

Index

Note: Page numbers with “f” denote figures; “t” tables; “b” boxes.

A

- Apse line rotation
 - angular momentum, 325
 - orbit intersection, 322–323, 322f
 - point of intersection, 323
 - radial velocity, 325
 - trigonometric identity, 323, 326
- Astronomical data, 721
- Averaging method, orbital perturbations
 - angular momentum, 688
 - eccentricity, 689
 - inclination, 692
 - mean motion, 687
 - perigee, 692–695, 694f
 - time-averaged variation, 688
 - true anomaly, 690–691

B

- Bac–cab rule, 9, 9b–10b
- Barker’s equation, 163
- Bi-elliptic Hohmann transfer, 299–300, 308–312, 309f

C

- Chase maneuvers, 328–332
- Chasles’ theorem, 459
- Circular orbits, 147, 147f
 - earth’s gravitational parameter, 82
 - geostationary equatorial orbit, 83, 86f
 - inertial angular velocity, 83
 - low earth orbit, 82
 - period of, 81
 - space shuttle main engines, 82
 - space shuttle orbiters, 82
 - specific energy, 81–82
 - velocity of, 81
- Clohessey–Wiltshire (CW) equations, 385, 385f
 - angular velocity, 383
 - matrix notation, 386–387
 - relative velocity, 384–385
- Conversion factors, 722
- Coordinate transformation, three-dimensional space orbits
 - arccosine function, 212–213
 - arcsine function, 215–216
 - asymmetric Euler sequences, 210
 - Cartesian reference axes, 202, 203f
 - classical Euler sequence, 210, 211f, 212

- column vector, 212
- direction cosine matrix, 204
- inverse transformation, 205–206
- orthogonal matrix, 205
- rotation of, 207–209, 208f, 209f
- six symmetric Euler sequences, 210
- transpose matrix, 204
- unit vectors, 202
- unprimed unit vectors, 203
- yaw, pitch and roll sequence, 213–214, 214f
- Cowell’s method, 653, 654f
- CW equations. *See* Clohessey–Wiltshire (CW) equations

D

- Dual-spin spacecraft, 157b–159b, 587f, 591f
 - angular momentum, 560
 - despun platform, 561
 - dual-spin axisymmetric configuration, 559, 559f
 - “energy sink” procedure, 559, 562
 - oblate spinner, 558
 - OSO-I, 559
 - TACSAT I, 559
 - total rotational kinetic energy, 560
 - total transverse moment of inertia, 560

E

- Earth’s oblateness
 - definition, 219
 - Molniya telecommunications satellites, 223–227, 223f
 - node regression, 220–221, 221f
 - perigee advance, 222–223
 - second zonal harmonics, 219–220, 220t
 - zonal variation, 219–220
- Elliptical orbits
 - angular velocity, 149
 - apoapsis and radial coordinate, 85
 - apse line distance, 85–86, 87f
 - Bessel functions, 160, 161f
 - Cartesian coordinate system, 88, 88f
 - eccentric anomaly, 149, 149f, 162
 - eccentricity calculation, 90
 - eccentricity plot, 159–160, 159f, 160f
 - energy conservation, 89
 - geocentric elliptical orbit, 154f
 - Kepler’s formula, 151, 152f
 - Kepler’s second law, 89

Elliptical orbits (*Continued*)

- Lagrange series, 158–159
- Laplace limit, 159
- mean motion, 149
- mean vs. true anomaly, 148, 148f
- Newton's method, 152, 153f
- periods and energies, 90, 90f
- Pythagorean theorem, 87
- quadrant ambiguity, 150, 150f
- rectilinear ellipse, 90
- semimajor axis, 86, 91
- specific energy, 89
- $\tan(E/2)$ value, 151, 151f
- trigonometric identity, 150
- true anomaly, radial coordinate, 87
- truncated Bessel series solutions, 160–162, 161f

Encke's method

- Lagrange coefficients, 654
- perturbed and osculating orbits, 654, 655f
- rectification, 655–656, 655f, 656b
- two-body motion, 653

Equations of motion, three-body system, 725f

- accelerations, 726
- components, 726
- gravitational forces, 725
- threebody.m function, 728
- velocities, 726

Euler's equations

- absolute angular acceleration, 497
- angular momentum, 496
- comoving coordinate system, 496
- relative angular acceleration, 498–502

F

Fehlberg coefficients, 49

G

Gauss method, 280f

- binomial theorem, 283
- constant angular momentum, 281
- dot product, 281
- eighth-order polynomial, 285
- geocentric position vector, 279
- Lagrange coefficients, 280, 282
- scalar triple product, 283
- slant range, 283–284

