# Fundamentals of Astrodynamics and Applications 2nd Ed

## Errata

October 18, 2003

This listing is an on-going document of corrections encountered in the book. I appreciate any comments and questions you find. I use RHS for right hand side when referring to equations. You may reach me at: davallado@raytheon.com or valladodl@worldnet.att.net

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

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

**Page 38**, Eqtn before Eq 1-40 **:** Add "$m_i$" in the middle summation.

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

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

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

**Page 83**, Text of Fig 2-11 **:** Change "Fig 4-10" to "Fig 2-10".

**Page 93**, Eqtn above 2-65 **:** The ydot term should be positive.

**Page 94**, Last equation **:** The unnumbered Taylor series expansion of $r$ should be a function of "0", not "$\tau$".

**Page 111**, Para above Eq 2-91 **:** Change to read "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 116**, Eq 2-97 **:** Add the $f_r$ multiplier to the COS($i$) term in the denominator of the last two equations. In addition, the elements should include the additional symbol notations ($a_f$, $n$, $a_g$, $L$, $\chi$, $\psi$). Change the text for $f_r$ to "It's +1 for all direct orbits, and –1 for nearly retrograde orbits."

**Page 118**, Eq 2-99 **:** Delete the sine terms in $g_p$ and $h_p$. Delete the minus signs before the radical for $G_p$ and $H_p$. Insert a minus sign before the 2 in the radical for $h_p$ and $H_p$.

**Page 125**, Example problem 2-6 **:** The numerical values should use $e$ = 0.83285 and $v$ = 92.335 throughout. The numerical results change slightly, and the final vectors are:

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

**Page 133**, 1st equation **:** Remove the plus sign before $r$ in the $m$ equation.

**Page 163**, 2nd para **:** The words "pitch" and "yaw" are switched in two places after the first sentence.

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

**Page 172-174**, Sec 3.4.3 **:** The references to IJK are ambiguous and should be changed to ECEF (earth Fixed) in Eqtn 3-26, and ECI (Inertial) for the remaining, except for the SEZ transformation, which should be deleted and replaced with "Transformations between SEZ and satellite body":

$$\hat{r}_{Body} = \text{ROT3}(Yaw)\text{ROT1}(Roll)\text{ROT2}(Pitch)\hat{r}_{SEZ} \tag{3-3}$$

**Page 174, 177**, Sec 3.4.4 **:** Change the reference from "IJK" to "ECEF".

**Page 178-179**, Alg 13 **:** Change "$a$ = 1" to "$a = R_\oplus$". Also reverse the inequalities in the IF statements.

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

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

**Page 208,** Top eqtn **:** The velocity term should add the cross product $\vec{\omega}_{\oplus} \times \dot{\vec{r}}_{pef}$, and both vectors should be identified as *pef*, not *x*.

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

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

**Page 219**, 1st para in Section 3.7.5 and Eq 3-66 **:** The obliquity of the ecliptic should be $\bar{\epsilon}$, not $\epsilon$. This occurs in two places in the text, and in equation 3-65. Change the velocity expression in Eq 3-66 to include $-\dot{\vec{\omega}}_{\oplus} \times \dot{\vec{r}}_{PEF}$.

**Page Page 221, 222,** Several **:** In Eq 3-70 and the algorithm on page 222, change rITRF to rPEF. Change the first full para first sentence with "By using $\dot{\vec{r}}_{PEF}$, 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 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 $-\dot{\vec{\omega}}_{\oplus} \times \dot{\vec{r}}_{PEF}$. Finally, the transposes should all be changed in the equations to maintain consistency with the preceding discussions. They are correct as written, but are inconsistent with the previous material and this could cause confusion.

**Page 224-225**, Example **:** Change the velocity vpef to -2.905 263 1"0", and the vITRF to -3.187 01"7 92" and -2.905 271 2"3".

**Page 251**, Eqtn 4-6 **:** Change "IJK" to "ECEF".

**Page 252**, Several **:** Change LST to λ in the equations. Divide $\theta_{LST}$ into 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 $\theta_{LST}$ which approximates the major numerical difference with the coordinate systems."

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

**Page 264**, Fig 5-1 **:** Move the I-axis to the right, and identify the unlabaled arrow as **"**$\phi_{ecliptic}$".

**Page 273-275**, Moon longitude equation **:** The constant should be 481,267.883, not 481,267.88"1"3.

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

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

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

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

**Page 347**, just above the definition of synodic period **:** " k" should be replaced by $\frac{2\pi}{\omega_{int} - \omega_{tgt}}$.

