Index

Note: Page numbers followed by f indicate figures, t indicate tables, and b indicate boxes.

A	Attitude change using thrusters, 663-665, 664f
Absolute	Averaging of osculating elements, 513
acceleration, 18, 19 <i>f</i> , 23–24, 27, 31, 33, 56–58, 63, 118, 529, 544–545, 553, 641–642, 654	В
angular acceleration, 26, 546–552, 577–581, 594, 654 angular velocity, 23–24, 63–64, 78, 544–552, 557, 562–563, 566–567, 589–590, 624, 636, 654, 678–681, 689	Bac-cab rule (vector identity), 8–9, 69, 232, 235, 557, 610 Ballistic coefficient, 486–487, 508–510
frame (inertial frame), 545	Barker's equation for the parabola, 157, 158f
velocity, 26, 30–32, 56, 378, 448–457, 468, 556, 566–567,	Bessel functions, 153, 155, 155 <i>f</i>
581, 667, 708	Bielliptic Hohmann transfer, 287, 295–298, 295–297f
Acceleration of gravity, 15–16, 15 <i>f</i> , 18, 47–49, 287–288, 329,	Binomial expansion theorem, 243
333, 488, 655, 707, 710–712, 714	Binormal, 12–14, 474
Acceleration vector, 10 <i>f</i> , 13–14, 31, 59, 63, 353, 474, 497, 539,	Bisection method, 122–124, 123 <i>f</i> , 125 <i>t</i>
706	Blackbody, 520–521
Advance of periapsis, 213–215, 213 <i>f</i>	Body-fixed frame, 546–552, 577, 588, 590, 597, 605, 613, 619
Aiming radius of a hyperbola, 96, 102, 405–407, 410–411	641–642, 644, 654, 673
Angles-only orbit determination, 268	Burnout velocity, 130, 130f, 403, 711–712, 723–726, 726f, 73
Angular acceleration vector, 353	
Angular impulse, 20–21, 556, 661	C
Angular impulse-momentum principle, 556	Cannonball model, 520–521
Angular momentum	Cartesian coordinate system, 3, 3f, 9, 13, 21–22, 64, 82, 92–93
about a fixed point, 557, 563	92f, 96, 97f, 102, 186, 195, 202, 220–221, 488, 563, 565
about center of mass in, 554-555, 557, 565-567, 582-583,	568, 751
634, 638–645, 647, 651, 660–661, 664–668, 673–676	Cartesian coordinate transformations, 202, 600
of a continuum, (AU: The term is not referred in the text.	Celestial sphere, 183–185, 183f, 249
Please check.)	Center of curvature, 12–14, 706
central force motion, (AU: The term is not referred in the text.	Center of mass, 18, 56–58, 60–62, 61–62f, 64f, 66–67, 77,
Please check.)	116–119, 125, 128, 397, 399, 407, 488–489, 543,
for hyperbolic arrival, 387	552–563, 565–567, 571–576, 581–582, 584, 586–588,
for hyperbolic departure, 386, 398–399, 439, 442	593–595, 633–634, 641, 649–651, 653–654, 656–657,
Angular velocity vector, 22, 352, 543–544, 546–552, 559, 564,	659, 663, 666–667, 673–678, 675 <i>f</i> , 685, 687–688, 688 <i>j</i>
567, 577, 612–618, 622, 636, 639, 641, 643, 647–648,	690, 695
673, 679–681, 688–689	Characteristic energy, 98
Apparent solar ecliptic longitude, 523	Characteristic equation, 568–569, 659–660, 692
Apse line, 71, 73–74, 81–82, 94–95, 102, 143–144, 213,	Chase maneuver, 287, 313–317
215–217, 289, 303–308, 306 <i>f</i> , 387–388, 399, 412–414,	Chasles' theorem, 543
447 <i>f</i> , 518	Circular orbit
Apse line rotation, 308–309f, 309–313, 312f, 319, 319f, 331, 480–481, 508	energy, 76, 387
Argument of periapsis, 213, 499–500, 506–513	period, 74 <i>f</i> , 76, 118, 125, 175–176 speed, 74 <i>f</i> , 91, 294, 357, 386, 437, 441, 483, 582–583, 708
Arrival trajectory	Classical Euler angle sequence, 203, 210, 588, 588f, 600, 602
interplanetary, 385–387, 391, 396–397, 427–430, 432–433	Clohessy-Wiltshire (CW) equations, 365–369, 365 <i>f</i> , 372,
lunar, 441, 449	374–375
Astronomical unit (AU), 386 <i>f</i> , 423, 520, 523	Clohessy-Wiltshire (CW) frame orbital elements from the
Atmospheric drag, 479–480, 483–487, 508–510, 521	state vector, 378, 378f
Attitude change by coning, 660–663, 660 <i>f</i> , 662–663 <i>f</i>	Comoving reference frame, 56 <i>f</i> , 63

