

MARKET FEASIBILITY ON THE CONSTRUCTION OF A MODERN VERTICAL WIND TUNNEL FOR SKYDIVING

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Abstract: This study evaluates the technical and economic feasibility of developing a large-scale recirculating indoor vertical wind tunnel (4.2-5.2m flight chamber, up to ~300 km/h wind speed) in Romania to serve both civilian users and military freefall training. The information is combined into a multi-segment demand assessment (domestic leisure, inbound tourism, sport skydivers, corporate groups, and military units) with a techno-economic model of capital costs, operating costs, and risks associated. Civilian total addressable demand is estimated at 50,000-100,000 flight sessions/year nationally, with a realistic serviceable share of ~40,000 sessions in Year 1, ramping to almost 100,000 sessions by Year 5 under base-case assumptions. The reference technical configuration is a ~2 MW recirculating tunnel with total CAPEX of ~€9 million and steady-state OPEX of ~€0.6 million/year, yielding projected revenues of ~€2-2.5 million/year at maturity and an approximate internal rate of return of approximately 15-18% with a payback period between 5 and 6 years. Sensitivity analyses highlight utilization and electricity prices as key value drivers, while qualitative risk assessment underscores the importance of early military and corporate block-booking, advanced energy-efficient tunnel design, and robust acoustic and community-acceptance measures. Overall, the project is found to be technically feasible and financially attractive in the capital region, with competitive potential as a regional training and tourism hub for Eastern Europe.

Keywords: Vertical wind tunnel, feasibility study, techno-economic analysis, military and civilian training

1. Introduction

Indoor recirculating vertical wind tunnels have evolved from niche entertainment attractions into multi-purpose testbeds for sports, training, and applied research.[1,2] They enable safe simulation of freefall conditions for skydivers and military personnel, while also serving as high-throughput leisure facilities and platforms for aerodynamic experiments and human-factors studies.[1] In Western Europe and North America, such tunnels are now part of a mature industry with standardized technical solutions, as shown in figure 1., diversified business models, and established user communities.[2,3,4] By contrast, Eastern Europe remains significantly underserved, with limited access to large-scale, high-performance facilities capable of supporting both civilian and professional training requirements.

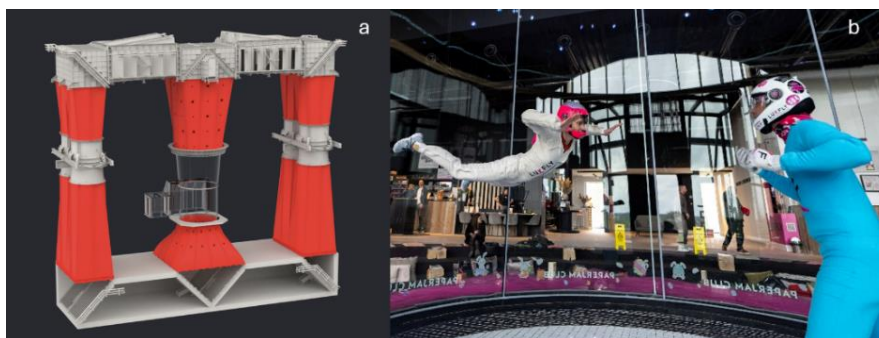


Fig. 1. a. Example of Vertical Wind Tunnel Design [4]; **Fig. 1. b.** LuxFly, Belgium [4]

Romania is a particularly relevant case within this regional context. The country combines a growing middle class and rising tourism [5] with an expanding defense and security sector that increasingly relies on advanced training capabilities. At present, Romanian skydivers, indoor skydiving athletes, and military freefall units must either rely on a small number of regional facilities abroad or operate without access to a domestic large diameter recirculating vertical wind tunnel. A prior attempt to integrate a wind tunnel into an entertainment resort near Bucharest named the Freelo Project, shown in Figure 2. Was attempted and illustrates both the perceived market potential and the execution challenges; the project was announced with an investment of about EUR 8 million [6] but the project was never realized. This situation creates both a capability gap for professional users and a missed economic opportunity in terms of domestic spending, tourism capture, and technology development. A large-scale recirculating vertical wind tunnel could address these shortcomings if it can be shown to be technically and financially feasible under local conditions.