**Page 354**, Algorithm 46, before "Find $\lambda_{true}$": 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 $\lambda_{true}$ for interceptor at $t_1$ $\lambda_{true_{int1}} = \Omega + \lambda_u$

**Page 361**, Last para **:** Add the following sentence to the last paragraph on the page, "If $r_i$ is the initial radial distance,". Replace "*R*" with "$r_i$" in the final equations.

**Page 366**, Ex 6-12 **:** The vehicle acceleration should be $4.0\times10^{-3}$ m/s$^2$, not $4.0\times10^{-6}$ m/s$^2$.

**Page 385**, Figure 6-27 **:** The top 3 *x* labels should be $x_0$, and they are all positive. The bottom 2 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 **:** The equation should not have the "335" in the rotation.

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

**Page 406-410**, Several **:** 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.

**Page 416**, Eqtn 7-12 **:** The last term should have the $D_2$ term squared in the numerator.

**Page 425**, 2nd equation in the example **:** The values for *JD* should be switched.

**Page 427**, 2nd equations **:** The values of $f_3$ and $g_1$ in the example are switched.

**Page 428**, Eq after 7-17 **:** Add a minus sign before the ½ in the unnumbered equations after Eq 7–17.

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

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

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

**Page 486**, Problem 2 **:** The times are incorrectly incremented. They should increment by 10 minutes, and they cross from May 14 to May 15 after 23:50.

**Page 496**, Algorithm 59**:** Change $\dot{\bar{r}}_p$ to $\dot{\bar{v}}_p$ for the velocity term.

**Page 517**, 2nd equation **:** Move the overbars on the *C* and *S* terms to the RHS of the equations.

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

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

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

**Page 530**, Eq 8-33 **:** Add a "/" to the units. It should be $m^2$/Hz.

**Page 544**, 1st sentence **:** Change to "where $D_{aphelion}$ is $2\pi$ 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 **:** $\phi_{inc}$ and $\phi_{ref}$ should be measured to the normal (dashed) line, not the horizontal line as shown. The final paren before the brace should be moved, in both equations, before the n-vector.

**Page 549**, 2nd to last equation **:** Delete the 1st term on the RHS of $a_{3\text{-}body}$.

**Page 552**, Eq 8-52 **:** Insert a "$r_k$" after $R_{\oplus}^6$ in the $a_k$ equation.

**Page 594**, Eq above Eq 9-27 **:** Both right hand terms should be negative in the $\mathcal{H}$ equation.

**Page 606**, Equation 9-38, 1st line **:** The "15" should be a "5".

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

**Page 648**, Next to last equation **:** The coefficients in the brackets before the radicals should be -36, -4, 48 and 40, -5, -72.

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

**Page 687**, Eq 10-7 **:** The *b* term should be a matrix (bold). This also occurs in the paragraph just above.

**Page 691**, End of example problem **:** Change "7992" to "7792".

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

**Page 712**. 2nd equation from the top : Switch the $\beta$ and $\rho$ subscripts in the W matrix.

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

**Page 727**, Last equation in algorithm 63 **:** The first RHS term in $\hat{\boldsymbol{P}}_{k+1}$ should be the identity matrix (I).

**Page 732, 734**, Predicted State equation **:** Change the or after PKEPLER to:

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

**Page 739-740**, Several **:** Change "IJK" to "ECEF" and LST to λ.

**Page 747**, Third para : Change "epoch state at *t*" to "epoch state at $t_o$".

**Page 748**, 2nd equation : The last term in the velocity equation should not have a 2 in the denominator.

**Page 825-835**, corrections for ECI/ECEF **:** 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.

**Page 860**, definitions for $\epsilon$ **:** Switch the true and mean descriptions.

**Page 869**, Eq after B-11 **:** Remove $35^4$, $R_{pole}^2$, and $C_4$ from the equation for *k*.

**Page 893**, equations in C-33 and eqtn C-34 **:** Add "i" to the Zroot subscripts for the angle calculation instead of "/$r_j$". The second equation in C-34 should have a minus sign after the $y_j^2$.

**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 elevation values.
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 values, 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, $\tau$.
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.
5. Any other parameters at the same time (range, azimuth, etc.) are found using coefficients from Eq. (C-39) formed with the function values, and the root used in step 3.

**Page 911**, Tables **:** The units are not supplied for *a*, they are all in AU's.