Coning of spinning spacecraft conservative force, 660–663, 660 <i>f</i> , 662–663 <i>f</i>	Eccentricity vector, 71–72, 72–73f, 74, 190, 232–233, 443, 445 494, 499
Continuous medium, 552f	Ecliptic plane, 182f, 183–184, 223, 385, 459–460, 460f,
Control moment gyro, 633, 682–683, 683f, 685	521–522, 530
Coordinate transformation, 195–208, 196 <i>f</i> , 263, 588, 610–612	Effective exhaust velocity, 709
Coriolis acceleration, 27–29, 33	Eigenvalues, 567–570
Coriolis force, 1, 34	Eigenvectors, 567–571, 613–614
Cowell's method, 480–481, 481f, 486	Elementary rotation matrices, 203, 597–598
Cranking maneuver, 287–288, 317–318	Elliptical orbit
Cross product, 4–5	energy, 83
Circular restricted 3-body problem, 116–132	period, 84, 143
equations of motion, 118–120	Elliptic mean anomaly, 144, 182f
,	Elliptic orbit equation., 72
_	Encke's method, 481–483, 482–483f, 493f, 494
D	Energy sink method of stability analysis, 651, 653
Direction cosine matrix (DCM)	Ephemeris, 184–185, 185 <i>t</i> , 423–427, 457–461, 459 <i>f</i>
for Euler angles, 204–206, 205–206b, 553	Equations of motion
from quaternion, 755–756	control moment gyros, 682
for yaw-pitch-roll angles, 206, 207–208b, 598	dual-spin spacecraft, 651
Declination, 181–188, 183f, 220–223, 256–257, 259–260,	gravity turn trajectory, 705
262–264, 269, 276, 508–510	gyro-stabilized spacecraft, 672–685
Delta-v	rigid body rotation, 553–557
for Hohmann transfers, 292–293, 295–298, 296–298b,	spinning top, 583–588
333–334	Equilibrium points (Lagrange points), 120–126, 122f
for non-Hohmann transfers, 303-304, 305-308b	Escape velocity (parabolic orbital speed), 90, 130–131
for plane change, 317–318, 320, 324–326b, 326	Euler angle rates vs. angular velocities, 593
for a rocket, 287, 705, 716	Euler angles, 189–190, 206, 543–544, 588–597, 612,
Departure trajectory	617 <i>f</i>
interplanetary, 385–388, 390f, 396–403, 401–403b, 407, 415,	Euler angle sequences
427, 429–431 <i>b</i>	asymmetric, 203
lunar, 294, 439, 442, 449–451	symmetric, 203
Derivative of a moving vector, 21–26	Euler axis, 600–603, 605, 610, 612–613, 618f
Diagonal matrix, 559, 614	Euler symmetric parameters (quaternion), 602
Direction angles, 4, 4f	Euler's equations for torque-free motion, 641–642
Dissipative effects, 648	Euler's equations of motion, 688
Distance along path, 11	Euler's modified equations of motion, 577
Dot product, 4–5	Euler's numerical integration method, 39
Drag coefficient, 485	Exhaust velocity, 709, 731
Drag loss, 711–712, 714	•
Dual-spin spacecraft, 421, 633, 650–653, 650f, 676–678b, 676f	
_	F
E	Fehlberg coefficients, 45–46
Earth-centered inertial frame, 29f	Flattening factor, 266, 276
Earth-centered rotating frame, 29f, 473f	Flight path angle, 16–17, 73f, 74, 88, 91, 134–136,
Earth's oblateness, 212–224, 212t, 213f, 217–220b	138, 304 <i>f</i> , 307–308, 318, 343, 440, 443, 444 <i>f</i> ,
Eccentric anomaly	706, 708, 711
ellipse, 155, 159	Force, 1, 14, 18
hyperbola, 159, 161, 163	Frame of reference, 9, 11, 18, 21–24, 29–30, 52, 55–56, 60 <i>f</i> ,
Eccentricity, 55, 60, 71–72, 82–85, 87, 89–90, 97, 100,	63–64, 116–117, 181, 191–193, 209, 256, 351,
112–113 <i>b</i> , 153, 155, 189–190, 240–241, 254, 290, 311,	357–359, 423, 427, 446, 454 <i>f</i> , 544–546, 559, 588,
398–399, 406–407, 409, 414, 437–439, 443–445, 495,	610–612, 627, 742
502 508 514-515	Frozen orbits, 518

