{r}_{pef} = \text{ROT3}(-s')\text{ROT1}(y_p)\text{ROT2}(x_p)\vec{r}_{ITRF}$$
$$\vec{v}_{pef} = \text{ROT3}(-s')\text{ROT1}(y_p)\text{ROT2}(x_p)\vec{v}_{ITRF} + \vec{\omega}_{\oplus} \times \vec{r}_{pef}$$

Page 209, Eq 3-52 **: Correction :** The constant should be “84,381.448”, not “84,381.948”.

Page 211, algorithm **: Correction :** The vectors should be identified as *pef*, not *x* and the sign on the second equation should be positive.

Page 213, Fig 3-26 **: Clarification :** Change the orientation of the vernal equinox direction to be aligned through the center of the Earth.

Page 219, 1st para in Section 3.7.5, Eqtn 3-66**: Correction :** The obliquity of the ecliptic should be the mean value, not the true value indicated. This occurs in two places, and in equation 3-65. The following footnote should be added. Because the angle is actually measured along the mean equator and then projected onto the true equator, we use the mean obliquity of the ecliptic. The velocity expression should include $-\vec{\omega}_{\oplus} \times \vec{r}_{PEF}$.

Page Page 221, 222, Several **: Correction :** In Eq 3-70 and the algorithm on page 222, change rITRF to rPEF. Change the first full para first sentence with “By using $\vec{r}_{PEF}$, we correct the velocity before the final transformation for polar motion.” Delete the sentence beginning with “Also, we need the ITRF” in that same paragraph. Replace the rFK5 with rJ2000 on that page. Insert the following sentence after “rotating coordinate system” in the next to the last para, “If the acceleration is also needed, use Eq. (3-24) similar to the use of Eq. (3-23) in Eq. (3-70) above”. The velocity expression should include $-\vec{\omega}_{\oplus} \times \vec{r}_{PEF}$. Finally, the transposes should all be changed in the equations to maintain consistancy with the preceding discussions. They are correct as they are written, but are inconsistent with the previous material and this could cause confusion.

Page 224-225, Example **: Correction :** Change the velocity vpef to -2.905 263 10, and the vITRF to -3.187 017 92 and -2.905 271 23.

Page 227, 1st para**: Clarification :** Change the first paragraph to start as follows.

An exact and consitent definition of TEME is difficult to find in the literature. In general though, there are three features to select from—the number of terms in the nutation calculation, the inclusion of the kinematic terms in the equation of the equinoxes, and any truncation for small angles.

Chapter 4.

Page 241, 3rd para **: Clarification :** Change “broadcast a planar, continuous” to 'broadcast a planar, continuous-wave.”

Page 247, Last sentence of 2nd para **: Clarification :** Change “possible, even though you need the velocity only for error prevention” to “possible—even if you need the velocity only to resolve ambiguities at zenith”.

Page 251, Eqtn 4-6 **: Correction :** Change “IJK” to “ECEF”.

Page 252, Several **: Correction :** Change LST to λ in the equations. Break out AST and λ in the figure. Add the following footnote: A simplification is sometimes used when the differences of ECI and ECEF are not important. In these cases, λ is replaced by θ_{LST} which approximates the major numerical difference with the coordinate systems.

Page 254, Alg 27 **: Correction :** Change IJK to ECEF and LST to λ.

Page 255, Last sentence**: Correction :** Change “each” to “all”.

Page 256-7, General comment **: Clarification :** Change the geocentric references to a generic latitude. Change the middle sentence from “I include these equations because they are valid within a particular frame (MOD, TOD, etc.). Although this problem seldom arises in actual operations,” to “Although I include these equations, they are only valid for an observer in the PEF frame, and an object in the uniform equinox of date (because θ_{LST} is used). Thus, it is not accurate enough for modern applications, but”. Finally, replace the last sentence at the end of the first full paragraph on pg 256. “The type of latitude is not specified because it’s implied by the observations, that in turn are measured from a particular plane. For azimuth, this plane is typically the horizontal plane, which determines the type of latitude.”

Chapter 5.

Page 263, Several, First para of 5.1.1**: Correction :** Change “sections” to “section”. Change “accuracy of as” to “accuracy of”. Reorganize the first para in 5.1.1.

Page 264, Fig 5-1 **: Correction :** Move the I-axis to the right, and identify the ecliptic latitude.

