Index

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

| Α | column vector, 212 |
|---|--|
| Apse line rotation | direction cosine matrix, 204 |
| angular momentum, 325 | inverse transformation, 205–206 |
| orbit intersection, 322–323, 322f | orthogonal matrix, 205 |
| point of intersection, 323 | rotation of, 207–209, 208f, 209f |
| radial velocity, 325 | six symmetric Euler sequences, 210 |
| trigonometric identity, 323, 326 | transpose matrix, 204 |
| Astronomical data, 721 | unit vectors, 202 |
| Averaging method, orbital perturbations | unprimed unit vectors, 203 |
| angular momentum, 688 | yaw, pitch and roll sequence, 213–214, 214f |
| eccentricity, 689 | Cowell's method, 653, 654f |
| inclination, 692 | CW equations. See Clohessy–Wiltshire (CW) equations |
| mean motion, 687 | · · · · · · · · · · · · · · · · · · · |
| perigee, 692–695, 694f | D |
| time-averaged variation, 688 | _ |
| true anomaly, 690–691 | Dual-spin spacecraft, 157b–159b, 587f, 591f |
| true unomary, 676 671 | angular momentum, 560 |
| В | despun platform, 561 |
| | dual-spin axisymmetric configuration, 559, 559f |
| Bac–cab rule, 9, 9b–10b | "energy sink" procedure, 559, 562 |
| Barker's equation, 163 | oblate spinner, 558 |
| Bi-elliptic Hohmann transfer, 299–300, 308–312, 309f | OSO-I, 559 |
| • | TACSAT I, 559 |
| C | total rotational kinetic energy, 560 |
| Chase maneuvers, 328–332 | total transverse moment of inertia, 560 |
| Chasles' theorem, 459 | - |
| Circular orbits, 147, 147f | E |
| earth's gravitational parameter, 82 | Earth's oblateness |
| geostationary equatorial orbit, 83, 86f | definition, 219 |
| inertial angular velocity, 83 | Molniya telecommunications satellites, 223-227, 223f |
| low earth orbit, 82 | node regression, 220-221, 221f |
| period of, 81 | perigee advance, 222–223 |
| space shuttle main engines, 82 | second zonal hormonics, 219-220, 220t |
| space shuttle orbiters, 82 | zonal variation, 219-220 |
| specific energy, 81–82 | Elliptical orbits |
| velocity of, 81 | angular velocity, 149 |
| Clohessy-Wiltshire (CW) equations, 385, 385f | apoapsis and radial coordinate, 85 |
| angular velocity, 383 | apse line distance, 85-86, 87f |
| matrix notation, 386-387 | Bessel functions, 160, 161f |
| relative velocity, 384–385 | Cartesian coordinate system, 88, 88f |
| Conversion factors, 722 | eccentric anomaly, 149, 149f, 162 |
| Coordinate transformation, three-dimensional space orbits | eccentricity calculation, 90 |
| arccosine function, 212–213 | eccentricity plot, 159-160, 159f, 160f |
| arcsine function, 215–216 | energy conservation, 89 |
| asymmetric Euler sequences, 210 | geocentric elliptical orbit, 154f |
| Cartesian reference axes, 202, 203f | Kepler's formula, 151, 152f |
| classical Euler sequence, 210, 211f, 212 | Kepler's second law, 89 |

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

contour plots, 305-306, 306f eccentricity, 302 elliptical orbit tangent, 301 inner planet, 426, 428f outer planet, 426, 427f

Impulsive maneuvers propellant mass fraction vs. Δv, 300, 301f pumping maneuver, 300 specific impulses, 300, 300t

