

REFERENCES

- [1] WHO, “Environmental noise guidelines for the European Region,” www.who.int, 2018. <https://www.who.int/publications/i/item/9789289053563>
- [2] T. Brooks, D. Stuart, and M. Marcolini, “NASA Reference Publication 1218 Airfoil Self-Noise and Prediction,” 1989. Available: <https://ntrs.nasa.gov/api/citations/19890016302/downloads/19890016302.pdf>
- [3] Vasishta Bhargava Nukala and Chinmaya Padhy, “Concise review: aerodynamic noise prediction methods and mechanisms for wind turbines,” *International Journal of Sustainable Energy*, vol. 42, no. 1, pp. 128–151, Feb. 2023, doi: <https://doi.org/10.1080/14786451.2023.2168000>.
- [4] P. W. Bearman and J. K. Harvey, “Golf Ball Aerodynamics,” *Aeronautical Quarterly*, vol. 27, no. 2, pp. 112–122, May 1976, doi: <https://doi.org/10.1017/s0001925900007617>.
- [5] J. Choi, W.-P. Jeon, and H. Choi, “Mechanism of drag reduction by dimples on a sphere,” *Physics of Fluids*, vol. 18, no. 4, p. 041702, Apr. 2006, doi: <https://doi.org/10.1063/1.2191848>.
- [6] L. Duan and M. Choudhari, “Effects of Riblets on Skin Friction in High-Speed Turbulent Boundary Layers,” 2012. Available: <https://ntrs.nasa.gov/api/citations/20120001342/downloads/20120001342.pdf>
- [7] F. Gattere, A. Chiarini, and M. Quadrio, “Dimples for Skin-Friction Drag Reduction: Status and Perspectives,” *Fluids*, vol. 7, no. 7, p. 240, Jul. 2022, doi: <https://doi.org/10.3390/fluids7070240>.
- [8] H. Ali, Mohammad Rasidi Rasani, Z. Harun, and Muhammad Ashhad Shahid, “Passive flow-field control using dimples for improved aerodynamic flow over a wing,” *Scientific Reports*, vol. 14, no. 1, Jun. 2024, doi: <https://doi.org/10.1038/s41598-024-63638-z>.
- [9] Yasin Kaan İlter, Aras Çetinkaya, and Uğur Oral Ünal, “Large eddy simulations of the turbulent channel flow over dimpled surfaces,” *Journal of Turbulence*, vol. 24, no. 3–4, Mar. 2023, doi: <https://doi.org/10.1080/14685248.2023.2186415>.
- [10] C. Hunter, S. Viken, R. Wood, and S. Bauer, “Advanced Aerodynamic Design of Passive Porosity Control Effectors,” 2001. Accessed: Oct. 06, 2025. [Online]. Available: <https://ntrs.nasa.gov/api/citations/20010013824/downloads/20010013824.pdf>
- [11] “Riblets as a Viscous Drag Reduction Technique | AIAA Journal,” *AIAA Journal*, 2024, doi: <https://doi.org/10.2514/6.2023-1111>
- [12] A. J. Smits and S. Ogg, “Aerodynamics of the Golf Ball,” *Bioengineering, Mechanics, and Materials: Principles and Applications in Sports*, pp. 3–27, 2004, doi: https://doi.org/10.1007/978-1-4419-8887-4_1.
- [13] C. M. J. Tay, B. C. Khoo, and Y. T. Chew, “Mechanics of drag reduction by shallow dimples in channel flow,” *Physics of Fluids*, vol. 27, no. 3, p. 035109, Mar. 2015, doi: <https://doi.org/10.1063/1.4915069>.
- [14] P. R. Spalart, M. Shur, M. Strelets, A. Travin, K. B. Paschal, and S. P. Wilkinson, “Experimental and numerical study of the turbulent boundary layer over shallow dimples,” *International Journal of Heat and Fluid Flow*, vol. 78, p. 108438, Aug. 2019, doi: <https://doi.org/10.1016/j.ijheatfluidflow.2019.108438>.
- [15] K. Aoki, K. Muto, and H. Okanaga, “Aerodynamic characteristics and flow pattern of a golf ball with rotation,” *Procedia Engineering*, vol. 2, no. 2, pp. 2431–2436, Jun. 2010, doi: <https://doi.org/10.1016/j.proeng.2010.04.011>.