Gauss method, 231, 268–282 iterative improvement, 274–282, 284 Gauss planetary equations, 501, 507–508 <i>b</i> , 510–513, 522–523, 533, 536, 540 Gauss variational equations, 480, 494, 498–513 Geocentric ecliptic plane, 522, 530 Geocentric equatorial frame, 181, 185–189, 190 <i>f</i> , 209–212, 249, 256, 258, 261–262, 351, 360, 423, 461, 469, 485, 499, 509 <i>f</i> , 522 Geocentric latitude, 254–256, 255 <i>f</i> , 490–491 Geocentric right ascension-declination frame, 181–185 Geodetic latitude, 254–256, 255 <i>f</i> Geopotential perturbations, 480	Impulsive moment and coning, 661 Inclination of an orbit, 213–215, 225, 239, 321, 322 <i>f</i> , 460 <i>t</i> Inertia, 14 Instantaneous axis of rotation, 21–22, 543–544, 544 <i>f</i> , 612–613 Interchange of the dot and cross (vector identity), 9, 49, 501 Interplanetary Hohmann transfers, 385–387 J 2000, 251, 423–425, 427 <i>f</i> , 430, 457, 523, 531 Jacobi constant, 55, 126–132 Jet thrust, 709 JPL Horizons online planetary ephemeris, 457, 466 Julian day (JD), 231, 249–251, 523, 531
Geostationary equatorial orbit (GEO), 78–80, 79–80 <i>f</i> , 302 <i>f</i> , 320–321, 324–326, 324 <i>f</i> , 333–334, 533 <i>t</i> , 703, 734 Gibbs method, 231–238, 269, 283 <i>t</i> Gradient operator, 58, 488, 750 Gravitational constant, 14, 50, 57, 487 Gravitational parameter, 63, 67, 77–78, 191–193, 213, 398, 401–403, 406, 415, 437, 464–465, 470, 535, 738 <i>t</i> Gravitational perturbations, 487–494, 518, 540 Gravitational potential energy, 127–128, 487, 750, 752 Gravitational torque, 688	K Keplerian orbit, 72, 99, 395–396, 474, 479, 495, 497 Kepler's equation for the ellipse, 147, 147 <i>f</i> , 155, 170 series solution, 148–153 Kepler's equation for the hyperbola, 161, 162 <i>f</i> , 163 Kepler's first law, 72, 739 Kepler's second law, 69, 84, 739 Kepler's third law, 84, 739 Kinetic energy of a rigid body, 543, 581–583
Gravity assist flyby, 421–422 Gravity-gradient stabilization, 685–697, 696 <i>f</i> , 704 Gravity loss, 711, 714–715 Gravity turn trajectory, 705, 707–708, 715–716, 715–716 <i>f</i> Greenwich meridian, 29–30, 249, 253–254 Greenwich sidereal time, 249, 251–254, 257 Ground tracks, 181, 220–224, 224 <i>f</i> Gyroscopic moment, 586–588, 631 Gyrostat, 650–651	Lagrange brackets, 538 Lagrange f and g functions, 231, 495 series expansion, (AU: The term is not found in the text. Please check.) Lagrange matrix, 497–498, 538–539 Lagrange multiplier technique, 726–733 Lagrange planetary equations, 479 Lagrange points (equilibrium points), 55, 120, 126, 128, 130
Halo orbits, 125–126 Heliocentric ecliptic frame, 423, 423f, 425, 427 Heliocentric orbits, 387–388, 396 Heliocentric state vector, 267–268 Heun's predictor-corrector method, 44–45 Hohmann transfer, 289–295, 308, 313–317, 325f, 337 Horizontal parallax, 530–531, 530f Hour angle, 581 Hyperbolic excess speed, 98, 137, 166, 397–399, 402, 406–407, 410, 430 Hyperbolic mean anomaly, 159, 163, 167 Hyperbolic orbit, 97, 137, 170, 448 Impulse of a force, 19 Impulsive maneuvers, 287–288, 305, 308–311, 318, 345, 347, 351, 369–376, 415–421, 661	Lagrange points (equilibrium points), 55, 120–126, 128–130, 139 Lambert's problem, 231, 238–249, 239 <i>f</i> , 247–248 <i>f</i> , 287, 313–317, 385, 427 Laplace limit, 153 Laplace vector, 71 Latitude, 29–30, 32, 79–80, 183–184, 212, 215–216, 220–223, 253–256, 259, 264–266, 283–285, 321–329, 321–322 <i>f</i> , 348, 399–400, 400 <i>f</i> , 427 <i>f</i> , 460, 488, 490–494, 500, 500 <i>f</i> , 504, 506, 530–531 Latus rectum, 74, 74 <i>f</i> , 328, 328 <i>f</i> Launch azimuth, 321–329, 322–323 <i>f</i> , 348 Leading-side flyby, 412–415 Legendre polynomials, 489, 490 <i>f</i> , 538, 601 Linear momentum, 19–20, 67, 75, 334, 554–555 Linearized equations of relative motion, 361 Local horizon, 29–30, 74, 257, 305, 307 <i>f</i> , 309, 352, 499, 501, 688–689, 695 Longitude, 29–30, 183–184, 184 <i>f</i> , 249, 523, 530