Page 265, 2nd para **: Clarification :** Add the following reference after Taff, “or Brouwer and Clemence, 1961, 76”.

Page 267, Example problem **: Clarification :** Add the following statement. “Computer implementations should first find $\delta_{\odot}$, and then use ATAN2 to find $\alpha_{\odot}$ with

$$\mathrm{SIN}(\alpha_{\odot}) = \frac{\mathrm{COS}(\epsilon)\,\mathrm{SIN}(\lambda_{ecliptic})}{\mathrm{COS}(\delta_{\odot})} \qquad \mathrm{COS}(\alpha_{\odot}) = \frac{\mathrm{COS}(\lambda_{ecliptic})}{\mathrm{COS}(\delta_{\odot})}\text{“}$$

Page 270, Ex problem**: Clarification :** Remove the Sun symbol from GMST.

Page 273-275, Moon longitude equation **: Correction :** The constant should be 481,267.883, not 481,267.8813.

Page 275, Next to last sentence in the example problem **: Clarification :** Add the following comment. Computer programs should use ATAN2 with Eq. (4-20) to first find α. Also, the last few digits of the angles should be declination = -20.477 702, and alpha = 113.308 897, or 246.691 103.

Page 285, Fig 5-6**: Clarification :** Change the figure to add additional information..

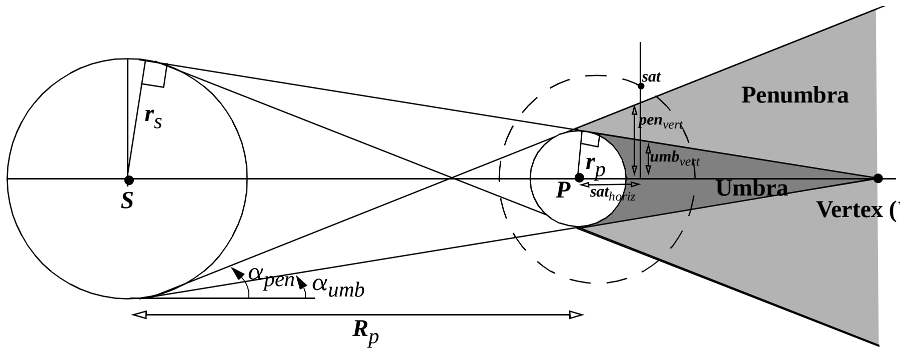

Figure 0-1. **Eclipse Geometry.** The general geometry for eclipses involves a primary body (Earth) and a secondary body (Sun). Eclipses occur within the umbra and the penumbra regions. Notice the scales are greatly exaggerated; the actual angular departure of the penumbra from the umbra region is actually rather small (See also Fig. 5-2). For the Sun-Earth system, $PV \approx 1.384 \times 10^6$ km, or about four times the distance to the Moon. The angles are useful for quick calculations. The dashed line represents an arbitrary orbit. The vertical and horizontal components are used in determining instantaneous shadow positions.

Page 287-288, Algorithm 34 **: Correction :** Remove the absolute value around the first "if" statement. Change the "1's" to "$R_{\oplus}$" on the following page.

Page 298, Moon parallax example **: Correction :** The value should be "0.9507° (57') for the Moon".

Page 301, first full para**: Correction :** Change "geocentric, topocentric" to "geocentric and topocentric". Also, add a new section for the semi-diameter.

Semi-diameter

The semi-diameter is half the angular extent of an object. It's often used in calculations to determine if the field-of-view of a sensor will come near an object (Sun, Moon, Earth). Don't confuse this with parallax. The semi-diameter is measured from a single location. Consider the following figure. We can develop a simple expression for the semi-diameter.

$$\mathrm{TAN}(\alpha_{sd}) = \frac{r_{object}}{|\vec{r}_{Sat2object}|} \quad (3\text{-}4)$$

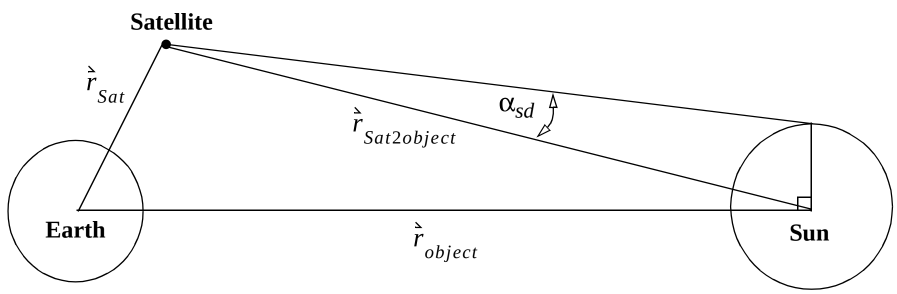

Figure 5-13. Semi-diameter. The semi-diamter is the angular extent of an object viewed from a single location. This figure is greatly exaggerated.

