Institute of Aeronautics and Applied Mechanics

Prospectus

PW-ZOOM during its Antarctic mission (MONICA project)

Warsaw 2026/27

Institute of Aeronautics and Applied Mechanics

The Institute of Aeronautics and Applied Mechanics (IAAM) proudly continues the traditions of Poland's oldest academic center offering education in aeronautical engineering.

In the academic year 1922/1923, the Faculty of Mechanics at the Warsaw University of Technology established the Aeronautical Group, later known as the Division of Aeronautical Engineering. Studies in aeronautics were conducted during semesters 5 to 8, and students were admitted after completing the so-called half-diploma—that is, the first four semesters of study. This moment marked the beginning of formal aeronautical education at the University, preparing engineers for Poland's aviation industry, research institutions, and armed forces.

A major milestone in the Institute's development was the construction of the Institute of Aerodynamics between 1925 and 1928. It conducted both theoretical and experimental research, contributing significantly to the advancement of the Polish aviation industry. The Institute's pioneering work led to the creation of innovative aircraft and engine designs, securing the Warsaw University of Technology a prominent place among the world's leading research centers in aircraft design and engineering.

During the Second World War, the University's activities were largely limited to underground education. After the war, the situation was extremely difficult: the Institute's building had been destroyed, laboratories were in ruins, and there was a shortage of both teaching and research staff.

In 1951, a major reorganization took place following the merger of the Wawelberg and Rotwand School with the Warsaw University of Technology. The Institute of Aerodynamics was dissolved, and the Faculty of Aeronautics was established. That same year, construction began on two new facilities—the Aeronautics Building and the Heat Engineering Building.

In 1960, the Faculties of Mechanics and Design and of Aeronautics were merged to form the **Faculty of Power and Aeronautical Engineering**, which continues to operate under this name today. During the academic year 1970/1971, aeronautical education was temporarily suspended due to national plans to limit aviation-related activity, and the Faculty was renamed the Faculty of Mechanics and Power Engineering (FPAE). Fortunately, this change proved temporary, and soon the original name—Faculty of Power and Aeronautical Engineering—was restored.

In 1975, Professor Marek Dietrich, then Dean of the Faculty, proposed merging two of its institutes: the Institute of Applied Mechanics and the Institute of Aviation and Hydro-aeromechanics. With University approval, these two units—both established in 1970—were combined to form the **Institute of Aeronautics and Applied Mechanics (IAAM)**. The existing structure and staff assignments were preserved. This decision ensured the continuation of aeronautical education at a time when the national aviation sector was at risk of closure.

Directors of the Institute of Aeronautics and Applied Mechanics

Years	**Director**
1975–1981	Prof. Marek Dietrich
1981–1990	Prof. Jerzy Ostrowski
1990–1993	Prof. Jacek Stupnicki
1993–2002	Prof. Krzysztof Kędzior
2002–2016	Prof. Krzysztof Arczewski
2016–2020	Prof. Grzegorz Krzesiński
2020	Prof. Teresa Zielińska
Since 2020	Prof. Tomasz Goetzendorf-Grabowski

Teaching and Research Activities

The Institute conducts a wide range of teaching and research activities across seven divisions:
1. Division of Aerodynamics
2. Division of Automation and Aeronautical Systems
3. Division of Mechanics
4. Division of Fundamentals of Machine Design
5. Division of Aeroplanes and Helicopters
6. Division of Theory of Machines and Robots
7. Division of Strength of Materials and Structures

The staff of the Institute possess extensive expertise in key technological fields of the 21st century. Research areas include aerodynamics, mechanical design, material properties, aviation, biomechanics, and robotics—all of which require interdisciplinary knowledge and innovation.

Many members of the academic staff hold leading positions in international scientific organizations and professional associations. The Institute also operates an airfield in **Sieraków**, equipped with modern laboratories that support both theoretical and practical training. Its state-of-the-art infrastructure and continuously modernized facilities provide a solid foundation for high-quality education and cutting-edge research.

The following sections of this brochure present detailed information about each division of the Institute.

Division of Aerodynamics

1. Research interest

The area of research of the Division of Aerodynamics (DA) is manifold and ranges from fundamental problems of fluid mechanics and aerodynamics to various applications in aerospace, biomechanical and environmental/wind engineering. The research activities in the DA cover wide scope of investigation methodologies and techniques: theoretical, computational and experimental, usually conducted in combination.

Main research areas include:

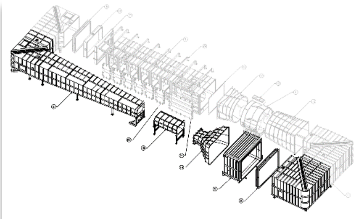
- Computational and experimental aerodynamics of flying and ground vehicles including cars, urban aerodynamics and wing engineering
- Hydrodynamics stability and transition to turbulence (computer simulations and experiment)
- Fluids: passive and active methods for improved efficiency of transport phenomena in fluids, environmental fluid mechanics, computational fluid dynamics (FVM, h/p-spectral FEM, LS-FEM), geometric/topological optimization methods in fluid mechanics and aerodynamics including optimal control of fluid/thermal phenomena, data-based and machine learning methods in fluid mechanics (emerging area)
- Aeroacoustics
- Development, efficient implementations and various applications of the Lattice Boltzmann methods
- Flows: internal and external compressible and flows in porous media (computer simulations and experiment), modelling and computational methods for multiphase flows, mathematical and numerical modelling of turbulent flows
- Dynamics of droplets, surface-tension driven flows, surface-fluid interactions at hydrophobic and super-hydrophobic coatings
- Thermodynamics of ice-repelling smart surfaces for multipurpose applications
- Surface waves dynamics and met materials
- Uncertainty quantification, robust optimization, surrogate-based optimization.

2. Research laboratories

The Aerodynamics Laboratory in IAAM is a part of the Laboratory of the Turbine Aerodynamics and Combustion (LATiS). The main LATiS' assets are:

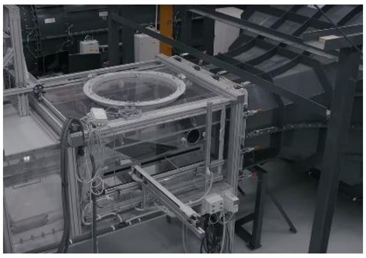
- Variety of wind tunnels and experimental stands
- Advanced methods and data analysis
- HPC Cluster

Adjustable Turbulence Wind Tunnel (ATWT)



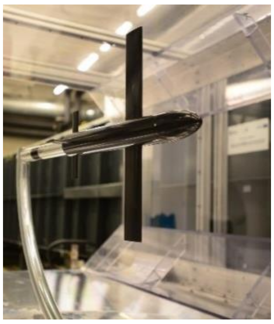
- Closed-loop wind tunnel with fan power 250kW, featuring two closed test sections: environmental and aeronautical.
- Wide range of velocities, 5-90 m/s (test-section dependent).

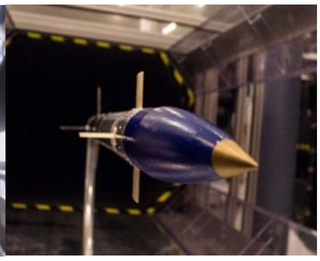
Desired turbulence level can be obtained by employing removable meshes.



Aeronautical test section:

- Test section dimensions: 0,9m x 1,25m
- Velocity: up to 90m/s
- Turbulence level below 0,1%
- Reynolds number up to 3 million





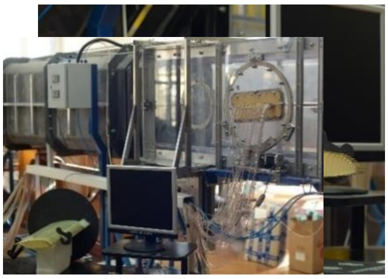
Environmental test section:

- Test section dimensions: 2,6m x 2,0m
- Velocity up to 25m/s
- Atmospheric boundary layer development length: 10m


Low Turbulence Wind Tunnel (LTWT)

Aeronautical test section:

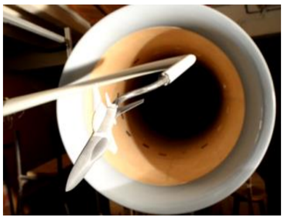
- Dimension of test section: 0,45m x 0,65m
- Velocity up to 60m/s
- Turbulence level up to 0,2%
- Reynolds number up to 2 million

Aeronautical Wind Tunnel (AWT)

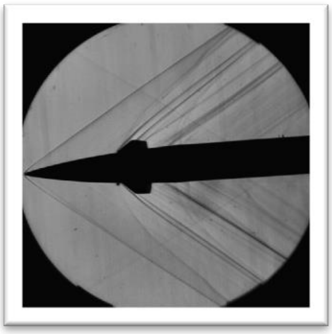
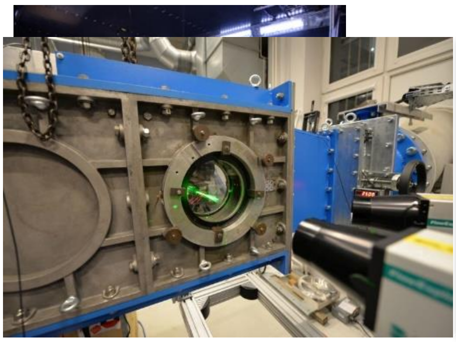
Aeronautical test section**:**

- Dimension of test section: ϕ =1,16m
- Velocity up to 40m/s
- Reynolds number up to 1 million
- 3D aircrafts & vehicles

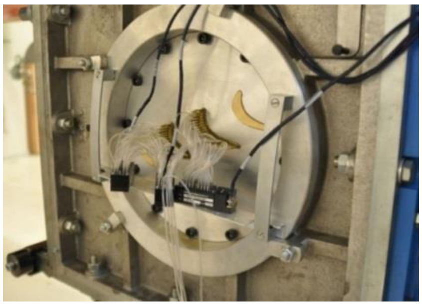




Transonic Wind Tunnel (TWT)

- Several test sections (Length = 1m): 0,44m x 0,1m, 0,35m x 0,35m
- Velocity 0,5 – 2,5 Ma
- Duration of measurement: 0,5 – 10 s


Cascade Wind Tunnel (CWT)



Test section:

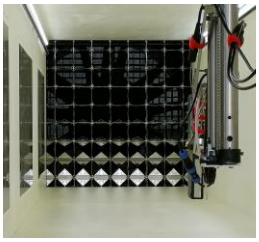
- Dimensions: 0,35m x 0,1m
- Blades in cascade: 4-8
- Velocity: 0,2 – 0,35 Ma

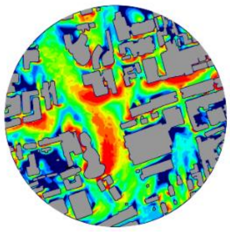
Duration of a measurement 0,5 – 10 s.

Environmental Wind Tunnel (EWT)

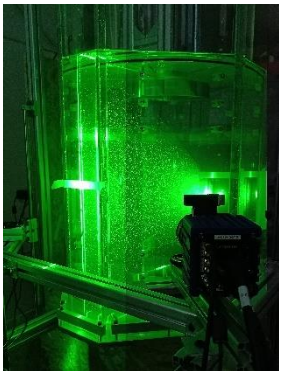
Test section:

- Dimensions of test section: 1m x 1m
- Velocity up to 25m/s
- Atmospheric boundary layer development length: 4m
- Fitted with an 8 x 8 low-blockage active grid



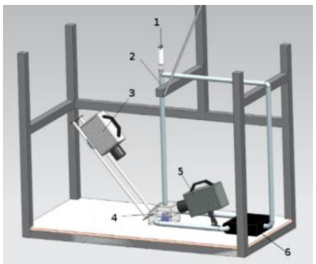


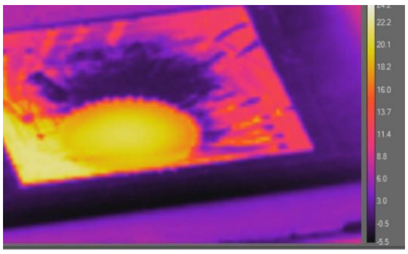
Experiments on surface wettability and icing

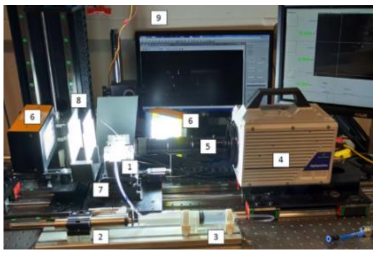


Several test stands e.g.:

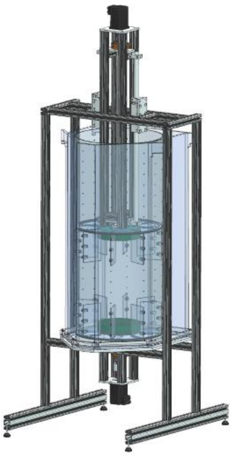
- Measurement of static and dynamic contact angles, contact angle hysteresis
- Icing chamber for droplet interaction $T_{ambient}$ = -30°C ~ 25°C; $T_{surface}$ = -30°C ~ 25°C
- Thermocouples
- Fast thermographic camera (FLIR X6580 SC)







Experimental stand for swirling flows (Von Kármán tank)

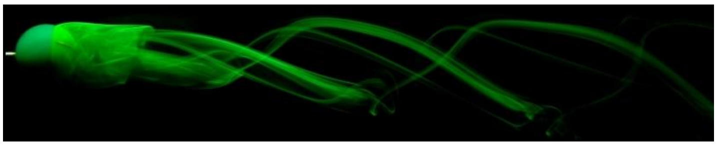


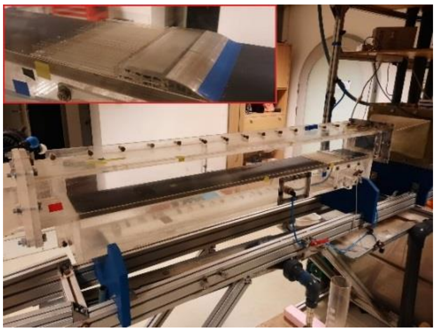
- Diameter of the tank: 0.5m
- Adjustable height (up to 1m)
- Can be fitted with baffles (up to 8 along the circumference)
- Propelled by two stepper motors (up to 150rpm)
- Maximum turbulent Reynolds number: c.a. 800
- Excellent optical access (allowing convenient PIV measurements)

Water Tunnels (WT)

Test section:

- Dimension of test section: 0,1m x 15m
- Velocity: up to 15-20 cm/s





LATIS's measuring and visualization equipment

Flow field measurements - modern and diversified apparatus used for 2D and 3D flow fields: PIV, LDA, CTA.

- PIV (Particle Image Velocimetry) provided by LaVision
- 3x Stereo system, based on lasers:
    - NDYAG 200mJ @ 15Hz
    - Litron 20mJ @ 20kHz
    - 1W constant light, laser DPSS
- LDA (Laser Doppler Anemometry) provided by Dantec Dynamics
    - 1x2 components
    - 1x1 component
- CTA (Constant Temperature Anemometer) provided by Dantec Dynamics
    - mini CTA,
    - Streamline Pro + Calibration

Pressure field measurements - modern and diversified apparatus used for pressure measurements

Multi-channel piezoresistive scanners type - PressureSystems

- 350 sensors @ 1kPa

- 96 sensors @ 34kPa
- 96 sensors @ 1bar

Piezoresistive microsensors Kulite type

- 48 sensors + 2x National Instruments Pxi

Water manometers

- single channel
- multi-channel

Force measurements (external and internal sting type balances).

- External and sidewall balances
  - up to three force and three moment components,
  - force range 150 - 2kN,
  - moment range 15 - 200Nm,
  - Acquisition rate up to 50kHz,
- Internal (sting type balances)
  - up to 3 force and 3 moment components,
  - force range 150 - 1kN
  - moment range 15 - 50Nm
  - Acquisition rate up to 50kHz

Fast imaging, 3D printing and software

Thermographic fast camera Flir X6580sc

- Max 4500fps
- Temperature range -50°C ~ 350°C

Fast cameras

- Photron SA-Z, SA-5, SA-1 up to 2,5 M fps

3D printers, 3D scanners, CNC workshop

Software: MATLAB, Ansys, Tecplot, Siemens NX, Lab View.

3. Key research projects

1. 2025-2026. European Space Agency (ESA). Project Number 4000146370/24/NL/RK. "Martian Re-Entry Flows over Aerodynamically Rough Surfaces" (Przepływy wokół powierzchni chropowatych uzyskiwanych podczas wejścia w atmosferę Marsa). prof. Sławomir Kubacki.

   Atmospheric entry puts high mechanical and thermal stress on the entering object. In the case of Mars missions, the maximum heat flux may reach very high values, and special ablative thermal protection systems (TPS) must be used on the first layer of the heat shield. The surface of such ablative TPS materials becomes rough during entry. The ablation process and surface roughness may thus impact the boundary layer parameters and accelerate a laminar-turbulent transition.

The existing correlation-based predictive models and related numerical/experimental data are not sufficiently accurate for rough surfaces in the case of highly compressible flows. This negatively impacts future Mars missions: the engineering design of heat shields requires including design margins to cover the modelling uncertainties.

The plasma wind tunnel experiments will be used to obtain accurate surface scans of TPS after ablation. Using the obtained surface roughness profiles, the Direct Numerical Simulation and experiments will be designed and executed to represent the Martian entry conditions and allow the development of improved correlations for laminar-turbulent transition. The DNS and experimental results will offer relevant data to improve the correlation models for heat flux and shear stress estimation on rough surfaces. This project gives a unique opportunity to significantly reduce the uncertainties in predicting the heat load during future European missions.