Low earth orbit, 16–17, 76–77, 126, 135, 213–214, 220, 229, 287, 320–321, 324–326, 324f, 437, 438f, 471–474, 633, 688, 694, 734 Lunar ecliptic latitude, 530–531 Lunar ephemeris, 457–461, 465, 470, 475 Lunar gravity perturbation, 534f Lunar inclination vs. time, 458–459b, 459f Lunar position algorithm, 531t Lunar trajectories by numerical integration, 469–474 Lunar trajectory as a circular restricted three body problem, 116–132, 470 LVLH frame, 352, 365, 499	Newton's second law of motion, 1, 17, 50, 57, 75, 708 Node line, 189–191, 210, 213–214, 229, 328, 382, 494, 503–504, 506, 583, 589–590 Nn-Hohmann interplanetary trajectories, 427–433 Non-Hohmann transfers, 287, 303–308, 303f, 306f Non-impulsive orbital maneuvers, 329–334 Normal acceleration, 13–14, 17, 706 Numerical integration, 1, 34–49, 131, 287, 350, 440, 469–474, 472f, 480, 483, 494, 527, 615–623, 741–743, 745–747 Nutation angle, 588–589, 597, 602, 621–623, 634–635, 640, 643, 697, 699, 702 Nutation damper, 633, 653–660
L v L11 frame, 332, 303, 499	•
Magnitude of a vector, 2 Major axis spinner, 647, 651, 659, 693–694, 700 Mass, 1, 14–18, 66, 76–77, 118, 122, 182–183, 287–288, 487, 521, 543, 552–553, 557, 559–563, 593, 634, 653–655, 664, 666–667, 672–673, 717, 722 Mass flow rate, 709–714	Oblate spheroid, 212, 253–254, 254 <i>f</i> , 488 Oblate spinner, 633, 647, 650 Oblateness (flattening), 212–224, 231, 254, 480, 488, 490–491, 493 Obliquity of the ecliptic, 181–182, 521–522, 524, 527, 531–535 Optimal <i>N</i> -stage rocket mass, 726 Optimal rocket staging, 726–733
Mass ratio (rockets), 118, 122, 124–125, 646–647, 650–651,	Orbit equation, 72, 74, 81, 90, 93, 102, 108–109, 115, 149–151,
656–660, 710–711, 716–717, 720, 734 Mean anomaly ellipse, 143–144, 167 hyperbola, 143, 164 Mean anomaly of the Sun, 523 Mean longitude of the Sun, 523 Mean motion, 144, 217–219, 364–365, 367, 371, 374–375, 377, 380–383, 388, 391–392, 513, 518, 539, 688–690, 693–694, 696 Method of averaging, 480, 513–519 Minor axis spinner, 647, 659, 693–695 Modified Euler equations of motion, 543, 591, 612, 670 Molniya orbit, 181, 216–220, 216f	155, 164, 233, 303, 306–307, 309–313 Orbital elements, 181, 189–195, 210, 217–219, 221–222, 225, 236–238, 240, 245, 266–268, 275–276, 282–285, 296, 316, 348, 355, 358, 423–427, 424 <i>t</i> , 428 <i>f</i> , 429, 434, 454–457, 468, 475, 479–480, 495–499, 501, 506–508, 511, 513–514, 518, 522, 527, 533, 536, 539 Orbital energy, 76 Orbital inclination vs launch azimuth, 322 Orbits from angle and range data, 261–268 Orthogonal matrix, 198, 563, 589 Orthogonal triad, 12 <i>f</i> , 63 Osculating orbit, 480–482, 481–482 <i>f</i> , 496–497, 499, 501, 507–508, 537, 539
Moment of a force, 19–20	Osculating orbital elements, 480, 497, 501, 507–508, 539
Moment of a force, 19–20 Moment of inertia tensor of a rigid body principal directions of inertia, 559 principal moments of inertia, 559, 568–570, 573	Osculating orbital elements, 480, 497, 501, 507–508, 539 Osculating plane, 12–13, 474
Momentum exchange systems, 672–673 Momentum wheels (reaction wheels), 633, 673–676, 678–679, 682, 682f, 684–685, 703 Moon-fixed frame, 446, 454f, 465, 467, 473 Moving reference frames, 64f, 378, 546–552, 579–581	Parabolic mean anomaly, 158–159 Parabolic orbit, 157–159 Parabolic orbital speed (escape velocity), 55, 90, 130–131 Parabolic orbit equation, 90–93 Parallel axis theorem, 571–576, 587, 675 Parallelogram rule, 2–3, 2f
N	Parallel staging, 719–720, 719 <i>f</i>
Net external force on a continuum, 552	Parameter of an orbit, 76, 84, 87–90, 92
Net external moment on a continuum, 644-645, 684	Patched conic method
Net internal force on a continuum, 552	interplanetary missions, 385, 387-388, 421, 423
Net internal moment on a continuum, 552	lunar missions, 440, 460, 460t
Newton's law of gravitation, 14-17, 57, 392-393	Patch point, 441–442, 444–446, 449–454, 463–466, 475
Newton's method for finding roots, 148f, 276–278	Path (trajectory), 10–11

