

References

- Alberts B, Johnson A, Lewis J, Raff M, Roberts K, Walter P (2008) *Molecular biology of the cell*. Garland, New York, NY
- Alexandrou AN (2001) *Principles of fluid mechanics*. Prentice-Hall, Englewood Cliffs, NJ
- Askeland DR (1994) *The science and engineering of materials*, 3rd edn. PWS Kent, Boston, MA
- Ayad S, Boot-Handford R, Humphries MJ, Kadler KE, Shuttleworth A (1994) *The extracellular matrix FactsBook*. Academic Press, New York, NY
- Bell ET (1986) *Men of mathematics*. Simon & Schuster, New York, NY
- Binnig G, Quate CF, Gerber C (1986) Atomic force microscope. *Phys Rev Lett* 56:930–933
- Birk DE, Southern JF, Zycband EI, Fallon JT, Trelstad RL (1989) Collagen fiber bundles: a branching assembly unit in tendon morphogenesis. *Development* 107:437–443
- Boorstin DJ (1985) *The discoverers*. Vintage Books, New York, NY
- Boresi AP, Sidebottom OM, Seely FB, Smith JO (1993) *Advanced mechanics of materials*. John Wiley & Sons, Chichester
- Boyer CB (1949) *The history of the calculus*. Dover, New York, NY
- Butler DL, Awad HA (1999) Perspectives on cell and collagen composites for tendon repair. *Clin Orthop Relat Res* 367S:S324–S332
- Butler DL, Goldstein SA, Guilak F (2000) Functional tissue engineering: the role of biomechanics. *J Biomech Eng* 122:570–575
- Carrel A, Guthrie CC (1906) Results of the biterminal transplantation of veins. *Am J Med Sci* 132:415–422
- Carter DR, Beaupré GS (2001) *Skeletal function and form: mechanobiology of skeletal development, aging, and regeneration*. Cambridge University Press, Cambridge
- Carver W, Nagpal ML, Nachtigal M, Borg TK, Terracio L (1991) Collagen expression in mechanically stimulated cardiac fibroblasts. *Circ Res* 69:116–122
- Comroe JH, Dripps RD (1977) *The top ten clinical advances in cardio-vascular-pulmonary medicine and surgery 1945–1975 (Vols. I and II)*. Public Health Service Document 017-043-00084-6. US Government Printing Office, Washington, DC
- Costa KD, Yin FCP (1999) Analysis of indentation: implications for measuring mechanical properties with atomic force microscopy. *J Biomech Eng* 121:462–471
- Cowin SC (2001) *Bone biomechanics handbook*, 2nd edn. CRC Press, Boca Raton, FL

- Cowin SC, Doty SB (2007) *Tissue mechanics*. Springer, New York, NY
- Criscione JC, Lorenzen-Schmidt I, Humphrey JD, Hunter WC (1999) Mechanical contribution of endocardium during finite extension and torsion experiments on papillary muscles. *Ann Biomed Eng* 27:123–130
- Cui Y, Bustamante C (2000) Pulling a single chromatin fiber reveals the forces that maintain its high order structure. *Proc Natl Acad Sci U S A* 97:127–132
- David G, Humphrey JD (2004) Redistribution of stress in a nonlinear, anisotropic membrane due to the introduction of a circular hole. *J Biomech* 37:1197–1203
- Davidson JM, Giro MG (1986) Control of elastin synthesis: molecular and cellular aspects. In: Mecham RP (ed) *Regulation of matrix accumulation*. Academic Press, New York, NY, pp 177–217
- Davis SE, Doss DJ, Humphrey JD, Wright NT (2000) Effects of heat-induced damage on the radial component of thermal diffusivity of bovine aorta. *J Biomech Eng* 122:283–286
- Delp MD, Colleran PN, Wilkerson MK, McCurdy MR, Muller-Delp J (2000) Structural and functional remodeling of skeletal muscle microvasculature is induced by simulated microgravity. *Am J Physiol* 278:H1866–H1873
- (1988) *Dorland's illustrated medical dictionary*. Philadelphia, PA: WB Saunders
- Ethier CR, Simmons CA (2007) *Introductory biomechanics: from cells to organisms*. Cambridge University Press, Cambridge
- Fawcett DW (1986) *Bloom and Fawcett: a textbook of histology*, 11th edn. W.B. Saunders, Philadelphia, PA
- Ferry JD (1980) *Viscoelastic properties of polymers*. John Wiley & Sons, Chichester
- Findley WN, Lai JS, Onaran K (1976) *Creep and relaxation of nonlinear viscoelastic materials*. Dover, New York, NY
- Fox RW, McDonald AT (1992) *Introduction to fluid mechanics*, 4th edn. John Wiley & Sons, New York, NY
- Frangos JA (1993) *Physical forces and the mammalian cell*. Academic Press, New York, NY
- Fung YC (1984) *Biodynamics: circulation*. Springer, New York, NY
- Fung YC (1990) *Biomechanics: motion, flow, stress, and growth*. Springer, New York, NY
- Fung YC (1993) *Biomechanics: mechanical properties of living tissues*, 2nd edn. Springer, New York, NY
- Fung YC, Liu S (1991) Changes of zero-stress state of rat pulmonary arteries in hypoxic hypertension. *J Appl Physiol* 70:2455–2470
- Fung YC, Liu S (1992) Strain distribution in small blood vessels with zero-stress state taken into consideration. *Am J Physiol* 262:H544–H552
- Galbraith CG, Skalak R, Chien S (1998) Shear stress induces spatial reorganization of the endothelial cell cytoskeleton. *Cell Motil Cytoskeleton* 40:317–330
- Gelman RA, Poppke DC, Piez KA (1979) Collagen fibril formation in vitro. The role of the nonhelical terminal regions. *J Biol Chem* 254:11741–11745
- Genovese K, Lee YU, Lee AY, Humphrey JD (2013) An improved panoramic digital image correlation method for vascular strain analysis and material characterization. *J Mech Behav Biomed Mater* 27:132–142
- Glass L, Hunter PJ, McCulloch AD (1991) *Theory of heart*. Springer, New York, NY
- Gooch KJ, Blunk T, Vunjak-Novakovic G, Langer R, Freed LE (1998) Mechanical forces and growth factors utilized in tissue engineering. In: Patrick CW Jr, Mikos AG, McIntire LV (eds) *Frontiers in tissue engineering*. Pergamon, Oxford

