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Editorial

Flow Control Techniques: Advances in Flow System Analysis, Modeling and Applications

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Flow control has assumed a key role in many applied aspects of fluid dynamics and propulsion in efforts toward CO2-neutral growth in air, ground and maritime transportation. Moreover, thrust control and vectoring also demonstrate the advantages of reusable rocket engines for entering space. The ambitious goals of this roadmap push designers toward highly optimized solutions for flow devices of all kinds. Aggressive and highly optimized design of flow devices at the on-design condition often makes them more susceptible to instability or abrupt performance losses in other operating conditions. Therefore, flow control, both passive and active, represents a way to improve the performance of aerodynamic devices and to increase safety margins under all operating conditions.

The key aspects of flow control applications are as follows: (i) the derivation of accurate real-time models of the nonlinear flow field; (ii) the development of reliable flow manipulators and sensing systems, composed of a network of physical or virtual sensors; (iii) the design of robust control laws, tailored to the specific system (e.g., model-based) and the objectives of each phase of the flight mission; and (iv) the study and design of innovative actuation systems and flow manipulators.

This special issue, "*Flow Control Techniques: Advances in Flow System Analysis, Modeling, and Applications*," brings together some of the most recent advances in the above research and development topics, with interesting contributions covering aspects of active control, passive manipulation, and characterization of flows of applied interest using both numerical and experimental approaches. The contributions also cover areas related to the study and modeling of actuators and flow manipulators. The problem of identifying instabilities in dynamic systems using artificial intelligence-assisted techniques is also addressed.

The first study presented in this Special Issue focuses on the active control of flows using Synthetic Jet (SJ) actuators. Murillon-Rincón and Duque-Daza [1] study the application of SJ manipulators and their effect on the noise of a turbulent and incompressible circular jet. The analysis is based on a quasi-Direct Numerical Simulation (qDNS) approach capable of predicting the effects of turbulence with high accuracy. The flow response is characterized in terms of both turbulence statistics and far-field acoustic response, the latter based on the Ffowcs–Williams–Hawkings (FWH) acoustic analogy. It should be noted that synthetic jet flow manipulators exhibit very complex behavior [2] with markedly nonlinear responses at high frequencies [3–5]. Their effectiveness has been demonstrated in numerous contexts, and is illustrated well in the extensive review by Ho et al. [6], also included in this Special Issue.

A classic flow manipulation strategy is based on the injection of a jet transversely to the main flow. In this context, Martins and Pereira [7] use DNS methods to study the three-dimensional near-field flow interaction of square and circular jets emitted normally to the main flow. The objective is to analyze the effect of the cross-section of the injected jet on

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the vortical structures that form in the crossflow. The analysis focuses on jets in transverse flow with moderate Reynolds numbers (Re =200–300).

The dynamics and control of supersonic jets are studied numerically in two other studies presented here. Marsilio et al. [8] illustrates a specific technique for thrust vectoring in a linear aerospike nozzle. Aerospike is a type of advanced supersonic nozzle for space access, widely studied for its ability to self-adapt to altitude without significant thrust losses.In this case, a fluidic thrust vectoring method, namely, differential throttling, is studied, which does not require any mechanical movement of the nozzle.

Furthermore, the flow structure in convergent–divergent micro-nozzles is investigated by Mendoza-Anchondo et al. [9] using the Z-type Schlieren optical setup. The supersonic flow patterns generated at the exit of different nozzle geometries are visualized. It is highlighted how these small nozzles can offer significant advantages in scientific research applications in fields such as space micropropulsion or the cooling of microelectronic systems.

The study by Aguirre-López et al. [10] investigates the influence of surface roughness on the flow around them at high Reynolds numbers ($Re = 6 \times 10^6$). A delayed detached vortex (DDES) numerical approach is used. The effects of roughness and corrugations (e.g., riblets) on flow are of particular interest in the study of bio-inspired passive control and aerodynamic drag reduction [11–14]. The influence of roughness on aerodynamics and CFD modeling of roughness have become even more relevant with the introduction of additive manufacturing techniques for aerodynamic devices [15,16].

The Special Issue then focuses on actuator studies and modeling. The study by Bernal-Orozco et al. [17] focuses on the numerical modeling and assessment of plasma actuators such as Dielectric Barrier Discharge (DBD) actuators. The performance of three numerical models of DBD actuators for CFD applications are studied and compared to the experimental results. Modifications are proposed that can significantly improve the models' ability to reproduce the effects of a DBD actuator on the flow.

Flow control effectiveness is also related to the performance and capabilities of the actuators used. In this context, Jin et al. [18] analyze the flow dynamics and damage characteristics of control valves, also identifying the main failure mechanisms.

Furthermore, Wiley and Huang [19] study the effect of bifurcated geometry on the diodicity of Tesla valves, which are fluidic diodes that allow for unidirectional flow while preventing reverse flow without the use of moving parts. This feature translates into faster response and fewer malfunctions.

On the topic of artificial intelligence and flow control, the work of Zanotti et al. [20] is presented. They develop a deep learning algorithm that, starting from a time sequence of compressor dynamics, can predict both the system's permanence in stable operating conditions as well as the potential onset of different instabilities. The results show that it is possible to identify both rotating stall and surge instability with good accuracy.

Overall, this Special Issue highlights a rapidly evolving field. The collection focuses on new directions in active and passive flow control and highlights the significant opportunities that lie ahead for future scientific and technological progress.