Payload burnout velocity vs. number of rocket	Precession angle, 588–589, 591, 661, 664–665
stages, 724	Precession of a spinning top, 583–588, 586f
Payload mass, 716, 720–721, 731, 734	Precession of the vernal equinox, 182–185, 185 <i>t</i>
Payload ratio, 716–717, 718 <i>f</i> , 720–721, 723–724, 733–734	Precession rate in torque-free motion, 633–642, 639f
Periapsis, 73–75, 80–81, 85, 94–95, 98, 98 <i>f</i> , 102, 134, 136–137,	Principal angle, 600–602, 609 Principal directions of inartic 550, 567, 560, 576, 626
141–144, 143 <i>f</i> , 147, 169–170, 213, 289–290, 293,	Principal directions of inertia, 559, 567, 569, 576, 626 Principal moments of inertia, 559, 568–570, 576, 626
305–308, 311–313, 349, 386, 398–399, 405, 407–418,	*
422, 431–432, 434, 446, 499–500, 506–513, 543–544	Principal normal, 12–14, 17
Perifocal frame, 55, 102–105, 103 <i>f</i> , 115, 209–212, 217–219,	Prograde orbit, 213, 321–322, 399–400, 402
234, 343, 446, 499 Paried 32, 55, 60, 62, 76, 77, 77f, 84, 85f, 88, 00, 116, 118, 124f	Prolate spinner, 647–648, 650–651 Propellant mass, 288, 288 <i>f</i> , 333, 434, 711, 713, 716, 722,
Period, 32, 55, 60–62, 76–77, 77 <i>f</i> , 84, 85 <i>f</i> , 88–90, 116–118, 124 <i>f</i> , 126, 141–144, 147, 149–151, 177–178, 182–183, 189,	724–725, 729, 732–733
194–195, 215–220, 222–223, 224f, 240, 294, 297–303,	Pumping maneuver, 287–288
299f, 314–316, 346, 357, 359f, 380–382, 387–392,	Pythagorean theorem, 3, 82
410, 411 <i>f</i> , 422, 437–439, 443–444, 449–451, 459, 463,	1 ydiagorean dicorem, 5, 82
480, 485, 513, 518, 615, 679, 682, 693–694, 697,	0
703–704	Q
Perturbation	Quadrant ambiguity, 145–146, 186–188, 190–193, 239, 264
of angular momentum, 78	Quadratic equation, 172, 585, 693
of angular momentum, averaged, 104	Quaternion
of argument of periapsis, 90–93	addition, 602–603
of argument of periapsis, averaged, 517–519	from direction cosine matrix, 602, 605–608, 610–611,
of right ascension, 67, 87-89	615–616, 619, 621
of right ascension, averaged, 111-112	multiplication, 602–604
of true anomaly, 80-90	norm, 602
of true anomaly, averaged, 105-116	rotation operation, 607, 609–610 time derivative, 612–613
Perturbation of earth orbit	time derivative, 012–013
