Fundamentals of Astrodynamics and Applications 4^{th} Ed

Consolidated Errata

February 6, 2017

This listing is an on-going document of corrections and clarifications encountered in the book. I appreciate any comments and questions you find. I use RHS for “right hand side” when referring to equations and N/A for not applicable. You may reach me at: dvallado@agi.com or davallado@gmail.com. Changes in equations are sometimes indicated by circles. I have tried to indicate changes that were present in previous editions as I know many of you have those copies. For many corrections in the 2^{nd} edition, the first and second printings had identical pages, unless otherwise noted with the first printing pages being in parentheses. The exact description may differ, but it should get you close enough.

Page xiv, Algorithm 1**:** The cross reference should say pg 63, not 71.

Page 14, Equation 1-1**:** (3^{rd} pg 14, 2^{nd} pg 14, 1^{st} pg 11) The radius values should all be vectors. Fig 1-4 should show the radii as vectors also.

Page 53, Fig 2-4**:** (3^{rd} pg 61, 2^{nd} pg 61, 1^{st} pg 220) The turning angle should be 130.76 deg and φ_S should be divided by 2 in the figure. Note that the turning angle extends past the page to the satellite asymptote.

Page 65, 71, 75, Alg 2, 1st equation, Alg 4**:** (3^{rd} pg 73, 79, 2^{nd} pg 73, 79, 1^{st} pg 232, 237) The top line should be $-\pi < M < 0$ or $\pi < M < 2\pi$.

Page 107, Fig 2-19**:** (3^{rd} pg 115, 2^{nd} pg 115, 1^{st} pg 142) The units for Mean motion should be (rev/day^2/2) and for Mean motion second derivative (rev/day^3/6). The Mean motion second derivative should have a negative sign in the box before the 0 exponent. The superscripted values were missing. The checksum for the first line should be 9 and the check sum for the second line should be 6.

Page 110, 2^{nd} equation**:** (3^{rd} pg 118) The velocity equation should be

$$v\begin{bmatrix} -\mathrm{COS}(\alpha)\,\mathrm{SIN}(\delta)\,\mathrm{COS}(\beta)\,\mathrm{COS}(\phi_{fpav}) - \mathrm{SIN}(\alpha)\,\mathrm{SIN}(\beta)\,\mathrm{COS}(\phi_{fpav}) + \mathrm{COS}(\alpha)\,\mathrm{COS}(\delta)\,\mathrm{SIN}(\phi_{fpav}) \\ -\mathrm{SIN}(\alpha)\,\mathrm{SIN}(\delta)\,\mathrm{COS}(\beta)\,\mathrm{SIN}(\phi_{fpav}) + \mathrm{COS}(\alpha)\,\mathrm{SIN}(\beta)\,\mathrm{COS}(\phi_{fpav}) + \mathrm{SIN}(\alpha)\,\mathrm{COS}(\delta)\,\mathrm{SIN}(\phi_{fpav}) \\ \mathrm{COS}(\alpha)\,\mathrm{COS}(\delta)\,\mathrm{COS}(\phi_{fpav}) + \mathrm{SIN}(\delta)\,\mathrm{COS}(\phi_{fpav}) \end{bmatrix}$$

Page 120, Position and velocity vectors**:** (3^{rd} pg 127-128, 2^{nd} pg 126) the last 2 decimal places of the position and velocity vector components should be 68, 32, 19 and 79, 40, and 10.

Page 158, First paragraph**:** (3^{rd} pg 166, 2^{nd} pg 163, 1^{st} pg 44) It should be just “clockwise”.

Page 173, Algorithm 13**:** (3^{rd} pg 180, 2^{nd} pg 178) The equation for b should be corrected as follows:

$$b = R_{\oplus}\sqrt{(1-e_b^2)}\mathrm{SIGN}(r_K) = r_b$$

Page 193, Eq 3-52**:** (3^{rd} pg 199) The last term should be “–” instead of “+” (TDB_0).

Page 208, Fig 3-26**:** The IAU 1976 precession matrix elements should be reversed and of opposite sign.

Page 213, Last para**:** (3^{rd} pg 219, 2^{nd} pg 212) The summation should go from 0 - 4, not 0 - 5.

Page 216, Eq 3-67**:** (3^{rd} pg 221) The constant should be -0.000 029 956T^4.

