Answers to Selected Exercises

Chapter 1

1.1 For an ideal basketball and golf ball, the golf ball would rebound to a height of 10.9 m. For a real basketball and golf ball dropped on a driveway, the height was only about 4 m which resulted in the golf ball being lost on the garage roof.

1.2 A 3×3 matrix containing the outer product of **r**

$$\frac{\partial \mathbf{a}}{\partial \mathbf{r}} = \frac{-\mu}{r^3}\left[I - 3\,\frac{\mathbf{r} \otimes \mathbf{r}}{r^2} \right]$$

1.3

$$M_y(\alpha = 0) = \frac{3\,GM}{r^3}(I_{zz} - I_{xx})\frac{r_x r_z}{r^2} = \frac{3\,GM}{r^3}(I_{zz} - I_{xx})\sin\epsilon\cos\epsilon$$

1.4

$$r_l = k_z\cos\epsilon - k_x\sin\epsilon + k_z\cos\epsilon - k_x\sin\epsilon$$
$$\Delta r = k_z\sin\epsilon - k_x\cos\epsilon - k_z\sin\epsilon + k_x\cos\epsilon$$

1.5

$$\dot{\alpha} = \frac{3}{2}\left(\frac{GM}{r^3}\right)\left[\frac{I_{zz} - I_{xx}}{I_{zz}}\,\frac{\cos\epsilon}{\omega_e}\right] = 2.450 \times 10^{-12}\ \text{rad/s}$$

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1.6 This problem makes use of the following:

$$\left[\frac{\partial(I\Omega)}{\partial I_e}\right]^T = \Omega^T \frac{\partial I^T}{\partial I_e}$$

$$\frac{\partial I^T}{\partial I_e} = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$

1.7 $\bar{v} = 725\,\text{m/s}$

1.8 Assume that the volume swept out by all the molecules between collisions is equal to the volume of the container and the frequency of collisions is the reciprocal of the mean time between collisions. The mean free path is approximately 5.029×10^{-7} m and the number of collisions per second for one molecule is 9.639×10^8.

1.9 Tyrannosaurus rex's watch will have gained 0.61 s and will read Jan 1 2017 12:00:01 AD if we round up. Photon's watch will read Jan 1, 65,000,000 12:00:00 BC. Photon will have no memory of the trip and t rex was probably wiped out by an asteroid, but his watch survived.

1.10 For 30° integration step size and evaluating function on right side of interval,

$$\int_0^{90} \sin(x)dx \approx \frac{\pi}{6}\left[\sin(30) + \sin(60) + \sin(90)\right] = 1.23$$

For evaluation in middle of interval,

$$\int_0^{90} \sin(x)dx \approx \frac{\pi}{6}\left[\sin(15) + \sin(45) + \sin(75)\right] = 1.01$$

For 10° integration step size and evaluation on right side of interval the integral was 1.084 and for evaluation in middle of interval the integral was 1.0013

Chapter 2

2.1 R = 15,255 ft, H = 1800 ft

2.2 R = 5.80 miles

2.3 The thrust is 1164 pounds and the drag force is 19.8 pounds.

2.4 The equations of motion are

$$y = v_0 \sin(\theta)t - \frac{t^2}{2g_0}$$

$$x = v_0 \cos(\theta)\, t$$

and the trajectory is

$$y = \tan(\theta)\, x - \frac{g_0}{2v_0^2 \cos^2\theta}\, x^2$$

2.9

$$\begin{aligned}
C_{20} &= \frac{1}{Ma^2} \iiint_V (-\frac{1}{2}x^2 - \frac{1}{2}y^2 + z^2)\, \rho(r, \lambda, \phi)\, dV \\
C_{21} &= \frac{1}{Ma^2} \iiint_V xz\, \rho(r, \lambda, \phi)\, dV \\
S_{21} &= \frac{1}{Ma^2} \iiint_V yz\, \rho(r, \lambda, \phi)\, dV \\
C_{22} &= \frac{1}{4Ma^2} \iiint_V (x^2 - y^2)\, \rho(r, \lambda, \phi)\, dV \\
S_{22} &= \frac{1}{2Ma^2} \iiint_V xy\, \rho(r, \lambda, \phi)\, dV \qquad (1.1)
\end{aligned}$$

Chapter 3

3.2 For F negative, $\sinh(F) + \cosh(F) = e^F$ which for large negative F is very small. Since e^F is obtained by differencing two very large numbers $(\sinh(F),\ \cosh(F))$ their is a loss of significance.