- [16] O. W. G. van Campenhout, M. van Nesselrooij, Y. Y. Lin, J. Casacuberta, B. W. van Oudheusden, and S. Hickel, "Experimental and numerical investigation into the drag performance of dimpled surfaces in a turbulent boundary layer," *International Journal of Heat and Fluid Flow*, vol. 100, p. 109110, Jan. 2023, doi: <https://doi.org/10.1016/j.ijheatfluidflow.2023.109110>.
- [17] V. B. Ananthan, R. A. D. Akkermans, T. Hu, P. Q. Liu, and N. Rathje, "Trailing-edge noise reduction potential of a locally applied shallow dimpled surface," *Journal of Sound and Vibration*, vol. 525, p. 116745, May 2022, doi: <https://doi.org/10.1016/j.jsv.2022.116745>.
- [18] Y. Xie, Y. Rao, Y. Cheng, and W. Tian, "Investigation into the laminar separation control of airfoils at low Reynolds numbers by dimple vortex generators," *Aerospace Science and Technology*, vol. 129, p. 107841, Oct. 2022, doi: <https://doi.org/10.1016/j.ast.2022.107841>.
- [19] "Computational Aeromechanics of Paper Airplanes | Journal of Aircraft," *Journal of Aircraft*, 2019, doi: <https://doi.org/10.2514/ja.2019.56.issue-5>.
- [20] J. Winslow, H. Otsuka, B. Govindarajan, and I. Chopra, "Basic Understanding of Airfoil Characteristics at Low Reynolds Numbers (104–105) | Journal of Aircraft," *Journal of Aircraft*, vol. 55, no. 3, 2017, doi: <https://doi.org/10.2514/ja.2018.55.issue-3;journal:journal:ja;website:website:aiaa-site;wgroup:string:AIAA>.
- [21] S. Yarusevych and M. Kotsonis, "Steady and transient response of a laminar separation bubble to controlled disturbances," *Journal of Fluid Mechanics*, vol. 813, pp. 955–990, Jan. 2017, doi: <https://doi.org/10.1017/jfm.2016.848>.
- [22] A. Ducoin, J.-C. . Loiseau, and J.-C. . Robinet, "Numerical investigation of the interaction between laminar to turbulent transition and the wake of an airfoil," *European Journal of Mechanics - B/Fluids*, vol. 57, pp. 231–248, May 2016, doi: <https://doi.org/10.1016/j.euromechflu.2016.01.005>.
- [23] C. E. Brunner, J. Kiefer, M. O. L. Hansen, and M. Hultmark, "Study of Reynolds number effects on the aerodynamics of a moderately thick airfoil using a high-pressure wind tunnel," *Experiments in Fluids*, vol. 62, no. 8, Aug. 2021, doi: <https://doi.org/10.1007/s00348-021-03267-8>.
- [24] R. K. Amiet, "Noise due to turbulent flow past a trailing edge," *Journal of Sound and Vibration*, vol. 47, no. 3, pp. 387–393, Aug. 1976, doi: [https://doi.org/10.1016/0022-460x\(76\)90948-2](https://doi.org/10.1016/0022-460x(76)90948-2).
- [25] S. Pröbsting and S. Yarusevych, "Laminar separation bubble development on an airfoil emitting tonal noise," *Journal of Fluid Mechanics*, vol. 780, pp. 167–191, Sep. 2015, doi: <https://doi.org/10.1017/jfm.2015.427>.
- [26] D. Lockard, "A Comparison of Ffowcs Williams-Hawking;s Solvers for Airframe Noise Applications," 2002. Available: <https://ntrs.nasa.gov/api/citations/20030012929/downloads/20030012929.pdf>
- [27] C. Teruna, F. Avallone, D. Ragni, and D. Casalino, "On the noise reduction of a porous trailing edge applied to an airfoil at lifting condition," *Physics of Fluids*, vol. 33, no. 5, May 2021, doi: <https://doi.org/10.1063/5.0047512>.
- [28] M. Gad-el-Hak, "Flow Control," Aug. 2000, doi: <https://doi.org/10.1017/cbo9780511529535>.
- [29] J. C. Lin, "Review of research on low-profile vortex generators to control boundary-layer separation," *Progress in Aerospace Sciences*, vol. 38, no. 4–5, pp. 389–420, May 2002, doi: [https://doi.org/10.1016/s0376-0421\(02\)00010-6](https://doi.org/10.1016/s0376-0421(02)00010-6).
- [30] G. Godard and M. Stanislas, "Control of a decelerating boundary layer. Part 1: Optimization of passive vortex generators," *Aerospace Science and Technology*, vol. 10, no. 3, pp. 181–191, Apr. 2006, doi: <https://doi.org/10.1016/j.ast.2005.11.007>.