Typical values for the Sun are 0.2666° or about 16', and for the Moon, 0.259°, or about 15' 54".

Chapter 6.

Page 316, Eqtn 6-9**: Correction :** Add absolute values to make the equation completely general.

Page 320, 1st para of example **: Correction :** The example problem should reference Example 6-1.

Page 321, 4th Eqtn **: Clarification :** The two equations appearing on the same line should be more clearly separated.

Page 321, Last sentence**: Correction :** Change "with an large" to "with a large".

Page 322-323, Last para and 1st para**: Clarification :** Change "*perigee as possible*" to "*periapsis as possible*", and change "to burn near perigee" to "to burn near periapsis".

Page 331-335, general comment **: Clarification :** The longitude of ascending node could be changed to the RAAN as suggested on page 107.

336, 2nd para **: Clarification :** Add the following footnote to the end of the paragraph. "Practical maneuver planning uses optimization techniques to simultaneously solve specific thruster characteristics (thrust, fixed-$\Delta \boldsymbol{v}$, orientations, etc.) and mission constraints (placement and frequency of burns), given knowledge of the vehicle (ephemeris accuracy, thrust models, etc.)."

Page 340, 1st para, 4th sentence : **Clarification** : Add the following statement to the end of the sentence, "the previous section, but if the fixed-Δv Δi isn't acceptable, another motor may be required."

Page 342-343, Example problem **: Clarification :** The payload angles should be included in the FIND section. The subscripts should be changed on the payload angles to match the terminology defined on page 305. The text on pg 343 should be as follows:

If we assume that the booster can provide the calculated change in velocity, we can determine the orientation of the burns using Algorithm 43. Note that this is usually not the case. If the fixed-Δv doesn't match 4721 m/s, another analysis, or motor will be needed.

$$\cos(\gamma_a) = -\frac{v_{initial}^2 + \Delta v_a^2 - v_{trans_a}^2}{2 v_{initial} \Delta v_a} = -\frac{0.985\,377^2 + 0.314\,057^2 - 1.296\,206^2}{2(0.985\,377)0.314\,057}$$

$$\cos(\gamma_b) = -\frac{v_{trans_b}^2 + \Delta v_b^2 - v_{final}^2}{2 v_{trans_b} \Delta v_b} = -\frac{0.201\,967^2 + 0.227\,973^2 - 0.388\,957^2}{2(0.201\,987)0.227\,973}$$

$\gamma_a = 9.4384°$, and $\gamma_b = 50.5439°$

Page 342, Next to last equations **: Clarification :** Each of the inclination change should be negative. Δv_a should be equal to 0.312 405 ER/TU.

Page 346, just above the definition of synodic period**: Correction :** " k" should be replaced by $\frac{2\pi}{\omega_{int} - \omega_{tgt}}$.

Page 354, Algorithm 46: **Correction :** To find the true longitude, insert the following.

Find the equatorial component of u_{int} using Fig. 6-8 and Eq. (C-23).

$$\text{TAN}(\lambda_u) = \text{COS}(i)\text{TAN}(u_{int})$$

Find λ_{true} for interceptor at t_1 $\lambda_{true_{int1}} = \Omega + \lambda_u$

Page 361, Last para **: Correction :** Add the following sentence to the last paragraph on the page, "If r_i is the initial radial distance,". The equations also should replace "R" with "r_i".

Page 362, 1st para **: Clarification : **pp. 333–335/362- The units of *vacc* and *ai* on the graphs are not stated. The numbers for *ai* in Figure 5–23 are missing.**

Page 366, Ex 6-12 **: Correction :** The vehicle acceleration should be 4.0×10^{-3} m/s^2, not 4.0×10^{-6} m/s^2.