Page 225, Eq 3-82**:** (3rd pg 230, 2nd pg 210, 1st correct) The equations actually were from 1996 values and are thus a little different. They should be as follows:

$$M_{☾} = 134.962\,981\,39° + (1325r + 198.867\,398\,1)T_{TT} + 0.008\,697\,2T_{TT}^2 + 1.78\times10^{-5}T_{TT}^3$$

$$M_{\odot} = 357.527\,723\,33° + (99r + 359.050\,340\,0)T_{TT} - 0.000\,160\,3T_{TT}^2 - 3.3\times10^{-6}T_{TT}^3$$

$$u_{M☾} = 93.271\,910\,28° + (1342r + 82.017\,538\,1)T_{TT} - 0.003\,682\,5T_{TT}^2 + 3.1\times10^{-6}T_{TT}^3$$

$$D_{\odot} = 297.850\,363\,06° + (1236r + 307.111\,480\,0)T_{TT} - 0.001\,914\,2T_{TT}^2 + 5.3\times10^{-6}T_{TT}^3$$

$$\Omega_{☾} = 125.044\,522\,22° - (5r + 134.136\,260\,8)T_{TT} + 0.002\,070\,8T_{TT}^2 + 2.2\times10^{-6}T_{TT}^3$$

Page 226, Sentence after Eq 3-86**:** The end should say "the equation after Eq. (3-72)".

Page 232, Text of table 3-6**:** The velocity units should be "m/s", not "mm/s".

Page 244, bottom equation**:** (3rd pg 250, 2nd pg 238 (236)) The equation should be as follows:

$$\rho = \frac{c\left|(t_{s-rec}) - (t_{trans})\right| + \left|(t_{rec}) - (t_{s-trans})\right|}{2}$$

Page 277-281, Sun algorithm**:** (3rd pg 279-283, 2nd pg 265-269 (263-267), 1st 181-184) The equations should be made identical to the Almanac version, which is TOD, not MOD. The development shows where the equations come from, but the accuracy is slightly better using the truncated terms from the Almanac. It changes the example problem slightly, and this is evident in the Matlab approach which has been updated.

Page 284, first paragraph of text after the example: (3rd pg 287, 2nd pg 273 (271)) The "and 3000 m in altitude" can be deleted because it is not needed for the problem.

Page 288-289, Eq for magnitude of the Moon: (3rd pg 290-291, 2nd pg 276-277 (274-275), 1st 187-188) The numerator should be $R_{\oplus}$, not "1". this will give km for units.

Page 298, Example 5-5: (3rd pg 300, 2nd pg 286 (284), 1st 190-192) The "TU's" should be replaced by "day". This causes several calculations to be different.

$$\vec{r}_{XYZ} = -4.075\,931\,\hat{X} - 3.578\,308\,\hat{Y} + 0.105\,970\,\hat{Z}\text{ AU}$$

$$\vec{r}_{XYZ(J2000)}, \vec{v}_{XYZ(J2000)} = \mathbf{ROT1}(-\epsilon)\,\vec{r}_{XYZ}\,\vec{v}_{XYZ}$$

$$\vec{r}_{XYZ(J2000)} = -4.075\,931\,\hat{I} - 3.325\,169\,\hat{J} - 1.326\,186\,\hat{K}\text{ AU}$$
$$= -609{,}750{,}543\,\hat{I} - 497{,}438{,}245\,\hat{J} - 198{,}394{,}607\,\hat{K}\text{ km}$$

$$\vec{v}_{XYZ(J2000)} = 0.004\,889\,\hat{I} - 0.004\,846\,\hat{J} - 0.002\,197\,\hat{K}\text{ AU/day}$$
$$= 8.46560\,\hat{I} - 8.39137\,\hat{J} - 3.80323\,\hat{K}\text{ km/s}$$

Page 299, Last Eq: (3rd pg 301, 2nd pg 287 (285)) The umbra and penumbra equations should not have the "=" sign before the answer in degrees.

Page 362-364, Eq 6-38, Algorithm 44, and Ex 6-8 and Ex 6-9**:** (3rd pg 363-366, 2nd pg 348-352 (346-350), 1st 318-321) The equation should be $\vartheta = \pi - \alpha_L$ in each. In Ex 6-8, the target is "in front of" the interceptor, ω_{tgt}= 0.000 438 rad/s, the phasing value is "smaller" than the original orbit, and the interceptor enters a "lower" orbit. In Ex 6-9, the target is "in front of" the interceptor, ω_{tgt}= 0.000 072 9 rad/s, ω_{int}= 0.000 438 rad/s, and the target satellite begins "in front of" the interceptor.

