

FROM ICING TO HELIPADS: CFD-BASED SOLUTIONS TO CONTEMPORARY ROTORCRAFT CHALLENGES

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ABSTRACT

This paper presents an overview of how computational fluid dynamics (CFD) has been used to address a range of engineering and operational challenges in rotorcraft development. Drawing on the author's two decades of experience at the Łukasiewicz – Institute of Aviation in Warsaw, Poland, it highlights real-world applications of CFD in rotorcraft-related design and engineering. The case studies discussed include tail rotor icing in an unmanned helicopter, directional instability in a gyroplane, engine nacelle cooling in a modern helicopter, and airflow hazards near rooftop helipads in dense urban settings. Using multiphysics simulations, CFD helps reduce reliance on costly experiments, supports flight safety improvements, and informs regulatory decisions. The paper demonstrates the practical value of CFD as a tool in rotorcraft engineering and planning for urban air operations.

Keywords

computational fluid dynamics, rotorcraft, icing, heat transfer, flight stability, urban mobility.

1. INTRODUCTION

The Łukasiewicz – Institute of Aviation has been engaged in rotorcraft development almost since its inception in 1934, beginning with tests of the Cierva C.30 autogyro [1]. Selected rotorcraft prototypes designed at the Institute are shown in Fig. 1. Among these are Poland's first helicopters: the JK-1 "Trzmiel" (the "Bumblebee"), the BŻ-4 "Żuk" (the "Beetle") and the BŻ-1 "Gil" (the "Bullfinch"), all of them built and flight tested at the Institute's facilities [2, 3, 4].

Responding to evolving design trends, the Institute also developed new prototypes, including the light two-seat helicopter IS-2, the unmanned helicopter ILX-27 which inherited many design elements from the previous IS-2, and the I-28, an innovative, fast autogyro with a tractor configuration. Sadly, this marked a shift away from the tradition of assigning more romantic nicknames inspired by birds or insects, toward a more utilitarian system of alphanumeric designations.

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The IS-2 helicopter was the subject of the first computational fluid dynamics (CFD) analyses conducted at the institute [5]. Key components such as the rotor head and blades were inherited by its descendant, the ILX-27 unmanned vehicle. The I-28 gyrocopter served as a pioneering design for many ultralight technologies applicable to unpowered rotorcraft [6]. Its development revived interest in this type of rotorcraft within industrial practice, contributing to the formulation of certification regulations by the Polish aviation authorities.

Over the past two decades, the present author had the great privilege of participating in quite a number of these projects and, considering the limited availability of detailed information on them, wishes to share the knowledge and insights so gained in this article.



Fig. 1. Selected rotorcraft examples designed at the Institute of Aviation [7]:
a) the JK-1 Trzmiel (1957)[2], b) the BŻ-4 Żuk (1959), c) the BŻ-1 Gil (1960),
d) the IS-2 (1990), e) the ILX-27 (2012), f) the I-28 (2012).

Currently, work is underway on a multicopter transport vehicle project utilizing a hybrid motor, demonstrating that despite the continuously evolving conditions,

the Institute remains committed to advancing rotorcraft technologies. These technologies offer unique capabilities compared to other sources of lift.

The Łukasiewicz – Institute of Aviation maintains international collaborations with industry partners. Notably, the Institute has contributed to projects for the KOPTER company, including aerodynamic analyses of the SH-09 helicopter, evaluation of its performance across varying light conditions, and studies on cooling systems for the main rotor gearbox nacelle and engine oil cooler, which will be detailed below.

Much of the Institute's work extends beyond the rotorcraft itself to focus on its interaction with surrounding environments and other aircraft. To conclude, this paper presents a brief overview of elevated heliport operational safety – a growing concern at hospitals located in densely populated urban areas in Poland.

The use of computational techniques such as computational fluid dynamics (CFD) for analyzing rotorcraft aerodynamics is increasingly becoming the preferred approach. CFD enables more accurate initial design assumptions and facilitates the investigation of operational challenges like icing and aerodynamic interactions in urban environments – problems that traditionally require costly experiments or flight tests. Given the complex nature of these phenomena, which span multiple scientific disciplines, a “multiphysics” approach is often employed. This involves integrating various simulation models, including fluid flow, flight mechanics, heat transfer, and multiphase flow modeling (e.g., ice accretion or crop dusting). Consequently, engineers specializing in aerodynamics have expanded their expertise to encompass heat transfer, material properties, finite element method (FEM) analyses of stress, buckling, flutter, and more. Importantly, modern simulation software offers significantly more user-friendly modeling tools than before, enabling better initial design assumptions and thereby shortening the overall design process.

The most widespread form of CFD employs a Reynolds-Averaged Navier-Stokes (RANS) approach to solve fluid flow using the finite volume method. In this technique, the fluid domain – and also solids when necessary – is divided up into small discrete elements called *cells*, collectively forming a *mesh*. The software iteratively calculates the amount of fluid entering and exiting each cell through its faces, based on boundary conditions applied at the edges of the computational domain. The mesh density, defined by the size and number of cells, determines the smallest flow structures that can be resolved. Typically, the finest mesh is concentrated around surfaces, sharp edges such as the leading and trailing edges of blades, and regions prone to flow instabilities where vortex shedding occurs. These vortices are treated as dynamic flow features rather than mere increases in turbulence.

Flow modeling also involves task-specific approaches to turbulence modeling, boundary layer representation, and separation prediction. These aspects are critical for ensuring flight safety, predicting aerodynamic noise, and estimating parasitic drag. Several turbulence models are commonly used: the Spalart-Allmaras model [8], a robust one-equation model; the $k-\omega$ SST model [9], which employs different

equations to capture turbulence dissipation depending on proximity to surfaces; and the more advanced four-equation γ - Re_θ (gamma-Re-theta) model [10], which additionally accounts for the boundary layer's history and transition to turbulence along wetted contours through an intermittency factor. Earlier studies predominantly used the Spalart-Allmaras model; however, with the availability of the k - ω SST and γ - Re_θ models, these have been preferred for improved separation prediction, as applied in the IL-28 autogyro analyses presented below.

In addition to the integral form of the Navier-Stokes equations, which govern the conservation of mass and momentum by accounting for fluid flow in and out of each mesh cell, other equations are simultaneously solved during the simulation. Heat transfer is modeled through the energy equation and turbulence equations, which describe heat dissipation and the conversion of kinetic energy from vortices into thermal energy as these vortices break down into smaller scales and eventually dissipate. For slower flows or highly complex turbulent flow separations, Large Eddy Simulations (LES) are employed. However, LES requires extremely fine mesh resolution and significant computational resources, due to the large scale difference between the helicopter and the smallest turbulent structures being resolved.

Given that helicopter flows are generally turbulent – primarily due to the main rotor's influence – assuming fully turbulent flow is a conservative and practical approach. Under such conditions, even a relatively simple turbulence model like Spalart-Allmaras can provide valuable and sufficiently accurate information for many cases.

Depending on the available data and the problem at hand, various techniques are employed to model rotor aerodynamics. When only basic information such as rotor size and thrust is known, a pressure jump surface – commonly referred to as an *actuator disk* – with a constant pressure jump is used. If detailed information is available, including the airfoil shape, chord length, and blade pitch distribution, the pressure distribution can be derived from two-dimensional airfoil characteristics. To account for rotor-induced swirl in the downstream flow, the Virtual Blade Model is applied; this method, combined with 2D airfoil data, represents the rotor as a disc composed of fluid cells where aerodynamic forces are distributed across each fluid element rather than only at the cell boundaries. This approach enables the modeling of aerodynamic drag acting on the fluid, allowing the wake to develop swirling vortices. A third, most detailed method involves direct simulation of the blade geometry in motion; this method is utilized in the icing simulations described later in this paper.

In short, this paper presents selected examples drawn from over two decades of rotorcraft-related CFD work carried out by the author at the Łukasiewicz – Institute of Aviation. The goal is to highlight how simulation-based analysis has supported the design, testing, and operational safety of various rotorcraft platforms. The following sections examine four representative cases, each illustrating a distinct type of engineering challenge addressed using CFD methods.

2. THE ILX-27 UNMANNED HELICOPTER

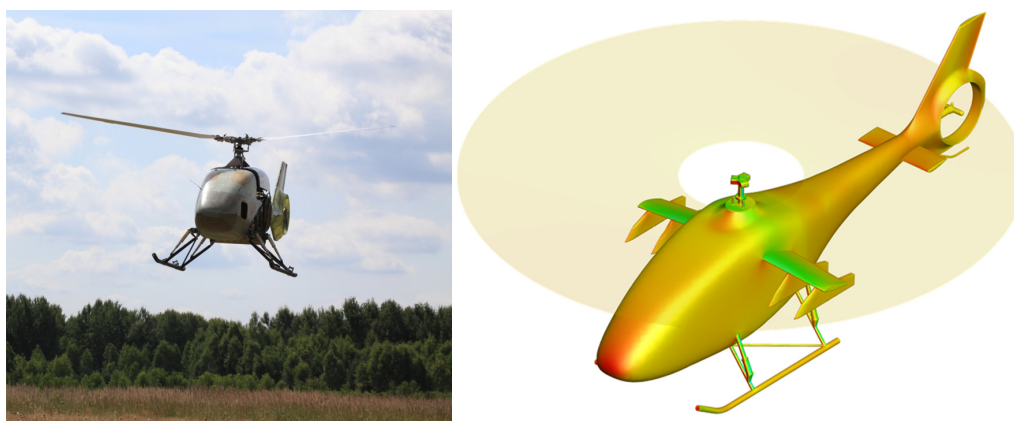


Fig. 2. Prototype of the ILX-27 unmanned helicopter in flight [7] and its computational model showing a pressure distribution map.

The ILX-27 unmanned vehicle (Fig. 2) is a light helicopter with a maximum take-off weight of 1100 kg and a payload capacity of 300 kg. It is powered by a 260-hp Lycoming O-540-F1B5 engine, capable of reaching a service ceiling of 4 km, a maximum speed of approximately 120 km/h, and a range of 440 km. Its primary advantage lies in its unmanned operation: the vehicle can safely access locations deemed too hazardous for piloted flight while transporting payloads up to 300 kg, equivalent to four wounded individuals [11].