2. 2014-2019 NCBR INNOLOT „Zaawansowany zespół turbiny niskiego ciśnienia o podwyższonej sprawności" (Advanced low-pressure turbine with improved efficiency), dr inż. Jerzy Majewski

   The main objectives were as follows:

   A) Virtual modelling and improvement of low pressure turbine (LPT) performance
   - development/improvement of LPT unsteady flow simulation technique and comparison of numerical results with experiment,
   - aerodynamic optimization of shapes of LPT sealing cavities.

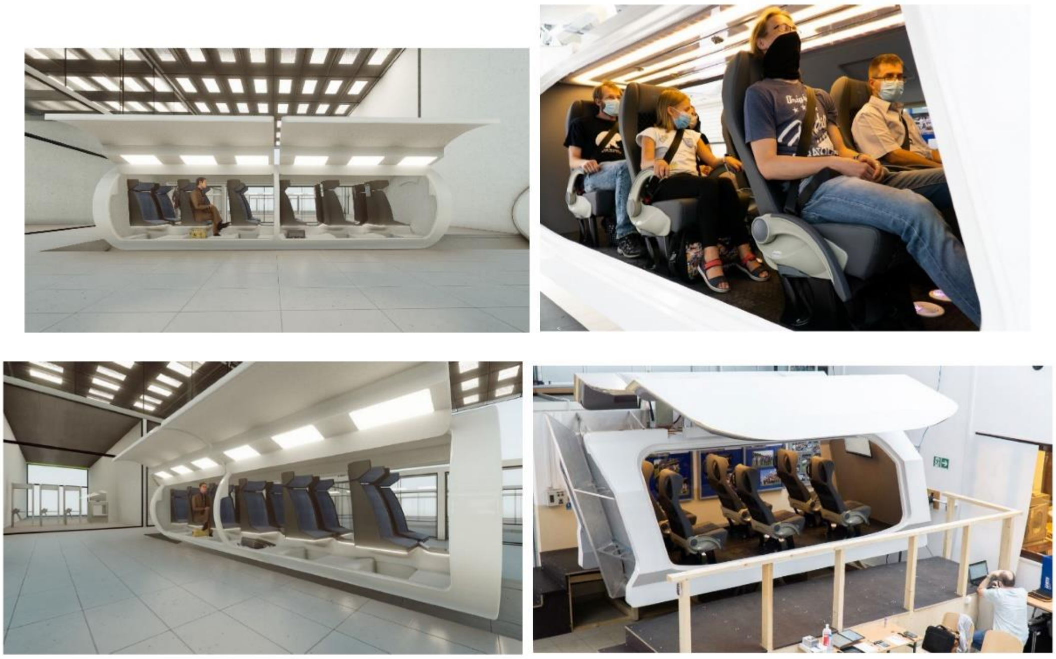
   B) Experimental modeling of LPT module
   - development of advanced instrumentation strategy and verification of the strategy on experiments by AvioPolska and WUT,
   - development of data reduction system and validation of the technique on benchmark cases defined by AvioPolska.
   -

3. 2014-2016 NCBR GEKON „Opracowanie i wdrożenie technologii Małych Elektrowni Wiatrowych o mocach 5kW i 10kW" (Design and technological implementation of Small Wind Turbines with the power of 5kW and 10kW), prof. Jacek Szumbarski

   This project aimed at development of highly-efficient small 5kW and 10 kW HAVTs. The role of the DA's teams was to design and optimize the rotors (with special emphasis on self-starting capabilities) and experimental evaluation of obtained performance).

4. 2019-2020 NCBR GOSPOSTRATEG „Potencjał rozwoju i wdrażania w Polsce technologii kolei próżniowej w kontekście społecznym, technicznym, ekonomicznym i prawnym” (Potential for the development and implementation of vacuum tube high-speed train technology in Poland in the social, technical, economic and legal context), HYPERLOOP, prof. Janusz Piechna.

During realization of this project the concept of an unconventional implementation of a Low Pressure Tube Transport (LPTT) system for a network with station-to-station distances of 300 km, based on the use of circular tunnels in which modular vehicles consisting of three interconnected functional segments move on wheels with airless tires, was proposed. The physical limitations associated with high-speed vehicle travel in tunnels have been taken into account. The reasons for the expected inconvenience in the travel system, compensated by short travel times, were justified. Assumptions for the use of locomotion, safety, and passenger segments in the construction of a vacuum modular vehicle were considered, as well as systems to ensure the efficient conversion of serial traffic in tunnels to parallel traffic in station areas. Schemes of station construction and traffic organization in the station area were presented, as well as assumptions for a number of systems increasing the safety of vehicle traffic used in emergency situations. Visualizations of some solutions were shown.
To check the proposed constructions and organization, two travel simulators of this railroad were built for the presented LPTT system, a mechanical and a virtual simulator. The mechanical simulator took into account the characteristic features and solutions of the passenger module. The virtual simulator additionally provided visualizations of the parts of the station available to passengers.

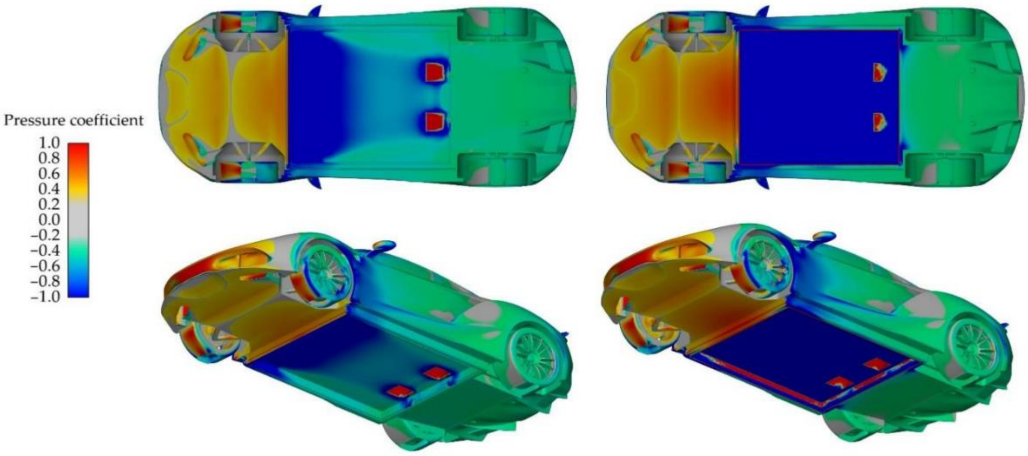


*Platform seen in virtual simulator (**left**), cockpit of mechanical simulator (**right**).*

5. 2015-2019 NCBR PBS 3 "Aktywny system tłumienia drgań pojazdu" (The active system of car body oscillation damping) , prof. Janusz Piechna.

Investigation made in this project was concentrated on the different aspects of the car aerodynamics. In the case of road cars, road safety is the primary factor. The geometry of high-speed road cars has no regulatory restrictions. In addition to the high engine power and effective shape, they can use various types of additional movable aerodynamic elements to adjust their aerodynamic characteristics to the road conditions. Based on the geometry of a two-seater prototype of such a vehicle, a numerical analysis of the influence of a number of additional movable aerodynamic elements on its aerodynamic characteristics was performed. Several of them were installed on the prototype. An electronic system recording a number of motion parameters of the entire car body and some of its movable elements installed on the body was designed and built. The system has been adapted to program the motion of additional aerodynamic elements according to the set algorithms of their activation, temporarily changing the aerodynamic characteristics of the car. An experimental study of the effect of changes in the aerodynamic characteristics of the prototype on its dynamic properties during a drive through a test road section was carried out. It was shown to what extent an average driver can increase the safe speed of the curve of the road using the possibilities of moving aerodynamic elements installed on it.
The simulations of the behavior of a car equipped with a movable wing during braking, while negotiating a curve, have been performed. At the outset, it was assumed that the vehicle is traveling at high speed on a curve of the road and there is a need for sudden braking. Two cases were analyzed. In the first, the vehicle brakes, but the rear wing is stationary. In the second, the vehicle brakes, but the rear wing changes its angle of alignment increasing aerodynamic downforce (negative lift) and aerodynamic drag. The differences in the behavior of the vehicle in the two cases were presented. The numerical model built consisted of a vehicle dynamics model (ADAMS), taking into account the action of inertial forces occurring on its moving components, coupled with an aerodynamic model (ANSYS-Fluent), allowing to calculate the instantaneous values of aerodynamic forces caused by dynamic changes in the position of the vehicle body with a flexible suspension and the rear fixed or moving wing. The motion of the vehicle relative to a stationary reference system - the road surface - was simulated. It was shown that when braking is required while driving on a curve of the road, activation of the movable wing results in stabilization of the vehicle's motion comparable to the action of the mechatronic ESP system.

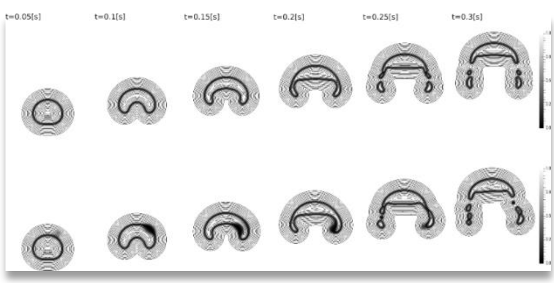
*Photographs of the vehicle prepared for passage in two different configurations. Asymmetrically inclined wing for cornering configuration (**left**) and braking configuration (**right**).*



*Pressure coefficient for the inlet speed of 20 m/s. On the (**left**), circulation fans generating air curtains were deactivated; on the (**right**)—they were active.*

6. 2017-2020 NCN OPUS 11 „Statystyczne modelowanie dwu-składnikowych przepływów turbulentnych z powierzchniami rozdziału" (Statistical modelling of two-phase turbulent flows with sharp interfaces) , dr inż. Tomasz Wacławczyk.

The main aim of this project was to design the physical/mathematical and numerical framework for efficient implementation of the turbulence models designed for numerical simulation of the turbulent two-phase flow. To this goal, the new modeling approach based on conditional averaging and closure of the unknown parameters by the conservative model was introduced [A]. The proposed solution allows to model interaction of the sharp interface between the two-phases with turbulent velocity field similarly to the phase transition. In the new statistical model of the interphase region, the interphase region evolution is depended on the local properties of the flow field (characteristic length and/or time scales). The results of this new approach are presented in the figure from work [C].



The top row depicts advection of the gas bubble in equilibrium case (without interaction with turbulent velocity field) the bottom row presents bubble which trajectory is affected due to presence of turbulent eddy with the known characteristic length scale. One can observe how presence of the turbulent eddy affects the local thickness of the interphase region that is statistical (ensemble averaged) representation of the sharp interface affected by stochastic, turbulent velocity field.
The main outcome of the project can be found in three publications:
[A] T. Wacławczyk, On a relation between the volume of fluid, level-set and phase field interface models, International Journal of Multiphase Flow, vol. 97, 2017, pp. 60–67
[B] T. Wacławczyk, Modeling of non-equilibrium effects in intermittency region between two-phases, International Journal of Multiphase Flow, vol. 134 , 2021, pp. 1–20
[C] T. Wacławczyk, On differences between deterministic and statistical models of the mesoscopic intermittency region, Acta Mechanica Sinica, vol. 38, 2022, 722045.

7. 2019-2022 NCN PRELUDIUM 15 „Stabilność hydrodynamiczna oraz intensyfikacja mieszania laminarnego w kanale poprzecznie pofalowanym do przepływu” (Hydrodynamic stability and laminar mixing enhancement in a transversely corrugated channel) , dr inż. Nikesh.

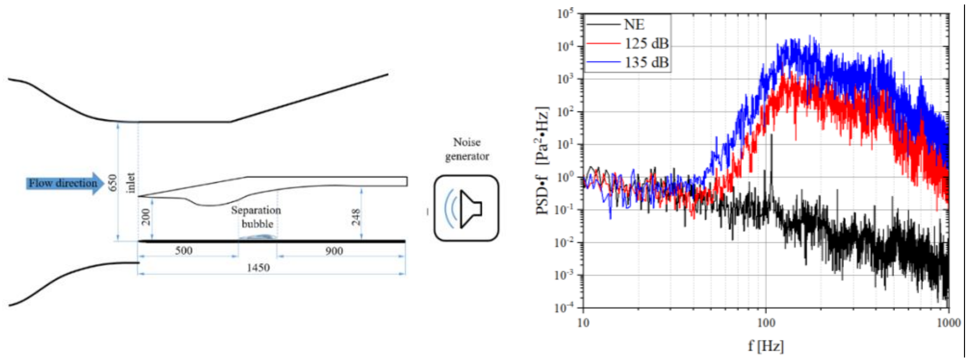
The main goal of this project was to explore the potential of natural instabilities in internal (channel) flows invoked by transversely-oriented wall corrugation for intensification of laminar mixing. In particular, various form of parametrized wall corrugations have been considered and optimized to minimize the critical Reynolds number while keeping hydraulic penalty as law as possible. Wide range of corrugation amplitudes and geometric periods has been considered leading to broad picture of possibilities of mixing enhancement.

7. 2019-2023 NCN OPUS 16 „Opracowanie i implementacja nowej metody modelowania przejścia laminarno - turbulentnego w warstwie przyściennej uwzględniającej utratę stabilności przepływu na skutek oddziaływania fal akustycznych”, (Development of a new laminar-to-turbulent transition model for boundary layer flow incorporating the effects of instabilities triggered by acoustic waves), prof. Sławomir Kubacki

The proposed project aimed at reducing the computational costs necessary to simulate the coupling of acoustics and boundary layer flow. It was believed that simulating simultaneously hydrodynamic instabilities and acoustic waves within a single CFD URANS solver was a right approach for achieving the main goals of the project.
The main objectives of the project were:

- Understanding the instability mechanism in the laminar and turbulent boundary layers triggered by the acoustic waves (direct numerical simulations and experiments);
- Formulation of guidelines, based on the collected DNS data, for closure of the unknow terms in the exact form of the Reynolds-stress transport and/or the laminar/turbulent kinetic energy equations;

- Development and testing of 3D URANS/hybrid RANS-LES aero-acoustics simulation/coupling strategies.



Left: Schematic of the test section and loudspeaker location, Right: power spectra density spectra at the test section outlet.

Outcomes of the project:

[1] Sokolenko V., Dróżdż A., Rarata Z., Kubacki S., Elsner W., 2024, Experimental study of a separated shear layer transition under acoustic excitation, Experimental Thermal and Fluid Science, 157, 111227/1-15, https://doi.org/10.1016/j.expthermflusci.2024.111227.

[2] Jagodzińska I., Olszański B., Gumowski K., Kubacki S., 2024, Experimental investigation of subsonic and transonic flows through a linear turbine cascade, European Journal of Mechanics / B Fluids, 103, 182–192, https://doi.org/10.1016/j.euromechflu.2023.10.002.

[3] Rarata Z., Dróżdż A., Gnatowska R., Sokolenko V., Elsner W., Kubacki S., 2023, Numerical study of an acoustic field effect on boundary layer transition mechanism, International Journal of Heat and Fluid Flow, 104, 109238/1-12, https://doi.org/10.1016/j.ijheatfluidflow.2023.109238.

[4] Kubacki S., Dick E., 2023, Improved prediction of low-pressure turbine wake mixing by Delayed Detached Eddy Simulation, including an algebraic model for bypass transition, International Journal of Heat and Fluid Flow, 103, 109206/1-15, https://doi.org/10.1016/j.ijheatfluidflow.2023.109206.

[5] Kubacki S., Rarata Z., Dróżdż A., Gnatowska R., Sokolenko V., Elsner W., 2023, Prediction of laminar-to-turbulent transition in a separated boundary layer subjected to an external acoustic forcing, Archives of Mechanics, 75 (5), 591–616, https://am.ippt.pan.pl/am/article/view/v75p591.

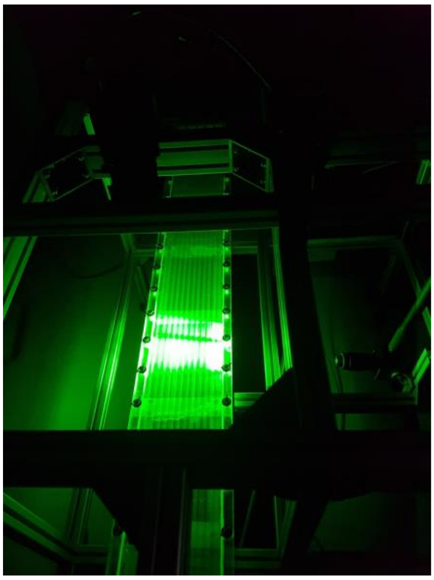
8. 2020-2024 NCN PRELUDIUM 18 „Dynamika granicy trójfazowej dla przepływów inercyjnych" (Triple line dynamics in inertial flows), dr inż. Michał Remer.