- Han HC, Ku DN (2001) Contractile responses in arteries subjected to hypertensive pressure in seven day organ culture. *Ann Biomed Eng* 29:467–475
- Han HC, Zhao L, Huang M, Hou LS, Huang YT (1998) Postsurgical changes of the opening angle of canine autogenous vein graft. *J Biomech Eng* 120:211–216
- Harris AK (1994) Multicellular mechanics in the creation of anatomical structures. In: Akkas N (ed) *Biomechanics of active movement and division of cells*. Springer, New York, NY, pp 87–129
- Harris H (1999) *The birth of the cell*. Yale University Press, New Haven, CT
- Hinz B (2010) The myofibroblast paradigm for a mechanically active cell. *J Biomech* 43:146–155
- Holzappel GA, Gasser TC (2001) A viscoelastic model for fiber-reinforced composites at finite strains: continuum basis, computational aspects, and applications. *Comp Meth Appl Mech Eng* 190:4379–4403
- Holzappel GA, Stadler M, Schulze-Bauer CAJ (2002) A structural model for the viscoelastic behavior of arterial walls: continuum formulation and finite element analysis. *Eur J Mech A Solids* 21:441–463
- Humphrey JD, Canham PB (2000) Structure, mechanical properties, and mechanics of intracranial saccular aneurysms. *J Elast* 61:49–81
- Humphrey JD, Strumpf RK, Yin FCP (1990) Determination of a constitutive relation for passive myocardium: I. A new functional form. *ASME J Biomech Engr* 112:333–339 and II. Parameter estimation. *J Biomech Eng* 112:340–346
- Humphrey JD, Barazotto RL, Hunter WC (1992) Finite extension and torsion of papillary muscles: theoretical framework. *J Biomech* 25:541–547
- Humphrey JD (2001) Stress, strain and mechanotransduction in cells. *J Biomech Eng* 123:638–641
- Humphrey JD (2002) *Cardiovascular solid mechanics: cells, tissues, and organs*. Springer, New York, NY
- Humphrey JD (2003a) Continuum biomechanics of soft tissues. *Proc R Soc (Lond)* 459:3–46
- Humphrey JD (2003b) Continuum thermomechanics and the clinical treatment of disease and injury. *Appl Mech Rev* 56:231–260
- Humphrey JD (2008) Vascular adaptation and mechanical homeostasis at tissue, cellular, and sub-cellular levels. *Cell Biochem Biophys* 50:53–78
- Humphrey JD, Taylor CA (2008) Intracranial and abdominal aortic aneurysms: similarities, differences, and need for a new class of computational models. *Ann Rev Biomed Eng* 10:221–246
- Humphrey JD, Holmes JW (2009) *Style and ethics of communication in science and engineering*. Morgan & Claypool, San Rafael, CA
- Humphrey JD, Holzappel GA (2012) Mechanics, mechanobiology, and modeling of human abdominal aorta and aneurysms. *J Biomech* 45:805–814
- Ingber DE, Heidemann SR, Lamoureux P, Buxbaum RE (2000) Opposing views on tensegrity as a structural framework for understanding cell mechanics. *J Appl Physiol* 89:1663–1678
- Johnson AT (1991) *Biomechanics and exercise physiology*. John Wiley & Sons, New York, NY
- Johnson GA, Livesay GA, Woo SLY, Rajagopal KR (1996) A single integral finite strain viscoelastic model of ligaments and tendons. *J Biomech Eng* 118:221–226
- Johnson MA, Beatty MF (1995) The Mullins effect in equibiaxial extension and its influence on the inflation of a balloon. *Int J Eng Sci* 33:223–245

- Khan AS, Huang S (1995) Continuum theory of plasticity. John Wiley & Sons, New York, NY
- Kucharz EJ (1992) The collagens: biochemistry and pathophysiology. Springer, Berlin
- Leckband D (2000) Measuring forces that control protein interactions. *Annu Rev Biophys Biomol Struct* 29:1–26
- Lefevre M, Rucker RB (1980) Aorta elastin turnover in normal and hypercholesterolemic Japanese quail. *Biochim Biophys Acta* 630:519–529
- Levesque MJ, Nerem RM (1985) The elongation and orientation of cultured endothelial cells in response to shear stress. *J Biomech Eng* 107:341–347
- Lodish H, Berk A, Zipurski SL, Matsudaire P, Baltimore D, Darnell J (2000) Molecular cell biology. W.H. Freeman, New York, NY
- McAnulty RJ, Laurent GJ (1987) Collagen synthesis and degradation in vivo. Evidence for rapid rates of collagen turnover with extensive degradation of newly synthesized collagen in tissues of the adult rat. *Coll Relat Res* 7:93–104
- Milnor W (1989) Hemodynamics. Williams and Wilkins, Baltimore, MD
- Moody LF (1944) Friction factors for pipe flow. *Trans ASME* 66:671–684
- Mortensen JD, Talbot S, Burkart JA (1990) Cross-sectional internal diameters of human cervical and femoral blood vessels: relationship to subject's sex, age, and body size. *Anat Rec* 226:115–124
- Mow VC, Hayes WC (1991) Basic orthopedic biomechanics. Raven, New York, NY
- Mow VC, Ratcliff A, Woo SLY (1990) Biomechanics of diarthrodial joints. Springer, New York, Volumes 1 and 2
- Mow VC, Hochmuth RM, Guilak F, Trans-Son-Tay R (1994) Cell Mechanics and cellular engineering. Springer, New York, NY
- Murray CD (1926) The physiological principle of minimum work. I. The vascular system and the cost of blood volume. *Proc Natl Acad Sci U S A* 12:207–214
- Na S, Sun Z, Meininger GA, Humphrey JD (2004) On atomic force microscopy and the constitutive behavior of cells. *Biomech Model Mechanobiol* 3:75–84
- Niedermuller H, Skalicky M, Hofecker G, Kment A (1977) Investigations on the kinetics of collagen-metabolism in young and old rats. *Exp Gerontol* 12:159–168
- Nigg BM, Hertzog W (1994) Biomechanics of the musculoskeletal system. John Wiley & Sons, Chichester
- Nimni ME (1992) Collagen in cardiovascular tissue. In: Hastings GW (ed) Cardiovascular biomaterials. Springer, New York, NY
- Ninomiya Y, Olsen BR, Ooyama T (1998) Extracellular matrix-cell interaction: molecules to disease. Karger, Basel
- Oberhauser AF, Marszalek PE, Erickson HP, Fernandez JM (1998) The molecular elasticity of the extracellular matrix protein tenascin. *Nature* 393:181–185
- Özkaya N, Nordin M (1999) Fundamentals of biomechanics: equilibrium, motion, and deformation. Springer, New York, NY
- Panfilov AV, Holden AV (1997) Computational biology of the heart. John Wiley & Sons, London
- Pioletti DP, Rakotomanana LR (2000) Non-linear viscoelastic laws for soft biological tissues. *Eur J Mech A Solids* 19:749–759
- Popov EP (1999) Engineering mechanics of solids. Prentice-Hall, Englewood Cliffs, NJ
- Pries AR, Secomb TW, Gaehtgens P (1995) Design principles of vascular beds. *Circ Res* 77:1017–1023