Gauss variational equations

- Cartesian inertial frame, 672
- direction cosine matrix, 672–674
- eccentricity, 675–676
- Gauss planetary equations, 674
- Keplerian elements, 672
- latitude argument, 673

orbital inclination, 679

orthogonal unit vectors, 672

osculating element, 671

periapsis argument

- algebraic manipulations, 685–687

- Gauss planetary equations, 681b–682b, 681–685

- node line vs. position vector, 680

- radial unit vector, 680

- tangential acceleration, 682–685

- tangential thrust, 682

perturbing acceleration, 674

right ascension, 677–679, 678f

specific angular momentum, 674–675

transverse unit vector, 672–673, 673f

true anomaly, 676–677

Gibbs method

- angular momentum, 241

- bac–cab rule, 241, 243

- coplanar vectors, 240, 240f

- perifocal coordinate system, 241

- position vectors, 242

- velocity, 241

Gravitational parameter, 722t

Gravitational potential energy, 736

- cosine law, 735

- point masses, 733, 733f

- position vector, 733

- symmetric mass distribution, 734–735, 734f

H

Heun's predictor–corrector method

- adaptive step size control, 50–52

- Fehlberg coefficients, 49

- MATLAB implementation, 47b, 50b

- RK1 method, 47

- truncation vector, 50

Hohmann transfer, 301f, 406–407, 407f, 408f

- angular momentum, 302, 304

- coaxial elliptical orbits, 304, 305f

- contour plots, 305–306, 306f

- eccentricity, 302

- elliptical orbit tangent, 301

- inner planet, 426, 428f

- outer planet, 426, 427f

- periapsis radius, 302

- specific energy, 301

- total energy expenditure, 302

I

Impulsive maneuvers

- propellant mass fraction vs. Δv , 300, 301f

- pumping maneuver, 300

- specific impulses, 300, 300t

Interplanetary trajectories

- aiming radius, 427–428, 431
- angular momentum, 428
- apoapsis radius, 431
- Cassini spacecraft, 443–444, 444f
- circular orbit planets, 408, 409f
- departure trajectory
 - angular momentum, 419
 - circular parking orbit, 418–420, 421f
 - heliocentric velocity vector, 420
 - hyperbolic trajectory, 418
 - locus of, 420, 421f
 - parabolic trajectory, 418
 - periapsis radius, 418–419
 - periapsis speed, 420
 - spacecraft departure, 418, 419f, 422f
 - spacecraft heliocentric speed, 421–423
- earth's sphere
 - gravitational force, 413, 413f
 - Keplerian orbit, 416
 - Newton's law of gravitation, 413–414
 - primary gravitational acceleration, 415
 - radius of, 416
 - secondary/perturbing acceleration, 415
 - spacecraft motion equation, 414
 - three-body system, 413–414, 414f
- eccentricity, 427
- gravity assist flybys, 443
- heliocentric departure trajectory, 437
- heliocentric ecliptic frame, 444, 445f
- heliocentric orbits, 407
- heliocentric velocity, 433–437
- Hohmann transfer, 406–407, 407f, 408f
 - inner planet, 426, 428f
 - outer planet, 426, 427f
- hyperbola family, 428–429, 429f
- hyperbola locus, 428–429, 429f
- hyperbolic excess velocity, 426, 436
- leading-side planetary flyby, 433, 434f
- minimum total time, 412–413
- non-Hohmann interplanetary trajectories, 449–455, 450f
- optimal periapse radius, 430
- orbital elements, 444–449, 447t
- orbital periods, 409
- patched conics method, 405, 417–418
- periapsis velocity, 430
- phase angle, 408–409, 411–412
- round-trip mission, 410, 410f
- scalar components, 434–436
- sensitivity analysis, 424–426
- synodic period, 409
- time of flight, 411
- trailing-side planetary flyby, 433, 435f
- true anomalies, 408

- turn angle, 426–427
- wait time, 411–412

J**Jacobi constant**

- earth–moon system, 135f, 136
- energy and angular momentum, 134
- secondary mass, speed, 133
- zero velocity, 134–135

L**Lagrange points**

- bisection method, 129–130, 129f, 130b
 - comoving coordinate system, 128
 - contour plot, 128, 129f
 - equilibrium points, 126–128
 - halo orbits, 132
 - linear equations, 127
 - Wilkinson Microwave Anisotropy Probe, 132–133
- Local vertical/local horizontal (LVLH) frame, 368, 368f

