A new Olympiad problem: Introducing students to a key challenge in hydroelectric power

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Three-part problem enables gifted high-school students to delve deeply into the physics of hydraulic jumps and their application in hydroelectric power plants to extract energy from flowing water.

Olympiads are an excellent way to fuel students' curiosity. By enabling them to apply their skills to highly relevant, real-world problems, these competitions can be a valuable way to train future generations of researchers. For now, however, Olympiad-style problems are still relatively new in physics and engineering – making it important to design questions that challenge gifted students, while staying closely tied to real-world applications.

In a study published in EPJ Special Topics, Diana-Stefania Catana at the University of Bucharest presents a new Olympiad-level problem. It focuses on the physics and engineering principles underlying hydroelectric turbines, asking students to calculate their energy yields and consider their sustainability in real-world conditions.

As a vital source of renewable energy, hydroelectric power is a cornerstone of technologies designed to mitigate climate change. By giving gifted high-school students a chance to explore a key challenge in its operation, Catana's problem could help prepare them for many of the issues they may encounter in their future careers.

A central concept in the problem is the phenomenon of hydraulic jumps: which occur when water flowing at high velocity is suddenly forced to slow down. This behaviour is particularly important for water jets flowing along shallow grooves, at the point where they interact with rotating hydroelectric turbines. During a hydraulic jump, the water's level abruptly rises – converting some of the flow's kinetic energy into gravitational potential energy, while the rest is dissipated as turbulent heat losses.

In Catana's three-part problem, students explore the physics of this effect and apply it to challenges faced by hydroelectric engineers. The first part addresses the conditions required for hydraulic jumps to occur. Students calculate the total energy lost to heat during a jump as a function of factors including the water's velocity, its height before and after the jump, and the dimensions of the groove.

In the second part, these principles are applied to a Pelton turbine: a widely used mechanism in hydroelectric power that extracts energy from the change in momentum of a water jet striking its blades. First, students calculate the turbine's rotation speed needed to achieve at least 50% efficiency. Then, the problem introduces a second device: a steam engine operating on the Rankine cycle – an idealised thermodynamic cycle describing how heat engines extract mechanical work from a working fluid.

In this scenario, the turbine is powered by water vapour produced using the heat dissipated during the hydraulic jump. Students calculate the quantity of vapour required for the turbine's yield to match that of an ideal Carnot engine. Finally, in the last section of the problem, they calculate the overall yield of the Pelton turbine and evaluate its efficiency with respect to the initial jet speed.

At each stage, students demonstrate a rigorous understanding of thermodynamics, heat engines, and phase transitions. The problem also encourages them to apply creativity when designing the hydroelectric system and to integrate their theoretical and applied knowledge of physics. Ultimately, Catana hopes the problem will introduce students to one of the key challenges in renewable energy – giving them both confidence and insight as they consider future careers. ■

Reference

[1] Catana, DS. Energy physics concepts for Olympiad curricula and a simple optimization of the Rankine cycle. Eur. Phys. J. Spec. Top. (2025). https://doi.org/10.1140/epjs/s11734-025-01551-w

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▾ Pelton turbine driven by a hydraulic jump