- Provenzano PP, Lakes RS, Corr DT, Vanderby R Jr (2002) Application of nonlinear viscoelastic models to describe ligament behavior. *Biomech Model Mechanobiol* 1:45–57
- Radmacher M, Tillmann RW, Fitz M, Gaub HE (1992) From molecules to cells: Imaging soft samples with the atomic force microscope. *Science* 257:1900–1905
- Ratner BD (2003) *Biomaterials science: introduction to materials in medicine*. Academic Press, San Diego, CA
- Roark RJ, Young WC (1975) *Formulas for stress and strain*. McGraw-Hill, New York, NY
- Robert L, Hornbeck W (1989) *Elastin and elastases, vol I*. CRC Press, Boca Raton, FL
- Roesler H (1987) The history of some fundamental concepts in bone biomechanics. *J Biomech* 20:1025–1034
- Rosen LE, Hollis TM, Sharma MG (1974) Alterations in bovine endothelial histidine decarboxylase activity following exposure to shearing stresses. *Exp Mol Pathol* 20:329–343
- Rubin CT, Lanyon L (1985) Regulation of bone mass by mechanical loading: the effect of peak strain magnitude. *Calcif Tissue Int* 37:441–447
- Shah AD, Humphrey JD (1999) Finite strain elastodynamics of saccular aneurysms. *J Biomech* 32:593–599
- Simon DD, Horgan CO, Humphrey JD (2012) Mechanical restrictions on biological responses by adherent cells within collagen gels. *J Mech Behav Biomed Mater* 14:216–226
- Skalak R, Chien S (1987) *Handbook of bioengineering*. McGraw-Hill, New York, NY
- Slattery JC (1981) *Momentum, energy, and mass transfer in continua*. Krieger, New York
- Stamenovic D, Ingber DE (2002) Models of cytoskeletal mechanics of adherent cells. *Biomech Model Mechanobiol* 1:95–108
- Sten-Knudsen O (1953) Torsional elasticity of the isolated cross striated muscle fibre. *Acta Physiol Scand* 28:7–240
- Strang G (1986) *Introduction to applied mathematics*. Wellesley-Cambridge Press, Boston, MA
- Suresh S (2007) Biomechanics and biophysics of cancer cells. *Acta Biomater* 3:413–438
- Tanner RI (1985) *Engineering rheology*. Oxford University Press, Oxford
- Ten Cate AR, Deporter DA (1975) The degradative role of the fibroblast in the remodelling and turnover of collagen in soft connective tissue. *Anat Rec* 182:1–14
- Timoshenko SP, Goodier JN (1970) *Theory of elasticity*, 3rd edn. McGraw-Hill, New York, NY
- Truesdell C, Noll W (1965) The nonlinear field theories of mechanics. In: Flugge S (ed) *Handbuch der Physik*. Springer, Berlin, Vol. III/3
- Tsao Y-MD, Boyd E, Wolf DA, Spaulding G (1994) Fluid dynamics within a rotating bioreactor in space and earth environments. *J Spacecraft Rockets* 31:937–943
- Usami S, Chen HH, Zhao Y, Chien S, Skalak R (1993) Design and construction of a linear shear stress flow chamber. *Ann Biomed Eng* 21:77–83
- Vaughn J, Czipura A, Humphrey JD (2002) Measurement of the finite strain dependent permeability of biomembranes. *J Biomech* 35:287–291
- Wagenseil J, Mecham RP (2012) Elastin in large artery stiffness and hypertension. *J Cardiovasc Trans Res* 5:264–273

- Waldman LK, Fung YC, Covell JW (1985) Transmural myocardial deformation in the canine left ventricle: normal in vivo three-dimensional finite strains. *Circ Res* 57:152–163
- Weibel ER (1963) *Morphometry of the human lung*. W.B. Saunders, Philadelphia, PA
- Wells PB, Thomsen S, Jones MA, Baek S, Humphrey JD (2005) Histological evidence for the role of mechanical stress in modulating thermal denaturation of collagen. *Biomech Model Mechanobiol* 4:201–210
- West JB (1979) *Respiratory physiology: the essentials*. Williams and Wilkins, Baltimore, MD
- Wiebers DO et al (1998) Unruptured intracranial aneurysms: risk of rupture and risks of surgical intervention. International study of unruptured intracranial aneurysms investigators. *N Engl J Med* 339:1725–1733
- Wineman AS, Rajagopal KR (2000) *Mechanical properties of polymers: an introduction*. Cambridge University Press, Cambridge
- Wolf DA, Schwarz RP (1991) Analysis of gravity-induced particle motion and fluid perfusion flow in the NASA-designed rotating zero-head-space tissue culture vessel. NASA Technical Paper 3143. NASA, Washington, DC
- Wolff J (1986) *The law of bone remodeling*. Springer, Berlin
- Wylie CR, Barrett LC (1982) *Advanced engineering mathematics*. McGraw Hill, New York, NY
- Zamir M (2000) *The physics of pulsatile flow*. Springer, New York, NY
- Zhu C, Bao G, Wang N (2000) Cell mechanics: mechanical response, cell adhesion, and molecular deformation. *Annu Rev Biomed Eng* 2:189–226
- Zubkov YN, Nokiforov BM, Shustin VA (1984) Balloon catheter technique for dilatation of constricted cerebral arteries after aneurysmal SAH. *Acta Neurochir* 70:65–79
- Zwolak RM, Adams MC, Clowes AW (1987) Kinetics of vein graft hyperplasia: association with tangential stress. *J Vasc Surg* 5:126–136

About the Authors

Jay D. Humphrey is John C. Malone Professor and Chair of Biomedical Engineering at Yale University. He received the Ph.D. degree in Engineering Science and Mechanics from The Georgia Institute of Technology and completed a post-doctoral fellowship in Cardiovascular Research at The Johns Hopkins University. He has authored a book titled *Cardiovascular Solid Mechanics: Cells, Tissues, and Organs*, co-authored a book titled *Style and Ethics of Communication in Science and Engineering*, co-edited a book titled *Cardiovascular Soft Tissue Mechanics*, and authored or co-authored chapters for over 20 other books or encyclopedias as well as over 225 archival technical papers. He served as founding co-Editor In Chief for the international journal *Biomechanics and Modeling in Mechanobiology* and has served as Associate Editor for five other technical journals. He is a Fellow of the American Society of Mechanical Engineers (Bioengineering Division) and the American Institute of Medical and Biological Engineers, and currently serves as Chair of the United States National Committee on Biomechanics.