periapsis radius, 302

specific energy, 301

total energy expenditure, 302

| Interplanetary trajectories | turn angle, 426–427 |
|---|---|
| aiming radius, 427-428, 431 | wait time, 411–412 |
| angular momentum, 428 | _ |
| apoapsis radius, 431 | J |
| Cassini spacecraft, 443–444, 444f | Jacobi constant |
| circular orbit planets, 408, 409f | earth-moon system, 135f, 136 |
| departure trajectory | energy and angular momentum, 134 |
| angular momentum, 419 | secondary mass, speed, 133 |
| circular parking orbit, 418–420, 421f | zero velocity, 134–135 |
| heliocentric velocity vector, 420 | zero verocky, 13 i 133 |
| hyperbolic trajectory, 418 | L |
| locus of, 420, 421f | _ |
| parabolic trajectory, 418 | Lagrange points |
| periapsis radius, 418–419 | bisection method, 129–130, 129f, 130b |
| periapsis speed, 420 | comoving coordinate system, 128 |
| spacecraft departure, 418, 419f, 422f | contour plot, 128, 129f |
| spacecraft departure, 416, 4171, 4221 spacecraft heliocentric speed, 421–423 | equilibrium points, 126–128 |
| earth's sphere | halo orbits, 132 |
| gravitational force, 413, 413f | linear equations, 127 |
| Keplerian orbit, 416 | Wilkinson Microwave Anisotropy Probe, 132–133 |
| Newton's law of gravitation, 413–414 | Local vertical/local horizontal (LVLH) frame, 368, 368f |
| | |
| primary gravitational acceleration, 415 | M |
| radius of, 416 | Moments of inertia, 476f |
| secondary/perturbing acceleration, 415 | angular momentum components, 475 |
| spacecraft motion equation, 414 | angular velocity vector, 482 |
| three-body system, 413–414, 414f | characteristic equation, 487 |
| eccentricity, 427 | coefficient matrix, 486 |
| gravity assist flybys, 443 | diagonal matrix, 477 |
| heliocentric departure trajectory, 437 | direction cosine matrix, 486 |
| heliocentric ecliptic frame, 444, 445f | eigenvector and eigenvalue, 487–489 |
| heliocentric orbits, 407 | matrix components, 476 |
| heliocentric velocity, 433–437 | orthogonal system, 483 |
| Hohmann transfer, 406–407, 407f, 408f | parallel axis theorem, 490–496, 490f |
| inner planet, 426, 428f | positive-definite matrix, 487 |
| outer planet, 426, 427f | second-order tensor, 483–486 |
| hyperbola family, 428–429, 429f | shapes of, 477, 478f |
| hyperbola locus, 428–429, 429f | unit vectors, 475 |
| hyperbolic excess velocity, 426, 436 | unit vectors, 475 |
| leading-side planetary flyby, 433, 434f | N |
| minimum total time, 412–413 | |
| non-Hohmann interplanetary trajectories, 449-455, 450f | Nearly equal numbers computation, 737 |
| optimal periapse radius, 430 | Newton's law of motion |
| orbital elements, 444-449, 447t | absolute acceleration, 21f |
| orbital periods, 409 | angular impulse, 21–23 |
| patched conics method, 405, 417-418 | angular momentum, 21 |
| periapsis velocity, 430 | linear momentum, 21 |
| phase angle, 408–409, 411–412 | resultant/net force, 19 |
| round-trip mission, 410, 410f | slug, definition, 19–20 |
| scalar components, 434–436 | Non-Hohmann transfers |
| sensitivity analysis, 424–426 | apse line, 317–322, 317f, 318f |
| synodic period, 409 | interplanetary trajectories, 449-455, 450f |
| time of flight, 411 | Nonimpulsive orbital maneuvers |
| trailing-side planetary flyby, 433, 435f | Cartesian component, 344 |
| true anomalies, 408 | elementary rocket dynamics, 345 |
| | |