One major limitation for manned helicopters is adverse weather conditions, with icing posing a significant threat in Poland's climate. While extensive research exists on main rotor icing, comparatively little is known about icing effects on ducted rotors. Notably, ice accumulation on ducted rotors can form large structures before centrifugal forces are sufficient to fragment and dislodge them.

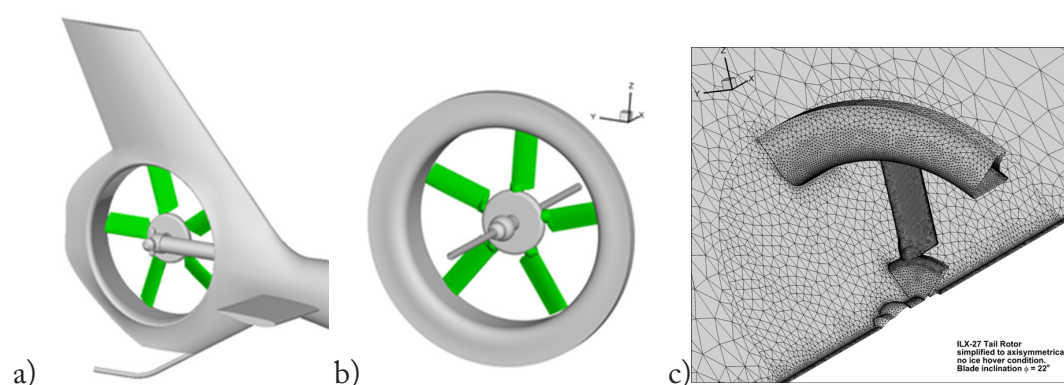


Fig. 3. a,b) Simplified representation of the duct, c) computational model showing the finite volume mesh of the periodic cutout of one blade, along with corresponding part of the simplified duct [12].

During computational research, a simulation of ice accretion on the tail rotor blades was conducted. Due to the complex geometry of the ice formation, only one blade was modeled along with the corresponding cutout section of the duct. The original duct geometry was significantly simplified, as illustrated in Fig. 3. Using this model – initially without icing – the study focused on determining the blade angle that, together with the duct, produces net thrust sufficient to counterbalance the main rotor torque during cruise conditions. An interesting finding appeared at zero-thrust conditions (blade inclination angle $\varphi = -3^\circ$, due to the asymmetric airfoil used): the blade functions as a centrifugal compressor, with its effect unhindered by the duct (Fig. 4).

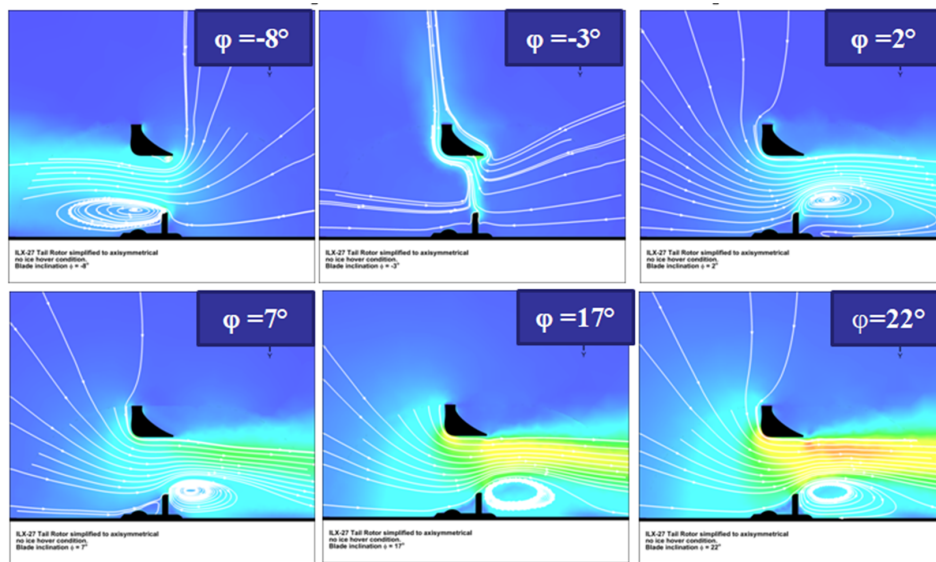


Fig. 4. Flowfield variation with the blade pitch angle, visualized by velocity magnitude color map and pathlines.

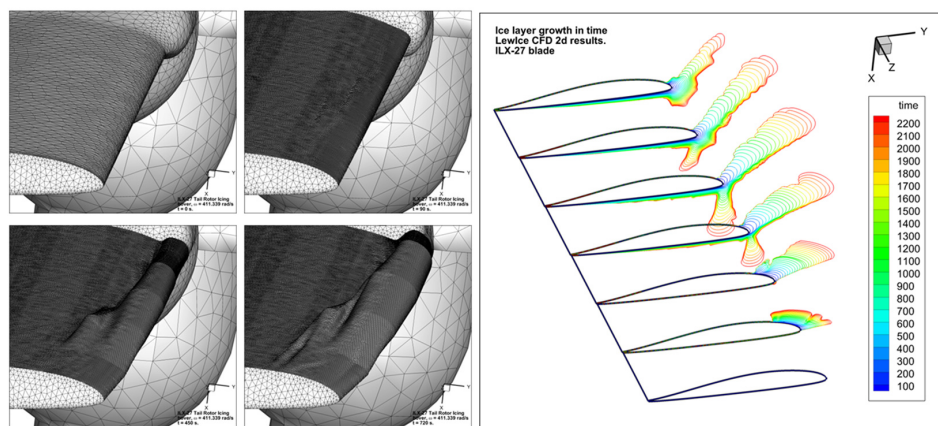


Fig. 5. Mesh changes and ice layer growth on a predefined blade cross-section, viewed along the radius (with blade tip at the bottom) [12].

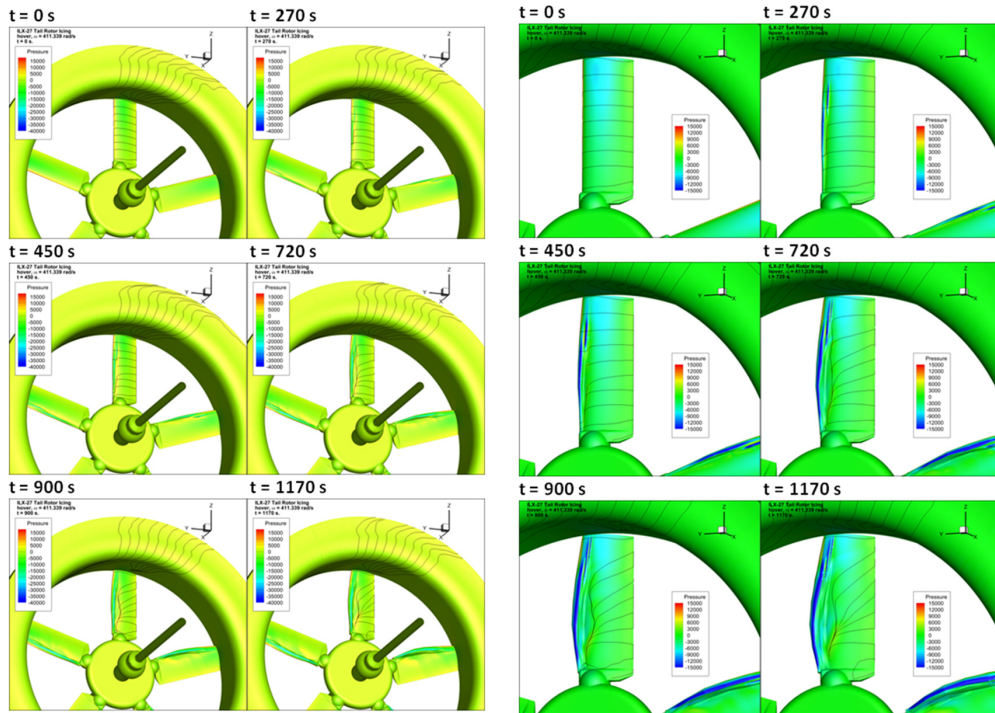


Fig. 6. The pressure distribution and pathlines on the blade and the duct surfaces during ice accretion [12].

To simulate ice layer growth on the blade over time, the widely recognized LEWICE software was employed. This code analyzes the flow along a 2D airfoil geometry and generates progressive shape changes as the ice layer grows under natural icing conditions (Fig. 5). LEWICE is one of the few codes validated with sufficient accuracy that its results are accepted by aviation authorities under Part 25 Appendix C (atmospheric icing conditions) regulations. The simulation utilized a specific set of conditions assuming maximum ice growth rate with corresponding liquid water content (LWC), median volume diameter of the droplet (MVD), and temperature.

The flow simulation was performed using ANSYS Fluent, an industry-standard software that solves flow problems using the finite volume method. This method enables reconstruction of the flow field through iterative solution of equations describing fluid motion dynamics. Three-dimensional models of the blades were created for several selected phases of ice accretion, and flow through the ducted fan was reconstructed for each phase (Fig. 6).

The simulation results showed that the total thrust of the ducted fan with a growing ice layer does not change significantly when rotational velocity remains constant. Figure 7 shows the distribution of axial aerodynamic force component (thrust) across the designated zones: duct, blade, and hub of the rotor. Notably, the thrust generated by the duct alone accounts for approximately 40% (!) of the total thrust.