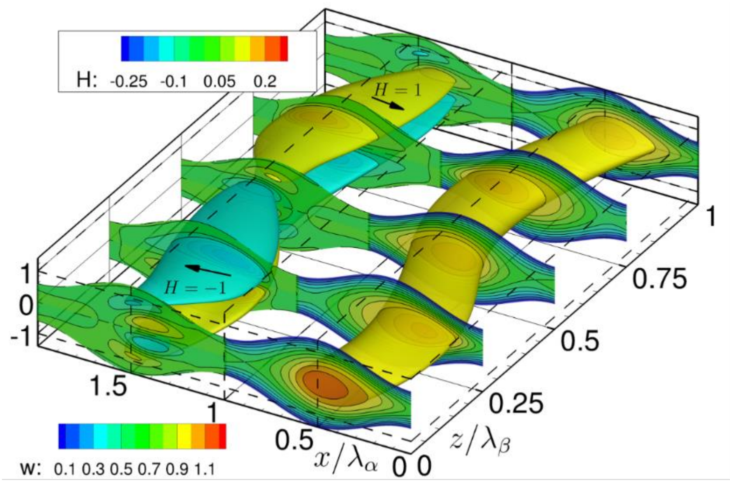
The main objective of the project is to investigate the dynamics of the interface in high velocity regime, where inertia forces cannot be neglected. The Weber number is a measure of the importance of the fluid's inertia over its surface tension, which might be useful parameter for inertia impact on θ_d during modelling. The main goal of the research is to determine physical relationship between the dynamic apparent contact angle θ_d and the velocity of the triple line V for dynamically moving triple line. This goal can be obtained by extending assumptions of Kistler/Shikhmurzaev model. High velocity range of the triple line is considered – for the capillary flows in tubes for the droplet impingement time dependent flows in capillary tubes (accelerated, decelerated). Kistler model describes accurately θ_d in case of hydrophilic surfaces in low range of Ca number. When wettability is altered the Kistler model seems to become invalid. This project will concern wide range of surface wettability level. Phenomenon of the dynamic interaction a water droplet with any surface is essential in many industrial applications such as ink printing, coating, anti-icing or internal flows. Some of them require high level of wettability while others require easiness of the water repel. Recent development allows to design and manufacture surfaces characterised by wide range of the macroscopic contact angle. Parameter θ_0 is not enough to set explicit statement which type of the droplet impact or the flow scenario will take place. On the other hand, relation between the dynamic contact angle θ_d and the velocity of the triple line V is the most crucial parameter, decisive about scenario of the flow. Also the rate of change of mentioned relation seems to be very important. Despite the fact that, there exist several models for $\theta_d(V)$ relation, the most commonly used of them - Kistler and Shikhmurzaev models, they are not taking into account inertia effects. Nowadays, it is more accessible to conduct numerical simulations of the multiphase flows, hence it is extremely important to state models which can give results that maximally approximate the reality.

9. 2020-2025 NCN SONATA 15 „Od niestabilności hydrodynamicznej do chaotycznej adwekcji i mieszania w przepływach laminarnych", (From hydrodynamic instability to chaotic advection and laminar mixing), dr inż. Stanisław Gepner.

The intention of the proposed project is to study flow dynamics and various hydrodynamic instability mechanisms in the case of flow through a channel whose walls are subject to geometric modifications in the form of large-scale corrugations. The research tasks planned in the project will be based on methods of hydrodynamic stability theory, methods adopted from theory of dynamical systems and used for characterization and onset of chaotic advection. The problem of mixing quantification will be approached from the perspective of stirring (intensification of mechanical mixing) in the Lagrangian framework, via investigation of strange eigen modes of the advection-diffusion operator used to estimate upper limits on the rate of mixing and via the classical norm-based approach.
The experimental part of the project will make use of currently available infrastructure and equipment purchased or manufactured in the scope of the proposed project. Flow measurements will be performed using particle image velocimetry (PIV), laser Doppler anemometry (LDA) and fluorescent dye visualization techniques. The experimental set-up is 3D printed and later CNC machined. It is planned to use materials that have same refraction coefficient as the working fluid (e.g.: glycerine and glass) to allow for visual measurements that are free of optical distortion.
The results of the project will significantly contribute to the development of knowledge in hydrodynamic stability, particularly in the field of linear and nonlinear stability theory of laminar internal flows. The implementation of the project will also contribute to the development of methods for analysing the efficiency of mixing processes in laminar flows, primarily by developing new or appropriate

adaptations of existing quantitative criteria/measures. Despite the purely basic nature of the research, the results of the project will shed light on future developments in laminar mixing technology and equipment.

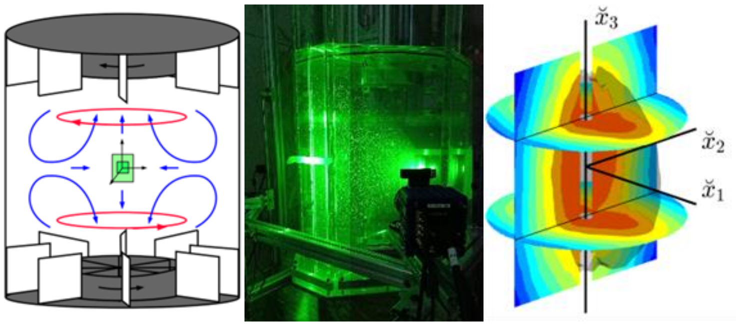




Experimental setup during PIV measurements (left) and main flow features past the bifurcation point (right)

10. 2021-2023 NCN POLS (Norwegian Fundings) „Badanie wielkoskalowych struktur w turbulentnym wirowym przepływie von Kármána z przegrodami" (Investigation of large structures in the von Karman swirling flow), dr inż. Paweł Baj.

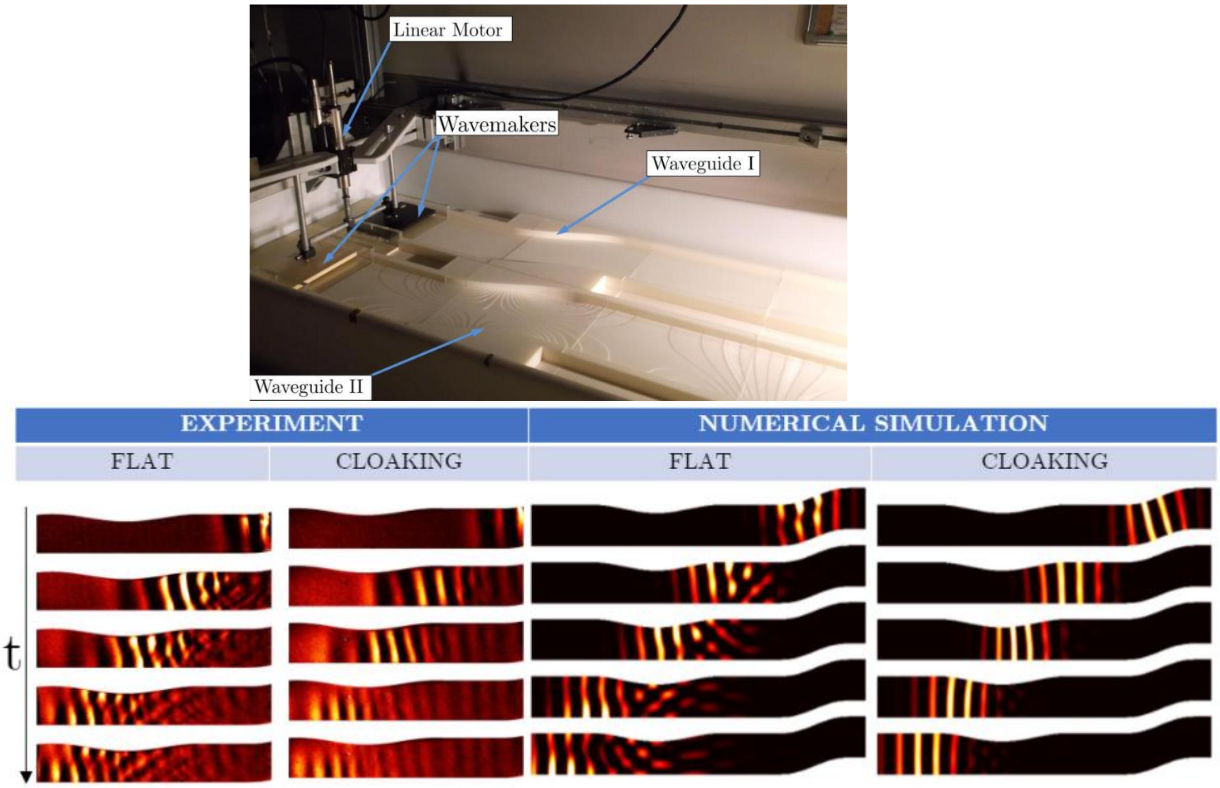
The project aims to explore the properties of turbulent von Karman swirling flow (VK flow). This flow is canonical in turbulence research and can be briefly described as flow within a vessel closed from both sides with impellers spinning in opposite directions. The project focuses on a recently observed low-frequency, large-scale motion (LSM) present in such a configuration. This feature is the strongest close to the vessel centre, where it accounts for more than half of the turbulence energy, and weakens progressively away from the centre. An experimental facility, suitable for the particular conditions of the project, was designed, built and equipped. In particular, it allows for the application of Particle Image Velocimetry, which is the primary experimental technique used within the project.
The research goals are to address the following four questions considering the studied flow feature: (i) is this phenomenon reproducible in different facilities, (ii) how sensitive is it to the history of the flow, (iii) how sensitive is it to the geometry of the vessel, (iv) can it be controlled via different stirring strategies. Two main stirring approaches are considered here, modulated stirring and random stirring.



Schematic of the von Karman flow (left), the experimental facility - PIV measurements (central), contours of velocity fluctuations energy associated with the LSM (right).

11. 2021-2024 NCN SONATA 16 „Bathymetry designs in water waves systems - is nature more efficient than a human?”, dr inż. Tomasz Bobiński.

Nature is probably the main source of inspiration for scientists. Deep understanding of patterns observed in surrounding environment can lead to better designs of products and constructions. The reason for this is the fact that evolution is typically producing the optimized response to external conditions. Chicken bone, having optimized external shape and internal architecture with respect to minimum weight and maximum strength, is one of the examples. Shape adaptation is also visible in case of trees. Depending on the wind loading, the optimal shape of tree’s cross-section might be provided by adaptive growth that fairly distributes the load (axiom of uniform stress)- there are no zones with locally excessive stresses nor regions not fully loaded. The evolution of shape can be observed in multiple natural systems. One of them is meandering river, which has attracted the world’s greatest thinkers. Morphodynamics of this type of systems is governed by the interaction between erodible walls and sediment-carrying fluid. River bed can be mobilized by a shear stress exerted onto the bed by water flow. When the flow carries large quantity of sediment then abrasion can enhance this effect. The magnitude of shear stress is governed by local water velocity. River shape is slowly evolving in time together with the flow and bottom topography. Curvature of the river shape is altering the flow in such a way that there are regions characterized by higher velocity, where the sediment is flushed away resulting in locally larger depth. In the regions, where the flow is slower the depth is smaller. This process renders typically smoothly varying bathymetry. In this research project we focus on the propagation of surface water waves in such system. From the viewpoint of surface waves, meandering river can be considered as a waveguide with spatially varying refractive index that depends on local water depth. By varying water depth one can alter the propagation of waves. Meanders of the waveguide can be considered as waveguide defects that enhance scattering of waves compared to a straight waveguide. Through proper design of bottom topography one can render these defects invisible to the incident waves can be perfectly transmitted despite the defects. Remarkably, bathymetry rendered by fluvial processes in meandering river is very similar to a specially designed bed that hides/cloaks defects of a meandering waveguide. The main objective of this research project is to answer the question whether natural changes occurring in bottom topography of meandering rivers can enhance transmitted energy flux with respect to surface water waves, and how this enhancement compares with human-designed bathymetry, or in other words, can human be more efficient? Can we learn from nature? To answer this question we will compare propagation of surface water waves in different waveguide geometries with bathymetries that were specially designed to hide the defects and bathymetries generated ”naturally” by the flow. The project includes performing experiments and numerical simulations.



Top: Experimental setup. Bottom: the wave packet temporal evolution within two waveguides: (i) with flat bottom and (ii) cloaking bathymetry (designed through conformal mapping).

12. 2022-2026 NCN OPUS 21 „Wpływ gradientu ciśnienia i przepływu dużej skali na przejście do turbulencji” (Effect of pressure gradient and large-scale-flow on transition to turbulence), dr inż. Łukasz Klotz.

Turbulence is a ubiquitous phenomenon commonly encountered in nature and in engineering applications, ranging from geophysical flows to flows around an airplane wing or within industrial pipelines. From an experimental perspective, turbulence is adverted by the bulk flow that flushes away turbulence out of the test section and, as a result, only finite time observations are possible. One possibility to solve this problem is to create the base flow with zero mean bulk velocity to keep the turbulent structures stationary in space and study their dynamics for an arbitrarily long time. During this project, two different experimental techniques will be used. With flow visualizations, turbulent and laminar regions will be optically detected and characterized statistically. With Particle Image Velocimetry (PIV), velocity fields will be measured to gain additional information about the dynamics of typical turbulent structures.

Selected projects funded by EU

- 2009-2012 EU Project, SCP7-GA-2008-218626, FLOWHEAD "Fluid Optimisation Workflows for Highly Effective Automotive Development Processes", prof. Jacek Rokicki.
- 2010-2014 EU Project, FP7-AAT-2010-265780, IDIHOM "Industrialisation of High-Order Methods Top-Down Approach", prof. Jacek Rokicki.
- 2011-2016, EU Project, ESPOSA "*E*fficient Systems and Propulsion form Small Aircrafts" project coordinator at WUT Prof. Z Goraj, project coordinators at Division of Aerodynamics: prof. J. Rokicki, prof. Slawomir Kubacki.
- 2013-2016 EU Project, FP7-AAT-2013-RTD-1, UMRIDA "Uncertainty Management for Robust Industrial Design in Aeronautics", prof. Jacek Rokicki, prof. Jacek Szumbarski.
- 2025-2026. European Space Agency (ESA). Numer projektu 4000146370/24/NL/RK. "Martian Re-Entry Flows over Aerodynamically Rough Surfaces" (Przepływy wokół powierzchni chropowatych uzyskiwanych podczas wejścia w atmosferę Marsa). prof. Sławomir Kubacki.

Selected commercial projects

1. 2019-2021 "Wykonanie badań eksperymentalnych wyznaczających oddziaływanie wiatru na elewację i konstrukcję budynku wieżowego BELLONA TOWER o zwiększonej wysokości do 175m i zmienionym kształcie budynku oraz wpływ budynku na komfort użytkowników tego budynku, zlokalizowanego przy ul. Grzybowskiej w Dzielnicy Śródmieście m.st. Warszawy" dla Projekt Polsko Belgijska Pracownia Architektoniczna Sp. z o.o., prof. Jacek Szumbarski.
   English: Experimental determination of the wind loads on the building BELLONA TOWER (175 m) and its impact on the pedestrian's comfort.
2. 2019-2022 „Wykonanie badań eksperymentalnych wyznaczających oddziaływanie wiatru na elewacje i konstrukcję budynku wieżowego CHOPIN TOWER o wysokości H =126m, oraz wpływ budynku na komfort wiatrowy przechodniów w jego otoczeniu i komfort użytkowników tego budynku, zlokalizowanego przy ul. Wroniej (róg Grzybowskiej) w Dzielnicy Śródmieście m.st. Warszawy" dla Projekt Polsko Belgijska Pracownia Architektoniczna Sp. z o.o., prof. dr hab. inż. Jacek Szumbarski.
   English: Experimental determination of the wind loads on the building CHOPIN TOWER (126 m) and its impact on the pedestrian's comfort.
3. 2022 „Badania aerodynamiczne kolarzy torowych wraz z opisem wyników" dla Polskiego Komitetu Olimpijskiego, mgr inż. Bartosz Olszański.
   English: Aerodynamic investigations of race track cyclists (ordered by Polish Olympic Committee).
4. Since 2016 - commercial research for PHILIPS division of R&D of the street lamps oriented on aerodynamic loads measurements. The aim of research is

measuring aerodynamic forces on lamps and resistance on high velocity up to 140km/h

5. 2017-2018 - commercial research for Institute of Aviation in Warsaw, of the gyrocopter oriented on the aerodynamic characteristics measurements. The aim of research was to find the influence of elements like the landing gear and the stabilizer setups.

4. Relevant achievements

1. Piechna J., Kurec K., Remer M. et al.: Układ do tłumienia drgań nadwozia pojazdu w czasie szybkiej jazdy i tylny płat dociskowy z aktywnymi elementami aerodynamicznymi, Wynalazek, Numer zgłoszenia (w pierwszym kraju zgłoszenia powyżej): P.426981, Numer patentu/prawa: PL 239050.
   English: Vibration damping system for vehicle body during high-speed driving and rear pressure wing with active aerodynamic elements. Invention, Application number (in the first country of filing above): P.426981, Patent/Right Number: PL 239050.
2. Piechna J., Laube T., Piechna A.: Rotacyjny naddźwiękowy silnik cieplny z komorą spalania z wirującą falą detonacyjną o zwiększonej sprawności , Wynalazek, Numer zgłoszenia (w pierwszym kraju zgłoszenia powyżej): P.430727, Numer patentu/prawa: PL 238626
   English: Rotary supersonic combustion chamber heat engine with rotating detonation wave with increased efficiency. Invention, Patent/Right Number PL 238626
3. Piechna J., Kindracki J., Piechna A. et al.: Rotacyjny naddźwiękowy silnik cieplny z komorą spalania z wirującą falą detonacyjną, Wynalazek, Numer zgłoszenia (w pierwszym kraju zgłoszenia powyżej): P.430728, Numer patentu/prawa: PL 238627 English: Rotary supersonic combustion chamber heat engine with rotating detonation wave. Invention, patent/right PL 238627.
4. Piechna J.: Uszczelnienie nośnej poduszki gazowej pojazdu kolei próżniowej, Wynalazek, Numer zgłoszenia (w pierwszym kraju zgłoszenia powyżej): P.425924, Numer patentu/prawa: PL 236112 English: Sealing of the carrier gas bag of a vacuum railway vehicle. Invention, patent/right PL 236112.
5. Mueller N., Piechna J., Sun G. [i in.]: Wave disc engine apparatus , Invention, Number patent/right: US 9856791
6. WUT Rector’s 1st-degree team award for scientific achievements in 2021 for prof. J. Piechna and dr M. Remer.
7. In 2021, Dr. Tomasz Wacławczyk was awarded the Scientist of the Future award by the chapter of the Intelligent Development Forum (FIR). During the conference, FIR presented its work on modeling multiphase flows in the context of their use in industry.