| Nonimpulsive orbital maneuvers (Continued) | absolute accelerations, 705 |
|---|--|
| energy equation, 347 | geocentric equatorial position, 707 |
| linear differential equations, 345 | horizontal parallax, 707, 707f |
| relative motion, 344 | lunar ecliptic latitude, 707–708 |
| scalar analysis, 348 | lunar ecliptic longitude, 707–708 |
| spacecraft mass, 347 | lunar position coefficients, 708, 709t |
| total energy, 347 | perturbing acceleration, 706 |
| velocity vector, 344 | spacecraft's earth orbit, 705, 706f |
| • | unit vector, 706–707 |
| ^ | parameter variation |
| 0 | acceleration, 668 |
| Orbital perturbations | Lagrange planetary equations, 670-671 |
| atmospheric drag | Lagrangian matrix, 670 |
| ballistic coefficient, 658 | orbital elements, 668–670 |
| drag force, 658 | perturbed motion, 669 |
| perturbing acceleration, 658 | position vector, 667–668 |
| spacecraft velocity, 658 | velocity, 668 |
| US Standard Atmosphere density profile, 656-657, 657f | solar gravity, 712–715 |
| averaging method | solar radiation pressure |
| angular momentum, 688 | atmospheric density, 697 |
| eccentricity, 689 | cannonball model, 696 |
| inclination, 692 | direction cosine matrix, 698 |
| mean motion, 687 | energy flux, 696 |
| perigee, 692–695, 694f | Gauss planetary equations, 698–699 |
| time-averaged variation, 688 | geocentric ecliptic frame, 697 |
| true anomaly, 690-691 | geocentric equatorial frame, 697–698 |
| Cowell's method, 653, 654f | magnitude of, 696 |
| drag effect, 652 | mean anomaly, 700 |
| Encke's method | perturbing acceleration, 696 |
| Lagrange coefficients, 654 | perturbing force, 696 |
| perturbed and osculating orbits, 654, | photon energy, 695 |
| 655f | position vectors, 701, 702f |
| rectification, 655-656, 655f, 656b | radiation intensity, 695 |
| two-body motion, 653 | shadow function, 696 |
| Gauss variational equations, 652. | solar ecliptic longitude, 697, 699 |
| See also Gauss variational equations | Stefan-Boltzmann constant, 695 |
| geopotential perturbations, 652-653 | Orbital position, 60f, 723 |
| gravitational perturbations | circular orbits, 147, 147f |
| Cartesian coordinates, 660 | elliptical orbits, 163 |
| gradient operator, 660 | angular velocity, 149 |
| gravitational potential energy, 660 | Bessel functions, 160, 161f |
| Legendre polynomials, 662, 663f | eccentric anomaly, 149, 149f, 162 |
| perturbing acceleration, 663 | eccentricity plot, 159-160, 159f, 160f |
| polar angle, 661–662 | geocentric elliptical orbit, 154f |
| Rodrigues' formula, 662 | Kepler's formula, 151, 152f |
| rotationally symmetric perturbation, 662 | Lagrange series, 158–159 |
| sectorial harmonics, 664–666 | Laplace limit, 159 |
| spherical coordinate system, 661-662, | mean motion, 149 |
| 661f | mean vs. true anomaly, 148, 148f |
| tesseral harmonics, 664–666 | Newton's method, 152, 153f |
| zonal harmonics, 662–663 | quadrant ambiguity, 150, 150f |
| Keplerian orbits, 652 | tan (E/2) value, 151, 151f |
| Lagrange planetary equations, 652–653 | trigonometric identity, 150 |
| lunar gravity | truncated Bessel series solutions, 160-162, 161f |
| | |