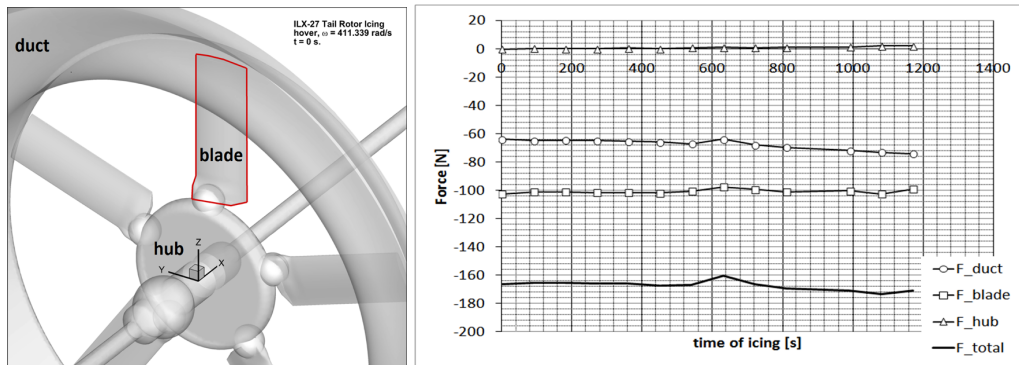


Fig. 7. Division of the model into named zones, the axial component of the aerodynamic force for the individual zones, and a total summary component [12].

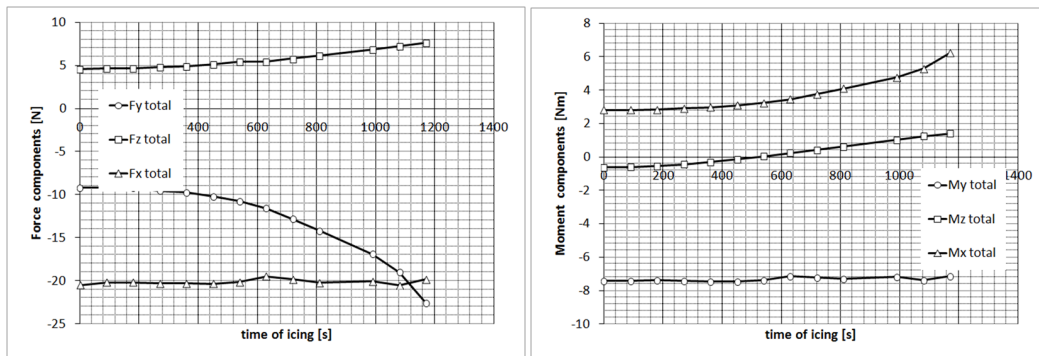


Fig. 8. The aerodynamic force and moment components calculated at the center of the hub for one blade of the tail rotor [12].

However, maintaining constant rotational velocity presents a significant challenge. Blade drag increases dramatically with ice layer growth, requiring more energy to be directed to the tail rotor instead of propelling the main rotor (Fig. 8). Within just 20 minutes of flight in icing conditions, the tail rotor torque doubles, following a non-linear progression. During the analyzed time period, the drag increase accelerated toward the end compared to the initial phase. Consequently, the available time to escape icing conditions is limited by the excess power available from the helicopter engine under these conditions.

Of course, the results presented above represent a fraction of the extensive calculations and analyses conducted within the ILX-27 project. However, they effectively demonstrate the level of detail required when analyzing complex problems related to rotorcraft operations and flight safety, and aircraft safety in general. These investigations can be carried out without endangering human life or health – except, we might say, that of the investigators themselves, given that the computational challenges are so considerable. Simulations involving moving computational mesh fragments and strongly non-streamlined geometries present non-trivial computational problems that require sophisticated modeling approaches.

3. THE I-28 AUTOGYRO

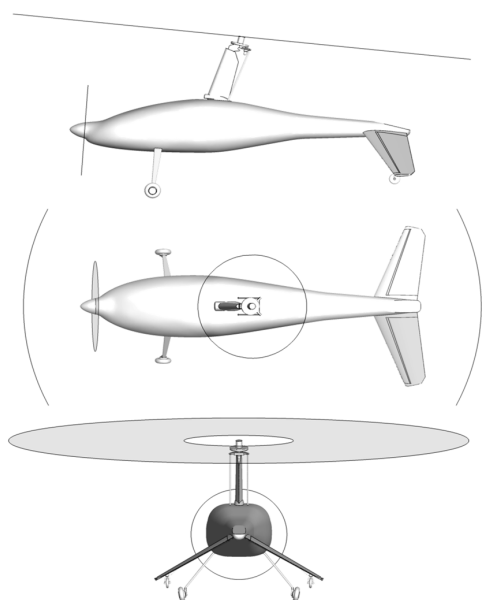


Fig. 9. The three views of the I-28 autogyro [13].

The I-28 autogyro (Fig. 9) was designed at the Institute of Aviation to become the first aircraft of its type in Poland to undergo supervised design and construction for official certification by aviation authorities. Although the autogyro concept is nearly 100 years old, it was not welcomed as personal transport in Poland for most of this period. Such rotorcraft could be easily designed and constructed in a garage, hence they could potentially allow individuals to escape beyond the “iron curtain” undetected. Moreover, these aircraft can fly below radar detection altitude and do not require large airports for landing operations. A similar concern – that anyone could build one – contributed to negative perceptions in Western countries, where autogyros

were often built cheaply with poor engineering understanding and questionable construction quality. However, this characterization should not be overstated. Despite having a simpler design than helicopters, autogyros are by no means simple to control. Particularly in harsh conditions, inexperienced pilots may excessively slow the main rotor, causing it to collide with the fuselage – a dangerous situation that is difficult to recover from.

Numerous fatal crashes of homebuilt gyroplanes have reinforced negative opinions about this entire family of “unpowered” rotorcraft. These factors contributed to the absence of established procedures for designing and certifying homebuilt gyroplanes in Poland until now. With the commercial success of locally produced “Xenon” autogyros, widespread interest in these vehicles has returned, leading many homebuilders to pursue such designs. The I-28 project paves the way for these builders.

The I-28 is a gyroplane in tractor configuration with a fuselage constructed primarily of composite materials, except for the central steel truss section housing the engine – similar to the Bell P-39 “Airacobra” fighter [14]. The tail empennage, designed in an inverted V-shape, functions solely as a rudder. This unique configuration necessitates a quadricycle landing gear arrangement with two main gear sets positioned forward (similar to a taildragger configuration) and two steerable landing gear sets at the tail tips. Tail gear shock absorption is provided by torsion

tubes within the fuselage, where the tail stabilizer functionally serves as a suspension arm for the wheel. The front gear employs a cantilever spring leaf design [15].

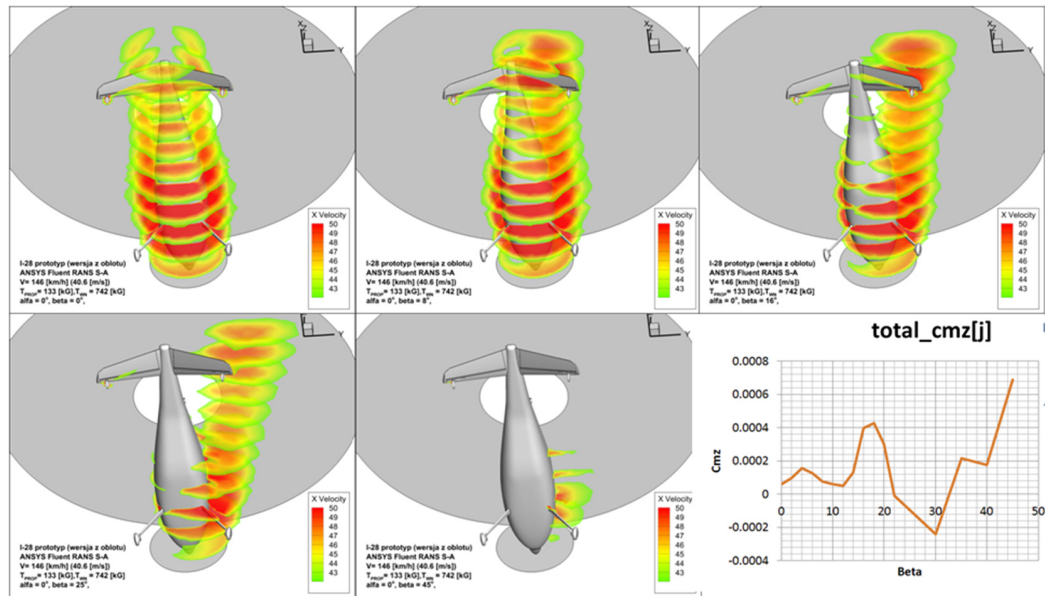


Fig. 10. Visualization of the rotor wake on a set of cross sections behind the propeller, and yawing moment coefficient as a function of sideslip angle [13]. The propeller wake at $\beta=25^\circ$ of sideslip angle (bottom right picture) is touching only the upper side of the left V-tail, causing negative stability.

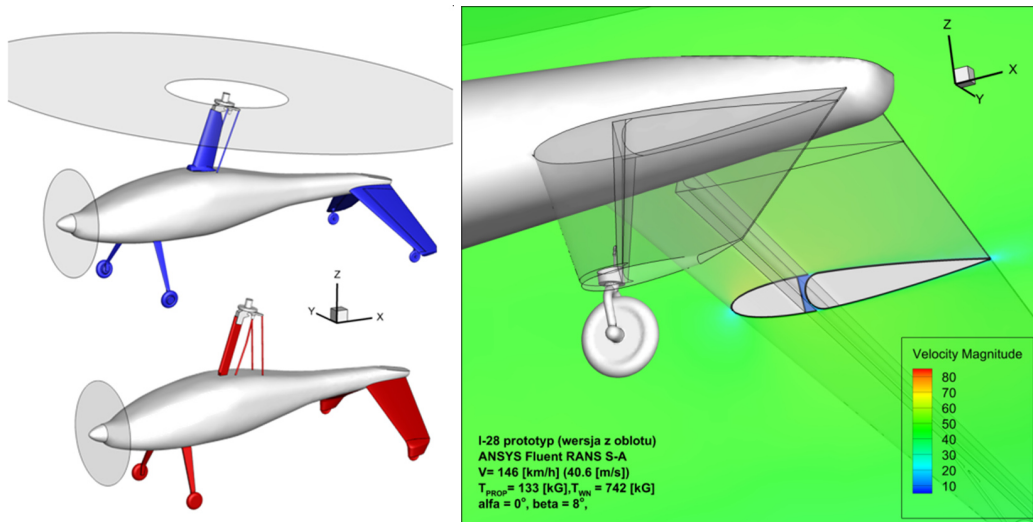


Fig. 11. The exact geometry of autogyro (above) compared to the one used for the preflight calculations (below), and a cross section through the tail surface including the gap geometry between the tail stabilizer and the rudder [13].