Sherry L. O'Rourke is a Technical Field Engineer at Medtronic, plc in the Cardiac Rhythm Disease Management Division. She received the B.S. and M.S. degrees in Biomedical Engineering from Texas A&M University and co-authored an archival paper on the biomechanics of the lens capsule of the eye, which is important in understanding device design for cataract surgery. Since graduation she has spent her professional life dedicated to designing, developing, and teaching programs to help physicians, residents, and nurses ensure that patients receive the maximum benefit from pacemakers and implantable defibrillators that are designed for those suffering from chronic heart disease.

Index

- Acceleration
 - cartesians, 112, 357–361, 363
 - convective, 349, 400, 415, 416, 451, 505, 594
 - cylindricals, 361
 - local, 359, 361, 505
 - sphericals, 362, 401, 415
- Actin, 12–15, 22–24, 335, 465, 466, 654, 656, 668
- Adventitia, 85, 94, 128, 322–325, 328, 330, 333
- AFM. *See* Atomic force microscope (AFM)
- Aneurysms, 5–8, 21, 24, 56, 87, 96, 112, 130, 131, 138–143, 159, 264, 304, 311, 314–316, 321, 323, 334, 340, 362, 444, 583, 604, 618–630, 661
- Angiogenesis, 445, 653
- Angiography, 442, 444
- Angioplasty
 - balloon, 8, 312
 - neuroangioplasty, 311, 312, 315–321, 340, 346
- Angular velocity, 365–367, 390, 391, 404, 483, 486, 487, 489, 516, 517, 519, 594
- Anisotropy, 88, 89, 93, 107, 350
- Anticlastic bending, 241
- Apoptosis, 16, 294, 322, 323, 654, 668
- Arterial grafts, 158, 474, 537
- Artery, 6, 8, 10, 23, 54, 94, 112, 126, 127, 133, 158, 159, 300, 311, 325–327, 334, 338, 340, 348, 439, 447, 453, 454, 474, 493, 497, 503, 509, 510, 521, 523, 536, 537, 542, 543, 578, 588, 589, 602, 613, 658, 666, 670
- Atherosclerosis, 7, 311, 321–323, 325, 332, 361, 456, 474
- Atomic force microscope (AFM), 42, 123, 125, 250–255, 280, 293, 294, 350, 601, 653, 669
- Beams**
 - curved, 286–287
 - deflections, 228, 242
 - shear/bending moment diagrams, 216, 218, 219, 222–224, 235
 - straight, 214, 226, 286
 - stresses in, 223–240
- Bernoulli equation, 393, 423–438, 442, 447, 573, 575, 657, 662
- Bessel functions, 501, 503
- Biaxial experiments, 106, 299, 304–311, 349
- Bifurcations, 5, 138, 333, 365, 443, 535, 551–555, 584, 585, 593, 614, 619, 658
- Bingham plastics, 386
- Biomechanics
 - definition, 3
 - father of, 3
 - scope of, 667
- Bioreactor, 136, 483–484, 487, 488, 517, 671
- Blood
 - cells, 10, 98, 138, 164, 379–381, 384–387, 454, 493, 523, 527, 528, 549, 563, 565
 - clotting, 383, 387
 - constituents, 385

Blood (*cont.*)

- constitutive relation, 333
- viscosity, 386, 387, 489, 523

Body force, 112, 143, 410, 411, 426, 444, 453, 455, 458, 469, 471, 472, 477, 485, 494, 621

Bone

- cancellous, 85, 89, 98, 164, 166, 198, 211
- cortical, 97, 107, 164, 165, 168, 191, 311, 655
- mechanobiology, 191
- properties, 97–99, 271
- structure, 4

Boundary conditions

- cantilever support, 252, 267
- free-end, 222, 243, 268
- free-surface, 512
- no-slip, 375, 392, 400, 463, 479, 484, 494, 495, 502, 507, 518, 521, 522, 568
- simple-support, 268

Boundary layers, 463, 588, 589

Buckingham Pi theorem, 556, 557, 559, 561, 562, 571, 581, 597, 657

Bulk modulus, 104

Buoyant force, 418, 419, 453, 594

Cable, 31, 32, 34–36

Cancer biomechanics, 653, 668

Cardiac cycle, 79, 80, 163, 179, 200, 292, 365, 382, 456, 496–498, 503, 519

Cardiopulmonary resuscitation (CPR), 286

Cartesian coordinates

- acceleration, 357, 367
- deformation gradient, 290
- equilibrium, 52, 59, 112, 115
- Hooke's law, 115
- Navier–Poisson, 376, 413
- Navier–Stokes, 413, 417, 494
- shear rates, 400
- strain, 51, 52, 54, 55, 59, 62, 63, 69, 77
- vorticity, 357, 367, 368, 400

Cartilage, 17, 18, 22, 136, 163–165, 353, 388, 389, 526, 631, 646, 650–653

Catheters, 41, 126, 159, 311, 436, 440, 474, 515, 517, 546, 588, 670

Cell

- cytoskeleton, 12–14, 41, 466
- mechanics, 13, 24, 41, 122, 250, 294, 295, 385, 653, 668
- structure, 251, 293

Cell types

- blood cells, 10, 138, 379, 381, 384–387, 454, 493, 523, 527, 528, 549, 563, 565
- endothelial cells, 6, 7, 17, 19–21, 23, 322, 323, 383, 456, 457, 463–467, 519, 541, 542, 556, 603
- fibroblasts, 126, 158

- platelets, 16, 21, 380, 383–385, 387

Centroids, 99, 119–121, 133, 142, 143, 151–155, 162, 169, 175, 206, 223, 227, 228, 231, 232, 236, 264, 273–277, 280, 284–286

Chordae tendineae, 88, 117, 118, 121, 122, 163

Coanda effect, 590

Collagen, 14, 17–22, 24, 42, 83–85, 88, 89, 94, 97, 116, 117, 122, 128, 137, 164, 167, 200, 295, 305, 319, 321–323, 333, 339, 346, 349, 474, 631, 651, 652, 669

Columns, 149, 213–287, 290, 312, 340–344, 348, 429, 439, 440, 488, 615, 626

Conservation of

- energy, 533
- linear momentum, 533
- mass, 373, 533

Constitutive relations

- bone, 80, 81, 84, 85, 89, 90, 93, 94, 97–99
- fung exponential, 346
- general formulation, 27, 100, 150, 374, 393
- Hooke's law, 91, 272
- Mooney–Rivlin, 349
- Navier–Poisson equation, 376, 377, 380
- Neo-Hookean, 316
- newtonian, 374–379
- non-newtonian, 379, 383, 385–388, 391–393

Continuum mechanics, 4, 9–11, 17, 25, 27, 28, 82, 83, 99, 100, 224, 319, 368, 410, 557, 579, 654, 668, 671