M**Moments of inertia, 476f**

- angular momentum components, 475
- angular velocity vector, 482
- characteristic equation, 487
- coefficient matrix, 486
- diagonal matrix, 477
- direction cosine matrix, 486
- eigenvector and eigenvalue, 487–489
- matrix components, 476
- orthogonal system, 483
- parallel axis theorem, 490–496, 490f
- positive-definite matrix, 487
- second-order tensor, 483–486
- shapes of, 477, 478f
- unit vectors, 475

N**Nearly equal numbers computation, 737****Newton's law of motion**

- absolute acceleration, 21f
- angular impulse, 21–23
- angular momentum, 21
- linear momentum, 21
- resultant/net force, 19
- slug, definition, 19–20

Non-Hohmann transfers

- apse line, 317–322, 317f, 318f
- interplanetary trajectories, 449–455, 450f

Nonimpulsive orbital maneuvers

- Cartesian component, 344
- elementary rocket dynamics, 345

Nonimpulsive orbital maneuvers (*Continued*)

- energy equation, 347
- linear differential equations, 345
- relative motion, 344
- scalar analysis, 348
- spacecraft mass, 347
- total energy, 347
- velocity vector, 344

O

Orbital perturbations

- atmospheric drag
 - ballistic coefficient, 658
 - drag force, 658
 - perturbing acceleration, 658
 - spacecraft velocity, 658
 - US Standard Atmosphere density profile, 656–657, 657f

averaging method

- angular momentum, 688
- eccentricity, 689
- inclination, 692
- mean motion, 687
- perigee, 692–695, 694f
- time-averaged variation, 688
- true anomaly, 690–691

Cowell's method, 653, 654f

drag effect, 652

Encke's method

- Lagrange coefficients, 654
- perturbed and osculating orbits, 654, 655f
- rectification, 655–656, 655f, 656b
- two-body motion, 653

Gauss variational equations, 652.

See also Gauss variational equations

geopotential perturbations, 652–653

gravitational perturbations

- Cartesian coordinates, 660
- gradient operator, 660
- gravitational potential energy, 660
- Legendre polynomials, 662, 663f
- perturbing acceleration, 663
- polar angle, 661–662
- Rodrigues' formula, 662
- rotationally symmetric perturbation, 662
- sectorial harmonics, 664–666
- spherical coordinate system, 661–662, 661f
- tesseral harmonics, 664–666
- zonal harmonics, 662–663

Keplerian orbits, 652

Lagrange planetary equations, 652–653

lunar gravity

- absolute accelerations, 705
- geocentric equatorial position, 707
- horizontal parallax, 707, 707f
- lunar ecliptic latitude, 707–708
- lunar ecliptic longitude, 707–708
- lunar position coefficients, 708, 709t
- perturbing acceleration, 706
- spacecraft's earth orbit, 705, 706f
- unit vector, 706–707

parameter variation

- acceleration, 668
- Lagrange planetary equations, 670–671
- Lagrangian matrix, 670
- orbital elements, 668–670
- perturbed motion, 669
- position vector, 667–668
- velocity, 668

solar gravity, 712–715

solar radiation pressure

- atmospheric density, 697
- cannonball model, 696
- direction cosine matrix, 698
- energy flux, 696
- Gauss planetary equations, 698–699
- geocentric ecliptic frame, 697
- geocentric equatorial frame, 697–698
- magnitude of, 696
- mean anomaly, 700
- perturbing acceleration, 696
- perturbing force, 696
- photon energy, 695
- position vectors, 701, 702f
- radiation intensity, 695
- shadow function, 696
- solar ecliptic longitude, 697, 699
- Stefan–Boltzmann constant, 695

Orbital position, 60f, 723

circular orbits, 147, 147f

elliptical orbits, 163

- angular velocity, 149
- Bessel functions, 160, 161f
- eccentric anomaly, 149, 149f, 162
- eccentricity plot, 159–160, 159f, 160f
- geocentric elliptical orbit, 154f
- Kepler's formula, 151, 152f
- Lagrange series, 158–159
- Laplace limit, 159
- mean motion, 149
- mean vs. true anomaly, 148, 148f
- Newton's method, 152, 153f
- quadrant ambiguity, 150, 150f
- $\tan(E/2)$ value, 151, 151f
- trigonometric identity, 150
- truncated Bessel series solutions, 160–162, 161f