- [31] D. W. Bechert and M. Bartenwerfer, “The viscous flow on surfaces with longitudinal ribs,” *Journal of Fluid Mechanics*, vol. 206, pp. 105–129, Sep. 1989, doi: <https://doi.org/10.1017/s0022112089002247>.
- [32] “Numerical Simulation of Supersonic Jet Flows and their Noise | Aeroacoustics Conferences,” *Aeroacoustics Conferences*, 2025, doi: <https://doi.org/10.2514/MAERO08;ctype:string:Book>.
- [33] “Reduction of Wind Turbine Noise Using Optimized Airfoils and Trailing-Edge Serrations | AIAA Journal,” *AIAA Journal*, 2025, doi: <https://doi.org/10.2514/aiaaj.2009.47.issue-6;website:website:aiaa-site;wgroup:string:AIAA>.
- [34] T. Geyer, E. Sarradj, and C. Fritzsche, “Porous Airfoils: Noise Reduction and Boundary Layer Effects,” *International Journal of Aeroacoustics*, vol. 9, no. 6, pp. 787–820, Jul. 2010, doi: <https://doi.org/10.1260/1475-472x.9.6.787>.
- [35] D. S. Miklosovic, M. M. Murray, L. E. Howle, and F. E. Fish, “Leading-edge tubercles delay stall on humpback whale (*Megaptera novaeangliae*) flippers,” *Physics of Fluids*, vol. 16, no. 5, pp. L39–L42, May 2004, doi: <https://doi.org/10.1063/1.1688341>.
- [36] J. Lan, Y. Xie, and D. Zhang, “Effect of leading edge boundary layer thickness on dimple flow structure and separation control,” *Journal of Mechanical Science and Technology*, vol. 25, no. S1, pp. 3243–3251, Dec. 2011, doi: <https://doi.org/10.1007/s12206-011-0823-z>.
- [37] P. Ligrani, J. Harrison, G. I. Mahmmoud, and M. Hill, “Flow structure due to dimple depressions on a channel surface,” vol. 13, no. 11, pp. 3442–3451, Nov. 2001, doi: <https://doi.org/10.1063/1.1404139>.
- [38] V. D’Alessandro, G. Clementi, L. Giammichele, and R. Ricci, “Assessment of the dimples as passive boundary layer control technique for laminar airfoils operating at wind turbine blades root region typical Reynolds numbers,” *Energy*, vol. 170, pp. 102–111, Mar. 2019, doi: <https://doi.org/10.1016/j.energy.2018.12.070>.
- [39] Olajide Sulaiman Olayiwola, “Optimization of Dimpled Surface of NACA0012 Airfoil to Enhance the Aerodynamic Performance,” *Tuijin Jishu/Journal of Propulsion Technology*, vol. 45, no. 03, pp. 3808–3821, 2024, doi: <https://doi.org/10.52783/tijpt.v45.i03.7860>.
- [40] S. Kumar, S. K. Singh, S. Jha, K. Baskaran, K. Srinivasan, and S. Narayanan, “On the reductions of airfoil broadband noise through circular dimples,” *Applied Acoustics*, vol. 217, p. 109819, Feb. 2024, doi: <https://doi.org/10.1016/j.apacoust.2023.109819>.
- [41] C. Zheng, P. Zhou, S. Zhong, and X. Zhang, “Experimental investigation on cylinder noise and its reductions by identifying aerodynamic sound sources in flow fields,” *Physics of Fluids*, vol. 35, no. 3, Mar. 2023, doi: <https://doi.org/10.1063/5.0138080>.
- [42] A. J. Stolt, A. H. Ullah, and J. Estevadeordal, “Study of Leading-Edge Dimple Effects on Airfoil Flow Using Tomographic PIV and Temperature Sensitive Paint,” *Fluids*, vol. 4, no. 4, p. 184, Oct. 2019, doi: <https://doi.org/10.3390/fluids4040184>.
- [43] T. R. Ricciardi and W. R. Wolf, “Switch of tonal noise generation mechanisms in airfoil transitional flows,” *Physical Review Fluids*, vol. 7, no. 8, Aug. 2022, doi: <https://doi.org/10.1103/physrevfluids.7.084701>.
- [44] C. E. Toppings and Serhiy Yarusevych, “Laminar separation bubble formation and bursting on a finite wing,” *Journal of Fluid Mechanics*, vol. 986, May 2024, doi: <https://doi.org/10.1017/jfm.2024.321>.