5. Selected relevant publications

1. Kurec Krzysztof, Olszański Bartosz, Gumowski Konrad, Klamka Michał, Remer Michał, Piechna Janusz, Kubacki Sławomir: **Air curtain as a SARS-CoV-2 spreading mitigation method in a small aircraft cabin**, Proceedings of the Institution of Mechanical

Engineers Part G-Journal of Aerospace Engineering, SAGE Publications, 2023, s. 1-25, DOI:10.1177/09544100231153703
2. Broniszewski Jakub, Piechna Janusz: **Fluid-Structure Interaction Analysis of a Competitive Car during Brake-in-Turn Manoeuvre**, Energies, vol. 15, 2022, s. 1-16, DOI:10.3390/en15082917
3. Piechna Janusz, Kurec Krzysztof, Broniszewski Jakub, Remer Michał, Piechna Adam, Kamieniecki Konrad, Bibik Przemysław: **Influence of the Car Movable Aerodynamic Elements on Fast Road Car Cornering**, Energies, vol. 15, nr 3, 2022, s. 1-28, DOI:10.3390/en15030689
4. Piechna Janusz: **A Review of Shock Wave Compression Rotary Engine Projects**, Energies, vol. 15,2022, s. 1-35, DOI:10.3390/en15249353
5. Gałecki Jakub, Szumbarski Jacek: **Adjoint-based optimal control of unsteady incompressible flows with concvective-like energy-stable open boundary conditions**, Computers & Mathematics With Applications, vol. 106, 2022, s. 40-56, DOI:10.1016/j.camwa.2021.12.004
6. Kurec Krzysztof, Olszański Bartosz, Gumowski Konrad, Klamka Michał, Remer Michał, Piechna Janusz, Kubacki Sławomir: **Air curtain as a SARS-CoV-2 spreading mitigation method in a small aircraft cabin**, Proceedings of the Institution of Mechanical Engineers Part G-Journal of Aerospace Engineering, SAGE Publications, 2023, s. 1-25, DOI:10.1177/09544100231153703
7. Klotz Łukasz, Lemoult Grégoire, Avila Kerstin, Hof Björn: **Phase Transition to Turbulence in Spatially Extended Shear Flows**, Physical Review Letters, American Physical Society, vol. 128, nr 1, 2022, s. 1-5, DOI:10.1103/physrevlett.128.014502
8. Di Vaira Nathan J., Łaniewski-Wołłk Łukasz, Johnson Jr. Raymond L., Aminossadati Saiied M., Leonardi Christopher R.: **Influence of particle polydispersity on bulk migration and size segregation in channel flows**, Journal of Fluid Mechanics, vol. 939, 2022, s. 1-32, DOI: 10.1017/jfm.2022.166
9. Gruszczyński Grzegorz, Łaniewski-Wołłk Łukasz: **A comparative study of 3D cumulant and central moments lattice Boltzmann schemes with interpolated boundary conditions for the simulation of thermal flows in high Prandtl number regime**, International Journal of Heat and Mass Transfer, vol. 197, 2022, s. 1-16, DOI:10.1016/j.ijheatmasstransfer.2022.123259
10. Yadav Nikesh, Gepner Stanisław: **Slowing down convective instabilities in corrugated Couette Poiseuille flow**, Journal of Fluid Mechanics, nr 950, 2022, s. 1-28, DOI:10.1017/jfm.2022.805
11. Baj Paweł, Portela F. Alves, Carter D.W.: **On the simultaneous cascades of energy, helicity, and enstrophy in incompressible homogeneous turbulence**, Journal of Fluid Mechanics, vol. 952, 2022, s. 1-28, DOI:10.1017/jfm.2022.912
12. Gepner Stanisław, Yadav Nikesh, Szumbarski Jacek: **Secondary flows in a longitudinally grooved channel and enhancement of diffusive transport**, International Journal of Heat and Mass Transfer, 2020, vol. 153, s.1-11. DOI:10.1016/j.ijheatmasstransfer.2020.119523
13. Gepner Stanisław, Floryan J.M. : **Use of Surface Corrugations for Energy-Efficient Chaotic Stirring in Low Reynolds Number Flows**, Scientific Reports, 2020, vol. 10, nr 1, s.1-8, Numer artykułu:9865. DOI:10.1038/s41598-020-66800-5
14. Kizilova Natalya, Sauermoser M., Kjelstrup S. [i in.]: **Fractal-like flow-fields with minimum entropy production for polymer electrolyte membrane fuel cells**, Entropy, 2020, vol. 22, nr 176, s.1-23. DOI:10.3390/e22020176

15. Sauermoser M., Pollet B.G., Kizilova Natalya [i in.]: **Scaling factors for channel width variations in treelike flow field patterns for polymer electrolyte membrane fuel cells - An experimental study**, International Journal of Hydrogen Energy, 2021, vol. 46, s.1-15. DOI:10.1016/j.ijhydene.2021.03.102
16. Liu T., Semin B., Klotz Łukasz [i in.]: **Decay of streaks and rolls in plane Couette–Poiseuille flow**, Journal of Fluid Mechanics, 2021, vol. 915, s.1-21. DOI:10.1017/jfm.2021.89
17. Klotz Łukasz, Pavlenko A. M., Wesfreid J.E.: **Experimental measurements in plane Couette–Poiseuille flow: dynamics of the large- and small-scale flow**, Journal of Fluid Mechanics, 2021, vol. 912, nr A24, s.1-31. DOI:10.1017/jfm.2020.1089
18. Marchlewski Krzysztof, Łaniewski-Wołłk Łukasz, Kubacki Sławomir: **Aerodynamic Shape Optimization of a Gas Turbine Engine Air-Delivery Duct**, Journal of Aerospace Engineering, 2020, vol. 33, nr 4, s.1-12. DOI:10.1061/(ASCE)AS.1943-5525.0001157
19. Rarata Zbigniew, Dacko Adam, Polak Szymon [i in.]: **Vibro-acoustic response of spacecraft instrument subjected to diffuse sound field: Numerical simulations and experimental verification**, Applied Acoustics, 2021, vol. 184, s.1-14. DOI:10.1016/j.apacoust.2021.108338
20. Wacławczyk Tomasz: **Modeling of non-equilibrium effects in intermittency region between two-phases**, International Journal of Multiphase Flow, 2021, vol. 134, s.1-20. DOI:10.1016/j.ijmultiphaseflow.2020.103459

Aircraft Design Division

Research interest

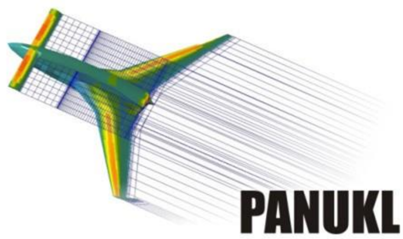
There are three research teams working within Aircraft Design Division. They are involved in:

- Aircraft design research
- Aerospace numerical analyses
- Aircraft composite structures investigations

Research laboratories

Aircraft Design Department uses the following research infrastructure:

- commercial computer-aided design tools CAD/CAM (NX Unigraphics)
- commercial numerical tools for the analysis of:
  - aerodynamic characteristics (potential flow methods, Euler's methods)
  - aircraft flight mechanics
  - structures strength (Ansys, Nastran)
  - mechanism operation
- proprietary software, including:
  - aerodynamic analysis software implementing the low-order panel method (PANUKL)
  - export of numerical model for FEM analysis (integration with Calculix)
  - software tool for mass analysis of an aircraft's structure
  - dynamic stability analysis of an aircraft (stability, simulation, and control) – SDSA
  - numerical optimisation software
  - software for propellers design
  - integration of in-house tools with the commercial software ANSYS



- strength laboratory
  - strength test stand for full-size aircraft tests in elevated temperature (up to 60°C)
  - INSTRON strength testing machine with 10 kN and 200 kN load cells, and a

set of extensometers
  - ElectroPlus machine with 3kN load cell for fatigue testing
  - strain measurement systems, including DIC and strain gauge measurement system
  - linear position sensors
  - OmniScan MX2 Phased Array
  - SYLES S-Line-400 interrogator
- mechanical workshop allowing small aircraft assembly
- bonding laboratory allowing small-batch manufacture of composite components
  - 4m x 1m x 8 m oven for curing polymer composites at temperatures up to 200°C,
  - vacuum pumps
  - temperature and pressure recorders
  - hot bonder with a set of electric heated blankets, thermocouples, and a vacuum system
  - portable system for composite material removal,
- processing workshop allowing CNC milling and lathing, electro-erosive processing and 3D printing of polymers and metals
  - AVIA X-5 1000/500 five-axis machining centers
  - 3D printers: (Fortus 450MC, Orleas Creator)
- access to aerodynamics laboratory
- access to Przasnysz airfield with flight test infrastructure

Key research project

- Flying laboratory for electric propulsion testing at various altitudes of flight (NCN, 2022-2026)

- Design and development of a flying research platform to verify the concept of an unmanned aircraft with hybrid propulsion

- Further development of PW-6 glider – development of PW-X10 and PW-X20 flying laboratories (Glider Factory „JEŻÓW, 2022-2023)Participation in the design, manufacture, testing, and certification processes of the ORLIK unmanned aerial vehicle (2020–2023)

- Design and development of a mid- and long-range unmanned aerial vehicle dedicated to carry loads or measurement equipment (Smart Growth Operational Programme, Spectre Solutions Sp. z o.o., 2018–2021)

- Design of a new fuselage for an aerobatic glider with an FES drive system (Glider Factory „JEŻÓW”, Smart Growth Operational Programme)

- CENTRELINE – Demonstration of the proof of concept for a ground-breaking approach to synergistic propulsion-airframe integration, the so-called propulsive fuselage concept, (EU, H2020, 2017 – 2020)

- Fuel cell-based Hybrid Drive of a lightweight aircraft (NCBR, 2015 –2019)

- AFLONEXT - Proving and maturing highly promising flow control technologies for novel aircraft configurations to achieve a quantum leap in improving aircraft's performance and thus reducing the environmental footprint, (EU, FP7, 2013-2018)

- MONICA - A new approach to monitoring climate changes in Antarctic ecosystems - development of the PW ZOOM unmanned aerial vehicle and its deployment during an Antarctic expedition to conduct research into the Antarctic ecosystem, (POL-NOR, 2013-2016)

- MOSUPS - Dynamically similar model of joined-wing aircraft (NCBR, PBS1, 2013–2016)

- ESPOSA - Development and integration of novel design and manufacture technologies for a range of small gas turbine engines up to approx. 1000 kW to provide aircraft manufacturers with better choice of modern propulsion units, (EU, FP7, 2011-2016)

- Development of assumptions, design, and prototype manufacture of a new-generation TSA hybrid aircraft – dynamic stability analysis (ATP AVIATION Sp. z o.o., 2013–2015)

- Development of non-adhesive metal-composite lock joint for introducing concentrated loads into primary layered structures made of carbon/epoxy prepregs (NCBR, 2012–2015)

- Development of an out-of-autoclave manufacturing process for composite aircraft structures made of carbon/epoxy prepregs (NCBR, 2012–2015)

- Tests of a micro UAV with a LEX and in a pusher propeller configuration (NCN, Preludium, 2012–2014)

- Nowa koncepcja sterowania samolotem wysokomanewrowym, (NCN, Preludium, 2011-2013)

- PPLANE - systematic approach to radical and novel ideas for Personal Air Transport System, (EU, FP7, 2009-2012)

- New-generation multi-functional two-seater motor glider (Ministry of Science and Higher Education, 2008–2012)

- SimSAC - Simulating Aircraft Stability and Control Characteristics for Use in Conceptual Design, (EU, 6th Framework Programme, 2006–2010)

- Unmanned Airplanes with strake wing (Ministry of Science and Higher Education, 2009–2012)

- NACRE - New aircraft concepts research, (EU, FP6, 2005-2010)

- Lightweight unmanned aerial vehicle (technology demonstrator vehicle) for surveillance in civilian applications – SAMONIT (Ministry of Science and Higher Education, 2007–2009)

- CAPECON - aimed to advance the utilisation of safe and low cost Unmanned Air Vehicles (UAVs) in the civilian commercial sphere, (EU, FP5, 2002-2005)

Relevant achievements

- Implementation of the proprietary software developed by team in the teaching process (University of Brighton)
- Application of software modules for conceptual studies (Airbus Poland)
- CENTRELINE – Consortium with 9 partners from Germany, France, Sweden, Netherlands, United Kingdom
- AFLONEXT – Consortium of 40 partners from 15 countries.
- MONICA - Consortium with partner from Norway
- ESPOSA – Consortium of 44 partners from 15 countries.
- PPLANE – Consortium of 44 partners from 11 countries.
- SimSAC – Consortium of 13 partners from 9 countries.
- NACRE – Consortium of 36 partners from 10 countries.

- CAPECON - Consortium of 19 partners from 8 countries.
- Design of the airframe of the first Polish multifunctional two-seater motor glider with electric propulsion (AOS-71), followed by prototype test flights and placing into service (KB/68/12823/IT1-B/U/08, 2008-2012); further development (AOS-H2) of this design with a fuel cell (PBS3/A6/24/2015, 2015-2018)

- Prime Minister's 1st Degree Team Award for the outstanding scientific and technical achievement: "PW-6 two-seater new-generation training glider"; implementation of the glider into batch production and support for its further development (Smart Growth Operational Programme 2020); more than 60 gliders have been built and sold all over the world
- PW-5 glider's win in the FAI "world-class glider" competition in 1993; implementation of the glider into batch production and production support (more than 300 gliders have been built and sold all over the world)

Selected relevant publications

Books

- Galiński C., Wybrane zagadnienia konstrukcji samolotów, Wydawnictwa Politechniki Warszawskiej, Warszawa 2020, ISBN 978-83-8156-115-0 https://itlims-zsis.meil.pw.edu.pl/pomoce/BIPOL/Galinski_Wybrane_zagadnienia_konstrukcji_samolotow.pdf
- Galiński C., Wybrane zagadnienia projektowania samolotów, Wydawnictwa Instytutu Lotnictwa, Warszawa 2016, ISBN: 978-83-63539-31-3, eISBN: 978-83-63539-36-8, https://ilot.lukasiewicz.gov.pl/Cezary_Galinski_Wybrane_zagadnienia_projektowania_samolotow.pdf

Papers

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Division of Automation and Aeronautical Systems

Research Interests

The research team in the Division of Automation and Aeronautical Systems conducts research into various aspects of aeronautics, including flight dynamics, control and navigation systems, and simulators. The team is actively involved in scientific activities such as modelling and simulating the dynamics of various mobile platforms, including aircraft, missiles, land vehicles, sea vessels, and spacecraft.

Division staff have designed advanced control methods and algorithms using analytical mechanics to create automatic flight control systems for these platforms. The team has also created simulators that accurately replicate the experience of flying or operating a variety of vehicles and systems.

The team's research activities also include studying navigation methods and systems, as well as complex system-of-systems problems. They study the aeromechanics of rotorcraft and analyse human-machine systems.

The Division of Automation and Aeronautical Systems is committed to advancing the field of aviation through innovative research and development. They are committed to pushing the boundaries of what is possible and shaping the future of flight.

Research Laboratories

The Division of Automation and Aeronautical Systems boasts advanced research and laboratory infrastructure complete with cutting-edge technologies and equipment to support on-going research projects.

The Simulators Lab provides advanced research capabilities in **the simulation of moving object and onboard system**. It supports student education through individual projects and diploma theses in the broad field of simulation.

Research projects at the lab include:

- **Modelling** the dynamics of moving object, control system operation, and onboard systems;
- **Testing** these systems (hardware and software) in HIL/SIL environments;
- **Analysing** human factors and human-machine interfaces.

The Simulators Lab is equipped with a **Boeing B737 MAX simulator** (a result of collaboration with the Boeing Company), as well as a **PZL SW-4 helicopter simulator**, and several **unmanned vehicle training devices**.

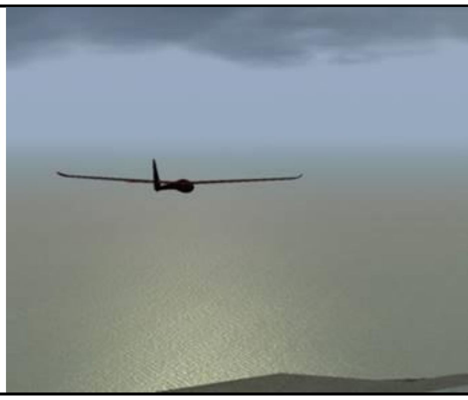
	
Leonardo PZL SW-4 simulator	Boeing B737 MAX simulator

The Laboratory of Autonomous Moving Objects is at forefront of research into the latest advances in autonomous technologies and artificial intelligence. The laboratory also supports education of students in the broad field of unmanned aerial vehicle (UAV) and unmanned ground vehicle (UGV) systems.

Research projects at the lab include:

- **Flight tests** of small UAVs and UGVs;
- **Design** and HIL/SIL testing of navigation and automatic control systems;
- **Analysing** human factors and human-machine interfaces.