Fig. 2. Freelo project proposed design [6]

The development of such infrastructure is capital intensive however and is highly sensitive to utilization rates, energy costs, and location decisions. Vertical wind tunnels require multi-megawatt drive systems, large building volumes, and specialized civil and MEP (Mechanical, Electrical, and Plumbing engineering), which together generate high up-front investment and long-term operational commitments.[2,7,8] In parallel, demand for tunnel time is fragmented across multiple segments-leisure customers, sport skydivers, corporate groups, and military users-with different willingness to pay, seasonality patterns, and booking behaviors.[1-3] In emerging markets like Romania, where historical data on indoor skydiving are limited, conventional rule-of-thumb approaches to feasibility assessment are insufficient. A structured techno-economic and locational analysis is needed to quantify market potential, to define realistic operating scenarios, and to identify the conditions under which such a project can be developed sustainably.

This study addresses that need by evaluating the opportunity to develop a large-scale indoor vertical wind tunnel in Romania, with a focus on serving both civilian and military users. First, the potential demand is assessed by segment, combining national demographic and income indicators with benchmarks from established tunnel markets and scenario-based assumptions on adoption rates.[2-5] Secondly, a comparative location analysis is conducted across major Romanian urban centers, considering population and tourism density, energy and land availability, proximity to military units, and regulatory or incentive frameworks. Third, a detailed techno-economic model of

the proposed facility is built, including capital expenditures, operating costs, pricing strategies, and cash-flow projections under base-case and sensitivity scenarios, drawing on international cost and performance benchmarks for the proposed tunnels. [2,7,8]

Beyond quantifying feasibility, the study aims to clarify the strategic positioning of a Romanian vertical wind tunnel within the wider Eastern European context. Technical design choices (e.g., tunnel size, configuration, energy-efficiency measures) and business model options (e.g., civilian retail vs. contracted military training blocks, regional team camps) are examined in terms of their influence on both risk and return.[1,2,7-10] The results highlight key value drivers—particularly utilization and electricity prices, and outline the conditions under which Romania could host a competitive regional hub for vertical freefall training and indoor skydiving.

2. Methodology

The study follows a techno-economic methodology, designed to evaluate feasibility and potential of a project based mainly on technical factors, and economic factors. Firstly, different types of indoor wind tunnels were analyzed based off already existing, active wind tunnels. Data was broken down into type of tunnel, chamber diameter, max air speed, power consumption, typical capex costs, and typical build times. The ratio of approximate capital expenditure (CAPEX) cost to chamber diameter, max air speed, and power was then done to compare the existing options.

Secondly, a further analysis of CAPEX was estimated including other costs other than just the tunnel. Wind-tunnel equipment, building and civil works, electrical and HVAC systems, fit-out and ancillary systems, engineering and project management, and contingency were all considered. Benchmark data for recirculating tunnels indicate that most projects in this size range require total investments of roughly EUR 6-10 million, depending on specification and local construction costs. [2,7] Operating expenditure (OPEX) was estimated, and structured into energy, staffing, maintenance, rent or land cost, insurance, marketing, and general administration. The model projects a 10-year profit and loss (P&L), cash flow, and key financial indicators (NPV, IRR, payback) under base-case, conservative, and optimistic utilization scenarios. Sensitivity analyses were then run on the most uncertain and impactful variables—primarily utilization, average price per minute, electricity tariffs, and CAPEX variance—to assess robustness, using industrial electricity prices around EUR 0.14/kWh as representative for Romanian medium non-household consumers.[11] Finally, qualitative risk identification and mitigation strategies were integrated with the quantitative results. This included analysis of demand risk (under-utilization), energy price volatility, construction and schedule risk, financing and interest rate risk, regulatory and community-acceptance risk (noise, traffic), and operational risk (safety incidents, equipment downtime).[1,2,7-10,11] Mitigation concepts such as early memorandum-of-understanding (MoU) blocks with military and corporate clients, energy-efficient tunnel design, phased investment options, and conservative leverage assumptions were considered in interpreting the model outputs and deriving location-specific recommendations.