- [45] S. Yarusevych, P. E. Sullivan, and J. G. Kawall, "On vortex shedding from an airfoil in low-Reynolds-number flows," *Journal of Fluid Mechanics*, vol. 632, pp. 245–271, Aug. 2009, doi: <https://doi.org/10.1017/S0022112009007058>.
- [46] D. Greenblatt, Hanns Müller-Vahl, and C. Strangfeld, "Laminar separation bubble bursting in a surging stream," *Physical Review Fluids*, vol. 8, no. 1, Jan. 2023, doi: <https://doi.org/10.1103/physrevfluids.8.1012102>.
- [47] "Michael Selig," www.michaelselig.com. <https://www.michaelselig.com/>
- [48] "Airfoil Optimization for High-Endurance Rotary Wings at Low Reynolds Numbers | Journal of Aircraft," *Journal of Aircraft*, 2025. <https://doi.org/10.2514/1.C037998> (accessed Oct. 07, 2025)
- [49] C. Bak, *Advances in wind turbine blade design and materials*. Elsevier Inc. Chapters, 2013.
- [50] S. Pröbsting, F. Scarano, and S. T. Morris, "Regimes of tonal noise on an airfoil at moderate Reynolds number," vol. 780, pp. 407–438, Sep. 2015, doi: <https://doi.org/10.1017/jfm.2015.475>.
- [51] L. W. Traub and C. Coffman, "Efficient Low-Reynolds-Number Airfoils," *Journal of Aircraft*, vol. 56, no. 5, pp. 1987–2003, Sep. 2019, doi: <https://doi.org/10.2514/1.c035515>.
- [52] "High-Lift Low Reynolds Number Airfoil Design | Journal of Aircraft," *Journal of Aircraft*, 2025, doi: <https://doi.org/10.2514/ja.1997.34.issue-1;journal:journal:ja;website:website:aiaa-site;wgroup:string:AIAA>.
- [53] E. V. Laitone, "Wind tunnel tests of wings at Reynolds numbers below 70 000," *Experiments in Fluids*, vol. 23, no. 5, pp. 405–409, Nov. 1997, doi: <https://doi.org/10.1007/s003480050128>.
- [54] V. Akbari, M. Naghashzadegan, R. Kouhikamali, and Wahiba Yaïci, "Evaluation of Regional Elevation and Blade Density Effects on the Efficiency of a 1-kW Wind Turbine for Operation in Low-Wind Counties in Iran," *Wind*, vol. 3, no. 3, pp. 320–342, Aug. 2023, doi: <https://doi.org/10.3390/wind3030019>.
- [55] "Vortex Generator - an overview | ScienceDirect Topics," www.sciencedirect.com. <https://www.sciencedirect.com/topics/engineering/vortex-generator>
- [56] C. Ladson, "Effects of Independent Variation of Mach and Reynolds Numbers on the Low-Speed Aerodynamic Characteristics of the NACA 0012 Airfoil Section," *NASA Technical Memorandum*, vol. 4074, 1988, Available: <https://ntrs.nasa.gov/api/citations/19880019495/downloads/19880019495.pdf>
- [57] B. Al Tlua and J. Rocha, "Experimental investigation of NACA-0012 airfoil instability noise with sawtooth trailing edges," *Wind Engineering*, p. 0309524X2110605, Dec. 2021, doi: <https://doi.org/10.1177/0309524x211060548>.
- [58] A. S. Lyrantzis, "Surface Integral Methods in Computational Aeroacoustics—From the (CFD) Near-Field to the (Acoustic) Far-Field," *International Journal of Aeroacoustics*, vol. 2, no. 2, pp. 95–128, Apr. 2003, doi: <https://doi.org/10.1260/14754720322775498>.
- [59] C. E. Toppings and S. Yarusevych, "Transient dynamics of stall and reattachment at low Reynolds number," *Journal of Fluid Mechanics*, vol. 1011, May 2025, doi: <https://doi.org/10.1017/jfm.2025.348>.
- [60] Trùng Hân, "ANSYS Fluent Theory Guide," *Academia.edu*, Jun. 19, 2017. https://www.academia.edu/33546431/ANSYS_Fluent_Theory_Guide (accessed Dec. 21, 2025)

[61]“-AnsysHelp,”*Ansys.com*,2025.

https://ansyshelp.ansys.com/public/account/secured?returnurl=/Views/Secured/corp/v242/en/flu_th/flu_th.html

[62]P. R. Spalart, S. Deck, M. L. Shur, K. D. Squires, M. Kh. Strelets, and A. Travin, “A New Version of Detached-eddy Simulation, Resistant to Ambiguous Grid Densities,” *Theoretical and Computational Fluid Dynamics*, vol. 20, no. 3, pp. 181–195, May 2006, doi: <https://doi.org/10.1007/s00162-006-0015-0>.