The laboratory has a fleet of unmanned rotorcraft and ground vehicles. It also provides an integrated vision navigation system, as well as software for designing and testing navigation and automatic flight control algorithms.

	
DAAS unmanned helicopter	DAAS UAV simulator

The Division has a fleet of small unmanned rotorcraft, aeroplanes, and ground vehicles. It also uses FLIGHTLAB and MATLAB, simulation and design software designed specifically to model the dynamics of flying vehicles and to design navigation and control systems.
The control and navigation laboratories are equipped with modern sensors, such as GNSS receivers, inertial navigation sensors, various types of magnetometers, image-processing cameras, an air data computer and PLC controllers.

Key Research Project

The Division of Automation and Aeronautical Systems has been involved in a wide range of projects, including international industry collaborations and national initiatives. These projects have advanced cutting-edge research and development in areas such as unmanned systems, flight control systems, and aircraft concepts. Below are some of the division's major projects. For several years, the DAAS research group has focused on developing various projects related to Unmanned Aerial Systems. These projects have included transferring technology to industry and creating systems and tools for monitoring and the widespread use of UAVs in everyday activities, with the aim of improving companies' technological processes. International projects sponsored by the industry:

- OpUSS (Optimization of Unmanned System of Systems),
- Student projects sponsored by The Boeing Company.

Projects of the 5/6/7 Framework Program and the H2020 Program of the European Union:

- SEA-AHED (Simulation Environment and Advisory System for On-board Help, and Estimation of Manoeuvring Performance During Design),
- ADFCS II (Affordable Digital Fly-By-Wire Flight Control Systems for Small Commercial Aircraft - Second Phase),
- NICE-TRIP (Novel Innovative Competitive Effective Tilt Rotor Integrated Project),
- NEFS (New Track Integrated Electrical Single Flap Drive System),
- NACRE (New Aircraft Concepts Research),
- TALOS (Transportable Autonomous patrol for Land bOrder Surveillance system),
- CAPECON (Civil UAV Applications & Economic Efficiency of Potentate Configuration solutions),
- ACROSS (Advanced Cockpit for Reduction of Stress and Workload),
- ONION (Operational Network of Individual Observation Nodes),
- NATO project "Virtual Reality Co-Simulation Environment for safe Multi-Domain Mobility".

Polish national projects:

- MAST - Digital twin of masts as an innovative inventory service using unmanned aerial vehicles and artificial intelligence.
- Development of advanced autonomous drone swarm technology for the digital security of critical infrastructure, ad hoc inspection applications and innovative entertainment.
- An Innovative Autonomous System for Monitoring the Railway Infrastructure with the use of Artificial Intelligence and Unmanned Aerial Vehicles (UAVforRail),
- Development of an innovative docking and charging station for Unmanned Aerial Vehicles using RES,
- An Autonomous System For Detecting and Destroying Non-Metallic Mines,
- PROTEUS (Integrated Mobile System Supporting Anti-Terrorist and Anti-Crisis Actions),

- SATSERWIS (Mutual Satellite Navigation System for In-Orbit Servicing and Formation Flight),
- MYSTERY (Aircraft Control System Synthesis Methodology, Taking Into Account High-Risk Situations),
- BPL (Unmanned Land Platforms),
- APN (Autonomous Surface Vessels),
- Development of Missile Control Systems Technology,
- HELIMARIS (Modification of an Optionally Piloted Helicopter for Maritime Mission Performance).

Relevant Achievements

The Division is currently collaborating with numerous academic and industrial partners in Europe and the USA through EU Framework Programmes, national programmes and external contracts. The main partners are: NASA, the Boeing Company, Lockheed Martin, Leonardo PZL Świdnik, General Electric and Thales Alenia Space.
The Division has also begun collaborating with the Brazilian technology institute ITA (Instituto Tecnológico de Aeronáutica).

Selected Relevant Publications

This chapter contains a list of relevant publications selected from those produced by the Division of Automation and Aeronautical Systems. These include books and key papers and conference materials from 2011 onwards. The books cover topics related to the control of nonlinear and mechanical systems, as well as satellite navigation systems. The key papers and conference materials cover topics such as mobile robot motion tracking, vibration analysis in crane systems, optimal control of helicopters, selection of UAV for ground target tracking, supervision of aircraft status , evaluation of helicopter autopilot performance, automated control of various UAS fleets, urban air mobility, control of helicopter during landing on a moving confined platform, and modelling of spacecraft.

List of books:

1. Jarzębowska E., „Dynamika i sterowanie układami mechanicznymi", Wydawnictwo Naukowe PWN, 2021.
2. Jarzębowska E., „Model Based Control of Nonlinear Systems", Modern Mechanics and Mathematics, 2012
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4. Narkiewicz J., „Podstawy układów nawigacyjnych", Wydawnictwa Komunikacji i Łączności, Warszawa 1999.

List of key papers and conference presentations:

1. Kukuryka M., Barciński T., Jarzębowska E.: Experimental study and modelling of the deployment process of a spool-first deployable boom, Nonlinear Dynamics, pp. 1-17, 2025.
2. Sochacki, Mateusz, Antoni Kopyt, Kacper Kaczmarek, and L. Stephens: Urban Air Mobility Traffic Analysis Tool for Testing Various ATM Methods, AIAA SCITECH Forum, AIAA SciTech, 1–10, American Institute of Aeronautics and Astronautics, Inc., 2025.

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Division of Fundamentals of Machine Design

Research interest

Experimental research and tribology

- strength and stiffness properties of composites,
- experimental methods in the construction and testing of machinery and equipment,
- field (optical) methods,
- incremental manufacturing of structural elements and buildings (3DCP).

Risk and reliability

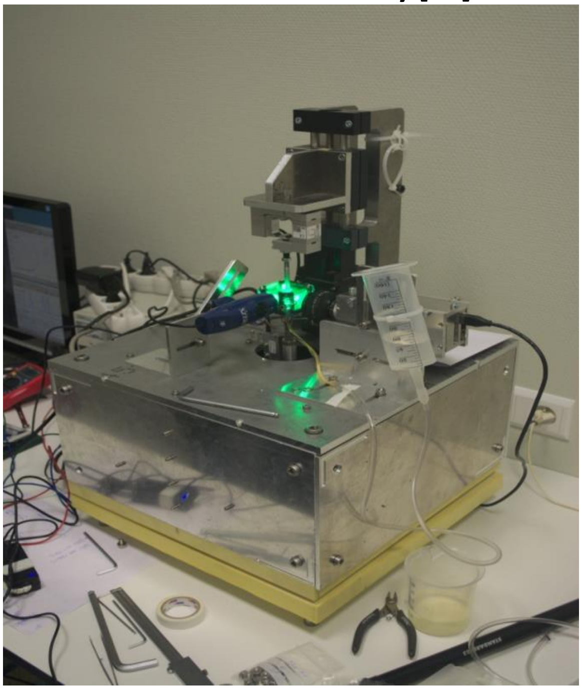
- risk estimation in selected human-technical-environment systems,
- modeling and analysis of occupational risks.

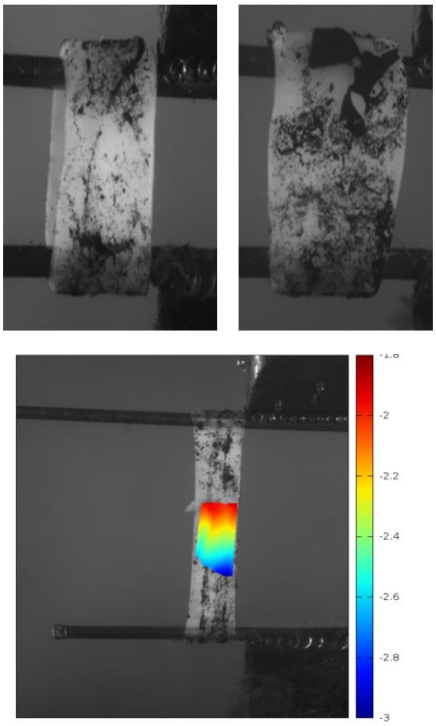
Biomechanics

- biomechanics of impact,
- biomechanics of sport,
- FEM modeling.

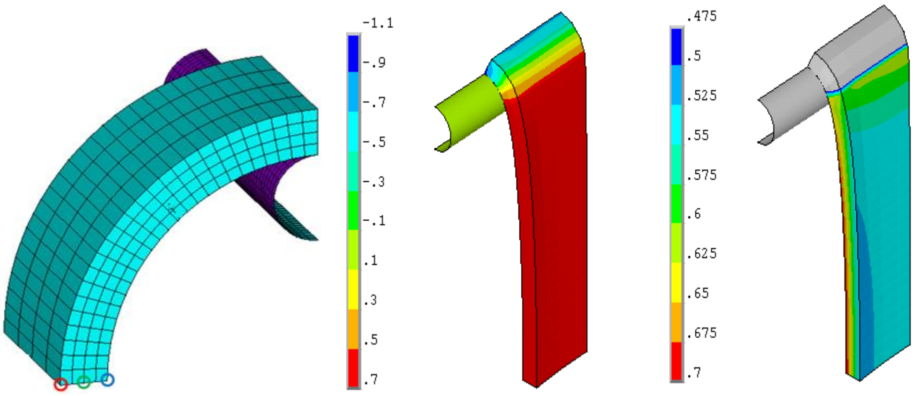
Research laboratories

Soft tissue research laboratory [15]





Experimental testing (DIC strain measurement)



FE modeling

Yacht laboratory

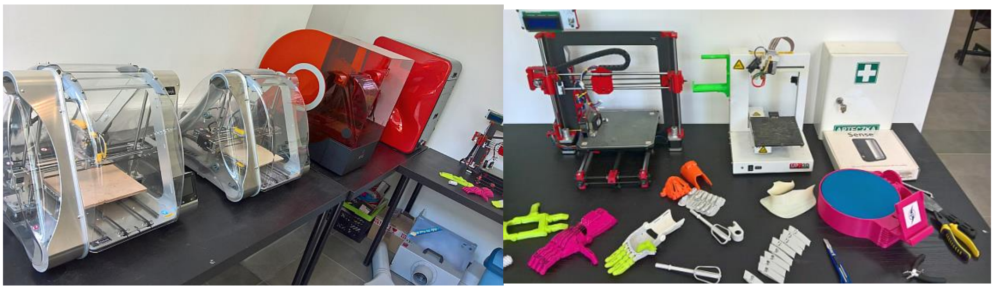
Remote controlled sailing boat used to analyse the mast stiffness influence on the yacht performance.

1:5 scaled hull of the OPEN 30 class

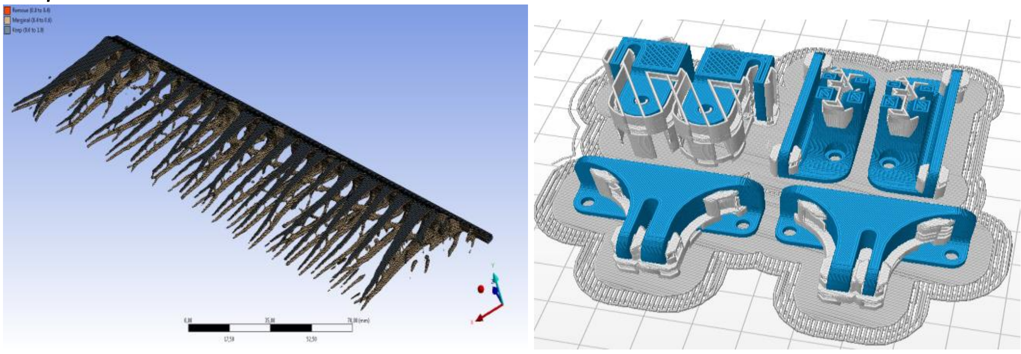
Forces, wind and velocity measurement

Sail shape registration

3D printing laboratory



3D printers



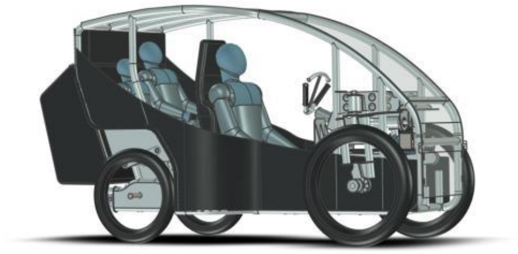
Topology optimization with FEM

Key research project

Division has developed an innovative gantry drive, offering an alternative to the traditional crankset. This solution requires less space, features more favourable dynamic characteristics, and opens new possibilities for the development of compact vehicles with the functionality of passenger cars, as well as watercraft.

Dynamic tests of the gantry drive in comparison with the crankset were carried out on custom-built test stands.

These stands enable the analysis of human–mechanism–environment systems, including user fatigue, and make it possible to determine directions for optimizing systems in which humans constitute the main source of mechanical energy.



As a result of Division work, a cycle with the utility features of a passenger car has also been developed, equipped with the gantry drive and an auxiliary motor (TRL 7). The vehicle was created as a response to the growing problem of transport exclusion. By using aluminium and modern joining techniques, along with the gantry drive, brushless auxiliary motors, and a high-capacity power bank, a construction resembling a microcar has been developed, which, according to current regulations, is classified as a bicycle.

Improving accessibility to culture and activating disabled and socially excluded people

Research project in the Gospostrateg program. The aim of the project is to activate people with disabilities.

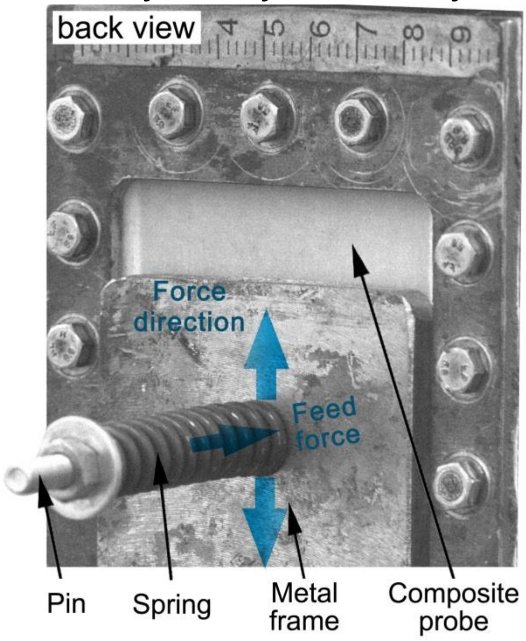
Selected objects of the test stand for the study of tactile reading sensations of spatial objects by blind and visually impaired people

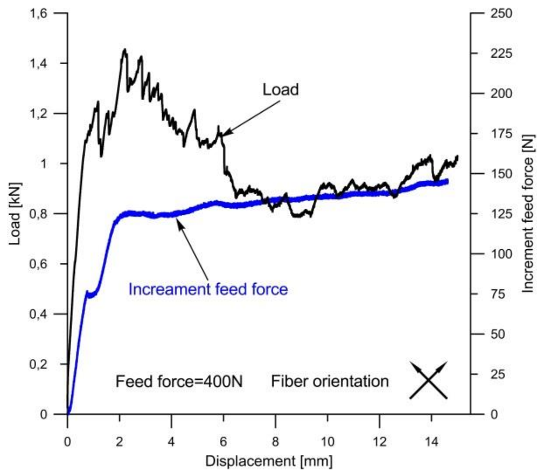
Innovative simulation technologies for evaluating vehicle automation systems in terms of road traffic safety [9, 11]

Mini-simulator stand for testing of Advanced Driving Assistance Systems (ADAS)

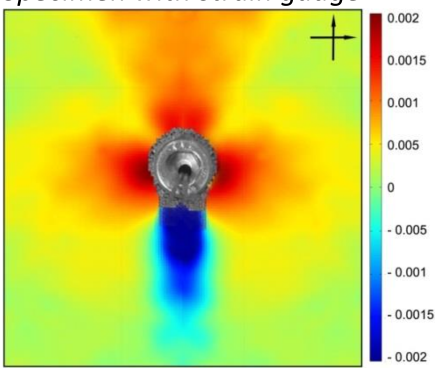
Screens from the testing environment

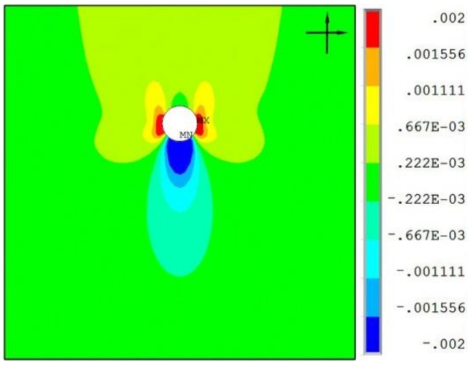
Research of riveted joints in aircraft composite structures [13, 14]





Specimen with strain gauge *Obtained laod displacement curve*





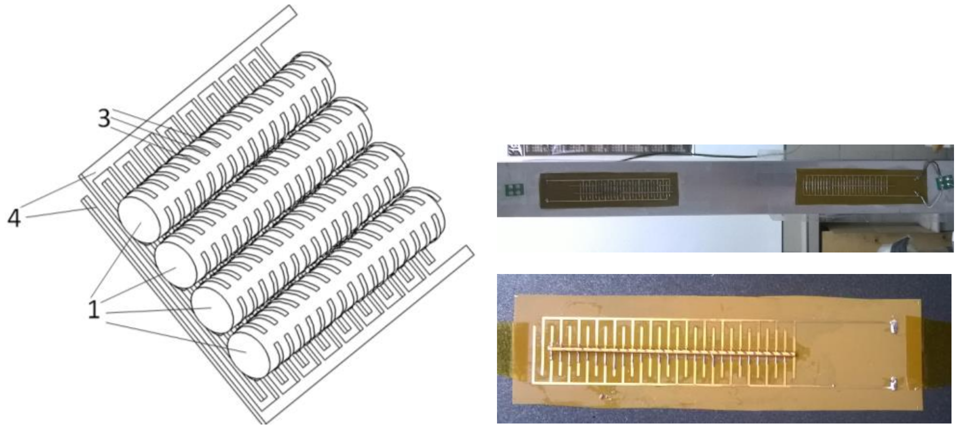
Results – comparison of strain from DIC and FEM