| hyperbolic trajectories | gravity acceleration, 16, 17f |
|---|--|
| eccentricity plot, 165, 165f | kinematics |
| hyperbolic cosine, 166 | binormal vector, 14 |
| hyperbolic tangent, 168 | Cartesian coordinate frame, 13 |
| hyperbolic trig identity, 168 | center of curvature, 14–15 |
| • • | |
| Kepler's equation, 167, 168f | crossproduct, 13 |
| parameters, 165–166, 166f | path/trajectory, definition, 11–12 |
| transcendental equation, 169 | position, velocity and acceleration vectors, 10, 11f |
| orbit formula, 145–146 | unit vectors, orthogonal triad, 13, 13f |
| parabolic trajectories, 163–164, 164f | "universal" clock, 10 |
| periapsis passage, 146 | mass, definition, 15 |
| universal variables | Newton's law of motion |
| energy equation, 174 | absolute acceleration, 21f |
| hyperbolic mean anomaly, 173 | angular impulse, 21–23 |
| Kepler's equation, 176 | angular momentum, 21 |
| Lagrange coefficient, 180–181 | linear momentum, 21 |
| Newton's algorithm, 177 | resultant/net force, 19 |
| periapse passage, 176 | slug, definition, 19–20 |
| semimajor axis, 173, 174t | nonrotating inertial frame, 31, 32f |
| Stumpff functions, 174–176, 175f | numerical integration, 36–37, 40 |
| universal anomaly, 177 | Cartesian components, three-dimensional space, 37 |
| universal Kepler's equation, 174–175 | elementary calculus, 37 |
| Orbiting Solar Observatory (OSO-I), 559 | first-order differential equations, 37 |
| | Heun's predictor-corrector method. See Heun's |
| P | predictor-corrector method |
| - | nonlinear differential equation, 38b-39b |
| Patched conics method, 405, 417–418 | particle mechanics, 37 |
| Phasing maneuvers, 312, 312f | position and velocity vectors, 38 |
| Plane change maneuvers | RK methods. See Runge-Kutta (RK) methods |
| cranking maneuver, 332 | Taylor series, 39 |
| delta-v formula, 335–336, 335f | truncation error, 39–40 |
| flight path angle, 333 | relative position vectors, 28, 28f, 32 |
| GEO satellites, 336 | relative velocity, 33 |
| impulsive plane change maneuver, | time derivatives, moving vectors |
| 334, 334f | absolute angular acceleration, 28 |
| intersection line, 332f, 333 | absolute time derivatives, 26 |
| launch azimuth, 338-344, 338f | angular acceleration, 23-24 |
| vs. orbit inclination, 337, 337f | differential time interval, 23–24, 24f |
| launch latitude, 336, 337f | inertial and moving frame, 26, 26f |
| noncoplanar orbits, 332, 332f | unit vectors, 27 |
| orbital plane rotation, 334, 335f | universal gravitational constant, 16 |
| orbit orientation, 337, 338f | vectors |
| prograde orbits, 336 | bac-cab rule, 9, 9b-10b |
| satellite launch, orbit view, 336, 336f | Cartesian components, 6 |
| transverse unit vector, 333 | Cartesian coordinate system, 3, 4f |
| trignometric identities, 333–334 | crossproduct, 7–9, 8f |
| velocity vector, 334–335 | definition, 2 |
| Point masses | direction angles, 4–5, 5f |
| absolute acceleration, 29, 34 | dot product, 5–6, 5f, 6f |
| absolute position vectors, 28, 28f | magnitudes and directions, 2, 2f |
| absolute velocity, 29, 33 | matrix determinant, 8 |
| angular velocity, 32 | parallelogram rule, vector addition, 3, 3f |
| Coriolis force, 2 | Pythagorean theorem, 4 |
| force, definition, 16 | unit vector, 3 |
| Toree, deminion, 10 | unit vector, 5 |
| | |

| Point masses (Continued) | geocentric latitude, 266 |
|---|---|
| vector algebra, 10 | geodetic latitude, 265 |
| vector triple product, 9 | meridian ellipse, 263–265, 264f |
| weight, definition, 16 | meridional coordinates, 265 |
| Preliminary orbit determination | oblate spheroidal earth, 263, 264f |
| from angle and range measurements | topocentric equatorial coordinate system, 266–267, 266f |
| coordinate transformation, 273 | topocentric equational coordinate system, 267–271, |
| | 268f |
| earth-based tracking station, 272 | two-body motion equations, 239 |
| earth-orbiting body, 272, 272f | two-body modoli equations, 239 |
| heliocentric state vector, 278–279 | _ |
| hour angle, 274 | Q |
| relative position vector, 273–274 | Quaternions, 523–524 |
| topocentric declension and right ascension, 275 | direction cosine matrix, 526 |
| topocentric equatorial direction cosines, 273 | Euler axis, 524 |
| trig identities, 274 | Euler principal rotation angle, 526 |
| velocity and acceleration, 272 | orthogonality property, 527 |
| angles-only orbit determination method, 279 | principal angle, 524 |
| Gauss method, 280f | time derivative, 528–532 |
| binomial theorem, 283 | unit quaternions, 526–527 |
| constant angular momentum, 281 | unit vector, 524–525 |
| dot product, 281 | unit vector, 324–323 |
| eighth-order polynomial, 285 | R |
| geocentric position vector, 279 | |
| Lagrange coefficients, 280, 282 | Relative motion |
| scalar triple product, 283 | angular acceleration, 369 |
| slant range, 283–284 | angular velocity, 369 |
| Gibbs method | bean-shaped orbit, 374–376 |
| angular momentum, 241 | circular and elliptical orbit, 374, 375f |
| bac-cab rule, 241, 243 | close-proximity circular orbits, 396-398, 396f, 398f |
| coplanar vectors, 240, 240f | CW equations, 385, 385f |
| perifocal coordinate system, 241 | angular velocity, 383 |
| position vectors, 242 | matrix notation, 386–387 |
| velocity, 241 | relative velocity, 384–385 |
| Julian day, 240 | linearization of equation |
| Lambert's problem, 248f | angular momentum, 379 |
| angular momentum, 251 | binomial theorem, 378 |
| binomial expansion theorem, 252 | chase vehicle, position vector, 376, 377f |
| Lagrange coefficients, 249–250, 253–258 | comoving frame, 379 |
| Newton's method, 251 | first-order differential equations, 381 |
| prograde trajectories, 248 | inertial geocentric equatorial frame, 377 |
| retrograde trajectories, 248 | linear second-order differential equations, 380–381 |
| series expansions, 252–253 | reference orbit, 378 |
| Stumpff functions, 251–252 | relative acceleration, 379 |
| true anomaly, 247 | LVLH frame, 368, 368f |
| sidereal time, 261f | Newton's second law, 367 |
| Greenwich sidereal time, 259, 261 | orthogonal transformation matrix, 369 |
| Julian epoch, 261 | position vector, 368 |
| solar time, 258–259 | relative position, velocity and acceleration, components, 370 |
| universal time, 258–259 | two-impulse rendezvous maneuvers, 387–395, 388f |
| vernal equinox, 259 | Rigid body dynamics |
| topocentric coordinate system | Chasles' theorem, 459 |
| eccentricity, 265 | Euler angles |
| • | absolute angular velocity, 512 |
| flattening, definition, 263–265 | classical Euler angle sequence, 510, 510f |
| geocentric equatorial coordinates, 265 | ciassical Euler angle sequence, 510, 5101 |