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References

1. Murillo-Rincón, J.; Duque-Daza, C. Evaluation of Synthetic Jet Flow Control Technique for Modulating Turbulent Jet Noise. *Fluids* **2023**, *8*, 110. https://doi.org/10.3390/fluids8040110.
2. Gad-el Hak, M. Flow Control: The Future. *J. Aircr.* **2001**, *38*, 402–418. https://doi.org/10.2514/2.2796.

3. Cattafesta, L.N.; Sheplak, M. Actuators for Active Flow Control. *Annu. Rev. Fluid Mech.* **2011**, *43*, 247–272. https://doi.org/10.1146/annurev-fluid-122109-160634.
4. Rumsey, C.; Gatski, T.; Sellers, W.; Vatsa, V.; Viken, S. Summary of the 2004 CFD Validation Workshop on Synthetic Jets and Turbulent Separation Control. In *Proceedings of the 2nd AIAA Flow Control Conference*; American Institute of Aeronautics and Astronautics: Reston, VA, USA, 2004. https://doi.org/10.2514/6.2004-2217.
5. Ferlauto, M.; Marsilio, R. A computational approach to the simulation of controlled flows by synthetic jets actuators. *Adv. Aircr. Spacecr. Sci.* **2015**, *2*, 77–94. https://doi.org/10.12989/aas.2015.2.1.077.
6. Ho, H.H.; Shirinzad, A.; Essel, E.E.; Sullivan, P.E. Synthetic Jet Actuators for Active Flow Control: A Review. *Fluids* **2024**, *9*, 290. https://doi.org/10.3390/fluids9120290.
7. Martins, F.C.; Pereira, J.C.F. Numerical Study of Laminar Unsteady Circular and Square Jets in Crossflow in the Low Velocity Ratio Regime. *Fluids* **2024**, *9*, 292. https://doi.org/10.3390/fluids9120292.
8. Marsilio, R.; Di Cicca, G.M.; Resta, E.; Ferlauto, M. Characterization of the Three-Dimensional Flowfield over a Truncated Linear Aerospike. *Fluids* **2024**, *9*, 179. https://doi.org/10.3390/fluids9080179.
9. Mendoza-Anchondo, R.J.; Alvarez-Herrera, C.; Murillo-Ramírez, J.G. Visualization and Parameters Determination of Supersonic Flows in Convergent-Divergent Micro-Nozzles Using Schlieren Z-Type Technique and Fluid Mechanics. *Fluids* **2025**, *10*, 40. https://doi.org/10.3390/fluids10020040.
10. Aguirre-López, M.A.; Hueyotl-Zahuantitla, F.; Martínez-Vázquez, P.; Márquez-Urbina, J.U. Passive Control of the Flow Around a Rectangular Cylinder with a Custom Rough Surface. *Fluids* **2024**, *9*, 253. https://doi.org/10.3390/fluids9110253.
11. Korkut, V. Additive manufacturing of surface riblets for aerodynamic optimization: From fabrication to flow visualization. *Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng.* **2025**. https://doi.org/10.1177/09544089251369051.
12. Harun, Z.; Abbas, A.A.; Ghopa, W.A.W.; Taha, T.G.; Khashehchi, M.; Nugroho, B.; Chin, R. Directional riblets as an airfoil passive flow control mechanism. *Int. J. Heat Fluid Flow* **2025**, *113*, 109772. https://doi.org/10.1016/j.ijheatfluidflow.2025.109772.
13. Elcrat, A.; Ferlauto, M.; Zannetti, L. Point vortex model for asymmetric inviscid wakes past bluff bodies. *Fluid Dyn. Res.* **2014**, *46*, 031407. https://doi.org/10.1088/0169-5983/46/3/031407.
14. Pakatchian, M.R.; Rocha, J.; Li, L. Advances in Riblets Design. *Appl. Sci.* **2023**, *13*, 10893. https://doi.org/10.3390/app131910893.
15. Wildgoose, A.J.; Thole, K.A.; Tuneskog, E.; Wang, L. Roughness Related to Cooling Performance of Channels Made Through Additive Manufacturing. *J. Turbomach.* **2024**, *146*, 051008. https://doi.org/10.1115/1.4064310.
16. Garg, H.; Sahut, G.; Tuneskog, E.; Nogenmyr, K.J.; Fureby, C. Large eddy simulations of flow over additively manufactured surfaces: Impact of roughness and skewness on turbulent heat transfer. *Phys. Fluids* **2024**, *36*, 085143. https://doi.org/10.1063/5.0221006.
17. Bernal-Orozco, R.A.; Carvajal-Mariscal, I.; Huerta-Chavez, O.M. Performance of DBD Actuator Models under Various Operating Parameters and Modifications to Improve Them. *Fluids* **2023**, *8*, 112. https://doi.org/10.3390/fluids8040112.
18. Jin, H.; An, H.; Wang, C.; Liu, X. Numerical Investigations of the Influence of the Spool Structure on the Flow and Damage Characteristics of Control Valves. *Fluids* **2025**, *10*, 99. https://doi.org/10.3390/fluids10040099.
19. Wiley, S.; Huang, H.P. The Effect of Bifurcated Geometry on the Diodicity of Tesla Valves. *Fluids* **2024**, *9*, 294. https://doi.org/10.3390/fluids9120294.
20. Zanotti, S.; Ceschini, D.; Ferlauto, M. AI-Based Detection of Surge and Rotating Stall in Axial Compressors via Dynamic Model Parameter Estimation. *Fluids* **2024**, *9*, 134. https://doi.org/10.3390/fluids9060134.

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