Control volume, 319, 405, 447, 527–597

- Coordinate systems, 29, 30, 37, 50, 51,
54–59, 62, 63, 67, 69–71, 73, 77, 78,
81, 82, 86, 87, 95, 99, 101, 103, 109,
111–113, 115, 135, 140, 149, 151,
152, 154, 155, 157, 186–188,
205–208, 214, 226, 227, 236,
273–276, 278, 302, 303, 324, 327,
355, 357, 358, 363, 368, 376, 378,
379, 395, 408, 410, 412, 415,
419–421, 423, 444, 447, 464, 472,
511, 513, 521, 522
- Couette flow, 374, 468–470, 558, 624
- Couple, 27–30, 43, 52, 113, 115, 118,
169, 209, 292, 383, 415, 416, 419,
447, 448, 456, 466, 497, 508, 588,
601–666
- CPR. *See* Cardiopulmonary resuscitation
(CPR)
- Creep, 416, 632, 633, 635–639, 641,
662–665
- Curl, 359, 367, 368, 396, 397
- Curvatures, 8, 131, 226–228, 242, 247,
251, 266, 268, 269, 284–286, 311,
313, 315, 316, 319–321, 422, 431,
436, 620
- Cylindrical coordinates
acceleration, 112, 357, 361, 415
deformation gradient, 87, 316, 326
equilibrium, 56, 58, 112, 329
Hooke's law, 94
Navier–Stokes, 415, 451, 478, 485
shear rates, 401
strain, 72
stress components, 53
vorticity, 367, 368
- Cytochalasin B, 466
- Darcy's law, 608, 610
- Deformation gradient, 87, 290, 298, 306,
316, 325, 326, 342, 604
- DEICE, 25, 27, 83, 92, 105, 308, 310, 311,
374, 393, 605, 631
- Delamination, 98, 176
- Del operator
cartesian, 115, 359, 395
cylindrical, 398
spherical, 368
- Denude, 541
- Design
optimal biological, 179
transducer, 250–255
- Determinant, 300, 343, 344, 616, 630
- Diagrams
bending, 219
control volume, 567, 571, 572
free-body, 7, 31, 34, 36, 37, 39, 41, 42,
47, 48, 56, 61, 99, 119, 129, 133, 140,
171, 173, 175, 179, 182, 193, 196,
202, 216–220, 225, 234, 235, 237,
246, 247, 258, 264, 265, 268, 326,
440, 444, 490, 506, 513, 536, 537,
542, 543, 633, 634, 636
- Differential equations, 11, 36, 37, 111–113,
115, 142, 143, 145, 148, 183, 221,
242–244, 256, 266, 268, 270, 272,
298, 350, 354, 367, 388, 405,
415–417, 419, 423, 427, 432,
444–455, 460, 469, 472, 479, 486,
495, 496, 499, 501, 516, 527, 534,
573, 584–588, 614, 615, 625, 626,
630, 631, 635, 636, 638, 659, 661
- Diffusion, 15, 17, 475, 527, 528, 584, 587,
589, 603–618, 656, 657, 659, 670
- Digital image correlation, 87
- Dilatant fluid, 404
- Displacement, 31, 32, 68–76, 78, 79, 82, 87,
99, 103, 114, 115, 142, 144, 149, 161,
169–173, 176–179, 191, 201, 205,
242, 243, 264, 272, 280, 283, 289,
290, 295, 306, 307, 356–358, 372,
392, 426, 439, 548, 567, 610, 614,
617, 620, 624, 631
- Displacement gradient, 71, 72, 74, 76, 79,
99, 201, 289, 290, 295, 307, 372, 631
- Divergence
theorem, 399–404, 532, 585
of a vector, 359, 373, 395
- Donnan swelling, 651
- Ductile, 86, 212, 236, 239
- Duffing equation, 614, 615, 617
- Elastic behavior, 25, 84, 85, 97, 104, 303,
374, 613, 641, 645
- Elastin, 17, 20, 21, 84, 85, 88, 116, 122, 128,
200, 295, 305, 322, 323, 333, 334,
465, 527, 669

- Elastodynamics, 131, 627, 657
- Elastohydrodynamics, 650, 657
- Endothelial cells, 6, 7, 17, 19–21, 23, 322, 323, 383, 456, 457, 463–467, 519, 541, 542, 556, 603
- Endothelin, 23, 456
- Energy equation
 - differential equation, 447, 534, 585
 - pipe-flow equation, 573, 575, 577
- Entrance length, 463, 477, 504, 588
- Equilibrium, 30–32, 34, 36, 38–40, 43, 47, 51, 52, 55, 56, 58, 59, 61, 62, 77, 78, 83, 109–162, 171, 174, 176–179, 181, 182, 185, 191, 194–196, 202, 214, 216, 219, 220, 224, 227, 255, 258–260, 263–265, 272, 281, 291, 292, 310, 312, 314, 318, 329, 348, 390, 392, 505, 603, 605, 613, 615–617, 620, 626, 629, 633, 639, 640, 651
- Eulerian description, 408
- Euler’s equation, 420, 423–427
- Experimental
 - designs, 125, 198–203, 555–566
 - needs, 559
 - set-ups, 81
- Extracellular matrix, 7, 14, 16–22, 116, 125, 253, 254, 322, 323, 334, 339, 466, 651, 668, 671
- Eye, 17, 117, 138, 240, 319, 320, 345, 580, 671

- Failure (material), 48, 86, 205, 340
- Fatigue, 260–262, 334
- Fibroblasts, 14, 16, 17, 19–24, 41, 116, 126, 128, 157, 158, 164, 179, 323, 383, 475
- Finite elements, 4, 113, 175, 176, 240, 350, 508, 509
- First law of thermodynamics, 405, 533, 568, 585
- Flexure formula, 228, 233, 255, 282, 283, 286
- Flow
 - creeping, 416
 - 1-D, 2-D, 3-D, 400, 421, 447, 458, 469, 471, 511
 - secondary, 432, 436, 475, 488
 - separation, 432
 - uni-directional, 458, 469, 471, 485
 - uniform, 400
- Fluid, 10, 68, 112, 168, 282, 293, 353, 409, 456, 533, 601, 668
- Fourier series, 497, 498, 502, 518, 627
- Fracture toughness, 197, 198
- Free-body diagram, 7, 31, 34, 36, 37, 39, 41, 42, 47, 48, 56, 61, 99, 119, 129, 133, 140, 171, 173, 175, 179, 182, 193, 196, 202, 216–220, 225, 234, 235, 237, 246, 247, 258, 264, 265, 268, 326, 440, 444, 490, 506, 513, 536, 537, 542, 543, 633, 634, 636
- Free surface, 167, 471, 513, 521, 591, 594
- Friction
 - belt, 36
 - coefficient of, 35, 38, 161, 388, 646
 - factor (fluids), 562, 565, 571–573, 577, 580, 595, 596
 - static, 36, 44
- Fully developed flow, 400, 458, 469, 471, 477, 494, 500, 570, 588