3. Analysis of existing tunnel types

The design of vertical wind tunnels for skydiving is driven primarily by requirements on flow uniformity, turbulence intensity, acoustic emissions, and operating cost. Existing facilities can be broadly categorized along three axes: openair shown in Figure 3 versus closed recirculating flow tunnels as shown in Figure 1, portable versus fixed installations, and small versus large test-section diameter. Each configuration imposes constraints on achievable flow quality and on the economic feasibility of intensive training or competitive use.



Fig. 3. Example of open-air wind tunnel [12]

3.1 Open-air versus closed-circuit vertical wind tunnels

Open-air (open-jet, non-recirculating) wind tunnels accelerate ambient air through a contraction and eject the jet to the surroundings after the test section. This configuration is structurally simpler and generally involves lower initial capital cost, as it avoids complex flow-conditioning loops. However, for skydiving applications, open-air tunnels exhibit several limitations. The jet is directly influenced by ambient conditions, leading to variations in density, temperature, and crossflow, which in turn affect air speed stability and perceived flight quality. Energy efficiency is also significantly lower, because the full volumetric flow must be continuously accelerated from rest. Closed-circuit recirculating tunnels route the flow through a return loop that may include turning vanes, diffusers, and heat exchangers. In vertical tunnels for skydiving, this configuration enables stringent control of airspeed and temperature, as the working fluid is reused and conditioned continuously. Recirculating designs achieve higher energy efficiency for a given free-stream velocity, particularly at the high volumetric flow rates required for human flight. The enclosed flow path also reduces external noise emissions and permits installation in urban environments. The main disadvantages are higher construction cost, increased structural complexity, and the need for precise aerodynamic design of corners and diffusers to minimize secondary flows and turbulence.

3.2 Portable versus fixed installations

Portable wind tunnels are realized as modular or containerized systems, using open-jet or partially ducted configurations. Their primary advantage is rapid deployment for temporary events, demonstrations, or short-term training programs. Structural elements, fan assemblies, and support systems are designed for transportability, which constrains achievable test-section diameter, maximum air speed, and overall stiffness. As a result, portable tunnels usually provide shorter flight columns, higher turbulence levels, and reduced throughput of flyers compared with permanent facilities. Fixed (non-portable) installations are integrated into purpose-built buildings or large industrial halls. These tunnels can employ full recirculating layouts with substantial flow-conditioning sections, vibration isolation, and large-diameter test sections. Fixed facilities allow optimization of structural dynamics, acoustic treatment, and safety systems, and can support continuous, high-volume operation. The trade-off is the requirement for significant capital investment, building permits, and constraints related to site selection and long-term occupancy.

3.3 Large-scale (4.3–5.2 m) recirculating vertical wind tunnels

Large-scale recirculating vertical wind tunnels with test-section diameters in the range of approximately 4.3–5.2 m represent the upper tier of current skydiving infrastructure. At these diameters, the flow can accommodate multiple flyers simultaneously, realistic skydiving

configurations, and advanced coaching scenarios while maintaining adequate wall clearance and safety margins. However, the cost of these facilities is considerable. A comparison between already existing facilities is illustrated in Figure 4.