During the flight test it became apparent that this design does not have a sufficient directional stability. After turning into the wind, the autogyro would orient itself to fly sideways and enter an uncontrolled spin. Only the exceptional skills of the test pilot prevented the spin from becoming truly uncontrolled. Upon landing, it was discovered that only the propeller and main landing gear sustained damage.

The phenomenon underlying this event was that the tail surfaces were no longer positioned within the propeller wake, which in this case caused negative directional stability of the rotorcraft (Fig. 10). The moment coefficient derivative $\delta C_{mz}/\delta\beta$ is negative within the sideslip angle range of $\beta = \langle 18^\circ, 30^\circ \rangle$, and above $\beta = 22^\circ$ even the moment coefficient itself becomes negative.

Since the actual cause of this autogyro behavior was initially unknown, an exact model of the aircraft's in-flight geometry was created (Fig. 11). This model incorporated the precise tail geometry including the gap between the moving control surface and stabilizer, actual tail and main gear configurations, and the geometry of the main rotor mast fairing including the air scoop. Without access to original drawings, the present author manually reconstructed the shape of the horn balance, the gap with sealing lips geometry, and the Bowden control lines for the tail landing gears by measuring the prototype aircraft with hand tools and paper templates.

Despite strong suspicions that these control lines were positioned unfavorably across the airflow where they would cause maximum disruption, simulation results proved this assumption incorrect (Fig. 12). The analysis revealed that the wire does not drastically alter flow separation patterns. Additionally, when the stabilizer surface area is extended, flow separation is delayed to higher sideslip angles. This finding provided the key insight for repairing the tail design.

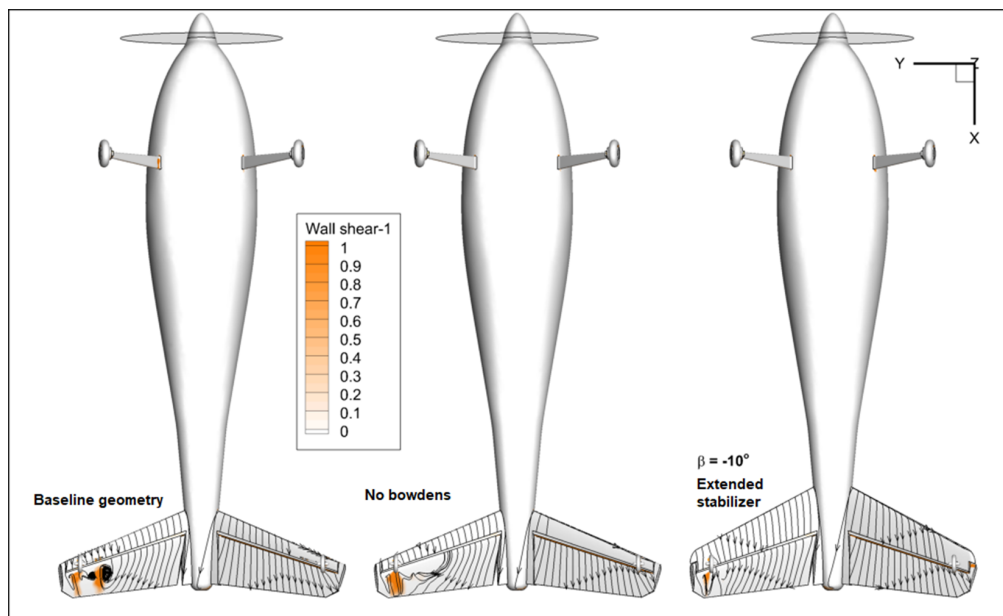


Fig. 12. Separation areas (reverse flows) appearing at the $\beta = -10^\circ$ sideslip angle.

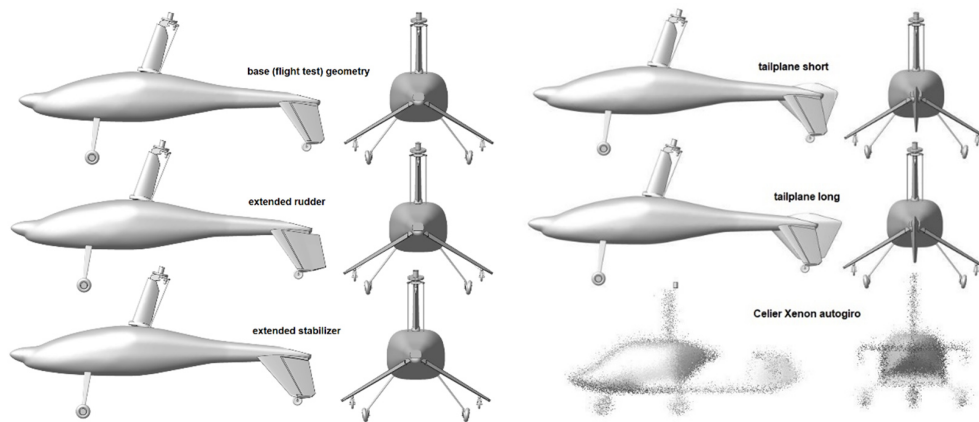


Fig 13. Analyzed modifications of the tail: upper left base geometry, extended rudder, and extended stabilizer (left), short and long tailplane and the Xenon autogyro in the same scale (right) [13].

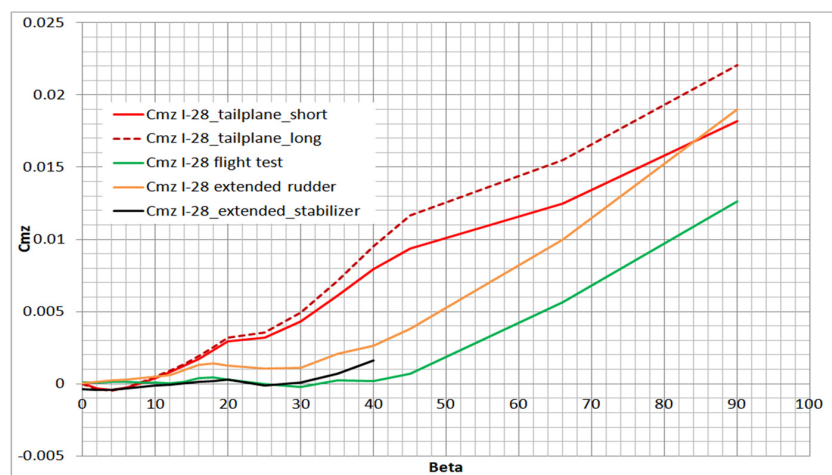


Fig 14. The yawing moment characteristics vs. sideslip angle of the tested configurations [13].

During the calculations, a set of tail modifications was investigated (Fig. 13). These results were also compared with the reconstructed geometry of the “Xenon” autogyro, obtained using scale modeling methods. The comparison demonstrated that even a simple rudder extension makes the yaw characteristics comparable to those of the “Xenon” (Fig. 14). The “Xenon” features a pusher configuration with the propeller positioned in front of the tail, continuously directing airflow onto its control surfaces. In contrast, the I-28 employs a tractor configuration and therefore requires greater inherent directional stability. Consequently, two versions of additional vertical tail surfaces (“tailplane short” and “tailplane long” in the legend) were tested. This surface incorporated a strake between the tail and main rotor, designed to generate a stabilizing vortex at high sideslip angles.

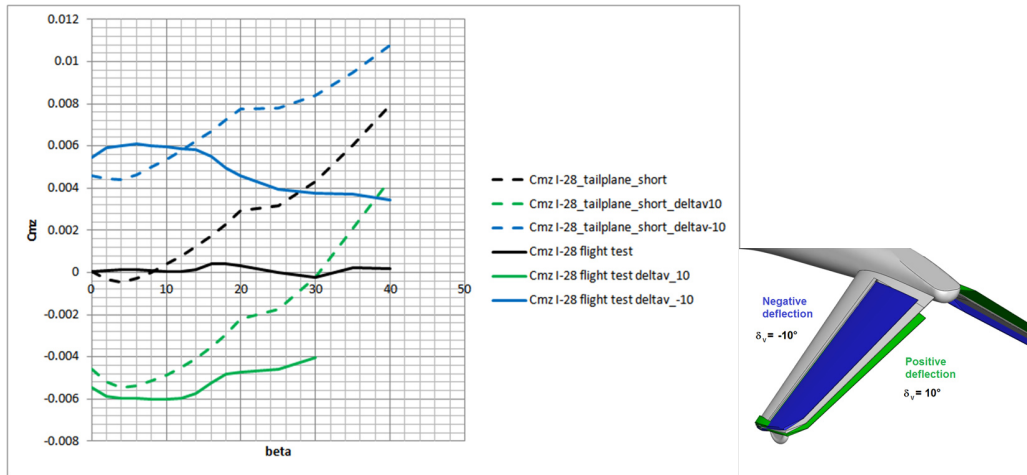


Fig. 15. Influence of ruder deflection on the yawing moment of the I-28 autogyro [13]. The dotted lines show the influence of the short tailplane on the deflected rudder, compared to flight test cases shown with continuous lines.

Next, the influence of the short tailplane (selected as the most promising option) on airflow after rudder deflection was tested (Fig. 15), with no negative impact on control effectiveness observed. Above 30° of sideslip, the gyrocopter will turn into the wind regardless of control input. The negative stability region has been eliminated since the tailplane generates a yawing moment that, at the corresponding sideslip angle, equals that produced by full $\delta_v = 10^\circ$ rudder deflection at zero sideslip angle. The autogyro should exhibit a “nose into wind” tendency beginning at sideslip angles above $\beta = 8^\circ$.

As in the previous section, only a fraction of the analyses conducted for this design have been presented here. However, these results again effectively illustrate how CFD methods can be valuable at every stage of design, including during the testing and operational phases of a rotorcraft’s lifecycle.