- Glycosaminoglycans, 17, 21–23, 333, 387, 651
- Gradient, 71, 87, 147, 289, 290, 293, 298, 306, 316, 325, 326, 337, 342, 359, 390, 395, 421, 428, 437, 447, 458, 459, 461, 462, 468, 469, 471, 473, 478, 480, 481, 484, 495, 498–500, 502, 503, 506, 511, 513, 515–517, 522, 536, 555, 565, 573, 587, 604, 608
- del operator, 395
- Green strain, 71, 72, 79, 80, 102, 163, 184, 289, 302, 316, 328, 342, 345
- Growth and remodeling, 14, 97, 129, 150, 157, 167, 211, 223, 300, 325, 332, 333, 338, 339, 475, 603, 604, 631, 656, 668, 669
- Growth factors, 16, 17, 22, 164, 322, 334, 467

- Haversian canals, 165
- Heart, 8, 14, 15, 17–19, 41, 75–77, 80, 88, 93, 117, 126, 136, 138, 143, 150, 163, 179, 180, 199, 200, 202, 209, 261, 286, 292, 296, 304, 322, 333, 334,

- 338, 349, 353, 354, 361, 382, 404,
430, 492–494, 497, 521, 526, 534,
546, 547, 603, 604, 619, 621, 651,
655, 656, 658, 669, 671, 673
- Heat equation, 587, 655
- Hematocrit, 381, 384–387, 563
- Hemodynamics, 5, 23, 24, 382, 383, 509,
510, 551
- Hemoglobin, 384, 404
- Homogeneous behavior, 89, 113, 115, 143,
213, 308
- Hooke's law, 91, 93–95, 97, 100, 103, 114,
115, 149, 160, 171, 184, 189, 227,
228, 241, 272, 295, 300, 303, 377, 631
- Hoop stress, 127, 138
- Hydraulic accumulator, 591
- Hydrodynamic lubrication, 646–651
- Hydrostatic pressure, 86, 104, 324, 355, 377,
378, 410, 417
- Hypertension, 131, 159, 160, 321–323, 325,
332, 338, 339, 443, 509, 537, 656, 669
- Hysteresis, 84, 85, 88, 124, 295, 382,
645, 662
- Ideal fluid**, 393, 417, 447, 575, 577, 657
- Identity matrix**, 290, 343, 348
- Incompressibility**, 122, 148, 308, 324, 328,
346, 377, 396, 409, 414, 415
- Incompressible flow**, 377, 401, 402, 404,
408, 409, 423–425, 454, 455, 458,
468, 471, 475, 477, 480, 483, 484,
494, 533, 535, 538, 539, 542–545,
570, 621
- Induction**, 25, 42
- Initial condition**, 354, 445, 448, 450,
617–619, 660
- Integrins**, 14–16, 22, 253–255, 522, 523, 668
- Intermediate filaments**, 12, 14, 24, 654, 668
- Interpolation**, 76, 77, 87, 201, 520
- Invariants**, 101, 104, 304, 355, 393
- Inverse of a matrix**, 343
- Inviscid fluid**, 10, 419, 420, 425, 613, 614
- Irrotational flow**, 367, 402, 423,
425–431, 452
- Isotropy**, 85, 86, 88, 91, 93–95, 97, 103, 104,
138, 198, 303, 304, 377
- Jacobian**, 343
- Kinematic constraint**, 260, 280, 385
- Kinetic energy**, 533, 563, 569, 573, 575,
576, 661
- Kinetic energy coefficient**, 569, 573,
575, 576
- Knee**, 261, 353, 388, 389, 646, 654
- Lagrangian description**, 377
- Lamé constants**, 114, 115
- Laminar flow**, 462, 465, 471, 477, 485,
494, 515, 576–578, 581, 593,
596, 597
- Laplace's equation**, 314
- Laser tweezers**, 24, 123
- Least squares**, 310, 345
- Length**
entrance, 463, 477, 504, 588
scale, 9, 10, 523, 558, 561, 606
- Lifelong learning**, 672–673
- Linear momentum balance**, 392, 405,
421, 422, 447, 458, 478, 494,
527, 539, 540, 585, 587,
622, 623
- Losses**
major (viscous), 577
minor (geometric), 577
tabulated values, 574
- Lubrication theory**, 650, 665
- Lungs**
basic anatomy, 526–527
pulmonary dimensions, 527
sheet flow in, 510, 563
- Mach number**, 593
- Macrophages**, 20–22, 116, 322
- Manometer**, 440, 441, 453
- Mass**
balance, 28, 408, 415, 425, 427–431,
434, 436, 437, 444–447, 458, 469,
478, 485, 494, 499, 527, 539, 540,
544, 548, 552, 570, 573, 585, 587,
622, 623, 662