Relevant achievements

Piezo transducer with spiral electrodes

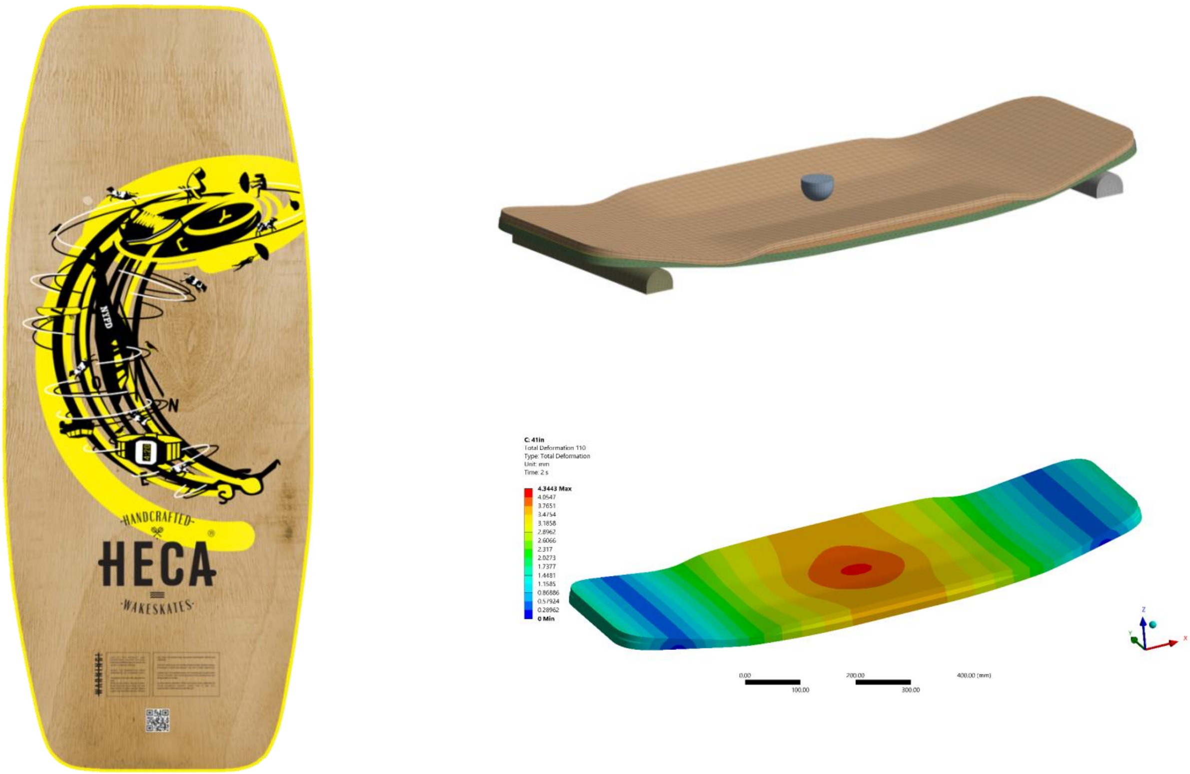
Patent No. 225481

New sensor [18] has good accuracy in the study of deformation. Possibility of application to study low-frequency waveforms, using the new charge amplifier with high impedance input.



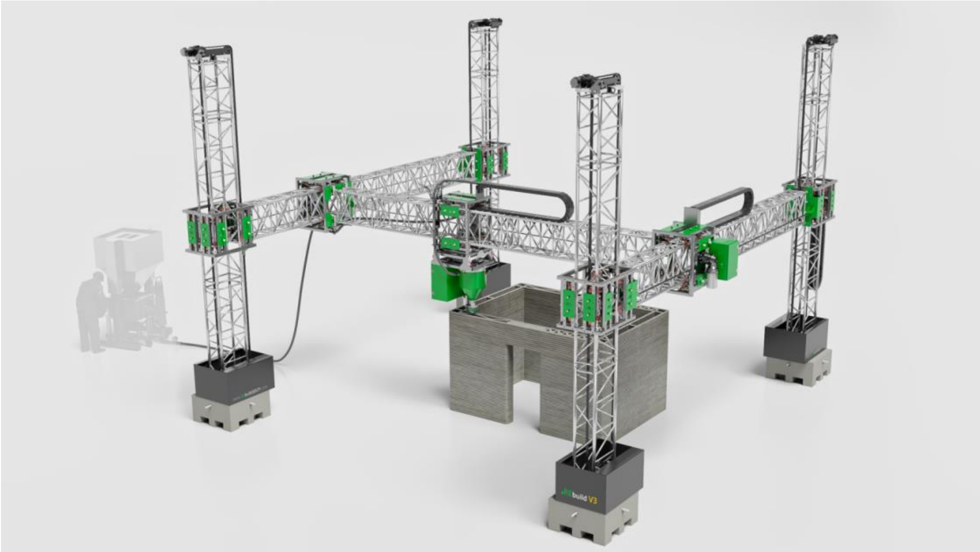
Transducer scheme and single fiber prototypes

Developing a line of innovative wakeskate boards
NCBR-funded implementation research project.
Development of an innovative wakeskate board based on tested and classified board parameters, allowing to reach its best and optimal features.



Final product and FEM analysis

3DCP – 3D Concrete Printing
System for manufacturing reinforced 3DCP prints



3D Printer designed for large-scale projects

First buildnig in Poland printed on site

RUF Guitars
Innovative composite instruments made of Ruffaine - the most advanced, fully adjustable material scientifically designed to get the perfect tone.

The product and Ruffaine in mold

Other information

Division of Fundamentals of Machine Design organizes bianualy Symposium on Experimental Mechanics in memory of prof. Jacek Stupnicki

Selected relevant publications

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Division of Theory of Machines and Robots

Research interest

- *Kinematics and dynamics of multibody systems* – modeling, identification, simulation, and optimization of complex mechanical systems, including systems with friction and redundant constraints.
- *Computational robotics* – advanced methods for trajectory planning, dynamic modeling, and control of manipulator and mobile robots, leveraging high-performance computing for large-scale simulation and optimization.
- *Design of robotic systems and mechanisms* – parallel and medical robots, rehabilitation and assistive devices, humanoids, prostheses, and novel robotic architectures.
- *Artificial intelligence for robotics and automation* – machine learning and neural network–based modeling, computer vision, and intelligent navigation in SLAM environments.
- *Control systems* – design and synthesis of control laws, data-driven modeling and control, and advanced algorithms for optimal and model predictive control (MPC) applied to robotic, multibody, and aerial systems.
- *Biomechanics* – injury and impact analysis, child restraint systems, and passive safety.

Research laboratories

Industrial Robotics Laboratory

Two KUKA LWR4+ robots with KR C2 controllers

Fig. 1 KUKA LWR4+ robots

The KUKA Lightweight 4 robots are kinematically redundant (i.e., seven DOF), have a total weight of less than 15 kG with a range up to 1.5 m. They have have high dynamic performance. Each joint has torque sensors coupled to the harmonic drive, with torque measurement error of less than 0.5%, the low pass filter eliminates the noise. Combination of position and torque sensors allows the implementation of position and impedance control.

<u>KUKA Agilus with KR C4 controller</u>

Fig. 2 KUKA Agilus

The KR AGILUS is our compact six-axis robot that is designed for particularly high working speeds.

Technical data:

- Maximum reach 901.5 mm
- Maximum payload 6 kG
- Pose repeatability (ISO 9283) ± 0.03 mm
- Number of axes 6
- Weight approx. 52 kG
- Cycle time: 150 cycles per minute (path: 25 mm / 305 mm / 25 mm, payload 1 kG)

<u>Fanuc M10iA robot with 2-axis positioner</u>

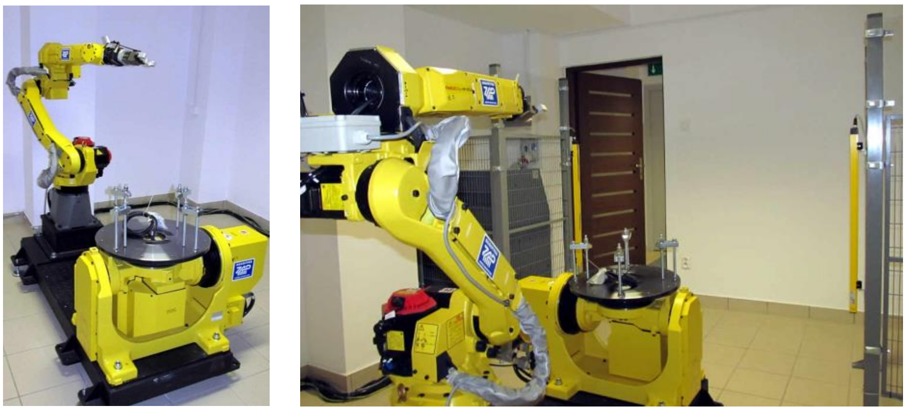


Fig. 3 Fanuc M-10iA

Fanuc M-10iA is a compact structure comparing to the other robots of its class, while maintaining high speed in its axes with very good repeatability. The M-10iA can carry loads weighing up to 10 kG with a horizontal range of 1420 mm.

Fanuc M1iA parallel manipulator with vision system and vacuum gripper

Fig. 4 Fanuc M-1iA

High-speed 6 axes delta robot has a payload 1 kG and a working range 420 mm. iRVision camera allows to locate the parts and the assising software allows to obtain its   precise position and orientation.

Mobile Robotics Laboratory

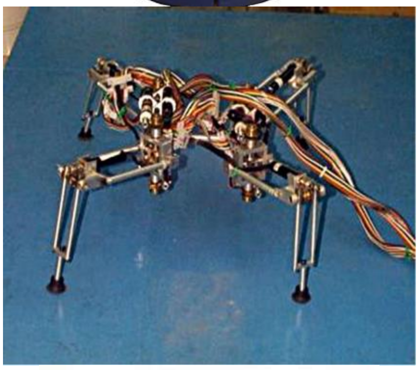
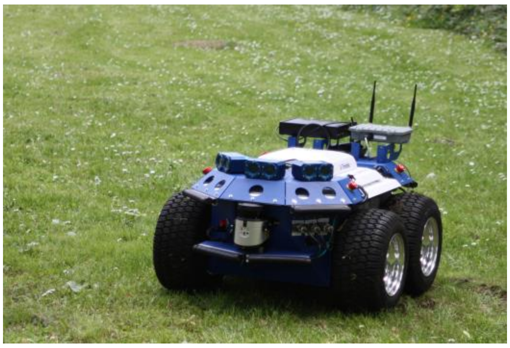
Research on:

- SLAM,
- machine intelligence and autonomy,
- sensor fusion,
- mobile robot navigation,
- path planning,
- robot cooperation,
- motion synthesis,
- humanoid robots design,
- humanoid robots motion generation,
- human-inspired control techniques,

On-board equipment of mobile robots:

- control computers,
- manipulators with grippers,
- on-arm cameras;
- stereo-vision sensors,
- laser distance scanners,
- wireless communication equippment,
- GPS,
- inertial measurement units,
- sonars,
- bumper sensor


RWI

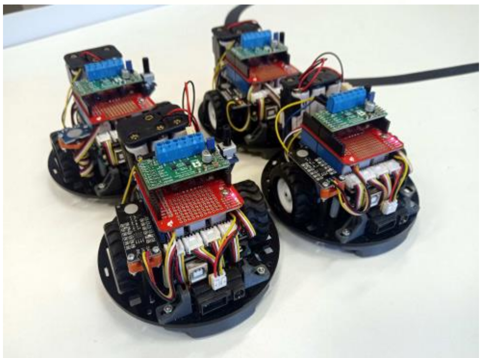
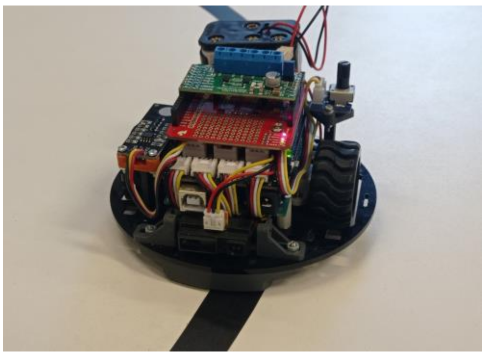




Fig. 5 Mobile Robotics Laboratory equipment

Measurements, Automation and Control Laboratory

Laboratory stands include:

- NI measurement computers (PXI 1078, CompactRIO 9038, myRio 1900) and an assortment of sensors and data acquisition cards,
- high-speed cameras (FASTEC TSCHERMS, PHANTOM 310v) with ancillary equipment
- 3D Smarttech scanner
- PLC test stand (Simatic S7-1200+HMI, Astraada One Compact ECC2100)
- QUANSER research platform
- Maxon EPOS2 testbeds

Fig. 6 Measurement, Automation and Control Laboratory equipment

Vision Systems Laboratory

The laboratory equipment consists of one Basler industrial camera and two LED lights with variable intensity and color temperature (Fig. 7), Jetbot robot with vision system (Fig. 8). The laboratory equipment is used in student research for engineering and master thesis, and laboratory of Digital Image Processing is currently focused on computer vision problems in varying light conditions.

Fig. 7 Two LED lights and a camera — research on the influence of the light condition on object detection (source: Maciej Zieja, The chess pieces detection system of a robot for chess games in changing lighting conditions, engineering thesis, 2023)

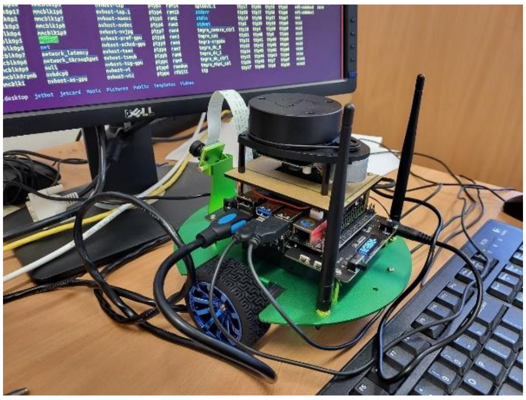


Fig. 8 Jetbot robot with the periphery equipment (Source: own elaboration)

The laboratoty is used to conduct research in the field of segmentation, detection, and tracking of the objects using visual data. Research concerns also color images acquisition like colorimetric calibration, vignetting correction, or image denoising. A part of the research is application of computer vision in robotics using the Robot Operating System (ROS).

Computational environment

A high performance ASUS ESC4000 G4 server is utilized as a hardware platform for running customised simulation algorithms, mainly from the field of multibody system dynamics. The machine is equipped with two Xeon Gold 6242 CPU, 192GB of DDR4 RAM, and 1 Nvidia Quatro RTX600 GPU. It runs Ubuntu Linux. Development toolchains, including GCC, LLVM, and other tools necessary for development are available at hand or installed on demand. The machine is used in research projects, mainly as a development and test platform for parallel simulation and optimization algorithms.

Key research projects

Hamiltonian approach toward efficient modeling of large-scale multibody systems with friction and toward real-time simulations of robotic systems (NCN OPUS 15, 2018-2022)

In the analysis, design, and optimization of numerous mechanical systems, there is a need for automatic modeling and investigation of complex multibody systems with many bodies and degrees of freedom. In this class of systems, multibody modeling methods are widely used in engineering branches and scientific research. The analyzed mechanical or interdisciplinary objects are becoming increasingly complex. The mentioned systems can be frequently found in such areas as robotics (dynamics of manipulators), automotive (testing of car components and complete vehicles), railroad (e.g., traffic safety), defense (e.g., design of tracked vehicles), aerospace (e.g., analysis of unmanned aerial vehicles or their formations). Multibody models are often used in control systems of many mechanical systems, e.g., in robotics. The developed models allow one to predict the behavior of such systems to achieve the desired response. The natural applications of MBS methods also emerge in space and exploratory robotics.

Multibody modeling techniques play a significant and vital role in applications wherein examining phenomena occurring in the existing system is expensive, time-consuming, or very difficult in technical realization. The analysis and simulation of large-scale multibody systems require significant numerical expenses. Simultaneous enforcement of computational efficiency and high-fidelity physical model requirements is sometimes challenging. However, recent studies suggest that using Hamilton's formalism for the description of multibody system behavior may enhance the performance and significantly increase the efficiency of such computations and, in consequence, may reduce specific barriers associated with real-time applications. In addition, fast calculations with parallel computers, equipped with multi-core processors and GPU card arrays, allow one to analyze systems with much greater complexity—with the number of degrees of freedom approaching tens of thousands (biomolecular systems) or even millions of bodies (granular media). The main objective of this project is to develop and investigate highly efficient methods for computer-aided modeling and analysis of complex multibody systems in a unified Hamiltonian approach. The proposed research focuses on three groups of issues in the field of modeling MBS:

- Research objective 1: Developing efficient sequential and parallel algorithms for modeling MBS in the Hamiltonian framework.
- Research objective 2: Research the methods for analyzing complex multi-rigid- or multi-flexible-body systems with friction.
- Research objective 3: Experimental research on complex robotic systems to the extent necessary for verification of the project's theoretical considerations and simulation results.