3.3 $\sin\gamma = \left(\frac{GM}{vh}\right) e \sin(\eta)$

3.4 The first spacecraft had an orbit insertion maneuver of 1021 m/s and the second spacecraft had an orbit insertion maneuver of 975 m/s followed by a maneuver at apoapsis of 30 m/s for at total of 1005 m/s. The second strategy is more fuel efficient.

3.7 1.638 years

Chapter 4

4.1 The radius of the can is $h = \left(\frac{V}{2\pi}\right)$ and the height is twice the radius.

4.2 1/3

4.3 The relevant term that determines the sign of the Hessian is given by $16a^2U_2 - 16b^2U_1$. Since a is greater than b, the Hessian is positive and the solution is a minimum.

4.4 The critical plane is defined in the velocity space. A maneuver performed in this plane will acquire the target and minimize ΔV.

4.6 In computing the partial derivatives of v with respect to γ, the partial of r_a with resect to γ is zero. The terms that multiply $\partial v/\partial \gamma$ are factored out and divided to form a fraction. The denominator may be discarded and the numerator is zero only if γ is zero.

Chapter 5

5.1 $p = 4\binom{52}{2} = 1.539 \times 10^{-6}$

5.2 $p = \binom{500}{5} = 3.265 \times 10^{-14}$

5.3 Caesar's box is in a narrow annulus of width 3 yards where the PDF is constant.

$$\sigma = \frac{50}{1.17741} \qquad p = \left[e^{\frac{-98.5^2}{2\sigma^2}} - e^{\frac{-101.5^2}{2\sigma^2}} \right] \frac{3}{200\pi} = 4.96 \times 10^{-5}$$

5.4 The probability of hitting Caesar's box, if that is the target, is approximately

$$p = 1 - e^{\frac{-3^2}{2\sigma^2}} = 2.49 \times 10^{-3}$$

5.5 The binomial coefficients for $m = 2$ are obtained from

$$(1 + x)^m = 1 + 2x + x^2$$

Since each coefficient for the next row of Pascal's triangle is the sum of the two coefficients in the row above, $B(m+1, k+1) = B(m, k) + B(m, k+1)$ and the solution is

$$B(m, k) = \frac{m!}{(m-k)!\,k!}$$

where

$$\binom{m}{k}\frac{m+1}{k+1} = \binom{m}{k} + \binom{m}{k}\frac{m-k}{k+1}$$

after factoring out B(m,k). The demonstration is complete if $B(2, k) = 1,\ 2,\ 1$ which it does.

Chapter 6

6.1 The rows of the matrix are $A(i, j)$. The measurement covariance (P_m), the inverse of the *a prior* matrix (P_0) and the estimated parameter *a prior* are set equal to zero. The number of measurements, which are assumed to be exact, is equal to the dimension of the matrix. Both the Kalman gain and the weighted least square gain give $A(i, j)^{-1}$.

6.2 Venus is the best guess since the maximum acceleration from Mars would be too small. In the real world, it was Mars. An early version of an orbit determination program left Mars out of the Equations of motion because the acceleration was believed to be too small to be detected. The actual ramp in the Doppler data was smaller than postulated for this problem and Venus was included in the equations of motion.

6.3 $E(X_2 X_1^T) = K\ E(Z_{1,2} X_1^T) + (I - KA)\ E(X_1 X_1^T)$

Since the data taken after t_1 is uncorrelated with X_1, $E(Z_{1,2} X_1^T) = 0$ and $P_{1,2} = P_2$

6.4 Draw a sample from $P_1 - P_2 = KAP_1$ and add it to X_1.

Chapter 9

9.1 33.3 m/s

9.4 $\Delta V_x = -3.858\,\text{m/s},\ \Delta V_y = 0,\ \Delta V_z = 3.858\,\text{m/s}$

9.5 $r_p = 3.04\,\text{km}$. The spacecraft crashes into Eros.

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