- Mass (*cont.*)
 density, 112, 197, 211, 356, 363, 382,
 406, 408, 409, 418, 419, 424, 441,
 451, 455, 488, 519, 537, 569, 573,
 594, 606, 613, 620
 scales, 597, 606, 613, 660
- Matrix
 metalloproteinases, 7, 20
 operations, 290
- Mechanobiology, 4, 7, 14, 16, 23, 41, 98,
 127, 132, 148, 163, 167, 168, 179,
 191, 255, 340, 508, 509, 602–603,
 654, 668, 670, 672
- Mechanotransduction, 14, 23–24, 41, 82,
 127, 157, 158, 164, 191, 213, 223,
 293, 321, 322, 337, 353, 388, 481,
 541, 601, 654
- Media, 85, 94, 128, 322, 323, 333, 458, 465,
 467, 484, 508, 519, 591
- Membranes
 biaxial stretching, 107
 constitutive behavior, 88, 96, 308
 definition, 12
 inflation, 106, 312, 314
 instability of, 346
- Metals, 83–86, 93, 125, 150, 197, 373, 656
- Method of pins, 39
- Microgravity, 7, 83, 167, 191, 354, 483,
 484, 487
- Microscopy
 atomic force, 24, 42, 123, 251–252, 255,
 271, 293, 350, 601, 669
 electron, 250, 251
 light, 250
- Mixture theory, 631, 645, 651–654, 657
- Modulus
 loss, 642–644, 664
 shear, 90, 93, 94, 184, 188, 190, 192, 198,
 202, 203, 205, 208–210, 212, 375, 606
 storage, 642, 664
 Young's, 90, 93, 94, 98, 103, 104, 107,
 170, 197, 210, 227, 252, 254, 280,
 281, 297, 311, 613
- Moens-Korteweg equation, 382, 613,
 658, 666
- Mohr's circle, 68
- Molecular mechanics, 24, 125, 668
- Moment-curvature relation, 228, 242, 247,
 266, 268, 269, 285
- Moment due to force, 220
- Moments of area
 first, 121, 151–162, 206, 274
 polar, 185
 second, 206–212, 273–276
- Mullin's effect, 312, 313
- Muscle, 14, 85, 117, 179, 322, 383, 456, 526,
 603, 668
- Myocardium, 14, 85, 88, 180, 199, 200, 203,
 303, 349
- Navier–Poisson relations, 377, 392, 621
- Navier Space equation, 392
- Navier–Stokes equation
 cartesians, 445
 cylindricals, 415, 416, 446, 451, 478,
 485, 494, 496
 sphericals, 415
 worksheets, 446
- Neuroangioplasty, 311, 312, 315–321,
 340, 346
- Neutral axis, 228, 242, 244, 261, 283–286
- Newtonian fluid, 375, 377, 380, 381, 385,
 386, 391, 392, 400, 415, 455, 458,
 463, 468, 470, 471, 477, 480, 483,
 484, 487, 488, 494, 497, 505, 506,
 508, 509, 514, 516, 575, 576, 596,
 621, 658, 662
- Nitric oxide, 23, 456
- Nondimensionalization, 563, 581, 595
- Non-Newtonian fluid, 11, 383, 386, 390,
 392, 393, 506, 516
- No-slip condition, 460, 469, 473, 485,
 486, 624
- Optical tweezers, 125
- Orthostatic intolerance, 484
- Orthotropy, 94, 303
- Osteoporosis, 175
- Papillary muscle, 88, 117, 118, 199–203,
 209, 349
- Parallel axis theorem, 273–288
- Parallel-plate flow, 517, 521
- Pascal,

- Pathline, 419, 443
 Pericardium, 96, 213, 305, 603, 604
 Permeability, 604, 605, 608–610, 612, 652
 Phase plane, 617
 Pitot tube, 441, 442
 Plasma, 14, 19, 20, 24, 380, 383–385, 387, 403, 511, 515, 523, 535, 603
 Plasticity, 11, 86
 Platelets, 16, 21, 380, 383–385, 387
 Poise, 381, 665
 Poiseuille flow, 458, 480, 511, 519
 Poisson's ratio, 90, 91, 93, 94, 105, 197, 210, 241, 652
 Poly methylmethacrylate, 197, 655
 Power, 123, 206, 320, 505, 506, 520–522, 549, 550, 553, 593
 Power-law fluid, 506, 520, 522
 Preconditioning, 296, 297, 312, 313
 Pressure
 - absolute, 418, 472, 483
 - drop, 404, 447, 517, 555, 561, 563, 565, 571, 573, 584, 588, 590, 593, 605
 - dynamic, 481
 - gauge, 418, 440, 472, 541
 - hydrostatic, 86, 104, 324, 355, 377, 378, 410, 417
 - stagnation, 441
 Principal values
 - strain, 77
 - stress, 64, 65, 100, 272
 Prosthesis (hip), 175, 260
 Proteoglycans, 17, 21, 22, 85, 88, 116, 295, 305, 322, 323, 604, 631, 651, 652
 Pseudoelasticity, 296
 Pseudoplastic, 379–381, 384, 386, 400, 403, 404, 504, 505, 508, 520
 Pulley, 35, 36, 38, 43
 Pulsatile flow, 333, 474, 496–504, 658
 Pulse wave velocity, 382, 383, 666

Rate-of-deformation, 295, 368–373, 392, 393, 409
Receptors (cell surface), 294, 668
Relaxation
 - function, 637, 645
 - spectrum, 645, 663
 - stress, 632, 633, 635, 636, 638, 639, 641, 662, 663**Residual stress**, 129, 150, 321–333, 336, 340
Resultants, 215, 220, 310, 313, 315, 345, 346, 584
Retardation spectrum, 663
Reynolds' number, 465, 467, 477, 482, 515, 562, 564, 571, 572, 580, 595, 646
Rheology, 385, 387, 393, 505
Rheopectic, 382
Right-hand rule, 55, 120, 181, 182
Rigid-body motion, 75, 76, 102, 290, 292, 293
Rod, 106, 142, 146, 150, 169, 170, 173, 181, 203, 212, 213, 224, 255, 264, 306
Rotation(s), 31, 32, 35, 38, 71, 72, 74–76, 87, 103, 104, 195, 198, 200, 202, 203, 242, 243, 272, 292, 293, 295, 338, 356, 357, 365–368, 378, 397, 425, 594
Rouleaux, 379, 380, 384, 386
Rubber, 83–85, 121, 125, 157, 312, 313, 316, 318, 340, 349, 453, 610, 644

Scales for nondimensionalization, 557, 563, 595
Serum, 383, 465
Shaft, 164, 165, 179, 181, 182, 190, 192, 194, 196, 197, 203, 208, 209, 213, 224
Shear force, 7, 55, 214–224, 229, 231, 235, 272, 284, 539
Shear modulus, 90, 93, 184, 188, 190, 192, 198, 202, 203, 205, 208–210, 212, 375, 606
Shear-rates, 354, 369, 373, 375, 376, 379–382, 384, 386–390, 392, 393, 400, 403, 404, 455, 456, 504, 505, 515, 520, 521, 631, 650
Sheet flow in lungs, 563, 565
Sickle cell, 387
Sign convention, 32, 38, 40, 51, 52, 181, 182, 214, 229, 230, 464, 477, 481, 490
Skin friction, 481, 515
Smooth muscle cells, 15, 17, 21–23, 158, 322, 323, 333, 334, 383, 474, 475, 603
 constitutive behavior, 94
Specific
 - gravity, 165, 383, 430, 452
 - weight, 430, 594**Spherical coordinates**
 - acceleration, 362, 401, 415
 - divergence, 401, 408

Spherical coordinates (*cont.*)

- equilibrium, 112, 113
- Navier–Stokes, 415, 622
- shear-rates, 376, 384
- strain, 56, 57, 71, 73, 95, 115, 138
- stress components, 53
- vorticity, 367

Stability

- beams, 615
- dynamic, 264, 583, 627, 630
- general, 262, 340
- inflated membranes, 313

Statically indeterminate, 39, 176, 178, 194–198, 258

Statics, 10, 28–44, 47, 51, 146, 174, 176, 194, 195, 214, 216, 219, 221, 230, 258, 260, 262, 264, 272, 282, 354, 378, 412, 417, 418, 440–442, 451, 464–467, 537, 594, 620