due to atmospheric drag, 60	
due to lunar gravity, 80–81f, 125t, 130–131, 533t	R
due to second zonal harmonic, 212, 212t	Radial velocity, 76, 100, 109–110, 113, 168, 172, 191, 301,
due to solar gravity, 85–86 <i>f</i> , 535–537	311–313, 319, 328–329
due to solar radiation, 79f, 116–132	Radiation pressure coefficient, 520–521, 527, 541
Perturbation of orbital parameters, 75–76	Radius of curvature, 12–14, 17, 50, 706
Phasing maneuvers, 287, 298–303, 300 <i>f</i> , 313–317, 342,	Radius of gyration, 559, 631, 667
387–388 Disconsistance of the second	Rayleigh quotient, 606
Photon energy, 520	Reaction wheel (momentum wheel), 633, 673–679, 682, 682 <i>f</i> ,
Photon momentum, 94–95	684–685, 703
Photosphere of the Sun, 520	Rectification in Encke's method, 482–483
Planck constant, 520 Planc change manager 215, 216, 287, 217, 220, 210f, 225f	Rectilinear trajectory, 134
Plane change maneuver, 215–216, 287, 317–329, 319f, 325f	Reference orbit, 360–361, 363–364, 366, 481, 483 <i>f</i> Regression of the node, 213, 213 <i>f</i> , 216–217, 492–493
Planetary ephemeris formulas, 423–427 Planetary flyby, 385, 412–422, 412–413 <i>f</i>	
Position vector, 8–11, 13, 26, 26 <i>f</i> , 28–30, 34, 56–57, 59–61, 63,	Relative acceleration, 23–24, 28, 31, 63–64, 118, 362, 539, 594 Relative acceleration equation, 594
65–66, 68–69, 69 <i>f</i> , 72, 74, 80–81, 102, 113, 118, 144,	Relative acceleration equation, 577–581, 594
178, 186–187, 211–212, 220–221, 220 <i>f</i> , 231–238, 240,	•
245, 248, 253–254, 256–258, 261, 263, 268–269, 305,	Relative angular velocity, 388, 594, 650–651, 675, 682, 701 Relative motion in orbit, 351–365
314–316, 329, 351–352, 357, 359, 361, 371–373,	Relative velocity, 1, 28, 30–31, 63, 68–69, 75, 351, 353,
388–389, 392–393, 427, 429, 440–443, 446, 448,	366–367, 369–372, 375, 377, 378 <i>f</i> , 381–383, 399–403,
454–457, 461–463, 465, 467–473, 485, 487, 495, 497,	445, 448, 452, 467, 485, 545
506, 523–526, 529, 532, 535, 544, 547–548, 552–555,	Relative velocity equation, 377
554 <i>f</i> , 557, 560–561, 581, 625, 653–654, 656–657, 663,	Relative velocity in close proximity circular orbits, 376–378
667, 685, 688–690, 742, 749	Restricted rocket staging, 716–726