Index

| Rocket vehicle dynamics (Continued) | inertial angular acceleration, 602 |
|---|--|
| step mass, 643-644, 646 | inertial angular velocity, 602 |
| total mass, 643 | local vertical/local horizontal orbital reference frame, 600 |
| motion equations | 601f |
| acceleration, 620-621 | major-axis spinner, 606 |
| aerodynamic drag force, 620 | minor-axis spinner, 606 |
| gravity force, 620 | moments of inertia, 599-600 |
| Newton's second law, 620-621 | orbital frame's angular velocity, 602 |
| satellite launch vehicle, 620, 620f | orbit eccentricity, 607-609 |
| sounding rockets, 625-628 | oscillation frequencies, 607 |
| spewing compressed gas, 619 | pitch oscillation frequency, 604 |
| thrust and specific impulse, 625 | quadratic equation, 605 |
| thrust equation, 619-620 | stability criteria, 606, 606f |
| effective exhaust velocity, 624 | gyroscopic attitude control |
| exhaust mass flows, 623 | absolute angular velocity, 590b-593b |
| one-dimensional momentum analysis, 622 | angular acceleration, 596b |
| rocket and propellants, 622, 623f | angular momentum, 584-585 |
| specific impulse, 624 | body frame components, 584 |
| unbalanced force, 624 | constant angular velocity, 593 |
| thrust-to-weight ratio, 625 | Euler's equation, 590b-593b |
| Runge–Kutta (RK) methods | inertial angular velocity, 585 |
| coupling coefficients, 41 | momentum exchange systems, 546, 583 |
| damped spring-mass system, 43, 43b, 44f | momentum wheels, 593, 594f |
| Euler's method, 42, 43b, 60f, 723 | parallel axis theorem, 586 |
| exponential factor, 45–47 | relative rotational velocity, 586b–587b |
| forcing function, 44 | spacecraft moment of inertia tensor, 589b-590b |
| Heun's method, 42, 43b, 723f | spin rate, 595 |
| RK3, 42, 43b, 723f | spin vector, inclination angles, 595, 595f |
| RK4, 43–47, 43b, 723f | total mass, 583 |
| second-order ordinary differential equation, 44 | two-gimbal control moment gyro, 594, 594f |
| Taylor series, 41 | nutation damper |
| • | absolute angular acceleration, 563 |
| • | absolute angular velocity, 563 |
| S | characteristic equation, coefficients, 568–569 |
| Satellite attitude dynamics | components, 567 |
| attitude control thrusters, 573-575, 573f | contact forces, 565 |
| Coning maneuver, 570-573, 570f, 571f, 572f | damper mass, 564–567 |
| control moment gyros, 544 | energy dissipation, 562–563 |
| dual-spin spacecraft, 587-589, 587f, 591f | inertial acceleration, 563 |
| angular momentum, 560 | linear differential equations, 568 |
| despun platform, 561 | matrix notation, 568 |
| dual-spin axisymmetric configuration, 559, 559f | Newton's second law, 564 |
| "energy sink" procedure, 559, 562 | Routh-Hurwitz stability criteria, 568-569 |
| oblate spinner, 558 | satellite-damper mass, 563 |
| OSO-I, 559 | spring force, 563–564 |
| TACSAT I, 559 | time derivative, 567 |
| total rotational kinetic energy, 560 | types, 562–563, 562f |
| total transverse moment of inertia, 560 | reaction/momentum wheels, 544 |
| gravity-gradient stabilization | spin-stabilized spacecraft, 543 |
| body frame components, 601–603 | torque-free motion |
| circular orbit, 597–598, 597f | absolute angular velocity, 546–547 |
| coefficient matrix, 605 | angular momentum, 544–545, 548–550, 549f |
| gravitational force, 597–598 | angular velocity components, 547, 547f, 549f |
| gravity-gradient torque, 604 | cylindrical shell, 551f |