Page 369, Ex 6-10**:** (3rd pg 371, 2nd pg 357 (355), 1st 326) ω_{tgt}= 0.000 072 9 rad/s, and ω_{int}= 0.001 045 7 rad/s,

Page 386, Eq 6-55**:** (3rd pg 388, 2nd pg 373 (371), 1st 342) The two summations should be divided, not multiplied.

Page 388, Ex 6-13 v_{acc} equation**:** (3rd pg 388, 2nd pg 374 (372)) The v_{acc} equation should be 0.75 (6578.136) / (845.0472). (remove the "1/")

Page 414-416, Alg 49 and 50 (3rd pg 412-416, 2nd pg 397-399(395-397), 1st pg 366-368) There have been several updates to match the final form given in Vallado and Alfano. 2014. Curvilinear Coordinate Transformation for Relative Motion. 118 (3):253-271, *Celestial Mechanics and Dynamical Astronomy* and the few errata in (2016) 125:263–264.

Page 432, Last equation**:** (3rd pg 428, 2nd pg 412 (410) 1st 386) The position vector in the velocity equation should have no subscripts. It's simply the position vector at the beginning of the equation.

Page 445, 2nd Eq after ELSE: (3rd pg 441, 2nd pg 425 (423), 1st 399) The denominator should be changed as follows:

$$e\,\mathrm{SIN}(\nu_2) = \frac{\mathrm{COS}(\Delta\nu_{32})e\,\mathrm{COS}(\nu_2) - e\,\mathrm{COS}(\nu_3)}{\mathrm{SIN}(\Delta\nu_{32})}$$

Page 473, 475, After 2nd para, and in Alg 56**:** (3rd pg 471, 2nd pg 454 (452), 1st 428) Add the following para and equation:

To find the minimum time with a_{min}, new values of α_e and β_e are required. Prussing and Conway (1992, 72) show the result.

$$\alpha_{min} = \pi \qquad \mathrm{SIN}\left(\frac{\beta_{min}}{2}\right) = \sqrt{\frac{s-c}{s}}$$

Change the α_e and β_e subscripts to "min" in Alg. 56.

Page 489, 3rd full para (3rd pg 486, 2nd pg 461(460), 1st pg 436) The reference is for pgs 231-236, not 193-198.

Page 496, Alg 59**:** (3rd pg 493, 2nd pg 468 (466), 1st 443) If *a* > 0.0, calculate the minimum values first, then find the subscripted *e* values.

$$\alpha_{min} = \pi \qquad \mathrm{SIN}\left(\frac{\beta_{min}}{2}\right) = \sqrt{\frac{s-c}{s}}$$

IF $\Delta\nu > \pi$

$$\beta_{min} = -\beta_{min}$$

$$a_{min} = \frac{s}{2}$$

$$t_{min} = \sqrt{\frac{a_{min}^3}{\mu}}\{\alpha_{min} - \beta_{min} + \mathrm{SIN}(\beta_{min})\}$$

$$\mathrm{SIN}\left(\frac{\alpha_e}{2}\right) = \sqrt{\frac{s}{2a}}$$

$$\mathrm{SIN}\left(\frac{\beta_e}{2}\right) = \sqrt{\frac{s-c}{2a}}$$

The $K(U)$ "n" coefficients should also be corrected as:

$$n = 0, 1, 2, \ldots \text{IF } 2n \ even$$

$$c_U = \frac{2(3n+1)(6n-1)}{9(4n-1)(4n+1)}$$

$$n = 0, 1, 2, \ldots \text{IF } 2n+1 \ odd$$

$$c_U = \frac{2(3n+2)(6n+1)}{9(4n+1)(4n+3)}$$

Page 542, **544**, Eq 8-15, Eq 8-17: (3rd pg 541, 2nd pg 516 (513), 1st 490). In Eq 8-15, the "2" is not needed outside the summation. Inside the summation, there should be a (2-δ_k) term defined as "k" was in Eq 8-22. In Eq 8-17, the (2-δ_k) term should be inside the integral. All three equations should use the δ_k parameter for consistency.