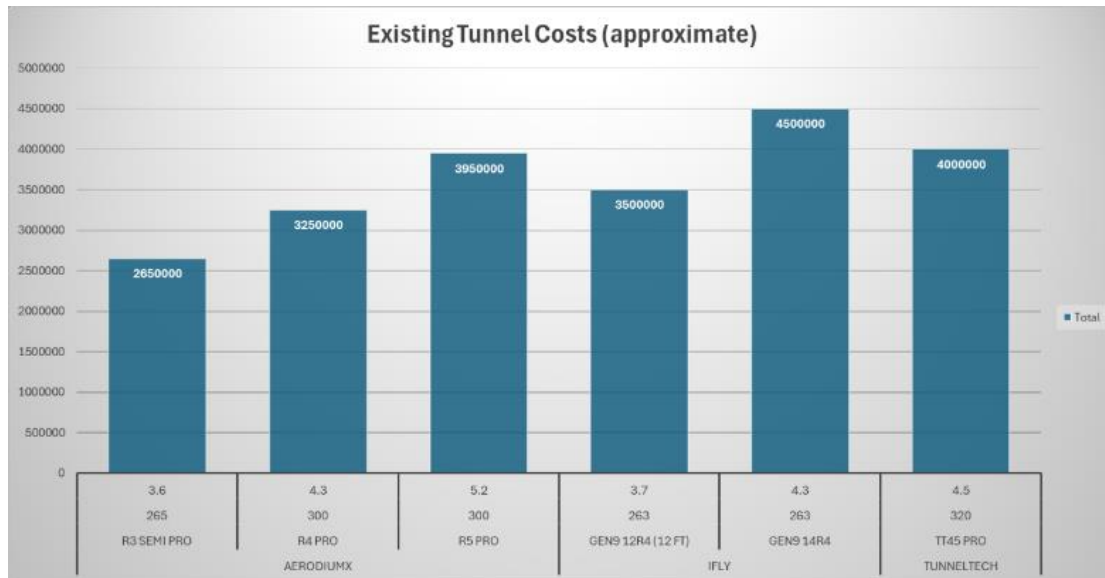


Fig. 4. Cost comparison between different existing manufacturers[4,12-14]

Nevertheless, for this study the choice of tunnel to be studied economically will be that will have a diameter of 5.2m, similar to the R5 Pro tunnel from AERODIUMX [12] shown in Figure 4 above.

4. Techno-Economic Evaluation and Sensitivity Analysis

The tunnel chosen for the Romanian market is therefore a 5.2m wind tunnel with a maximum air speed of around 300 km/h. This configuration offers highest amount of flexibility and allows for both general commercial uses, professional and possibly military training. This configuration is consistent with existing training-grade tunnels providing airspeed control from roughly 180 km/h for first-time flyers up to nearly 300 km/h for advanced maneuvers.[8] The CAPEX estimate, based on already existing data, is on the order of EUR 8-10 million, with EUR 9.5 million adopted in the base-case model.[2,6,7] Approximately EUR 4 million is allocated to tunnel equipment (fans, motors, VFDs, airflow ducts, flight chamber, control systems), about EUR 2.0 million to building and civil works (foundation, structure, cladding, interior fit-out), around EUR 0.8 million to electrical and HVAC systems (high-voltage connection, transformers, ventilation, cooling), roughly EUR 0.7 million to soft costs (design, engineering, project management, permitting), and about EUR 1.0 million to contingency to cover price volatility and scope changes.[2,7] These figures lie within the EUR 6-10 million range reported for most recirculating “PRO” tunnel projects.[2,7]

Operating expenditure is dominated by energy and staffing. Under realistic operating profiles (not full power continuously), annual energy costs are estimated in the EUR 150,000-200,000 range. This is consistent with an average effective power draw of several hundred kilowatts over the day, combined with Romanian industrial electricity tariffs around EUR 0.14/kWh and allowing for demand charges and ancillary fees.[8,11] Staffing a 7-day-per-week operation with instructors, front-office, technical, and management personnel requires roughly 15-20 full-time equivalents, corresponding to approximately EUR 200,000-250,000 per year in payroll. Additional OPEX items include maintenance and consumables (~EUR 50,000/year), rent or property tax (for owned land and building), insurance (~EUR 30,000/year), and marketing and administrative overheads (~EUR 50,000/year). In aggregate, steady-state annual OPEX for the base-case utilization is of the order of EUR 0.5-0.7 million, in line with cost structures reported for comparable facilities. [2,3,7,8]

On the revenue side, the estimated revenue per flight minute in the fifth year, including the time taken in between sessions, is around EUR 9.5. This calculation considered a mix of packages including basic 2 session packages, packages with 4 sessions, and “pro” packages with 10 sessions included as shown in Figure 5 below.