| dissipative effects, 556–558 | second zonal hormonics, 219-220, 220t |
|--|---|
| dot product operation, 544–545 | zonal variation, 219–220 |
| Euler's equation, 545, 554 | geocentric equatorial and perifocal frames, 216, |
| intermediate-axis spinners, 555 | 216f |
| major-axis/oblate spinner, 555 | components of, 218 |
| minor-axis/prolate spinner, 555 | coordinate system, 217 |
| nutation angle, 554, 554f | matrix multiplications, 217 |
| omega-perp, 547 | matrix notation, 217 |
| rotary kinetic energy, 556 | orthogonal matrix, 217 |
| rotational symmetric satellite, 544–545, 544f | geocentric right ascension–declination frame |
| satellite structure, 555, 558f | angular momentum, 188–189 |
| space and body cones, 549, 550f | celestial sphere, 189, 190f |
| time derivative, 556 | secondary (perturbing) gravitational forces, 188–189, |
| unstable motion, 555 | 189f |
| wobble angle, 549 | sky chart, 189, 190f |
| yo-yo despin mechanism | star Regulus, celestial coordinates, 191, 191t |
| absolute velocity, 577 | venus and moon ephemeris, 191, 191t |
| angular acceleration, 580 | vernal equinox line, 188, 188f |
| angular momentum, 578 | ground tracks, 227–231, 228f, 232f |
| angular velocity, 580 | Russian space program, 223 |
| despin process, 580, 581f | state vector |
| kinetic energy, 578 | and geocentric equatorial frame, 192–196, 192f |
| moment of inertia, 577 | orbital elements, 196–202, 196f |
| radial vs. tangential release, 581–583, 582f | Sun-synchronous orbits, 222–223, 222f |
| rotational kinetic energy, 577 | Topocentric coordinate system |
| spacecraft's angular velocity, 576 | eccentricity, 265 |
| string and mass systems, 576, 576f | flattening, definition, 263–265 |
| Sphere of influence (SOI) radius, 722t | geocentric equatorial coordinates, 265 |
| Sphere of influence (501) facility, 722t | geocentric equatorial coordinates, 203 geocentric latitude, 266 |
| Т | geodetic latitude, 265 |
| - | meridian ellipse, 263–265, 264f |
| Tactical Communications Satellite (TACSAT I), 559 | meridional coordinates, 265 |
| Three-dimensional space orbits | oblate spheroidal earth, 263, 264f |
| coordinate transformation | Topocentric equatorial coordinate system, 266–267, 266f |
| arccosine function, 212–213 | Topocentric equatoriar coordinate system, 267–271, |
| arcsine function, 215–216 | 268f |
| asymmetric Euler sequences, 210 | Translational motion equations |
| Cartesian reference axes, 202, 203f | absolute acceleration, 470 |
| classical Euler sequence, 210, 211f, 212 | • |
| column vector, 212 | continuous medium, mass element, 469, 469f |
| direction cosine matrix, 204 | Newton's second law, 469 |
| inverse transformation, 205–206 | position vectors, 469 |
| orthogonal matrix, 205 | resultant external force, 470 |
| rotation of, 207-209, 208f, 209f | Two-impulse Hohmann transfer, 312, 312f |
| six symmetric Euler sequences, 210 | U |
| transpose matrix, 204 | |
| unit vectors, 202 | Universal variable approach |
| unprimed unit vectors, 203 | energy equation, 174 |
| yaw, pitch and roll sequence, 213-214, 214f | hyperbolic mean anomaly, 173 |
| earth's oblateness effects | Kepler's equation, 176 |
| definition, 219 | Lagrange coefficient, 180–181 |
| Molniya telecommunications satellites, 223-227, 223f | Newton's algorithm, 177 |
| node regression, 220-221, 221f | periapse passage, 176 |
| perigee advance, 222-223 | semimajor axis, 173, 174t |
| | |