- hyperbolic trajectories
 - eccentricity plot, 165, 165f
 - hyperbolic cosine, 166
 - hyperbolic tangent, 168
 - hyperbolic trig identity, 168
 - Kepler's equation, 167, 168f
 - parameters, 165–166, 166f
 - transcendental equation, 169
- orbit formula, 145–146
- parabolic trajectories, 163–164, 164f
- periapsis passage, 146
- universal variables
 - energy equation, 174
 - hyperbolic mean anomaly, 173
 - Kepler's equation, 176
 - Lagrange coefficient, 180–181
 - Newton's algorithm, 177
 - periapse passage, 176
 - semimajor axis, 173, 174t
 - Stumpff functions, 174–176, 175f
 - universal anomaly, 177
 - universal Kepler's equation, 174–175
- Orbiting Solar Observatory (OSO-I), 559

P

- Patched conics method, 405, 417–418
- Phasing maneuvers, 312, 312f
- Plane change maneuvers
 - cranking maneuver, 332
 - delta- v formula, 335–336, 335f
 - flight path angle, 333
 - GEO satellites, 336
 - impulsive plane change maneuver, 334, 334f
 - intersection line, 332f, 333
 - launch azimuth, 338–344, 338f
 - vs. orbit inclination, 337, 337f
 - launch latitude, 336, 337f
 - noncoplanar orbits, 332, 332f
 - orbital plane rotation, 334, 335f
 - orbit orientation, 337, 338f
 - prograde orbits, 336
 - satellite launch, orbit view, 336, 336f
 - transverse unit vector, 333
 - trigonometric identities, 333–334
 - velocity vector, 334–335
- Point masses
 - absolute acceleration, 29, 34
 - absolute position vectors, 28, 28f
 - absolute velocity, 29, 33
 - angular velocity, 32
 - Coriolis force, 2
 - force, definition, 16
 - gravity acceleration, 16, 17f
 - kinematics
 - binormal vector, 14
 - Cartesian coordinate frame, 13
 - center of curvature, 14–15
 - crossproduct, 13
 - path/trajectory, definition, 11–12
 - position, velocity and acceleration vectors, 10, 11f
 - unit vectors, orthogonal triad, 13, 13f
 - “universal” clock, 10
 - mass, definition, 15
 - Newton's law of motion
 - absolute acceleration, 21f
 - angular impulse, 21–23
 - angular momentum, 21
 - linear momentum, 21
 - resultant/net force, 19
 - slug, definition, 19–20
 - nonrotating inertial frame, 31, 32f
 - numerical integration, 36–37, 40
 - Cartesian components, three-dimensional space, 37
 - elementary calculus, 37
 - first-order differential equations, 37
 - Heun's predictor–corrector method. *See* Heun's predictor–corrector method
 - nonlinear differential equation, 38b–39b
 - particle mechanics, 37
 - position and velocity vectors, 38
 - RK methods. *See* Runge–Kutta (RK) methods
 - Taylor series, 39
 - truncation error, 39–40
 - relative position vectors, 28, 28f, 32
 - relative velocity, 33
 - time derivatives, moving vectors
 - absolute angular acceleration, 28
 - absolute time derivatives, 26
 - angular acceleration, 23–24
 - differential time interval, 23–24, 24f
 - inertial and moving frame, 26, 26f
 - unit vectors, 27
 - universal gravitational constant, 16
- vectors
 - bac–cab rule, 9, 9b–10b
 - Cartesian components, 6
 - Cartesian coordinate system, 3, 4f
 - crossproduct, 7–9, 8f
 - definition, 2
 - direction angles, 4–5, 5f
 - dot product, 5–6, 5f, 6f
 - magnitudes and directions, 2, 2f
 - matrix determinant, 8
 - parallelogram rule, vector addition, 3, 3f
 - Pythagorean theorem, 4
 - unit vector, 3

Point masses (*Continued*)

- vector algebra, 10
- vector triple product, 9
- weight, definition, 16

Preliminary orbit determination

- from angle and range measurements
 - coordinate transformation, 273
 - earth-based tracking station, 272
 - earth-orbiting body, 272, 272f
 - heliocentric state vector, 278–279
 - hour angle, 274
 - relative position vector, 273–274
 - topocentric declension and right ascension, 275
 - topocentric equatorial direction cosines, 273
 - trig identities, 274
 - velocity and acceleration, 272
- angles-only orbit determination method, 279

Gauss method, 280f

- binomial theorem, 283
- constant angular momentum, 281
- dot product, 281
- eighth-order polynomial, 285
- geocentric position vector, 279
- Lagrange coefficients, 280, 282
- scalar triple product, 283
- slant range, 283–284