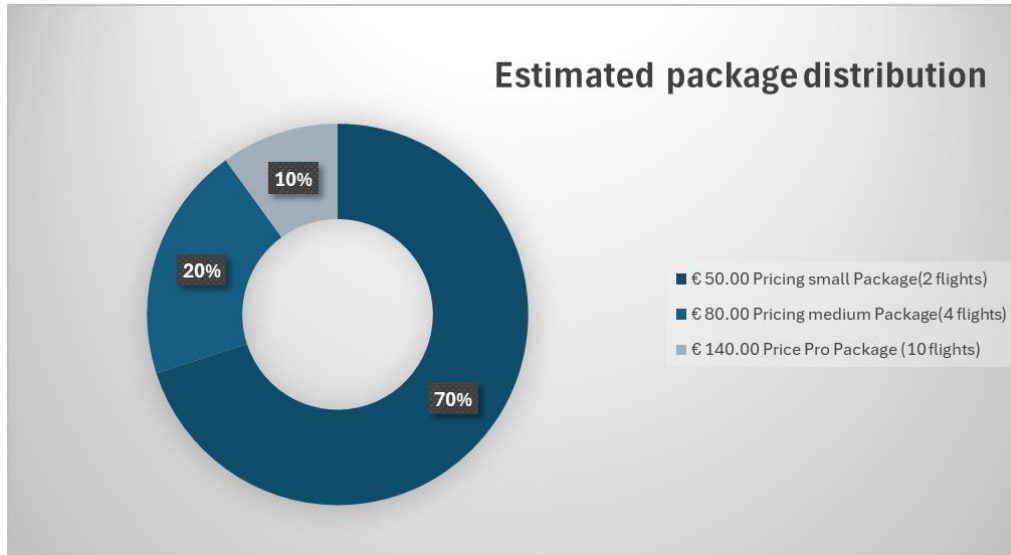


Fig. 5. Package pricing and distribution

This is just below international pricing, where first-time packages in Europe and North America typically range from about USD 60-100 (or EUR 50-90) for two to four minutes of flight, with substantially lower effective rates for bulk sport time.[3] Under the base-case utilization trajectory (ramping toward almost 100,000 sessions by year 5). This target ramp up is illustrated in figure 6 b.

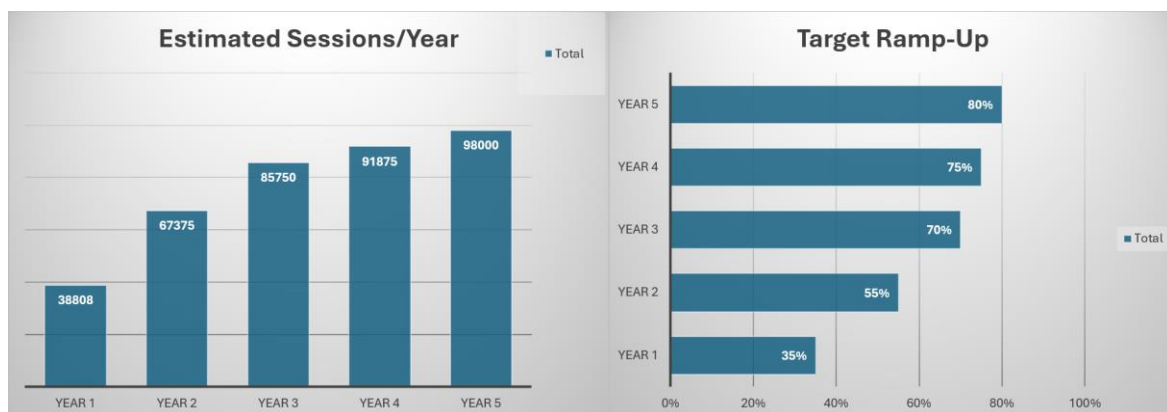


Fig. 6.a. Estimated sessions per year, Fig. 6.b. Target Ramp-up capacity

annual revenues at maturity are projected to be just over EUR 2 million euros per year. The calculation of revenue took into consideration estimated work hours of 14 hours per day, 330 days per year, average wind tunnel time of 1.5 minutes, time between sessions of 1 minute in the first year, dropping to 0.9 min after the first year and the Capacity utilization (rate) which is shown in Figure 4 b. The theoretical maximum revenue was also calculated considering the same data with 100% utilization. The projected revenue is compared to the theoretical maximum revenue and is shown below in Figure 5 below.