Page 374, 1st para **: Clarification :** Last paragraph is redundant — the same points are expressed on the previous page.

Page 375, 2nd sentence **: Clarification :** Replace "using another assumption about the" with "using the first-order criterion with the".

Page 376, 3rd equation **: Clarification :** The $\vec{\omega}$ vectors should have an "R" subscript.

Page 385, Figure 6-27 **: Correction :** The top *xo* labels should be xo, and they are positive. The bottom values are negative. Add the comment to the text in the figure caption. Note, these straight lines are not physically possible for an extended period of time.

Page 397, Top right equation **: Correction :** The equation should not have the "335" in the rotation.

$$[\boldsymbol{X}_{int}] = \mathrm{ROT}3(\Delta\ \Lambda_z)[\boldsymbol{X}_{int}]$$

Chapter 7.

Page 405, Fig 7-1 **: Correction :** Break out AST and λ in the figure. Change "LST and site latitude" to "the site latitude and longitude".

Page 406-410, Several **: Correction :** Change LST to λ, and change "IJK" to "ECEF". This change recognizes the distinction in using ECI and ECEF frames with the SITE-TRACK problem. The example is re-worked to show the corrected values.

Page 413, First sentence of third para**: Correction :** Change "and Eq. (7-5) first and" to "and Eq. (7-5) and".

Page 416, Eqtn 7-12 **: Correction :** The constant term should have the D_2 term squared

$$-\frac{4\mu^2 D_2^2}{D^2}$$

Page 419, 1st para after Eq 7-16 **: Clarification :** "After recalculating the coefficients. . . " should be "After calculating the coefficients. . . ".

Page 421, Algorithm equations **: Clarification :** The notation for the position vector estimates is confusing. It is clearer to write (here, and on pg 426 and 427)

$$\vec{r}_i = \rho_i \hat{L}_i + \vec{r}_{site_i} \qquad i = 1 \ldots 3$$

Page 425, 2nd equation in the example **: Correction :** The values for *JD* should be switched to $\tau_3 = JD_3 - JD_2 = 2{,}450{,}315.881\,944 - 2{,}450{,}315.868\,056$.

Page 426, 1st para **: Clarification : ** p. 402/426 In the matrix equation after the sentence "This value allows you to find. . . ", delete and 2 4. Also in the matrix equation after the sentence "Determine the initial guess of the slant ranges," delete)_3 3 5 (It should be obvious something is wrong, when a negative range is given!)**

Page 427, 2nd equations **: Correction :** The values of f_3 and g_1 in the example are switched. They should be $f_3 = 0.834\,289$ and $g_1 = -1.380\,055$.

Page 428, Eq after 7-17 **: Correction :** The unnumbered equations between Eq 7–17 and Eq 7–18 are missing a minus sign on the left side.

Page 429, Equation 7-20 **: Correction :** The "ar_2" should be "a_2".

Page 429, Eq 7-20 and para after **: Clarification :** The sentences right after Eq 7-20 should say "an angle θ greater than 90° because it implies the satellite is not in the field-of-view, where"

Page 430, Last para **: Clarification :** The function mapping "f()" should be "g()" from the last two occurrences on pg 430, through the first three occurrences on page 431.

Page 436, Last equation **: Correction :** "L" should be "L_g".

Page 443, 1st para **: Clarification : Last expression for *r*2, the terms multiplying ¨ *r*1 and ¨ *r*3 can be sim-plified, e.g. 2_*t*32 _ _*t*32 = _*t*32, and then simplified further by using definitions of _*t*. The complete simplification is given in Algorithm 49 on the next page. Stylistic - true**

Page 445, 3rd from last sentence**: Clarification :** Change the sentence to read **"**Lambert's original method ultimately reduces to two separate cases to provide a complete answer: whether or not the orbital segment includes the attracting focus, and if it includes the vacant focus (Danby, 1992, 182).**".**

Page 447, 1st para **: Clarification : p. 424/447 Sentence/unnumbered equation "For instance. . . " immediately above figure is a non sequitur; the equation is true regardless of the meaning of *a* and *r*. Don't need Fig 7-9 to know it's true**

Page 457, Last equation **: Correction :** The equation for *a* should not have the SIN(ΔE) term.