Page 550, Eq 8-27**:** (3rd pg 548, 2nd pg 524 (521), 1st 497) The final terms should be components of the position vector as follows:

$$a_I = \left\{ \frac{1}{r}\frac{\partial U}{\partial r} - \frac{r_K}{r^2\sqrt{r_I^2 + r_J^2}}\frac{\partial U}{\partial \phi_{gc_{sat}}} \right\} r_I - \left\{ \frac{1}{r_I^2 + r_J^2}\frac{\partial U}{\partial \lambda_{sat}} \right\} r_J - \frac{\mu r_I}{r^3}$$

$$a_J = \left\{ \frac{1}{r}\frac{\partial U}{\partial r} - \frac{r_K}{r^2\sqrt{r_I^2 + r_J^2}}\frac{\partial U}{\partial \phi_{gc_{sat}}} \right\} r_J + \left\{ \frac{1}{r_I^2 + r_J^2}\frac{\partial U}{\partial \lambda_{sat}} \right\} r_I - \frac{\mu r_J}{r^3}$$

$$a_K = \frac{1}{r}\frac{\partial U}{\partial r} r_K + \frac{\sqrt{r_I^2 + r_J^2}}{r^2}\frac{\partial U}{\partial \phi_{gc_{sat}}} - \frac{\mu r_K}{r^3}$$

Page 559, Next to last Eq**:** (3rd pg 557) The final Kp_4 and ap_4 terms should be divided by 6.

Page 575, Eq 8-35: The first equation denominators should be magnitudes, not vectors.

Page 589, Eq 8-50**:** (3rd pg 587, 2nd pg 550 (546), 1st 524) The F_{thrust} equation should have a "*g*" before "I_{sp}".

Page 600, Last paragraph**:** (3rd pg 596, 2nd pg 559) "verification" should be "validation".

Page 626, 2nd equation**:** (3rd pg 622, 2nd pg 584 (582), 1st 557) The Mean anomaly rate should have a "n" as the first term on the RHS.

Page 635, first equation**:** (3rd pg 631, 2nd pg 593 (591), 1st 566) The F_S term should have a SIN(ν) as well.

Page 636, first unnumbered equation**:** (3rd pg 632, 2nd pg 594 (592), 1st 567) The brackets should be as follows:

$$\frac{d\nu}{dt} = \frac{h}{r^2} + \frac{1}{eh}\left\{ p\,\mathrm{COS}(\nu)F_R - (p+r)\,\mathrm{SIN}(\nu)F_S \right\}$$

Page 709, last line of SP radial rate term**:** (3rd pg 705) The term should be (1+*e*cos(ν))^2.

Page 751, Center equation and text**:** (3rd pg 745, 2nd pg 694 (692), 1st 672) The text should be changed as follows

"For *N* unique sensor and observation type combinations,"

and

"Note that ***W*** contains the weights (as appropriate) for each measurement. For example, if one sensor records right ascension-declination, and another records range azimuth and elevation, and each sensor produces 1 measurement, the W matrix would be 5×5. If each sensor took 6 measurements, the ***W*** matrix would be 30×30! In practice, we accumulate measurements so the size of the ***W*** matrix is much smaller. In the example above, the ***W*** matrix would still be just 5×5 for all 6 measurements."

The equation should read $w_i = \frac{1}{\sigma_A} = w_A \qquad i = 1 \ldots N$.

Page 802-803, last equation and top equation (803)**:** (3^{rd} pg 793, 2^{nd} pg 743 (740)) The azimuth numerator and denominator are switched. Both terms in the numerator of the 3,3 matrix position should be squared.

Page 810, footnote equation**:** (3^{rd} pg 801, 2^{nd} pg 750) The Δt should be squared.

Page 865, first equation**:** (3^{rd} pg 854, 2^{nd} pg 788 (784), 1^{st} 760) The semimajor axis should be "7178.1363" instead of "1.12532".

Page 898-899, Eq 11-44**:** (3^{rd} pg 887, 2^{nd} pg 819 (815), 1^{st} 791) The second negative sign from the left should be "+". Top of 899, the Danielson reference should be from 2003.

Page 961, Ex 12-8**:** (3^{rd} pg 44, 2^{nd} pg 44 (44), 1^{st} 126) The last sentence should be "came within about 340,000 km of Jupiter—certainly far enough out to avoid encountering the atmosphere. This is close to the actual value due to some approximations used in this example.".

Page 972, second equation**:** (3^{rd} pg 44, 2^{nd} pg 44 (44), 1^{st} 126) The first terms should be 1/2 - u*.