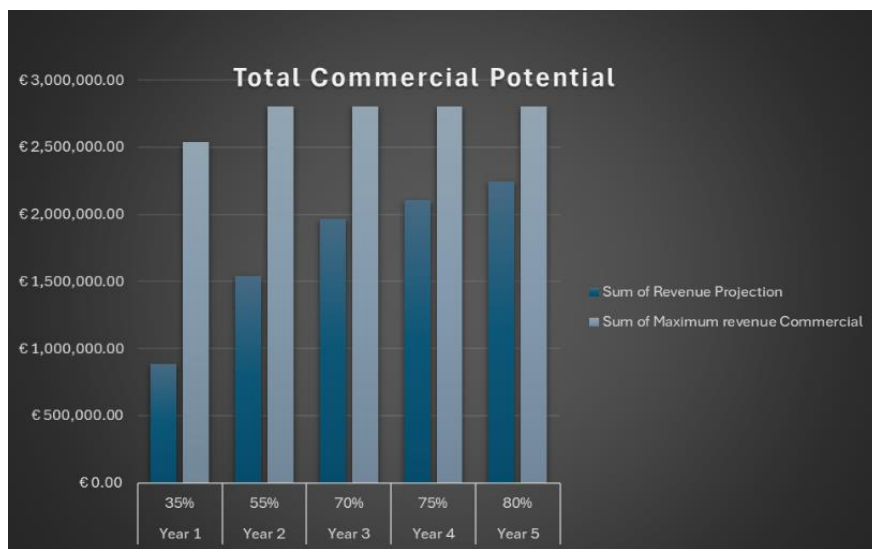


Fig. 7. Revenue projected compared against theoretical maximum revenue

combined with the OPEX structure described above, yields positive EBITDA margins and supports coverage of financing costs and depreciation.

Financial results indicate that the project can achieve an internal rate of return (IRR) on equity in the approximate range of 15-18% and a payback period of 5-6 years after opening, assuming a 10-year analysis horizon plus terminal value and a moderate leverage structure. Sensitivity analyses show that utilization and electricity prices are the dominant value drivers. A sustained shortfall in demand (e.g., 20-30% below base-case) materially reduces IRR and lengthens payback, while favorable utilization—supported by strong marketing and institutional contracts—can push IRR above 20%. Similarly, significant increases in electricity tariffs compress margins unless partially offset by dynamic power management, energy-efficient design measures, or long-term fixed-price supply contracts. [7,8,11] CAPEX overruns are also impactful but can be mitigated through staged contracting, robust contingencies, and potential access to local or EU development incentives.

Overall, the techno-economic evaluation confirms that a well-executed large-scale tunnel in Bucharest is financially viable under realistic assumptions but also exposes the project's dependence on high operational reliability, strong sales and partnership capability, and proactive management of energy and financing risks. These findings inform both the recommended configuration and the strategic risk-mitigation measures discussed with potential investors and stakeholders.

5. Conclusions

This research assessed the feasibility of developing a large-scale recirculating vertical wind tunnel in Romania by integrating multi-segment demand analysis with a detailed techno-economic model. The results indicate that Romania's combined civilian, tourism, and military markets can sustain a high-performance tunnel, provided the facility is developed in a major metropolitan area with strong transport connectivity and supported by professional marketing and institutional partnerships. From a financial perspective, a reference facility with approximately 2 MW installed power, a 4.2–5.2 m flight chamber, and CAPEX of about EUR 9 million can achieve revenues of EUR 2–3 million per year at maturity and generate mid-teens IRR with a 5–6-year payback period, assuming base-case utilization and current cost structures. However, the project's attractiveness is sensitive to utilization levels and electricity tariffs, underscoring the need for conservative planning, robust pre-sales (including military and corporate block bookings), and energy-efficient technical design. Beyond the narrow financial metrics, a Romanian vertical wind tunnel could deliver broader strategic benefits: retention of training expenditure currently spent abroad, development of a domestic indoor skydiving ecosystem, enhancement of military training capabilities, and creation of

a flagship leisure and tourism asset with regional reach in Eastern Europe. To realize this potential, early stakeholder engagement, careful integration into the surrounding urban and regulatory environment, and disciplined project execution will be critical. Future work may extend this analysis by incorporating more granular behavioral data for Romanian consumers, exploring alternative financing and ownership structures, and evaluating the role of public-private partnerships or EU-level funding in de-risking such high-impact recreational and training infrastructure.

Acknowledgments

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