Gibbs method

- angular momentum, 241
- bac–cab rule, 241, 243
- coplanar vectors, 240, 240f
- perifocal coordinate system, 241
- position vectors, 242
- velocity, 241

Julian day, 240

Lambert's problem, 248f

- angular momentum, 251
- binomial expansion theorem, 252
- Lagrange coefficients, 249–250, 253–258
- Newton's method, 251
- prograde trajectories, 248
- retrograde trajectories, 248
- series expansions, 252–253
- Stumpff functions, 251–252
- true anomaly, 247

sidereal time, 261f

- Greenwich sidereal time, 259, 261
- Julian epoch, 261
- solar time, 258–259
- universal time, 258–259
- vernal equinox, 259

topocentric coordinate system

- eccentricity, 265
- flattening, definition, 263–265
- geocentric equatorial coordinates, 265

geocentric latitude, 266

geodetic latitude, 265

meridian ellipse, 263–265, 264f

meridional coordinates, 265

oblate spheroidal earth, 263, 264f

topocentric equatorial coordinate system, 266–267, 266f

topocentric horizon coordinate system, 267–271, 268f

two-body motion equations, 239

Q

Quaternions, 523–524

direction cosine matrix, 526

Euler axis, 524

Euler principal rotation angle, 526

orthogonality property, 527

principal angle, 524

time derivative, 528–532

unit quaternions, 526–527

unit vector, 524–525

R

Relative motion

angular acceleration, 369

angular velocity, 369

bean-shaped orbit, 374–376

circular and elliptical orbit, 374, 375f

close-proximity circular orbits, 396–398, 396f, 398f

CW equations, 385, 385f

angular velocity, 383

matrix notation, 386–387

relative velocity, 384–385

linearization of equation

angular momentum, 379

binomial theorem, 378

chase vehicle, position vector, 376, 377f

comoving frame, 379

first-order differential equations, 381

inertial geocentric equatorial frame, 377

linear second-order differential equations, 380–381

reference orbit, 378

relative acceleration, 379

LVLH frame, 368, 368f

Newton's second law, 367

orthogonal transformation matrix, 369

position vector, 368

relative position, velocity and acceleration, components, 370

two-impulse rendezvous maneuvers, 387–395, 388f

Rigid body dynamics

Chasles' theorem, 459

Euler angles

absolute angular velocity, 512

classical Euler angle sequence, 510, 510f

- direction cosine matrix, 511
- inverse transformation, 512–513
- nonorthogonal Euler angle rates, 512
- precession rate, 512
- time-dependent Euler angles, 514
- Euler's equations
 - absolute angular acceleration, 497
 - angular momentum, 496
 - comoving coordinate system, 496
 - relative angular acceleration, 498–502
- kinematics, 460, 461f
 - absolute accelerations, 461
 - absolute angular acceleration, 461–462
 - absolute angular velocity, 460–461, 462f
 - gyro rotor, 467f
 - solar panel, 464f
 - time derivative, 460
- kinetic energy, 502–504
- mass distribution, 460
- moments of inertia, 476f
 - angular momentum components, 475
 - angular velocity vector, 482
 - characteristic equation, 487
 - coefficient matrix, 486
 - diagonal matrix, 477
 - direction cosine matrix, 486
 - eigenvector and eigenvalue, 487–489
 - matrix components, 476
 - orthogonal system, 483
 - parallel axis theorem, 490–496, 490f
 - positive-definite matrix, 487
 - second-order tensor, 483–486
 - shapes of, 477, 478f
 - unit vectors, 475
- quaternions, 523–524
 - direction cosine matrix, 526
 - Euler axis, 524
 - Euler principal rotation angle, 526
 - orthogonality property, 527
 - principal angle, 524
 - time derivative, 528–532
 - unit quaternions, 526–527
 - unit vector, 524–525
- rotational motion equations
 - absolute acceleration, 470
 - absolute angular momentum, 471–472
 - absolute linear momentum, 471
 - angular impulse–momentum principle, 474
 - angular momentum, 473, 475
 - center of mass, 472
 - net angular impulse, 474
 - position vector, mass element, 470, 471f
- spinning top, 504, 505f
 - angular velocity, 505–506, 508
- axisymmetric rotor, 508, 509f
- gyroscopic moment, 508–509
- moving coordinate system, 504–505
- quadratic equation, 507
- spin and precession rate, 507
- spin angular momentum, 508
- translational motion equations
 - absolute acceleration, 470
 - continuous medium, mass element, 469, 469f
 - Newton's second law, 469
 - position vectors, 469
 - resultant external force, 470
- yaw–pitch–roll sequence, 521f
 - angular velocity, 522
 - elementary rotation matrices, 520
 - inverse matrix, 521
 - inverse transformation, 522
 - MATLAB, 521
 - reverse transformation, 522
- RK methods. *See* Runge–Kutta (RK) methods
- Rocket vehicle dynamics
 - chemical energy, 619
 - drag loss, 625
 - field-free space
 - burnout velocity vs. number of stages, 640, 640f
 - dimensionless burnout speed vs. payload ratio, 631, 632f
 - empty stage mass, 638
 - gross mass, 630
 - mass ratio, 630, 635, 638
 - parallel staging, 633, 633f
 - payload burnout velocity, 638
 - payload ratios, 637
 - propellant mass, 635
 - restricted staging effect, 634
 - series/tandem two-stage rocket configuration, 631–633, 632f
 - single stage vehicle, 634
 - stage propellant mass, 638
 - structural mass, 630–631
 - structural ratio, 635, 638
 - tandem three-stage launch vehicle, 636, 637f
 - Taylor series, 639
 - two-stage payload ratio, 635
 - two-stage rocket, 634
 - velocity gain, 636
 - gravity turn trajectory, 619–620
 - Lagrange multiplier
 - bivariate function, 640–641
 - burnout velocity, 645
 - empty mass, 643
 - mass ratios, 643–644, 646
 - monotonically increasing function, 644
 - optimization procedure, 645
 - propellant mass, 646