Page 474, Algortihm 58**: Clarification :** The equation should be $\Delta\vec{v}_b = \vec{v}_{tgt_b} - \vec{v}_{trans_b}$.

Page 486, Problem 2 **: Correction :** The times are incorrectly incremented. They should increment by 10 minutes, and they cross from May 14 to May 15.

Chapter 8.

Page 491, 2nd and 3rd full paragraphs **: Clarification :** Add the following sentence to the 2nd paragraph, "Bate, Mueller, and White (1971, 385-386) introduce perturbations as follows." Replace "the perturbing force" with "a random perturbing force". Insert "both random and predictable. They include" before "the asphericity of ." Change the first sentence in the 3rd paragraph to "Don't get the idea that all deviations are small."

Page 493, Next to last para **: Clarification :** The line should be under the digits "9 216 302".

Page 495-496, Section 8.3**: Clarification :** The text should refer to "Encke's formulation" throughout. Add the following footnote. "I use the formulation terminology to be consistent with the discussion of Cowell's formulation. Encke did, however, use the phrase *neue methode* in Berliner Jahrbuch, c1857." Also, add the following statement at the end of the 1st full paragraph on pg 496. "can actually be greater. The process continues until a rectification point where the osculating orbit is re-initialized. In Algorithm 59, this point is governed by a tolerance. Kaplan (1976, 348) suggests about 1%. Battin (1987, 450) notes that the rectification is advantageous in controlling the errors."

Page 497, Algorithm 59: **Correction:** Change $\vec{r}_p$ to $\vec{v}_p$ for the velocity term.

Page 503, 2nd para **: Correction :** Missing right parenthesis in $[\dot{y}(t_{n+1}) = f(t, y(t))]$.

Page 504, 1st para **: Clarification : ** p. 480/504 Depending on how you count order, these might be called third order methods(?)**

Page 504, 3rd para **: Clarification :**Change the first sentence to be "The *summed differences* are a way to limit the accumulated error from the integrated variable."

Page 504, 2nd para **: Clarification : Insert "**Berry and Healy (2001) also give an updated discussion." after the 3rd sentence in the paragraph. Also, reword the last sentence after "if we include drag" as "we must compute the first integral, use an Adams-Bashforth-Moulton method, or use another …".

Page 508, 3rd para **: Clarification :** Change the parenthetical expression to be "[actually a *generalized Sundman transformation* because the index is not 1 as in Eq. (2-39)]." Also, "Sundmann" should be "Sundman".

Page 516, 3rd para : **Clarification:** Replace the first few words as "Older computers sometimes used". Add the following sentence to the end of the paragraph "Modern floating point computers don't require normalized values."

Page 517, 2nd equation**: Correction :** Correct the overbars as follows:

$$C_{\ell,m} = \frac{\bar{C}_{\ell,m}}{\Pi_{\ell,m}} \qquad S_{\ell,m} = \frac{\bar{S}_{\ell,m}}{\Pi_{\ell,m}} \qquad \bar{P}_{\ell,m} = \Pi_{\ell,m} P_{\ell,m}$$

Page 522, Next to last para **: Clarification :** There should be parens around $c_D A$.

Page 523, 2nd equation**: Correction :** Correct the signs as follows.

$$\vec{v}_{rel} = \begin{bmatrix} \frac{dx}{dt} + \omega_{\oplus} y + v_w \{-\cos(\alpha)\sin(\delta)\cos(\beta_w) - \sin(\alpha)\sin(\beta_w)\} \\ \frac{dy}{dt} - \omega_{\oplus} x + v_w \{-\sin(\alpha)\sin(\delta)\cos(\beta_w) + \cos(\alpha)\sin(\beta_w)\} \\ \frac{dz}{dt} + v_w \{\cos(\delta)\cos(\beta_w)\} \end{bmatrix}$$

Add the following footnote "The signs differ from Escobal because this equation finds the contribution of the wind using v_w and β_w in the SEZ system, and then rotates to the geocentric system {ROT3(-α) ROT2(-(90-δ))}".

Page 531, Eq 8-23 **: Correction :** Add a "/" to the units. It should be m^2/Hz.

Page 532, 1st para **: Clarification :** Add a footnote to explain the scale height.

Scale height is the fractional change in density with height. It can be useful in determining numerical partial derivatives. Wertz (1978, 108) shows that scale height is equal to k * Temperature / molecular weight * gravity, where k is the Boltzmann constant.