4. ENGINE NACELLE COOLING FOR THE KOPTER SH-09 HELICOPTER

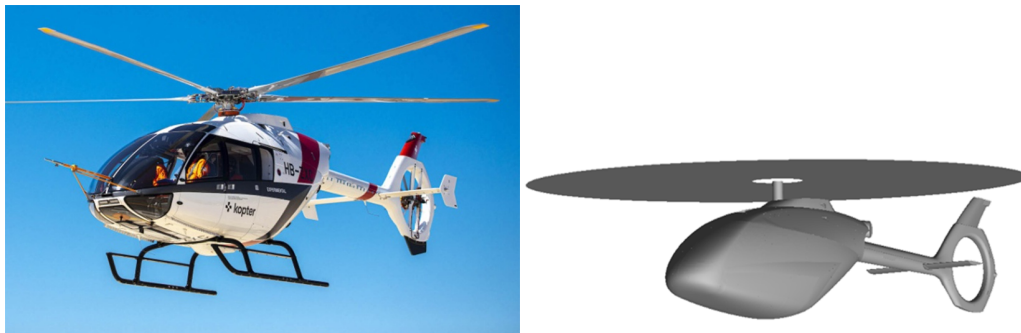


Fig. 16. The Kopter SH-09 helicopter in flight [16] and its simplified 3D model [17].

The Kopter SH-09 helicopter is a rotorcraft designed in the classic configuration with one main lifting rotor and one counter-torque tail rotor. The tail rotor is designed as a ducted fan. An interesting feature of this helicopter stemmed from a requirement to maintain a maximum available visibility from the cabin, resulting in an additional window on the floor between the pilots, where the radio – thrust control panel is usually placed.

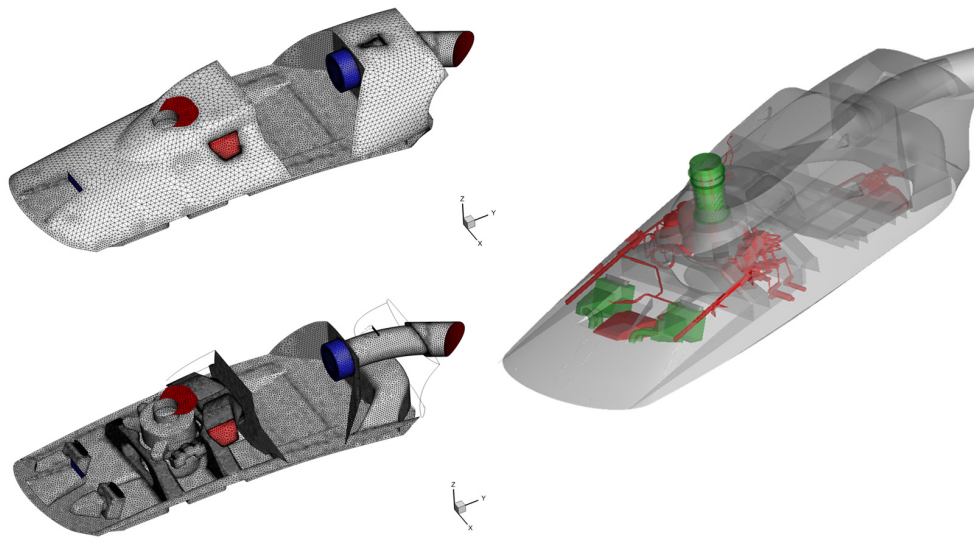


Fig. 17. Simplified version of the nacelle model compared to the complex one, including all the installations inside [17].

The nacelle cooling modeling was performed as follows: first, a simplified simulation was performed featuring only the interior portion of the nacelle (Fig. 17). This served to verify that all parameters were configured correctly. Subsequently, calculations were performed for the full, complex geometry including an external helicopter model equipped with additional, simplified rotor models. Forward, backward, and sideways flight cases were analyzed using this approach. Example flowfield results are shown in Fig. 18. Increased velocity was observed near the inlets, around the engine nozzle, and adjacent to the front and side walls of the nacelle. Higher velocities correspond to improved forced convection cooling of components.

Figure 19 displays the temperature field for standard flight conditions (0 m ASL, 15°C) and for elevated temperature conditions of 40°C during flight above 2000 m ASL. The significant change in temperature magnitude is readily apparent, though the distribution pattern remains similar.

Figure 20 presents the temperature field during forward, backward, and sideways flight configurations. The results clearly demonstrate that during forward flight, the tail compartment receives inadequate cooling. In backward flight, the temperature distribution is more uniform, while in sideways flight, the centrally positioned main gearbox becomes the hottest location.

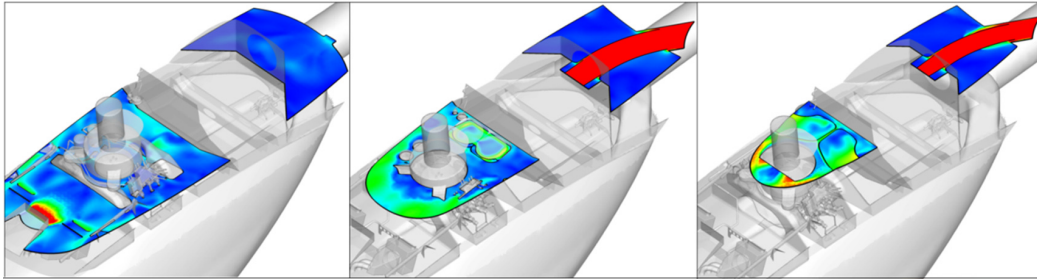


Fig. 18. The velocity magnitude visualization in a set of cross sections through the nacelle. Due to proprietary information constraints, only the colormap was shown in source [17] but the scale is identical in all cross sections..

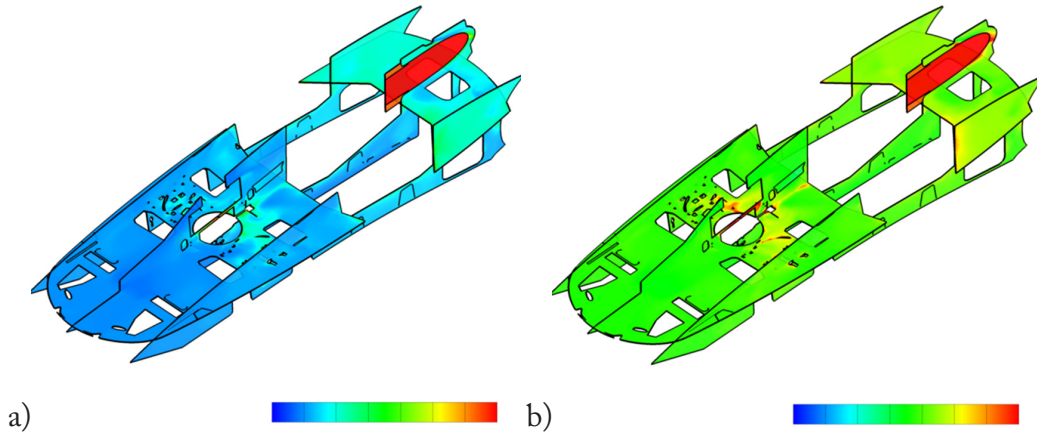


Fig. 19. The temperature field in hover for standard and “hot&high” conditions. Due to proprietary information constraints, only the colormap was shown in source [17] but the scale is identical in all cross sections.

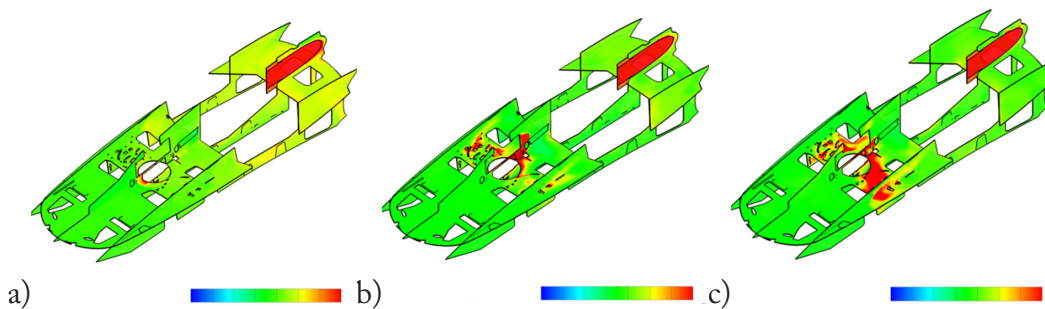


Fig. 20. The temperature field in “hot&high” conditions for forward (a), backward (b) and sideways flight (c) [17].

The results shown here represent only a partial contribution by the present author and constitute a small portion of the comprehensive analysis conducted for this helicopter. Nevertheless, they effectively demonstrate the versatility of computational fluid dynamics as a tool for analyzing multiphysics problems, extending beyond flow

separation to include heat transfer phenomena (convection and radiation models) and numerous other applications. Consequently, these phenomena can now be taken into account in earlier stages of the design process than was previously possible.

5. ANALYSES OF ELEVATED HELIPADS

Analyses of helipads were undertaken in response to the ongoing process of equipping hospitals in Poland with such facilities. This initiative stems from an obvious rationale: establishing the most efficient means to minimize patient transport time from the landing pad to the hospital's Intensive Care Unit (ICU). These analyses focus on two primary factors: the influence of wind (particularly crosswinds) on operational safety from the helipad, and the impact of rotor wake on both the surrounding environment and the helicopter itself. The first factor concerns how surrounding buildings affect flow turbulence along the approach path. The second addresses whether airflow deflection and partial vortex ring formation around the main rotor could cause the helicopter to be drawn into a wall or experience lift loss – both potentially fatal outcomes.