Rocket vehicle dynamics (*Continued*)

- step mass, 643–644, 646
- total mass, 643
- motion equations
 - acceleration, 620–621
 - aerodynamic drag force, 620
 - gravity force, 620
 - Newton's second law, 620–621
 - satellite launch vehicle, 620, 620f
- sounding rockets, 625–628
- spewing compressed gas, 619
- thrust and specific impulse, 625
- thrust equation, 619–620
 - effective exhaust velocity, 624
 - exhaust mass flows, 623
 - one-dimensional momentum analysis, 622
 - rocket and propellants, 622, 623f
 - specific impulse, 624
 - unbalanced force, 624
- thrust-to-weight ratio, 625
- Runge–Kutta (RK) methods
 - coupling coefficients, 41
 - damped spring-mass system, 43, 43b, 44f
 - Euler's method, 42, 43b, 60f, 723
 - exponential factor, 45–47
 - forcing function, 44
 - Heun's method, 42, 43b, 723f
 - RK3, 42, 43b, 723f
 - RK4, 43–47, 43b, 723f
 - second-order ordinary differential equation, 44
 - Taylor series, 41

S

Satellite attitude dynamics

- attitude control thrusters, 573–575, 573f
- Coning maneuver, 570–573, 570f, 571f, 572f
- control moment gyros, 544
- dual-spin spacecraft, 587–589, 587f, 591f
 - angular momentum, 560
 - despun platform, 561
 - dual-spin axisymmetric configuration, 559, 559f
 - “energy sink” procedure, 559, 562
 - oblate spinner, 558
 - OSO-I, 559
 - TACSAT I, 559
 - total rotational kinetic energy, 560
 - total transverse moment of inertia, 560
- gravity-gradient stabilization
 - body frame components, 601–603
 - circular orbit, 597–598, 597f
 - coefficient matrix, 605
 - gravitational force, 597–598
 - gravity-gradient torque, 604
 - inertial angular acceleration, 602
 - inertial angular velocity, 602
 - local vertical/local horizontal orbital reference frame, 600, 601f
 - major-axis spinner, 606
 - minor-axis spinner, 606
 - moments of inertia, 599–600
 - orbital frame's angular velocity, 602
 - orbit eccentricity, 607–609
 - oscillation frequencies, 607
 - pitch oscillation frequency, 604
 - quadratic equation, 605
 - stability criteria, 606, 606f
- gyroscopic attitude control
 - absolute angular velocity, 590b–593b
 - angular acceleration, 596b
 - angular momentum, 584–585
 - body frame components, 584
 - constant angular velocity, 593
 - Euler's equation, 590b–593b
 - inertial angular velocity, 585
 - momentum exchange systems, 546, 583
 - momentum wheels, 593, 594f
 - parallel axis theorem, 586
 - relative rotational velocity, 586b–587b
 - spacecraft moment of inertia tensor, 589b–590b
 - spin rate, 595
 - spin vector, inclination angles, 595, 595f
 - total mass, 583
 - two-gimbal control moment gyro, 594, 594f
- nutation damper
 - absolute angular acceleration, 563
 - absolute angular velocity, 563
 - characteristic equation, coefficients, 568–569
 - components, 567
 - contact forces, 565
 - damper mass, 564–567
 - energy dissipation, 562–563
 - inertial acceleration, 563
 - linear differential equations, 568
 - matrix notation, 568
 - Newton's second law, 564
 - Routh–Hurwitz stability criteria, 568–569
 - satellite-damper mass, 563
 - spring force, 563–564
 - time derivative, 567
 - types, 562–563, 562f
- reaction/momentum wheels, 544
- spin-stabilized spacecraft, 543
- torque-free motion
 - absolute angular velocity, 546–547
 - angular momentum, 544–545, 548–550, 549f
 - angular velocity components, 547, 547f, 549f
 - cylindrical shell, 551f