Page 540, 1st para **: Clarification : xxFirst paragraph: "Even with canonical units,. . . " This is irrelevant — numerical problems stemming from the subtraction of close large numbers are independent of scale factor (such as a unit conversion), as computers storing floating point numbers normalize the mantissa anyway. True**

Page 544, 1st sentence**: Correction :** Change “ where $D_{aphelion}$ is the days from when the Earth is at aphelion” to “where $D_{aphelion}$ is 2π times the days from when the Earth is at aphelion, as a fraction of the whole year”.

Page 545, Fig 8.12 and the equations **: Correction :** The incidence and reflection angles should reference the normal (dashed) line, not as shown. The equations should be

$$\vec{a}_{SR} = \frac{-RA\,\mathrm{COS}(\phi_{inc})}{mc}\left\{2\left(\frac{c_{Rd}}{3} + c_{Rs}\mathrm{COS}(\phi_{inc})\right)\vec{n} + (1 - c_{Rs})\vec{s}\right\}$$

$$\vec{a}_{SR} = -\sum_i\sum_j\frac{R_jA_i\mathrm{COS}(\theta_{ij})}{mc}\left\{2\left(\frac{c_{Rd_i}}{3} + c_{Rs_i}\mathrm{COS}(\phi_{inc})\right)\vec{n} + (1 - c_{Rs_i})\vec{s}\right\}$$

Page 549, 2nd to last equation **: Correction :** The two body term should be deleted from the 3-body acceleration.

Page 561, 1st paragraph: **Clarification** : Add “The general accuracy of the ephemerides is about 0.01". The Moon ephemerides are accurate to about 2 m (0.001") and the Sun is accurate to about 200 m (0.0003").”

Page 563, New problem **: Addition :** Add the following problem.

Chapter 9.

Page 594, Eq above Eq 9-27 **: Correction :** The equation for H is the negative of the correct expression (both right hand terms should be negative).

Page 606, Equation 9-38 **: Correction :** The “15” should be a “5”.

$$\left\{12 - 4e^2 - (80 + 5e^2)\mathrm{SIN}^2(i)\right\}$$

Page 630, Equation 9-52 **: Clarification :** Add $\Delta n = -\frac{3v_{cs}}{2a^2}\Delta a$ circular orbits .

Page 641, 1st equation**: Correction :** The second COS term should have signs (-) (+) instead of the two negatives.

Page 648, Next to last equation **: Correction :** The coefficients in the brackets should be

$$\dot{\Omega}_{J_2^2} \Rightarrow \frac{3J_2^2R_\oplus^4 n\,\mathrm{COS}(i)}{32p^4}\left\{-36 - 4e^2 + 48\sqrt{1-e^2} + (40 - 5e^2 - 72\sqrt{1-e^2})\mathrm{SIN}^2(i)\right\}$$

Chapter 10.

Page 682, 1st para **: Clarification : "Tracking systems such as GPS . . . rely on a transmitting and receiving clock." GPS receivers with four satellites in view does not rely on a receiving clock. True – clarify that it's about the receivers.**

Page 686, Footnote **: Correction :** The middle equation should have z squared.

Page 687, Eq 10-7 **: Correction :** The *b* term should be a matrix (bold). There is also an instance just above in the preceding paragraph.

Page 691, End of example problem **: Correction :** Change the paragraph as follows:

> This example illustrates detecting and eliminating a bad data point with the following results. Usually, the estimated accuracy for each state parameter is from the square roots of the diagonal terms in the covariance matrix (0.6071 $\Rightarrow$ 0.7792 and 0.0238 $\Rightarrow$ 0.1543). However, because this problem has no weighting (Sec. 10.2.2), we must multiply the covariance matrix variances by the sample variances of the observations. We find these sample variances by summing the squared (observed - calculated) residuals for each point (7.105 703), and dividing by n−1 (or 7). The square root of this quantity is multiplied by the variances of the covariance matrix from the least squares solution.
>
> $$y_{c_i} = -0.429 + 0.845 x_{o_i} \qquad \text{RMS} = 1.007\,522$$
>
> $\alpha = -0.429 \pm 0.847\,95$ and $\beta = 0.845 \pm 0.167\,886\,6$
>
> After eliminating point 7, the values become
>
> $$y_{c_i} = -0.131 + 0.721 x_{o_i} \qquad \text{RMS} = 1.300\,607$$
>
> $\alpha = -0.131 \pm 1.094\,585$ and $\beta = 0.721 \pm 0.216\,724\,4$

Page 692, Middle para **: Clarification :** Add "For *N* observations," to the paragraph and change the "8" values to "*N*" values. Add "i = 1 .. *N*" after the w_i matrices.