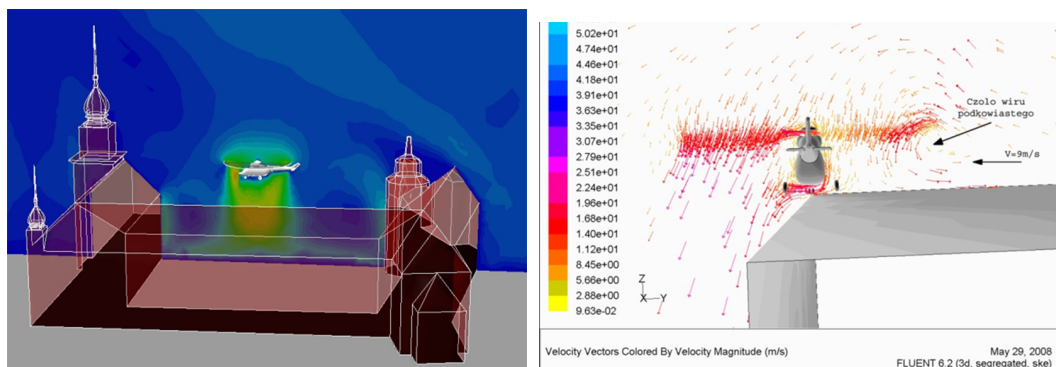


Fig. 21. The PZL W-3 “Sokół” helicopter hovering over the courtyard of the Royal Castle in Warsaw, Poland, and downwind over the high building with one of its main gear wheels touching the roof [18].

The analyses of helicopter operational safety in densely populated areas, inspired by Prof. Szumański, began for the present author almost from the commencement of his work at the Institute. Around 2005, an analysis was conducted of a W-3 “Sokół” helicopter hovering over the courtyard of the Royal Castle in Warsaw. Concurrently, an analysis of the same helicopter type positioned with one main gear wheel downwind on a high building’s roof was performed (Fig. 21). During this period, the author initiated effective collaboration with Dr. Łusiak, then affiliated with Lublin University of Technology, resulting in publications on hovering over well-shaped objects and the danger of helicopters being drawn downward into such structures due to rotor wake interaction (Fig. 22)

[19]. With this background, the present author subsequently proceeded to analyze elevated helipads.

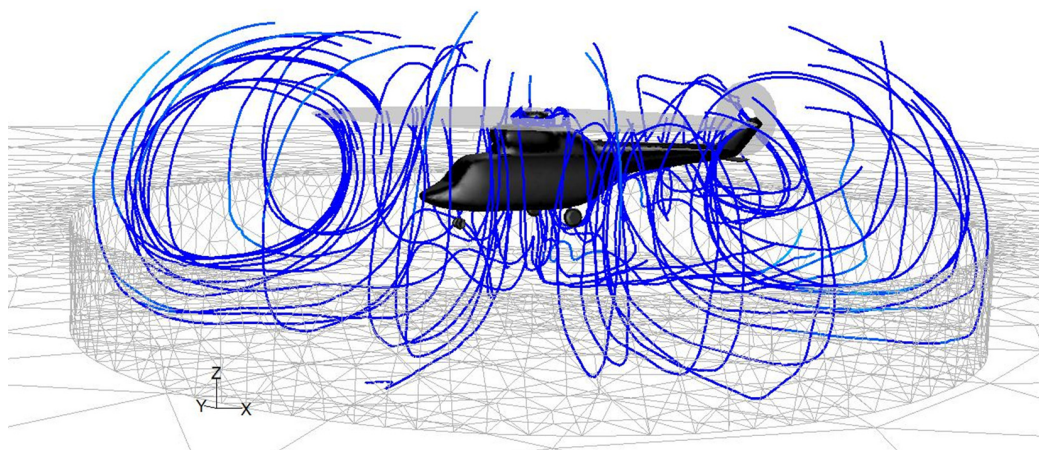


Fig. 22. The vortex ring appearing during a hover over a well-shaped structure [19].

Three principal configurations of elevated helipads and surrounding architecture are typically considered. The helipad may be positioned on the highest building's roof, configured as a compound structure (with the landing zone at the same level as surrounding building roofs), or placed adjacent to taller buildings (Fig. 23). Theoretically, positioning the landing surface on the highest building eliminates interference from surrounding architecture, but creates issues with upward-directed airflow caused by the building's windward wall. At the helipad's edge, a flow separation zone develops where significant vertical air velocity variations could endanger injured patients being transported by medical helicopter.

Placement at the same level as surrounding roofs is the least problematic configuration, though there, too, hovering over architectural fragments that form a well-shaped structure (Fig. 26) remains dangerous for the reasons described above. A helipad positioned near a taller building may also appear non-problematic since it receives protection from crosswinds on both fore and aft wind sides. However, all wind directions oblique to the approach and departure line create uneven flow above the landing surface. Additionally, steep changes in wind velocity occur when the helicopter leaves the area sheltered by the nearest building.

Figures 24 and 25 show examples of helipads analyzed in [21, 22], which are currently operational (except the last one in Gdynia, which was planned but cancelled). The results for the Katowice-Ochojec helipad prompted modifications to the design, resulting in increased height of the landing surface while maintaining the air gap below.

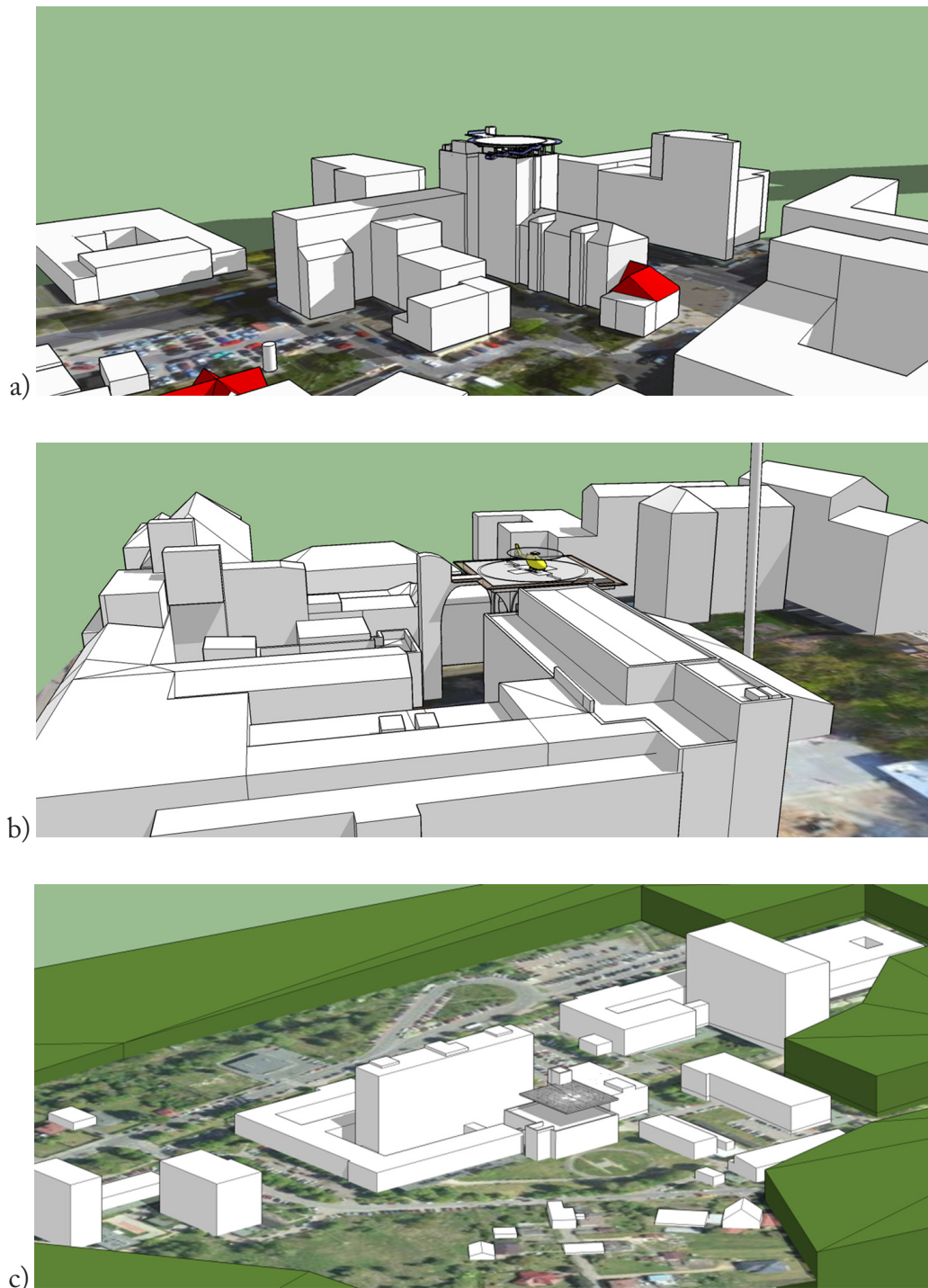


Fig. 23. Examples of elevated helipad configurations: a) on the highest building, b) at the level of surrounding roofs c) near the highest building [20].

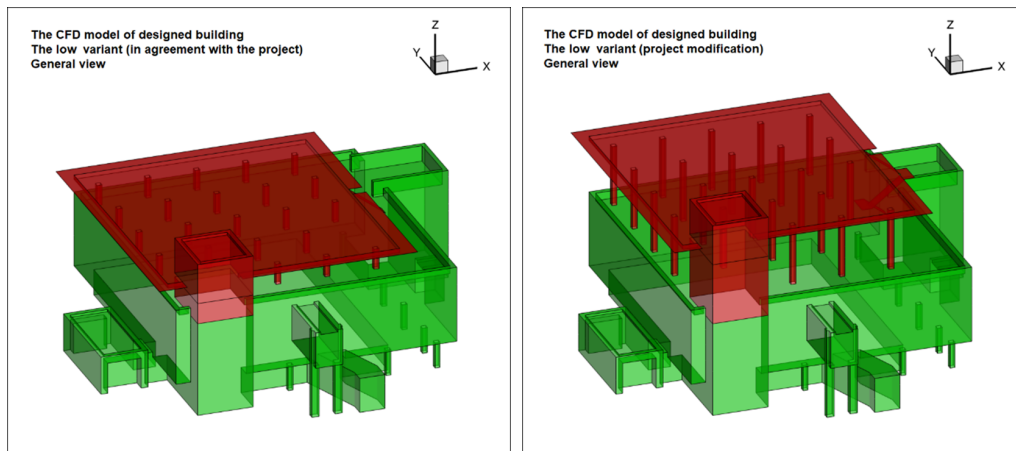


Fig. 24. Helipad atop the Hospital in Katowice-Ochojec, where lifting of the helipad was analyzed [20].