Retrograde orbit, 193, 195 <i>f</i> , 213, 321–322, 322 <i>f</i>	Spin stabilization, 633, 650
Right ascension, 181–190, 183 <i>f</i> , 210, 213, 220–223, 231,	Stability of a dual-spin spacecraft, 651
256–257, 262–263, 266, 268–269, 276, 382, 423, 461,	Stability of a spin-stabilized spacecraft, 651
493 <i>f</i> , 499, 503–505, 508–510, 516, 543–544	Stable orientations for gravity-gradient
Right ascension of the ascending node, 189–191, 210, 222, 423,	stabilization, 689, 693–695
486, 493 <i>f</i> , 499, 503, 508–510	State vector, 59–61, 64, 181, 185–195, 209, 261, 268, 276, 279,
Rigid body, 21–22, 22f, 543–623, 663	281, 333–334, 423, 427–428, 457, 461, 468, 470–472,
Rigid body kinetic energy, 581–583	480–481, 498
Rocket equation, 287–288, 705	State vector from the orbital elements, 181, 189–195
Rodrigues' formulas	Stefan-Boltzman constant, 520
for Legendre polynomials, 489, 601	Stefan-Boltzman law, 520
for vector rotation, 601, 609	Step mass of rocket, 729–733
Routh-Hurwitz stability criteria, 659–660	Structural ratio of a rocket, 716–717, 720–721, 724, 726, 729,
Runge-Kutta numerical integration method	731
adaptive step size, 47	Stumpff functions, 141, 168–169, 169 <i>f</i> , 174, 243
first order, 42, 47	Sun-synchronous orbit, 214–215, 215 <i>f</i> , 323–329
fourth order, 53	Sweep angle, 442–443, 444 <i>f</i> , 445, 449–451
second order, 41	Synodic period, 389, 392
third order, 36	Synodic period, 309, 392
tillita order, 50	Т
S	Tandem stage rockets, 717–719, 718f
Sectorial harmonics, 491–494	Tangential acceleration, 508
Secular terms, 367, 513	Tangent vector, 13–14, 50
Semilatus rectum, 74, 74f	Taylor series, 36–38, 113
Semimajor axis	Tesseral harmonics, 491–494
ellipse, 81, 84, 144, 194–195	Three-axis stabilization, 633, 679f
hyperbola, 95, 100–102, 168	Thrust equation, 705, 708–710
Semiminor axis	Thrust-to-weight ratio, 710–711
ellipse, 82, 86, 96	Time vs. position
hyperbola, 95–96	circular orbit, 142–143
Sensitivity of trajectory to initial errors, 403–405	elliptical orbit, 143–157
Series solutions of Kepler's equation, 153	hyperbolic orbit, 159–167
Shadow function, 520–521, 526, 528	parabolic orbit, 157–159