Steady flow, 127, 359, 363, 400–402, 419, 424, 425, 429, 443, 444, 456, 458, 469, 471, 474–483, 492–496, 499, 500, 502, 505, 512, 514, 519, 520, 535, 537, 546, 547, 568, 570, 575, 602, 658

Stenosis, 126, 334, 361, 365, 432, 433, 447, 474, 535, 573, 575, 584

Stent, 126, 240

Stiffness, 20, 49, 88, 90, 91, 97–99, 105, 117, 137, 197, 240, 251, 252, 255, 267, 268, 271, 293, 297–299, 307, 308, 320, 337, 382, 383, 392, 456, 613, 614, 633, 638, 651, 664–666

Strain

- gauges, 79, 81, 191, 201, 204, 280, 282, 307, 440
- green, 71, 72, 79, 80, 102, 163, 184, 289, 302, 316, 328, 342, 345
- infinitesimal/small, 72, 75, 80, 81, 84–86, 88, 89, 91, 93, 94, 97, 100, 114, 143, 149, 163, 178, 179, 181, 185, 190, 191, 199, 200, 203, 213, 223, 228, 272, 291, 294, 349, 350, 367, 392, 632, 641, 646
- microstrain, 91, 210

plane, 95, 96, 114

principal, 103, 104, 210, 328

shear, 103, 184, 190

transformations, 100, 276, 304

Strain energy, 105, 167, 302–304, 309, 345

Streamline, 419–431, 434, 437–438, 441, 443, 451, 575, 623, 662

Stress

Cauchy, 53, 58, 122, 130, 157, 161, 200, 206, 298, 301, 302, 313, 315, 329, 340, 354, 355, 392, 405, 410, 634

concentration, 118, 239, 240, 306, 350

first Piola-Kirchhoff, 161, 298, 300–302, 340, 354, 645

hydrostatic, 67, 68, 102, 104, 378, 379, 420

plane, 96, 114, 309

principal, 63–68, 102, 104, 107, 186–191, 236

relaxation, 632, 633, 635, 636, 638, 639, 641, 662, 663

residual, 129, 150, 321–334, 336, 340

second Piola-Kirchhoff, 302, 340

States of, 62, 76, 115, 117, 212, 262, 344

transformations, 58–63

yield, 107, 197, 212, 260, 381, 386

St. Venant's Principle, 118

Superposition, 134, 181, 204, 228, 255–262, 280, 282, 333, 645, 663

Surface

force, 410

tension, 123, 305, 374, 527, 594, 661

Synovial fluid, 382, 387, 388, 393, 646, 650

System, 1, 50, 111, 186, 214, 302, 334, 405, 457, 525, 608, 669

Taylor series, 109, 420, 615, 630

Temperature, 9, 83, 86, 90, 100, 255, 261, 334, 363, 375, 379, 386, 439, 441, 452, 468, 488, 511, 520, 534, 556, 557, 587, 654–656, 671

- first law of thermodynamics, 405, 533, 568, 585
- Tension, 4, 14, 17, 35, 36, 38–40, 43, 44, 50, 106, 107, 123, 162, 166, 191, 197, 198, 212, 261, 305, 311, 315, 320, 335, 374, 527, 594, 620, 651, 661
- Theory, 4, 11, 24–26, 28, 81–83, 92, 142, 144, 199, 212, 239, 250, 253, 255, 273, 282, 292, 294, 296, 300, 308, 336, 350, 372, 439, 441, 442, 465, 476, 523, 559, 577, 584, 605, 627, 630–632, 645–646, 650–654, 657, 665, 671, 672
- Thixotropic, 382
- Time, scales, 100, 631
- Tissue engineering, 42, 443, 474, 536, 668–670
- Torsion, 92, 106, 149, 163–212, 224, 225, 242, 260, 272, 349, 389
- Trace, 344, 616, 630, 631
- Transducer design
 - AFM, 250–255
 - load cells, 203
 - torque cells, 202, 203
- Transformations. *See* Strain; Stress
- Transpose, 290, 342
- Transverse isotropy, 93, 97, 138, 303, 304
- Tribology, 646
- Trigonometric identities, 60, 61, 64, 642
- Truss, 38–41, 44, 378
- Turbulent flow, 462, 482, 575, 577

- Uniform
 - flow, 400
 - stress, 121, 142, 157
- Universal solutions, 109–162, 204, 205, 256

- Vasospasm, 311, 361
- Vectors
 - curl, 359, 367, 396, 397
 - divergence, 359, 395, 396
 - scalar product, 395
 - vector product, 343, 348, 394–396
- Vein grafts, 157, 158, 474–476, 602, 603
- Velocity, 10, 68, 354, 409, 455, 527, 604
- Velocity gradients, 358, 363, 372, 428, 503, 527, 631
- Ventricular-assist device, 7, 353, 433, 456
- Vinculin, 466
- Viscoelasticity
 - Boltzmann model, 641–644
 - burger model, 664
 - characteristic behaviors, 261, 295–296, 632, 644
 - Kelvin-Voigt model, 636–638
 - Maxwell model, 633–636
 - quasilinear model, 645
 - standard model, 639, 665
- Viscometer
 - concentric cylinder, 389, 488–491, 515
 - cone-and-plate, 388–393, 403, 404, 488, 489, 516
 - descent of a sphere, 488
 - parallel plate, 392, 404
- Viscosity
 - absolute, 375, 579
 - apparent, 381, 382, 386, 387, 392, 403, 505, 520, 565, 650
 - of blood, 386, 387, 489, 523
 - dependence on, 11, 608
 - kinematic, 579
 - of plasma, 383
 - of water, 383
- Volume, 9, 92, 112, 168, 301, 369, 405, 461, 527, 607
- Volumetric flow, 404, 427, 429, 436, 442, 453, 461, 465, 468–470, 480, 503, 507, 511, 515–518, 521, 522, 533, 534, 542, 551, 555, 591–593, 605, 606, 647, 666
- Vorticity
 - cartesian, 367, 397, 400
 - cylindrical, 367
 - spherical, 368

- Wall shear stress, 391, 456, 457, 462–464, 467, 470, 475, 481, 482, 489, 490, 502, 503, 515, 518, 519, 521, 527, 537, 541, 551, 602, 612, 658
- Womersley’s number, 496, 503, 517, 564
- Work, 12, 41, 42, 97, 99, 136, 302, 308, 444, 467, 529, 533, 534, 550, 555, 567, 568, 585, 587, 658, 661, 670–673
- Working, 199, 568
- Worksheets, 445, 446
- Yield
 - criterion, 212
 - stress, 107, 197, 212, 260, 381, 386
- Young’s modulus, 90, 98, 103, 104, 107, 170, 197, 210, 227, 252, 254, 280, 281, 297, 311, 613
- Zero-stress state, 635, 636, 641