Page 694, Next to last equation **: Correction :** The unnumbered equation with partial derivatives of the residual has x_o subscripted with "1" instead of "*i*".

Page 695, 1st sentence **: Clarification :** Change "and use ..." to "and let the A^T be the left-hand $2 \times N$ matrix (similar to page 679).".

Page 701-703, *y* equations **: Clarification :** The observation quantities incorrectly have a bar over the symbol *y.*

Page 705,706. Eqtn for RAZEL: **Correction** : The time parameters need to be added.

$$\textbf{\textit{RAZEL}}\,(\vec{r}_{ECI_i}, \vec{v}_{ECI_i}, yr, mo, day, UTC, \Delta UT1, \Delta AT, x_p, y_p$$

$$\phi_{gd}, \lambda, h_{ellp} \Rightarrow \rho_m, \beta_m, el_m, \dot{\rho}_m, \dot{\beta}_m, \dot{el}_m)$$

Page 707. Last para: **Correction** : Add the following sentence. "Note that t_i represents the UTC time and the Earth Orientation parameters to change for ECI to ECEF."

Page 708. Alg 61: **Correction** : Correct the SITE and add the FK5 algorithm.

SITE-TRACK at each t_i

$$(\phi_{gd}, \lambda, h_{ellp}, \rho, \beta, el, yr, mo, day, UTC, \Delta UT1, \Delta AT, x_p, y_p \Rightarrow \vec{r}_{ECI}, \vec{v}_{ECI})$$

Page 712. 2nd equation from the top : **Correction** : The azimuth and range subscripts on the noise values are switched. The numerical values are correct.

Page 713, 1st para **: Clarification : **p. 702/713 Apparently, the standard deviation of the state vector is again being incorrectly computed as the square root of the diagonal elements of the covariance matrix. See correction for p. 693.**

Page 717, 1st full para **: Correction :** Change the reference to Eq 10-20 to Eq 10-19.

Page 726. Last para : **Clarification** : Insert state "and the state errors" exactly because".

Page 727, 1st para **: Clarification : The meaning of z_k used in the algorithm is not given. State that they are the observations**

Page 727, 732, 734-735, Several places**: Clarification :** The matrices ***R*** and ***z*** should not have "k+1" subscripts. Also, the ***H*** matrix should have a "k+1" subscript.

Page 727, Last equation in algorithm **: Correction :** First term should be the identity matrix.

$$\hat{\boldsymbol{P}}_{k+1} = [\boldsymbol{I} - \boldsymbol{K}_{k+1}\boldsymbol{H}_{k+1}]\bar{\boldsymbol{P}}_{k+1}$$

Page 729-730, last equation, and middle of next pg**: Clarification :** In the K_1 and K_2 equations, ***R*** should not have a bar over it.

Page 732, 734, Predicted State equation**: Correction :** Change the state tranistion matrix references to be

$$\text{or } \bar{\boldsymbol{X}}(t_{k+1}|t_k) = \int_{t_k}^{t_{k+1}} \dot{\bar{\boldsymbol{X}}}_k \, dt + \bar{\boldsymbol{X}}_k \qquad \text{Predicted State}$$

Page 739-740, Several **: Correction :** Change the reference to Eq 10-20 to Eq 10-19.

Page 742, Next to last sentence **: Clarification :** Insert the sentence "The state vectors are taken in a body-fixed frame (ITRF) because we apply accelerations in this frame." before the sentence beginning "The state and derivative ...".

Page 743, Last sentence **: Clarification :** Add "also" in the sentence "The equations of motion due to the nonspherical Earth [also] depend . . . ".

Page 747, Third para : **Correction** : The definition for the variational equations should state "epoch state at t_o" instead of "epoch state at t".

Page 748, Second equation : Correction : The last term in the velocity equation should not have the 2 in the denominator. Add the following at the end of the sentence, before "Thus", "and differentiation. Note that the final term in the velocity expression is simply the acceleration".