Sidereal time, 231, 249–253, 255, 257, 264–265	Topocentric coordinate system, 231, 253–256
Slant range, 257, 268–269, 272–274, 281	Topocentric equatorial coordinate system, 256–257
Solar constant, 520	Topocentric horizon coordinate system, 29-30, 257-261
Solar ecliptic longitude, 521–523	Trailing-side flyby, 385, 412–414, 413 <i>f</i>
Solar radiation, 520–521	Trajectory (path), 10–11
Solar radiation pressure, 479–480, 520–528, 535	Translunar injection (TLI), 440–442, 444, 446, 455f, 461, 469f
Sounding rocket, 705, 708, 711–714	Transverse velocity, 311, 328
Space and body cones, 639, 639f	True anomaly, 71, 72f, 90, 141, 143–144f, 189, 444, 502–503
Specific impulse, 287–288, 288 <i>t</i> , 288 <i>f</i> , 329–330, 333–334, 401,	True anomaly of the asymptote (hyperbola), 94, 164
705, 710, 717, 720, 726, 731	Turn angle of a hyperbola, 94–95
Speed, 1, 11, 75–76, 78, 90, 118, 127, 166, 172, 291, 295, 304,	Two-body vector equation
319 <i>f</i> , 320, 386–387, 397–398, 407, 422, 437, 438 <i>f</i> ,	of absolute motion, 56
	of relative motion, 63–67
439–440, 483, 508, 520, 633, 668, 682, 706–708 Sphere of influence, 179, 385, 392–398, 403, 405, 412, 414,	Two-impulse rendezvous maneuvers, 369-376
*	
427–430, 440, 441 <i>f</i> , 447 <i>f</i> , 454 <i>f</i> , 462 <i>f</i> , 466 <i>f</i> , 469	U
Spinning top	
nutation rate, 584	Unit quaternion, 602, 604–606, 609, 617 <i>f</i> , 755–756
precession rate, 584	Unit vector, 2–3, 12f, 102
Spin rate in torque-free motion, 697	Universal gravitational constant, 14, 57, 487

Universal Kepler's equation, 141, 168, 171–172 Universal variablesiables, 141, 167–177, 244–249 US Standard Atmosphere, 484–485, 484*f*, 521

۷

Vector, 1–9 Vector addition, 2–3, 2f Velocity vector, 10–11, 112f, 304, 312–313, 320, 320f Vernal equinox, 181–182, 184–186, 249, 427f, 430, 522

W

Wait times, 391–392 Wobble angle, 639, 699

Y

Yaw-pitch-roll rates vs. angular velocities, 597f, 598 Yaw-pitch-roll sequence, 597, 597f Yo-yo mechanism for despin, 666–672 cord length required, 669, 671–672 radial release, 671–672, 671f tangential release, 671, 671f

Z

Zonal harmonics, 212, 489-491