The results of this project are published in [1], [6], [7], [8].

Efficient indirect optimal control methods for multibody systems (Excellence Initiative, Research University in the field of Artificial Intelligence and Robotics, 2020-2022)

Current problems require engineers to predict how specific parameters or control inputs will affect the behavior of the complex multibody system. In the optimal control or design of MBS, an implicit dependency exists between state and design variables, further adding complexity to the problem. This branch of computer-aided engineering is tightly combined with **sensitivity analysis**, i.e., efficient computation of the derivatives. To this end, various families of methods have been derived, each having its own set of benefits and drawbacks. The **adjoint method** is one of the more interesting methods for systematically calculating the gradient. The concept behind this approach lies in invoking necessary conditions for the minimum of the optimized functional. Once obtained via variational calculus, these conditions constitute the system adjoint to the dynamic equations of motion – an underlying model of the MBS. Solving the adjoint system yields so-called **adjoint variables**, allowing for efficient gradient computation. The adjoint method can be applied to such problems as optimal control, optimal design, or parameter identification.

Furthermore, the indirect optimal control methodology provides offline (potentially online) trajectory generation tools that can be utilized as a feed forward signal in the control loop. A recent research project involved a practical implementation of the adjoint method in a feedback-feed forward control architecture shown in Fig. 9. A mathematical model has been derived, composed of an electromechanical device with a five-bar multibody system and two DC motors with a gear transmission (Fig. 10). Based on the derived outcome, the input control signal and corresponding trajectory predicted by the model were synthesized. Subsequently, these signals are introduced as reference values to the hardware and compared with classical control algorithms.

The block diagram in Fig. 9 presents a model-based control architecture. Symbol $\mathbf{r}$ denotes a reference signal that nominally must be enforced. Accordingly, this signal plays the role of an input to the adjoint-based optimization procedure founded on the mathematical model of the MBS. The optimization algorithm yields a control signal $\mathbf{u}_{\mathrm{ff}}$ (theoretically) capable of carrying out the required maneuver. The response generated by the model for $\mathbf{u}_{\mathrm{ff}}$ is depicted as $\mathbf{y}_{\mathrm{d}}$, becoming the actual reference trajectory for the system. Due to the discrepancy between the model and the plant, and the presence of disturbances $\mathbf{d}$ and measurement noise $\mathbf{n}$, it is required to introduce a feedback loop that generates minor corrections $\mathbf{u}_{\mathrm{fb}}$ during the execution on the hardware.

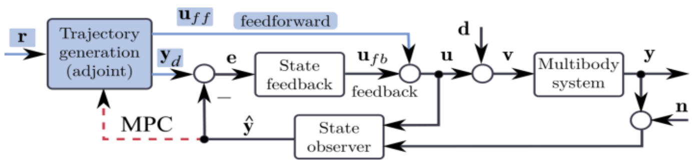


Fig. 9 A feedback-feedforward control architecture

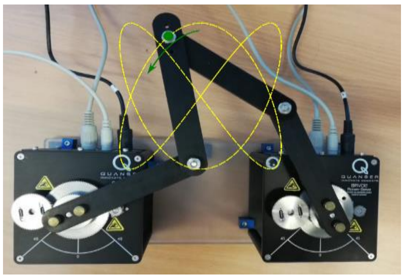


Fig. 10 Two-degree-of-freedom closed-loop robotic system

The results of this project are published in [9], [10].

Physics-Based and Data-Driven Multibody System Models For Prediction and Feed forward Robot Control (submitted as a project to NCN OPUS)

As suggested, the control performance stemming from feedback–feed forward control architecture heavily depends on the quality of MBS models, which predict how control inputs affect the system dynamics. First–principles (e.g., Newton–Euler formalism) and identification techniques can be used to derive multibody or robotic system models. Meanwhile, considerable progress has been achieved using machine learning–based approaches that extract complex dynamical behaviors directly from raw experimental or simulation data.

Moreover, for many robotics systems, the dynamics model derived from first–principles or solely based on data may not be sufficiently accurate, especially in the case of unmodelled nonlinearities (e.g., friction, flexibility). This imprecise model leads to a bad prediction of feed forward control, resulting in significant tracking errors, poor control performances, or even damage to the system. Neither a pure physics–based nor a pure **data–driven** approach can be considered sufficient for multibody/robotic tasks with high–dimensional state spaces and complex interactions.

These observations imply the recent group's interest in advancing understanding of the extent to which data–driven paradigms may be combined with pure physics–based models to simulate MBS and generate optimal trajectories. The available state–of–the–art suggests a knowledge gap in this field. Using its previous experience, the group is pushing its area of expertise to (i) integrate MBS formulations with data–driven techniques, (ii) develop a **hybrid modeling** approach for optimal trajectory generation based on the adjoint method, (iii) assess possibilities of practical applications of the developed hybrid models.

Optimal trajectory planning for redundant manipulators

A kinematically redundant structure increases the dexterity of the robotic manipulator and offers an ability to avoid obstacles and handle singularities. Therefore, redundant robots are well-suited for work in human-centered, cluttered environments. However, planning of the joint trajectory that satisfies the desired end effector trajectory and does not exceed the capabilities of the robot joints is not a trivial task.

The Predictive Quadratic Programming Inverse Kinematics with Scaling (PQPIK-S) designed in this project solves this quandary by combining the inverse kinematics (IK) problem with trajectory scaling and solving them simultaneously. The core of the PQPIK-S is the quadratic programming (QP) problem:

$$min_{\dot{q},\lambda} \frac{1}{2}\gamma_0\left(1-\dot{\lambda}\right)^2 + \frac{1}{2}(\dot{\boldsymbol{q}}-\dot{\boldsymbol{\varphi}})^T\boldsymbol{W}(\dot{\boldsymbol{q}}-\dot{\boldsymbol{\varphi}})$$

w.r.t. $\boldsymbol{J}\dot{\boldsymbol{q}} = \boldsymbol{\nu}\dot{\lambda}$, $\dot{\boldsymbol{q}}_{min} \leq \dot{\boldsymbol{q}} \leq \dot{\boldsymbol{q}}_{max}$, $0 \leq \dot{\lambda} \leq 1$.

The vector $\dot{\boldsymbol{\varphi}}$ defines an additional task for a redundant robot (such as obstacle avoidance), whereas parameters γ_0 and $\boldsymbol{W}$ are used to assign weights to different tasks. The end effector velocity $\boldsymbol{v} = \boldsymbol{\nu}\dot{\lambda}$ is parameterized in terms of virtual time λ, allowing to slow down the desired motion if (and only if) the joint constraints cannot be satisfied in any other way.

Moreover, the QP problem is formulated in such a way that it utilizes the prediction of the future joint states of the manipulator, allowing to begin the trajectory scaling early, if needed. Outside the prediction horizon, the desired end effector trajectory does not to be known, allowing for replanning when working in dynamic environments. The obtained joint trajectory is optimal: inside the prediction horizon, it satisfies the end effector trajectory (the main task), fulfills in the best way the secondary tasks (such as joint velocity minimization or obstacle avoidance), and maintains the least possible scaling, all with regards to the joint constraints.

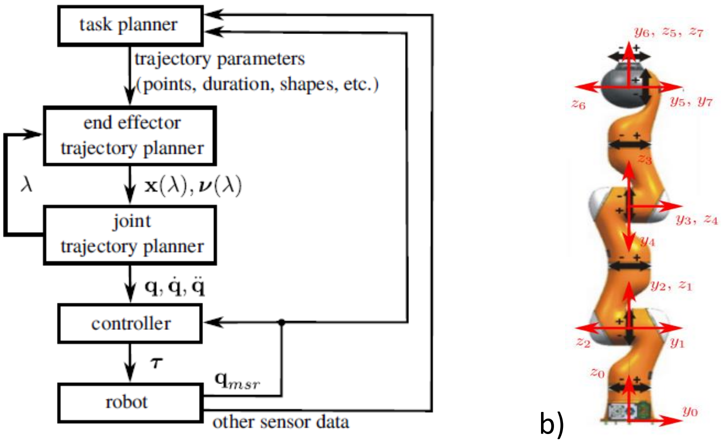
a)  b)

Fig. 11 a) PQPIK-S flow-chart, b) KUKA LWR local frames

The PQPIK-S plays the role of the *joint trajectory planner* block shown in the diagram. It was implemented in C++ with the use of the *Eigen* library for linear algebra and *qpOASES* containing the active-set solver for the QP problem.

Comprehensive simulation studies performed during this project prove the PQPIK-S's advantages compared to the classic IK methods. The most important feature of the PQPIK-S is the ability to satisfy the joint constraints, slowing down the end effector motion only when needed. Moreover, the PQPIK-S computations are done within a 10-millisecond cycle, allowing for a real-time operation. The experiments performed on KUKA LWR 4+ redundant robot present in the Division's Robotics Laboratory prove the feasibility of the PQPIK-S-generated joint trajectories. The experiments were performed with the use of the *Fast Research Interface* – KUKA's interface for the communication between the user's PC and KUKA Robot Controller (KRC).

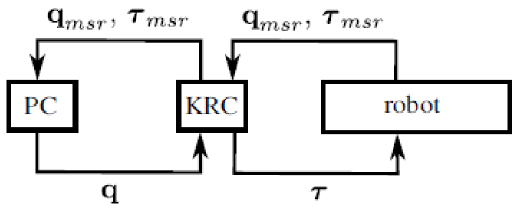


Fig. 12 Overview of control system arrangement

The results of this project are published in the doctoral dissertation: Woliński Ł., *Optimal trajectory planning for redundant manipulators working in a dynamic environment*, 2021 and in [13].

Formulation and Experimental Validation of Computationally Efficient Methods for Modeling of Hybrid – Rigid-Flexible Multibody Systems with Redundant Constraints–the OPUS-23 grant of National Science Centre of Poland in years 2023-2026 (no. 2022/45/B/ST8/00661)

This project is a continuation of earlier research described in [14], [15], [17], [18], [19], [20]

Multibody systems, i.e., mechanical systems having lots of bodies and degrees of freedom, are commonly used in many areas of modern engineering. Multibody simulation models can be found in diverse areas such as robotics (dynamics of manipulators), automotive (testing of car components and complete vehicles), railroad (e.g., traffic safety), defense (e.g., design of tracked vehicles), etc. Multibody models are also used in control systems.

A simulation model is always a compromise between several objectives; most often, a balance between the accuracy or fidelity of the model and its computational efficiency must be found. This compromise considers many factors, e.g., the availability of the data, the workload needed to build a model, computing capabilities, or the modeling goals. The analysis and simulation of large-scale multibody systems require significant numerical expenses. Simultaneous enforcement of computational efficiency and high-fidelity physical model requirements is difficult to obtain.

The rigid body assumption is frequently adopted in MBS modeling to obtain highly efficient methods. It significantly simplifies the system's physics; nevertheless, multi-rigid-body models can capture essential features of the investigated systems with satisfactory accuracy. There is, however, a broad class of mechanical systems for which the models that assume the rigidity of all the bodies provide erroneous solutions. These systems have redundant constraints (the same degrees of freedom are restrained several times). The redundancy results in the non-uniqueness of calculated joint reaction forces, which may also lead to the non-uniqueness of the simulated motion, making the model useless.

The main aim of the project is to develop general-purpose hybrid (rigid-flexible) modeling methods that will enable reliable simulation of redundantly constrained systems while maintaining high computing efficiency.

The project will be focused on removing or reducing limitations that diminish the scope of applications of the current methods in the context of the system structure, accuracy, efficiency, and fidelity. The research concentrates on the three groups of issues (that are illustrated in Fig. 13).

- Development and investigation of efficient hybrid methods for modeling redundantly constrained MBSs that ensure obtaining physically meaningful solutions. Within this objective, it is planned to propose methods dedicated to the conscious use of both rigid bodies and simplified accounting for compliance of parts in terms of equivalent stiffness or—in another variant—in the form of physics-based penalty factors (in the augmented Lagrangian formulation and similar methods). It should guarantee realistic solutions.
- Development of benchmark problems suitable for testing over constrained MBSs and examining the numerical properties of formulated modeling methods. One of them should be closely related to the planned experimental setup so that measurements could verify the numerical calculations. The extensive numerical tests will result in both qualitative and quantitative comparison and assessment of various variants of the developed methods.
- Experimental validation of the methods and verification of the simulation results. Within this research objective, it is planned to design and fabricate an experimental setup to conduct research on MBSs with redundant constraints. The test rig should allow for the adjustment of the assembly stresses.

Measurements of both static and dynamic loads ought to be available. Using an industrial robot for introducing external loads or kinematic drive is considered to ensure the repeatability of tests carried out.

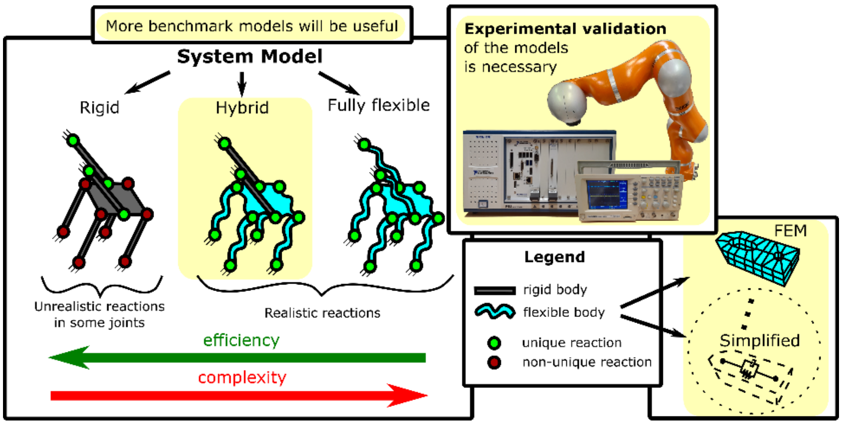


Fig. 13 Illustration of the objectives

The following effects of the research are expected:

- developing new numerical tools ready to be implemented in multibody simulation software to conduct automated analyses,
- providing experimental data to validate numerical tools and to get insight into redundancy problems,
- establishing validated benchmark problems for testing MBS models,
- contributing to the state-of-the-art by delivering high-quality papers,
- promoting research in the field of multibody systems with an emphasis on modeling dynamics of over constrained systems,
- contributing to the growth of the scientific qualifications of the research team members,
- alleviating existing limitations by providing tools for finding a solution to redundancy-related problems, making it possible to estimate—with acceptable precision—load distribution within an over constrained multibody system of arbitrary size and topology while maintaining high efficiency.

Tools and methods for novel robotics systems

The research concerns the design and implementation of real-time control systems, focusing on humanoids, walking machines and autonomous flying devices [21]. Motion synthesis methods [24] and design solutions for novel robotic systems inspired by biology are also investigated (Fig. 14 a, b, c, d).

The study of animal movement synergies is needed to translate them into robotic movement patterns. In our earlier research, a motion pattern generator inspired by the biological central pattern generator (CPG) had been developed). By selecting appropriate parameters, the generator captured the synergy of movement in the human hip and knee joints. The generator has been successfully implemented in the bipedal robot – Fig. 14 c.

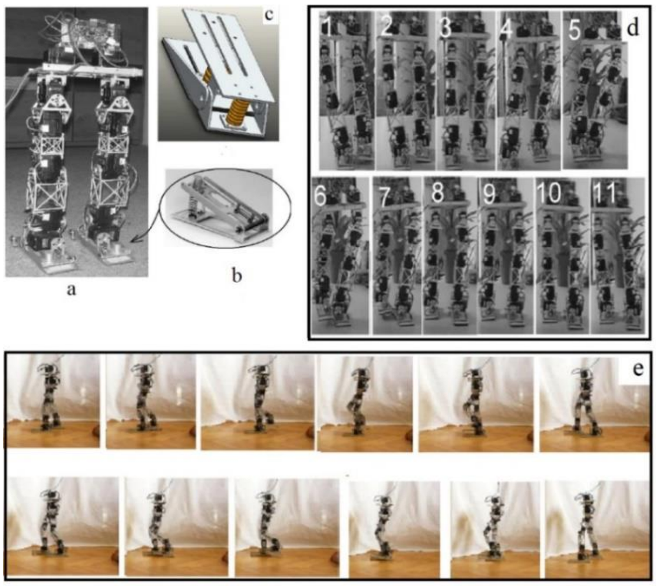


Fig. 14 Research inspired by biological patterns: (a) small bipedal robot, (b-c) leg with a compliant element, (d) images of the robot gait with compliant feet, (e) images of the gait generated by the Central Pattern Generator (left to right, top to bottom)

A motion similarity measure that allows for an easy and graphical comparison of the displacements of point masses as a function of time has been proposed [25].

Another research stream concerns the EMG based control. In the work [26] fuzzy logic neural network was used to deliver the mapping between the EMG signals and the planned angular position of the upper limb. The simplified dynamic model was used next to produce the based on the difference between the actual joint positions and planned joint positions.

Having in mind the needs of contemporary service robotics the research focuses on predicting human movements and actions using AI methods (Fig. 15). In 'learning by observation' the robot learns what sequence of its body postures is needed to perform a given action and then retrieves from its database the motion primitives (position specifications) to perform the observed sequence of postures. That is, in implementation, the action is defined as a transformation between postures (or primitives). The methods for posture classification using the data recorded by RGB-D cameras have been developed. The method enables the recognition of the activity represented by a sequence of human postures.

The concept of inferring actions based on recognizing elementary motion components using a semantic database or a decision tree also has been studied [27], [28].