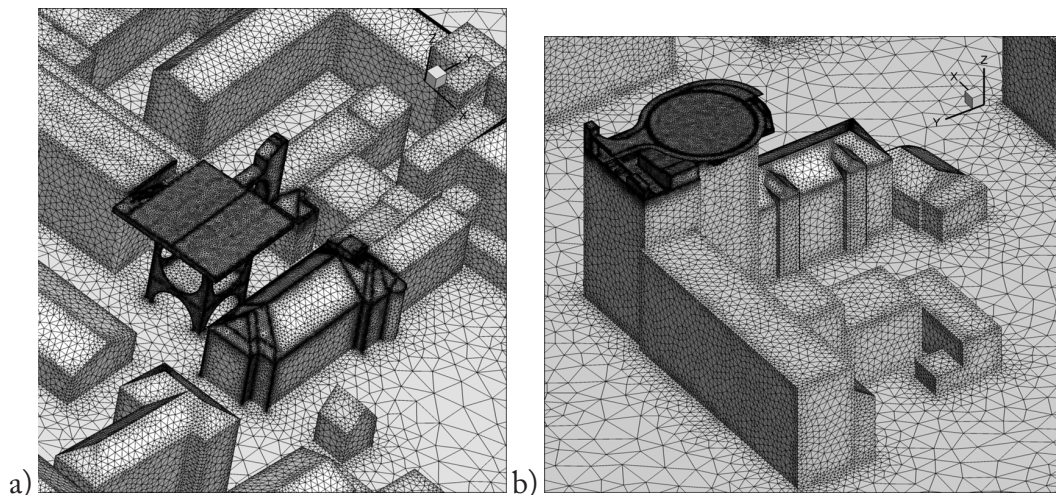


Fig. 25. Computational meshes for (a) at helipad at Copernicus Hospital in Gdansk, built on a platform at the level of surrounding roofs, and (b) a helipad built on the highest building in the vicinity, atop a hospital in Gdynia [22].

One tangible outcome of the present author's work is the incorporation of requirements for an unblocked air gap (between the landing surface and the actual building roof) into Polish regulations. This solution, widely adopted on offshore oil platform helipads, has proven effective for safe operations in strong wind conditions by reducing the highly turbulent flow that would otherwise appear over the helipad. Figure 27 demonstrates the difference in flow quality above the helipad when even a small air gap is present compared to a completely blocked configuration. Figure 28 visualizes the increased vertical velocity zone in front of the wall when the landing zone is positioned on the highest building, and demonstrates how this zone's size is reduced through air gap implementation.

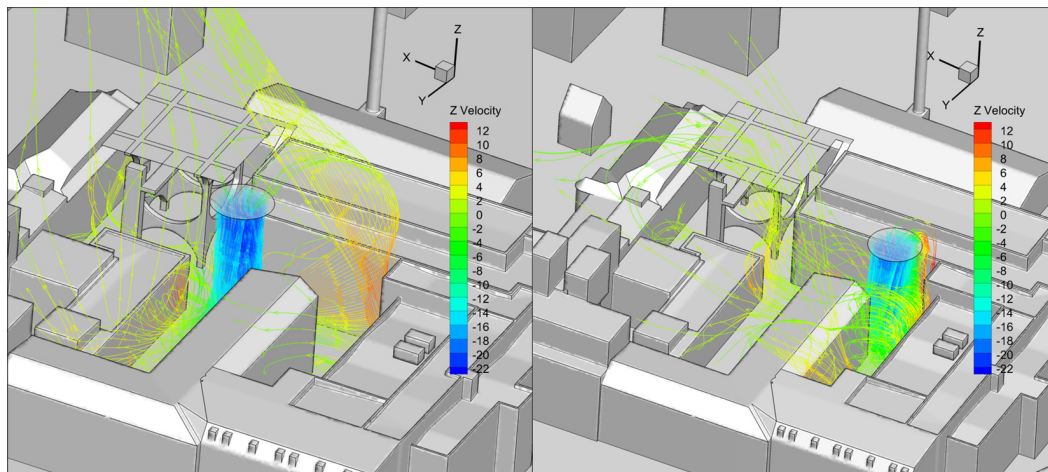


Fig. 26. Helipad built on the same level as the surrounding roofs, where the influence of the rotor wake in hover, while rather safe on the left, will cause a partial vortex ring on the right [21].

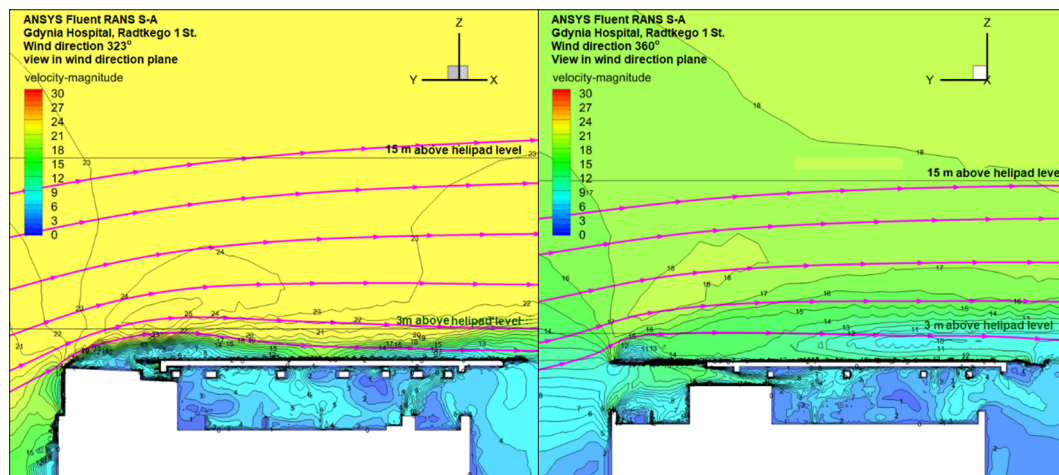


Fig. 27. Influence of a minimal air gap below the helipad surface on the flow quality above the helipad surface [20].

The final aspect worth mentioning regarding this topic is the modeling of surrounding urban area influence on the analyzed helipad. On one hand, urban area influence is incorporated using an appropriate vertical profile of wind velocity and turbulence, as described in Eurocode EN1991.1.4 regulations concerning wind effects on civil engineering designs. This code classifies terrain by treating architecture as “roughness” of specified height and density. However, it remains unknown how much one “characteristic” building should affect the flow path, potentially causing an unpleasant episode for a patient en route to the hospital (Fig. 29).

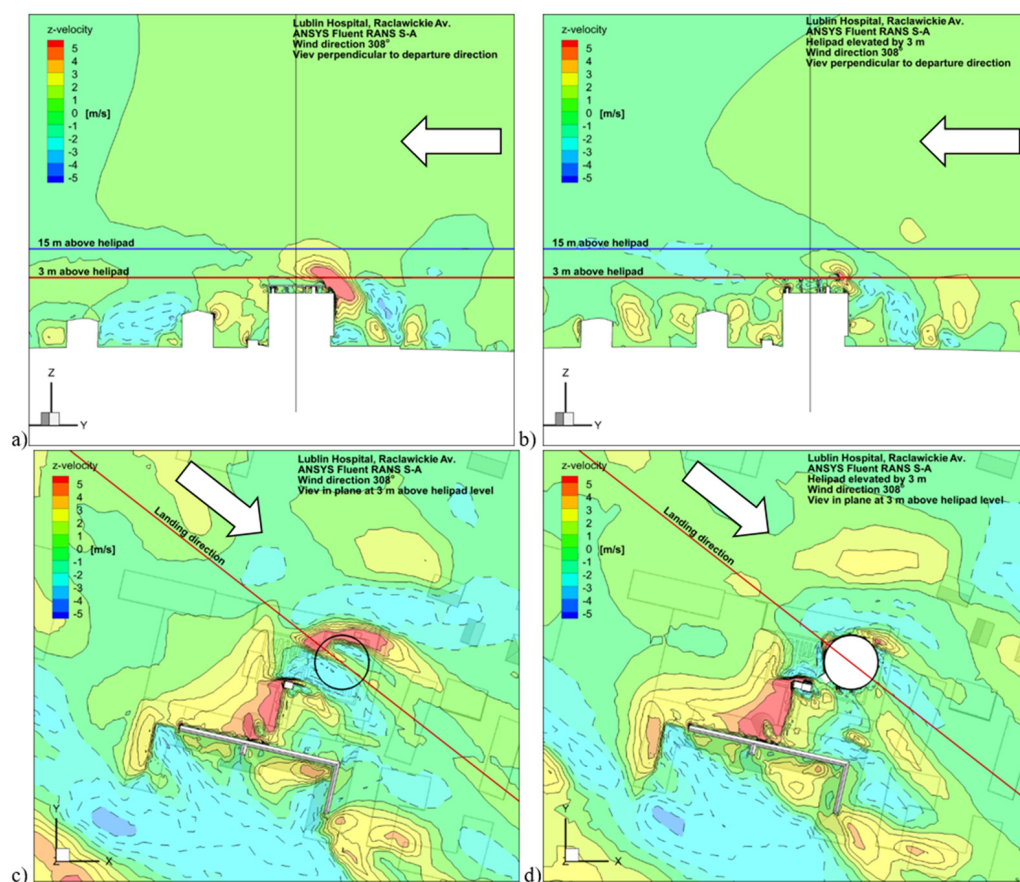


Fig. 28. Decrease in the size of the vertical velocity zone using an air gap: a,c – blocked, b,d – 3m unblocked air gap, with the arrow showing the wind direction.