- dissipative effects, 556–558
- dot product operation, 544–545
- Euler's equation, 545, 554
- intermediate-axis spinners, 555
- major-axis/oblate spinner, 555
- minor-axis/prolate spinner, 555
- nutation angle, 554, 554f
- omega-perp, 547
- rotary kinetic energy, 556
- rotational symmetric satellite, 544–545, 544f
- satellite structure, 555, 558f
- space and body cones, 549, 550f
- time derivative, 556
- unstable motion, 555
- wobble angle, 549
- yo-yo despin mechanism
 - absolute velocity, 577
 - angular acceleration, 580
 - angular momentum, 578
 - angular velocity, 580
 - despin process, 580, 581f
 - kinetic energy, 578
 - moment of inertia, 577
 - radial vs. tangential release, 581–583, 582f
 - rotational kinetic energy, 577
 - spacecraft's angular velocity, 576
 - string and mass systems, 576, 576f
- Sphere of influence (SOI) radius, 722t

T

- Tactical Communications Satellite (TACSAT I), 559
- Three-dimensional space orbits
 - coordinate transformation
 - arccosine function, 212–213
 - arcsine function, 215–216
 - asymmetric Euler sequences, 210
 - Cartesian reference axes, 202, 203f
 - classical Euler sequence, 210, 211f, 212
 - column vector, 212
 - direction cosine matrix, 204
 - inverse transformation, 205–206
 - orthogonal matrix, 205
 - rotation of, 207–209, 208f, 209f
 - six symmetric Euler sequences, 210
 - transpose matrix, 204
 - unit vectors, 202
 - unprimed unit vectors, 203
 - yaw, pitch and roll sequence, 213–214, 214f
- earth's oblateness effects
 - definition, 219
 - Molniya telecommunications satellites, 223–227, 223f
 - node regression, 220–221, 221f
 - perigee advance, 222–223

- second zonal harmonics, 219–220, 220t
- zonal variation, 219–220
- geocentric equatorial and perifocal frames, 216, 216f
 - components of, 218
 - coordinate system, 217
 - matrix multiplications, 217
 - matrix notation, 217
 - orthogonal matrix, 217
- geocentric right ascension–declination frame
 - angular momentum, 188–189
 - celestial sphere, 189, 190f
 - secondary (perturbing) gravitational forces, 188–189, 189f
 - sky chart, 189, 190f
 - star Regulus, celestial coordinates, 191, 191t
 - venus and moon ephemeris, 191, 191t
 - vernal equinox line, 188, 188f
- ground tracks, 227–231, 228f, 232f
- Russian space program, 223
- state vector
 - and geocentric equatorial frame, 192–196, 192f
 - orbital elements, 196–202, 196f
- Sun-synchronous orbits, 222–223, 222f
- Topocentric coordinate system
 - eccentricity, 265
 - flattening, definition, 263–265
 - geocentric equatorial coordinates, 265
 - geocentric latitude, 266
 - geodetic latitude, 265
 - meridian ellipse, 263–265, 264f
 - meridional coordinates, 265
 - oblate spheroidal earth, 263, 264f
- Topocentric equatorial coordinate system, 266–267, 266f
- Topocentric horizon coordinate system, 267–271, 268f
- Translational motion equations
 - absolute acceleration, 470
 - continuous medium, mass element, 469, 469f
 - Newton's second law, 469
 - position vectors, 469
 - resultant external force, 470
- Two-impulse Hohmann transfer, 312, 312f

U

- Universal variable approach
 - energy equation, 174
 - hyperbolic mean anomaly, 173
 - Kepler's equation, 176
 - Lagrange coefficient, 180–181
 - Newton's algorithm, 177
 - periapse passage, 176
 - semimajor axis, 173, 174t