| Universal variable approach (Continued) | inertial frame, motion equations |
|---|--|
| Stumpff functions, 174–176, 175f | absolute velocity and acceleration, 61 |
| universal anomaly, 177 | attractive forces, 63 |
| universal Kepler's equation, 174–175 | conservative force, 63 |
| | gravitational attraction, 60–61 |
| V | Newton's second law of motion, 61 |
| Vector-based approach, two-body system, 723, 723f | Newton's third law, 61 |
| angular momentum, 72, 75 | position vector, 61–63 |
| angular velocity, 77 | potential energy, 63 |
| angular verocity, // apse line, 76 | in spacecraft, 62b–63b |
| circular orbits | state vectors, 64–66, 64b |
| earth's gravitational parameter, 82 | two point masses 60, 60f |
| geostationary equatorial orbit, 83, 86f | two-point masses, 60, 60f |
| inertial angular velocity, 83 | lagrange coefficients |
| low earth orbit, 82 | angular momentum, 112–113 |
| period of, 81 | eccentricity, 117–120 |
| • | position and velocity vectors, 111–112 |
| space shuttle orbitors, 82 | radial velocity, 115–116 |
| space shuttle orbiters, 82 | Taylor series, 120, 122 |
| specific energy, 81–82 | trig identity, 114–115 |
| velocity of, 81 | true anomaly, 114–115 |
| curvilinear trajectory, 72, 73f | Laplace vector, 75–76 |
| eccentricity and true anomaly, 76–77, 77f eccentricity vector, 76 | latus and semilatus rectum, 79, 79f |
| | local horizon, 79 |
| elliptical orbits apoapsis and radial coordinate, 85 | orbit types, properties, 59–60 |
| apse line distance, 85–86, 87f | parabolic trajectories |
| Cartesian coordinate system, 88, 88f | Cartesian coordinate system, 97–99, 98f |
| eccentricity calculation, 90 | energy conservation, 96 |
| energy conservation, 89 | escape velocity, 96 |
| Kepler's second law, 89 | flight path angle, 97 |
| periods and energies, 90, 90f | trigonometric identities, 97 |
| Pythagorean theorem, 87 | true anomaly, 97, 97f |
| rectilinear ellipse, 90 | periapsis, 78 |
| semimajor axis, 86, 91 | perifocal frame position vector, 109–110, 109f |
| specific energy, 89 | * |
| true anomaly, radial coordinate, 87 | unit vector, 108, 109f |
| energy law, 80–81 | velocity, 110 |
| flight path angle, 79 | radial and azimuthal components, 77, 78f |
| hyperbolic trajectories, 100f | relative angular momentum, 72 |
| aiming radius, 102 | relative linear momentum, 72 |
| Cartesian coordinate system, 102, 103f | relative motion equations center of mass, 70–71 |
| hyperbolic excess speed, 104 | comoving reference frame, 68, 68f |
| Keplerian orbits, 104 | gravitational parameter, 67 |
| radial coordinate, 101 | nonlinear second-order differential equation, 68 |
| semimajor axis, 101, 106–108 | nonrotating Cartesian coordinate system, 69 |
| semiminor axis, 102 | relative acceleration components, 69 |
| specific energy, 104 | relative acceleration vector, 66 |
| "tool box", 104 | relative velocity, 68 |
| trajectories range, 104, 105f | time derivative, 69–70 |
| trig identity, 100 | relative position vector, 73, 74f |
| true anomaly, 100 | restricted three-body problem |
| turn angle, 101 | absolute acceleration, 125 |
| vacant orbit, 100–101 | gravitational forces, 126 |
| 01011, 100 101 | gravitational forces, 120 |

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

Υ

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