Chapter 11.

Page 778, Last sentence **: Clarification :** Change the sentence to read "Solve for the *general boresight angle*, η, using Eq. (C-19) (See Fig. 11-9)". ALso add the following footnote.

* Wertz (1978, 87) shows an alternate formula.

$$\tan(\eta) = \frac{R_{\oplus}\sin(\Lambda)}{R_{\oplus} + h_{ellp} - R_{\oplus}\cos(\Lambda)} = \frac{\sin(\eta_{horizon})\sin(\Lambda)}{1 - \sin(\eta_{horizon})\cos(\Lambda)}$$

Page 783, Before last sentence **: Clarification :** Add the following footnote about finding the node.

*The other orbital element to choose is the right acsension of the ascending node. This element lets us choose an orientation such as maintaining a solar panel perpendicular to the Sun (0600, 1800 orbits). You might be tempted to use UTC, but you should use mean local time. The local time is relative to the satellite longitude when it's over the ascending node. The mean time mitigates the effect of the equation of time (+16 min to –14 mins). The mean longitude of the Sun is α_{FMS} from pg 183. The GHA_{node} defines the time from local noon at Greenwich. If the Sun were overhead at this time, $\Omega = \alpha_{FMS} + GHA_{node}$. For completness, we use $\alpha_{\odot}$ and *GMST* to find the Sun's *GHA* at noon ($12^h - \alpha_{\odot} + GMST$). Combining both terms gives the final expression.

$\Omega = GHA_{node} + 12^h + GMST.$

Page 825-835, corrections for ECI/ECEF **: Correction :** There are several places in these algorithms where "IJK" should be replaced by "ECEF". The underlying rule is that for latitudes and longitudes that are fixed to the Earth, one must use ECEF coordinates. For numerical integration, ECI is required. The common approach in the literature is to simply rotate through GMST, (or sometimes AST). While this accomplishes the predominant portion of the change, it is technically incorrect as one needs to use the complete reduction matrix relations from ECEF to ECI.

Appendix.

Page 860, definitions for ϵ **: Correction :** The true and mean descriptions should be switched.

Page 882, Sentence before Equation C-5 **: Correction :** Should say ". . . the operation is not associative."

Page 875, Para after Eq B-15**: Correction :** Change "F_{81} is the calculated" to "F_{81} is calculated".

Page 886, Last sentence**: Correction :** Change "convenient relation permits" to "convenient relation that permits".

Page 892, Between equations in C-32**: Correction :** Add "Then, for all temporary real roots (Z_i)".

Page 893, equations in C-33 and eqtn C-34**: Correction :** Add “i” to the Zroot subscripts for the angle calculation. The second equation in C-34 shuold have a minus sign after the first term.

Page 895-897, several **: Clarification :** Change the subscripts “qd” to “pb” and “pb” to “c”. On page 897, change the first paragraph at the top to read

For the final answer, proceed as follows.

1. Find the coefficients from Eq. (C-39) using the function points.
2. Use these coefficients to find the roots of f_c in the first equation of Eq. (C-38). We can solve this analytically by the methods in Sec. C.5.1.
3. Find new coefficients from Eq. (C-39) using the time points, and then choose real roots from step 2 between 0.0 and 1.0 and substitute into the first equation of Eq. (C-38). The solution is the time answer, τ.
4. Use the same process with the second equation of Eq. (C-38). The sign of the rate of f_c in the original evalution will indicate a minimum or maximum.

Page 899-900, several **: Clarification :** Change the subscripts “qr” to “qi” for the equations at C-45 and beyond.

Page 897, Next to last sentence in Cubic Splining**: Correction :** Change “The result is curve” to “The result is a curve”.

Page 911, Tables **: Correction :** The units are not supplied for semimajor axes, they are all in AU’s.

Page 916, Top of page **: Correction :** The following paragraph should be moved back to the bottom of the last page.

Weekly predictions of x_p, y_p, and ΔUT1 are available from NIMA. The information is updated every Thursday.
http://164.214.2.59/GandG/sathtml/eopp.html

Page 921, 1st full sentence **: Correction :** Should say “its” not “it’s”.

Page 936, Title of reference **: Correction :** “Fort” should be “for”.