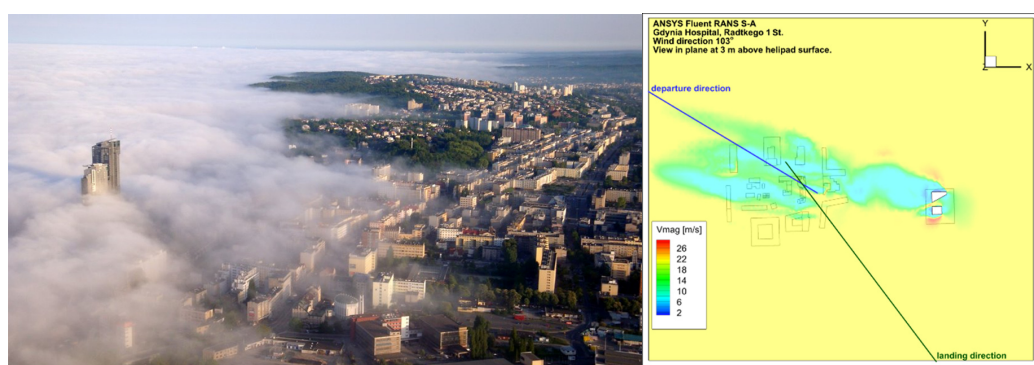


Fig. 29. The path approaching the Gdynia Hospital from behind the “Sea Towers” building on the Gdynia waterfront, shown here emerging from the clouds, and the corresponding model in CFD [22,23]. The CFD results are shown in the plane at 3m above the helipad level and are inverted with respect to the photo.

Therefore, there is legitimate justification for modeling all surrounding buildings that could cause aerodynamic influence on the helipad and approach/departure zones under analyzed wind configurations. Various tools are employed for this purpose, including construction documentation, CAD engineering software, and Google SketchUp with its photogrammetric module (Figs. 30 and 31), along with widely available LIDAR maps of selected areas that can be compared with the reconstructed model through overlapping (Figs. 32 and 33). The accuracy was manually verified by the author on actual buildings during work in Katowice-Ochojec, demonstrating that within a 30m range, the tested error was only a few centimeters.

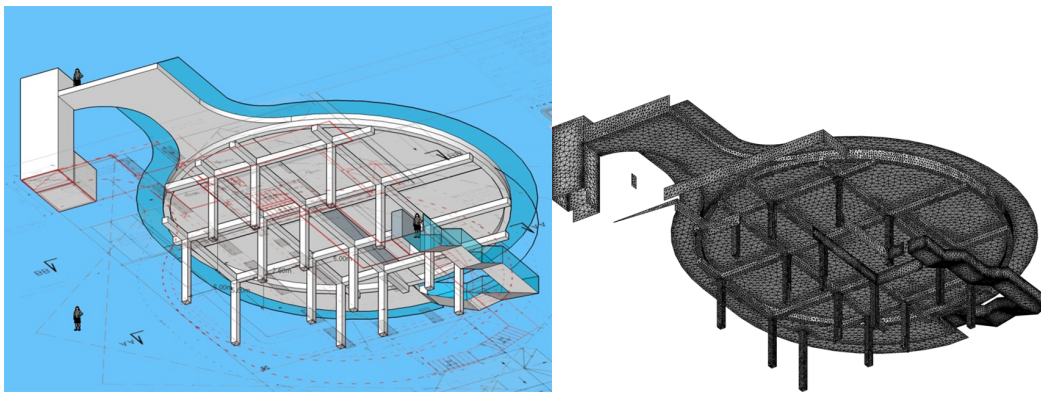


Fig. 30. The Gdynia Hospital Helipad: 3D model compared to the construction drawings, and the corresponding computational mesh.



Fig. 31. The Copernicus Hospital in Gdansk – photogrammetric comparison between the model and an aerial photograph [22].

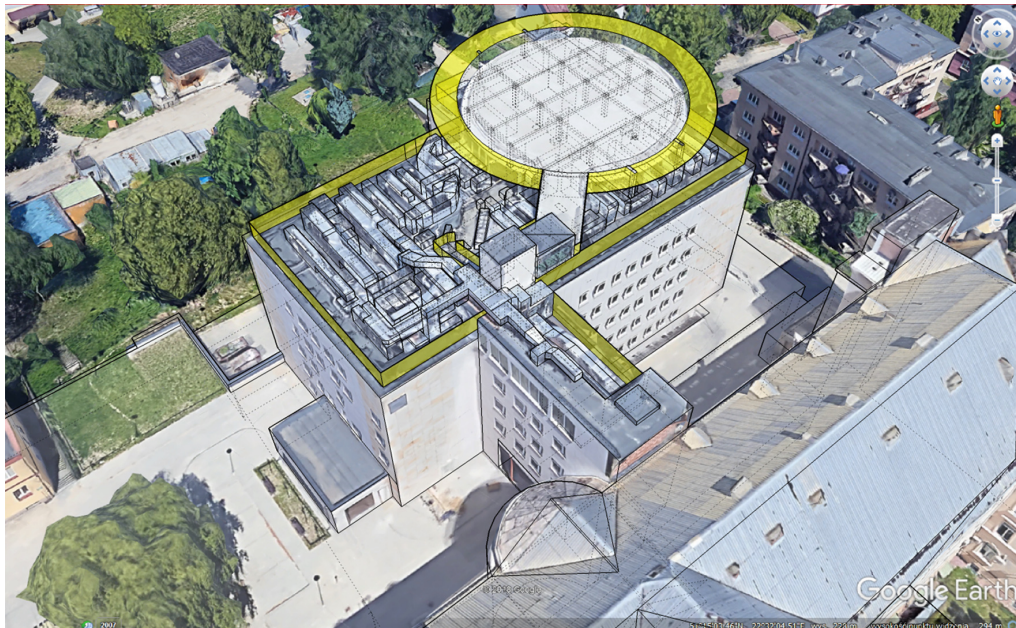


Fig. 32. Lublin Hospital helipad – photogrammetric comparison between the 3D and LIDAR model.



Fig. 33. Hospital in Rzeszów – overlapping LIDAR (textured) and 3D (yellow) model of whole city blocks.

The study of elevated helipads is a fascinating subfield of aerodynamic research, requiring expertise in both aviation engineering and civil engineering. A broad scope of applications can be anticipated, given increasing interest in aero-mobility, flying car implementation, and unmanned autonomous personal transport systems. Such analyses could lead to the development of maps, flight paths, or other communication methods for safely operating in urban environments while accounting for aerodynamic interference effects.

The research area presented above represents only a portion of the analyses conducted by the Institute of Aviation's aerodynamic department (in both of its divisions, numerical and experimental) and its space technologies department. However, it constitutes a significant part of the present author's research output and effectively demonstrates the extensive information obtainable through CFD analysis. Additionally, successfully creating aviation and architectural models for these simulations is a source of satisfaction from both engineering and aesthetic perspectives.

6. SUMMARY

In this paper, several cases selected from a wide range of fluid simulations have been presented to illustrate how CFD modeling of flow can be used to address real technical and operational problems. The information obtained through this method is becoming increasingly relevant with the evolution of computational techniques. Compared to wind tunnel testing, CFD has the ability to test flow at real scale, making translation through flow similarity rules less necessary than in experimental approaches. Additionally, the method is much safer than full-scale flight testing. If flight tests were to include icing conditions (as in the ILX-27 tail rotor icing example), loss of directional stability (as in the I-28 autogyro simulation), or flight under the influence of complex flows caused by buildings (as in helipad simulations), the danger to pilots would be (and indeed was, in the case of the autogyro) very real.

Operational problems sometimes emerge and require solutions during prototype testing (SH-09 helicopter), sometimes they can be predicted (helipads), and sometimes they result from observation (hover over well-shaped objects). These issues can also be addressed using computational methods, and because users can examine the entire flow field using cross-sections, this is the only method available to observe what could cause a mishap, crash, or other failure (SH-09 nacelle heating, I-28 tail, ILX-27 tail rotor icing). This ability to examine all areas represents an advantage over wind tunnel methods, though with modern visualization techniques such as particle image velocimetry (PIV), this gap is gradually closing. Nevertheless, PIV experiments require extensive preparation, high-speed cameras, specific lighting, and post-experiment particle contamination can affect other equipment. At present, wind tunnels and computational methods remain mutually necessary in this research area.

Computational capabilities represent a limiting factor, since urbanistic flows (helipads, buildings) are large compared to helicopters and cannot be meshed with similar accuracy – calculations would take prohibitively long, if computers could even generate such enormous meshes. Consequently, meshes in these simulations are much coarser than those used for rotor blade icing simulations. Element size increases with distance from the “area of interest” in the simulation. Dense boundary layer meshes are not always necessary because buildings have explicitly defined flow separation locations at wall edges. Otherwise, mesh density is set very high in areas where significant changes in flow parameters (pressure, velocity) are expected and are of interest – because flow features like vortices can be translated into increased turbulent viscosity and, over time, into temperature increases. These effects do not disappear in large cells, and their influence, in one form or another, is still accounted for.

Nevertheless, despite these limitations, the work described above, in addition to generating substantial knowledge, has also resulted in real-world solutions. For instance, the requirement for a 3-meter gap between roof and helipad was established as a regulatory requirement in helipad design standards. Through collaboration with the Polish Medical Air Rescue service (Lotnicze Pogotowie Ratunkowe, LPR), the necessity of such regulations was successfully demonstrated to the Polish Ministry of Infrastructure, using CFD results backed up by their flight experience.

Overall, the examples presented in this paper reflect the practical role of CFD in addressing real-world rotorcraft challenges. From concept development to operational analysis, CFD enables engineers to explore complex aerodynamic phenomena that are difficult or impossible to investigate through physical testing alone. Nonetheless, this valuable tool requires constant validation because it is a model of reality, not reality itself. It demands experience in setting flow models, determining mesh sizes, and integrating different physical interaction models. It also requires skepticism toward every result, as geometry accuracy and experimental results remain the foundation upon which CFD engineers build, and they must still validate their findings.

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