Universal variable approach (*Continued*)

- Stumpff functions, 174–176, 175f
- universal anomaly, 177
- universal Kepler's equation, 174–175

V

Vector-based approach, two-body system, 723, 723f

- angular momentum, 72, 75
- angular velocity, 77
- apse line, 76
- circular orbits
 - earth's gravitational parameter, 82
 - geostationary equatorial orbit, 83, 86f
 - inertial angular velocity, 83
 - low earth orbit, 82
 - period of, 81
 - space shuttle main engines, 82
 - space shuttle orbiters, 82
 - specific energy, 81–82
 - velocity of, 81
- curvilinear trajectory, 72, 73f
- eccentricity and true anomaly, 76–77, 77f
- eccentricity vector, 76
- elliptical orbits
 - apoapsis and radial coordinate, 85
 - apse line distance, 85–86, 87f
 - Cartesian coordinate system, 88, 88f
 - eccentricity calculation, 90
 - energy conservation, 89
 - Kepler's second law, 89
 - periods and energies, 90, 90f
 - Pythagorean theorem, 87
 - rectilinear ellipse, 90
 - semimajor axis, 86, 91
 - specific energy, 89
 - true anomaly, radial coordinate, 87
- energy law, 80–81
- flight path angle, 79
- hyperbolic trajectories, 100f
 - aiming radius, 102
 - Cartesian coordinate system, 102, 103f
 - hyperbolic excess speed, 104
 - Keplerian orbits, 104
 - radial coordinate, 101
 - semimajor axis, 101, 106–108
 - semiminor axis, 102
 - specific energy, 104
 - “tool box”, 104
 - trajectories range, 104, 105f
 - trig identity, 100
 - true anomaly, 100
 - turn angle, 101
 - vacant orbit, 100–101

inertial frame, motion equations

- absolute velocity and acceleration, 61
- attractive forces, 63
- conservative force, 63
- gravitational attraction, 60–61
- Newton's second law of motion, 61
- Newton's third law, 61
- position vector, 61–63
- potential energy, 63
- in spacecraft, 62b–63b
- state vectors, 64–66, 64b
- twobody3d.m function, 123–138
- two-point masses, 60, 60f
- lagrange coefficients
 - angular momentum, 112–113
 - eccentricity, 117–120
 - position and velocity vectors, 111–112
 - radial velocity, 115–116
 - Taylor series, 120, 122
 - trig identity, 114–115
 - true anomaly, 114–115
- Laplace vector, 75–76
- latus and semilatus rectum, 79, 79f
- local horizon, 79
- orbit types, properties, 59–60
- parabolic trajectories
 - Cartesian coordinate system, 97–99, 98f
 - energy conservation, 96
 - escape velocity, 96
 - flight path angle, 97
 - trigonometric identities, 97
 - true anomaly, 97, 97f
- periapsis, 78
- perifocal frame
 - position vector, 109–110, 109f
 - unit vector, 108, 109f
 - velocity, 110
- radial and azimuthal components, 77, 78f
- relative angular momentum, 72
- relative linear momentum, 72
- relative motion equations
 - center of mass, 70–71
 - comoving reference frame, 68, 68f
 - gravitational parameter, 67
 - nonlinear second-order differential equation, 68
 - nonrotating Cartesian coordinate system, 69
 - relative acceleration components, 69
 - relative acceleration vector, 66
 - relative velocity, 68
 - time derivative, 69–70
- relative position vector, 73, 74f
- restricted three-body problem
 - absolute acceleration, 125
 - gravitational forces, 126

- inertial angular velocity, 123
- Jacobi constant. *See* Jacobi constant
- Lagrange points. *See* Lagrange points
- mass ratios, 124
- Newton's second law, 126
- noninertial comoving reference frame, 123, 124f
- position vector, 125
- total mass, 124
- velocity components, 73, 73f

Y

- Yaw-pitch-roll sequence, 521f
 - angular velocity, 522
 - elementary rotation matrices, 520
 - inverse matrix, 521

- inverse transformation, 522
- MATLAB, 521
- reverse transformation, 522
- Yo-yo despin mechanism
 - absolute velocity, 577
 - angular acceleration, 580
 - angular momentum, 578
 - angular velocity, 580
 - despin process, 580, 581f
 - kinetic energy, 578
 - moment of inertia, 577
 - radial vs. tangential release, 581–583, 582f
 - rotational kinetic energy, 577
 - spacecraft's angular velocity, 576
 - string and mass systems, 576, 576f