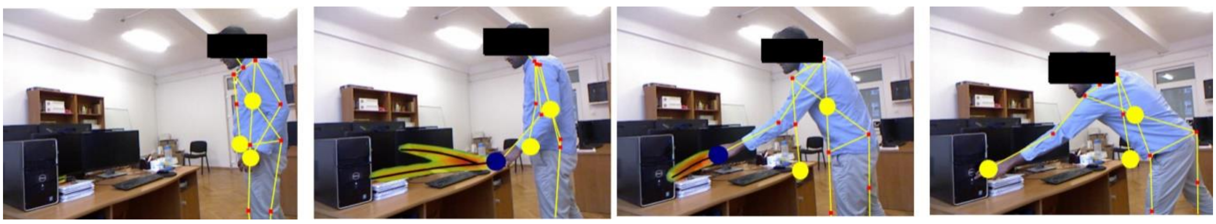
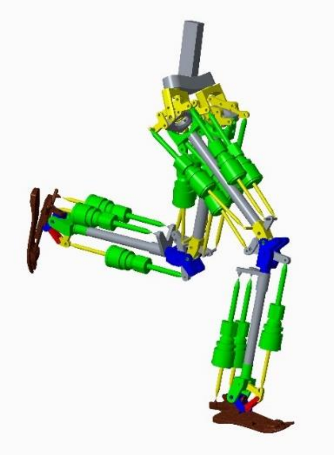


Fig. 15 Dynamic prediction of the trajectory of the hand movement (left to right)

The research concerns aslo the application of modern AI methods in industial robotics for recognition of the machinning defects [29].

Design of a fast two-legged robot with an electric drive using SEA

The project of an electrically driven bipedal robot with SEA (Serial-Elastic-Actuators) with elastic spring elements in the structure is being developed in cooperation with the Kaiserslautern University of Technology. The aim of the work is an attempt to recreate (built-in) in the technical system selected dynamic characteristics important for the walking / running process in order to further study the walking and running of a robot imitating human walking / running to use this knowledge in the construction of humanoid robots.



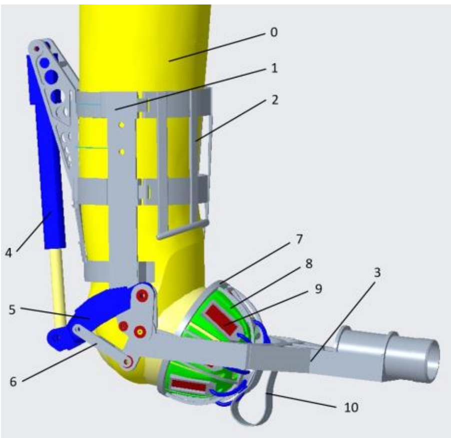
a)

b)

Fig. 16 Biped robot concept: a) CAD model of the robot, b) a prototype of a limb with 1 DOF made of carbon composite with an SEA actuator drive on a test stand

Design of an elbow joint prosthesis with an electric drive

New materials and technologies have been used to design the electrically powered elbow prosthesis. The main elements of the prosthesis are made of a composite material with the addition of Carbon Fiber Particles by 3D printing. 3D scans of the patient's arm were used to produce the arm support. The method allows for a precise adjustment of the prosthesis to the user's needs. The prosthesis is light, with drives selected to have the appropriate lifting capacity. After being equipped with a hand controlled by myopotentials, the patient will be able to manipulate everyday objects.

a) 

b) 

Fig. 17 Elbow joint prosthesis with an electric drive: a) CAD model, b) composite material 3D printed prototype of the prosthesis

Analysis of the possibility of reducing children's injuries during road accidents

Children transported by passenger cars require safety systems specially adapted to their needs due to anatomy, physiology and behavior different from adults. The proposed solution to reduce the risk of serious injuries is the use of safety belts integrated with the child restraint system with pretensioners, load limiters and the airbag. The purposes of the research:

- • to identify real life positions in which children travel (experimental research),
- • to assess the risk associated with these positions (numerical research),
- • to limit overloads acting on the child's body,
- • to estimate the effectiveness of the proposed safety systems,
- • to investigate statistically significant factors (statistical research),
- • to optimize safety systems for children in order to find the best possible solutions.

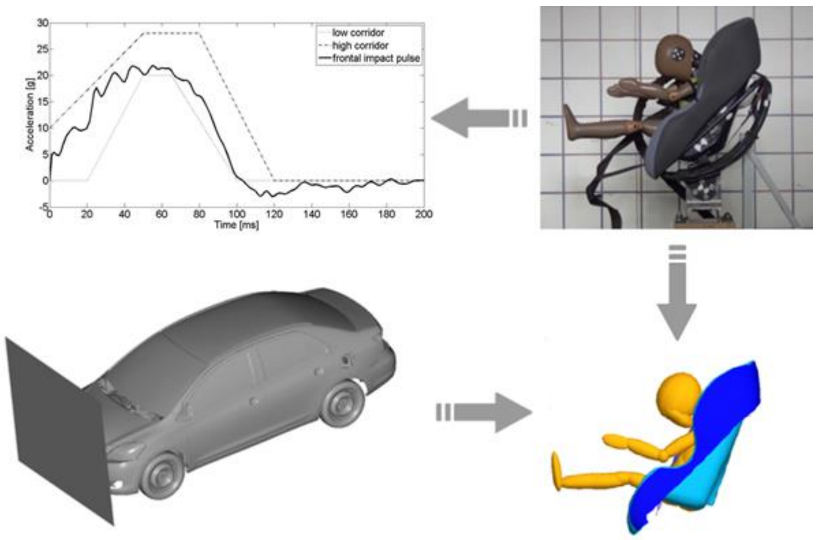


Fig. 18 Scheme of research work: the acceleration pulse obtained from the laboratory test and selected numerical models of the sled test and the frontal crash test (50 km/h, 27g, ECE R129)

The research was conducted under permission of the Ethics and Bioethics Committee. The precrash positions were identified in experimental research. The kinematic and injury criteria of the most important regions of the child's body were crucial during optimizing child safety systems (about 20 % risk of an AIS3+ injury).

2187 numerical simulations were performed in one of the statistical plan. Seatbelt parameters had the greatest overall effect on injury responses. The slack in the CRS harness caused a significant increase of injury criteria values. Using airbag resulted in a decrease in normalized values of all injury indicators by approximately 40 %. As a result of the multi-criteria optimization, many solutions near optimal one called Pareto optimal solution were obtained. The scope of the obtained results is even over 90 % for the HIC36 indicator and about 70 % for the HCUM3 indicator (whereas in homologation tests we obtain only one value).

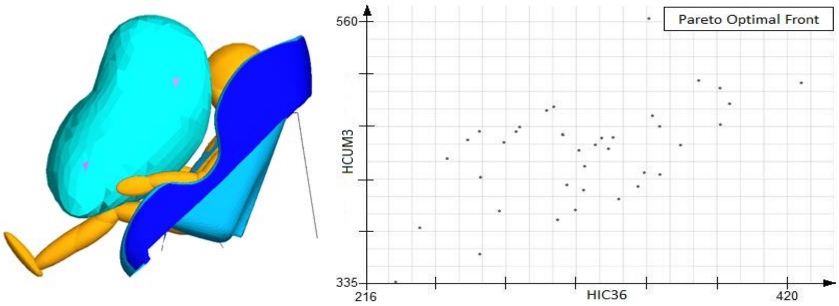


Fig. 19 The intelligent safety belts integrated with the child restraint system with pretensions', load limiters and the airbag (left) and Pareto optimal solution (right)

It was found that the use of properly adjusted to the individual needs of the child, child restraint system with pretensioners and load limiters reduces the likelihood of serious injuries and death as a result of the frontal collision more than 50 %. The future safety systems (e.g. used in autonomous cars) should cover most of the acceptable positions that a child can take in a properly used restraint system within the scope of road traffic regulations. This research and formulated recommendations may lead to increasing the effectiveness of future safety systems for children, improving methods of their testing and reducing the number of road traffic victims among the population of children in Poland. The team is working on the preparation of a series of patent applications to ensure:

- the child occupant safety by effective dissipation of collision energy,
- the improvement of the ergonomics of child restraint systems,
- the reduction of the risk of death, the minimization of the severity of injuries and long-term effects to the smallest possible level.

Model Predictive Control of a Fixed-Wing Vertical Take-Off and Landing (VTOL) Aircraft Using Indirect Methods (Scientific Council for the Discipline of Automation, Electronics, Electrical and Space Engineering, 2024-2025)

Project summary

Unmanned Aerial Vehicles (UAVs) are revolutionizing multiple sectors — from national security, disaster response, and environmental monitoring to infrastructure inspection and precision mapping. Among various UAV configurations, hybrid fixed-wing VTOL (Vertical Take-Off and Landing) systems are particularly attractive, as they combine the maneuverability of multirotor platforms with the efficiency and range of fixed-wing aircraft. However, controlling such vehicles remains one of the most complex and unsolved challenges in modern flight automation.

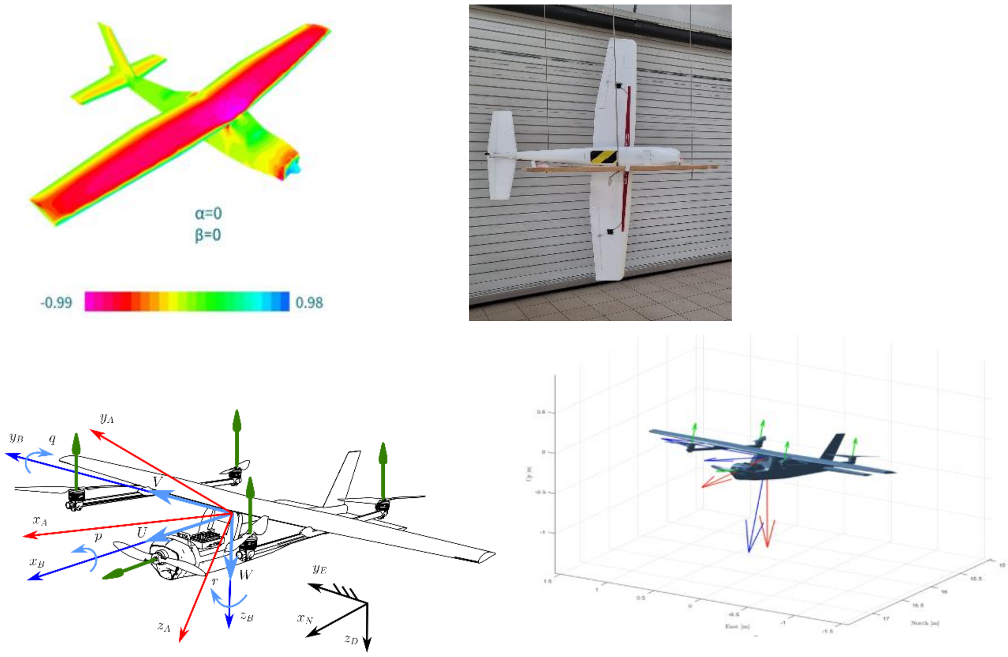


Fig. 20 Overview of the hybrid fixed-wing VTOL UAV and its modeling environment: (left top) experimental prototype, (right top) aerodynamic lift coefficient maps obtained from CFD analysis, (left bottom) distribution of aerodynamic forces and moments applied to the UAV, and (right bottom) simulation environment.

This project addresses the development of advanced gradient-based Model Predictive Control (MPC) methods for a hybrid fixed-wing VTOL aircraft, capable of seamless operation in all flight phases — take-off, transition, cruise, and landing. The research integrates aerodynamics, system dynamics, and control theory, combining the fields of Automation, Electronics, Electrical and Space Engineering (AEEiTK) and Mechanical Engineering (IM).

Scientific novelty

The proposed work introduces a unified control framework based on indirect gradient optimization techniques applied within a model predictive control paradigm. Unlike standard MPC approaches that rely on simplified or phase-specific control laws, the project focuses on continuous-time optimization using adjoint-based formulations and nonlinear aerodynamic modeling.

The novelty lies in:

- applying indirect optimal control methods (“optimize first, discretize later”) to the nonlinear and over actuated dynamics of hybrid UAVs;
- developing a hierarchical MPC architecture for managing the transition phases between rotor-based and fixed-wing flight modes;
- implementing a high-fidelity aerodynamic model validated experimentally on a custom-built hybrid UAV demonstrator.

Research objectives

1. Design and construction of a hybrid VTOL UAV test platform, integrating aerodynamic efficiency, stability, and controllability studies.
2. Development of a dynamic model including real aerodynamic loads and inertia properties obtained experimentally.
3. Implementation of adjoint-based gradient algorithms for indirect optimal control in a simulation environment.
4. Integration of gradient methods within MPC, enabling real-time optimization under flight constraints.
5. Validation of the predictive control strategy in simulated flight scenarios, including mode transitions and disturbances.

Expected impact

The project will contribute both scientifically and technologically to the growing field of autonomous aerial systems. The results are expected to:

- advance the state-of-the-art in nonlinear control and flight dynamics of over actuated UAVs,
- provide a computationally efficient MPC approach suitable for real-time onboard implementation,
- strengthen the domestic research and innovation capacity in UAV technologies, supporting the national strategy for intelligent systems and robotics,
- enable potential applications in search-and-rescue missions, surveillance, and autonomous logistics, particularly in environments inaccessible to conventional aircraft.

By integrating advanced optimization-based control with experimental validation, this project aims to establish a new methodological foundation for intelligent, dynamically adaptive flight control of hybrid UAV systems.

Relevant achievements

- Device for spine correction and measurement system: Wojciech Kaczmarek, Krzysztof Mianowski, Marcin Stańczuk, Grzegorz Kamiński, Rafał Rosołek – US Patent No **US 9949884**.
- Device for spine correction and measurement system (Urządzenie do korekcji kręgosłupa i system pomiarowy): Wojciech Kaczmarek, Krzysztof Mianowski, Marcin Stańczuk, Grzegorz Kamiński, Rafał Rosołek – Polish patent no: **PL 229766**.
- Device for children transpotation in vehicles (Urządzenie do przewozu dzieci w pojazdach): Michał Kowalik, Edyta Rola, Witold Rządkowski, Karol Suprynowicz – Polish patent no: **PL 236856**.
- Mianowski Krzysztof, Pękal Marcin, Wojtyra Marek, Barczak Tomasz, Kamińs ki Grzegorz, Surowiec Marek, Witkowski Marcin [i in.]: Sampling Device, in Particular for Bulk Materials, Wynalazek, Numer zgłoszenia: **EP 23180904**, Nr patentu: **EP 4300069**

- Wojtyra Marek, Mianowski Krzysztof, Kamiński Grzegorz, Barczak Tomasz, Pękal Marcin, Surowiec Marek, Witkowski Marcin [i in.]: Sampling Mechanism in Particular for Bulk Materials, Wynalazek, Numer zgłoszenia: **EP 23180879**, Nr patentu: **EP 4300068**.

Other information

The Division is involved in the acivities of HERITAGE network (https://www.ec-nantes.fr/international/our-international-networks/heritage-network) which aims to strengthen higher education cooperation (research and training) between Europe and India in the field of Engineering Sciences: exchange of expertise, organization of scientific workshops, joint participation in international projects, implementation of joint training programme and development of joint research projects as well as scientific diplomacy. The JEMARO – Japan-Europe Master of Advanced Robotics (https://jemaro.ec-nantes.fr/) is locally supervised and realized with the involvement of the Division staff. The Division supports the development of robotics resources in India within the framework of the project IRAS-HUB - 101083029 (Capacity Building in Robotics & Autonomous Systems in India). The aim of this Erasmus+ Programme Capacity Building project (2023-2025) is to set up three hubs devoted to Robotics and Autonomous Systems (RAS) in India. The Division is involved in staff training and advising laboratory organization with helping to develop the courses in robotics at the undergraduate and postgraduate level.

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Division of Strength of Materials and Structures

Research Interest

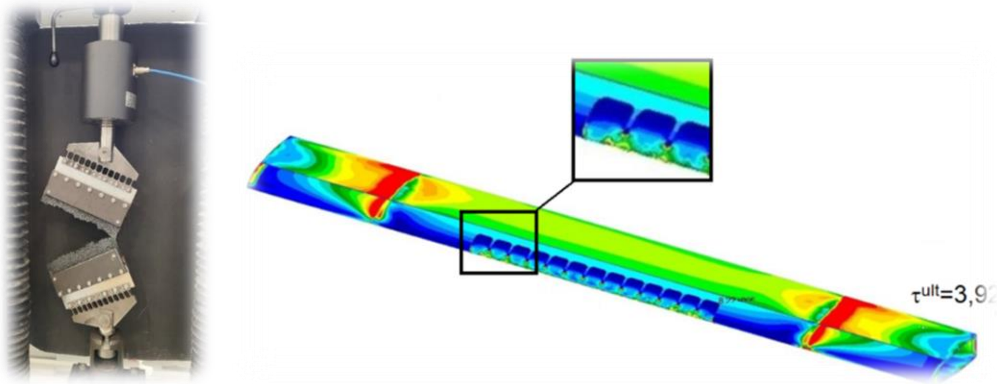
- Biomechanics:
    - Implants and bone remodeling (hip implants, spinal disc implants, dental implants)
    - Inner ear biomechanics
- Power engineering:
    - Problems of strength of rotating turbomachinery
    - Finite element modeling of material fatigue and cracking problems for steam power system HP devices exposed to thermal shocks
    - FE analysis of the turbine blade locking piece defects
    - Structures of DEMO fusion reactor (2014-2022)
- Composites, cellular solids, smart and intelligent materials:
    - The prediction of optimal material layout for elastic continum structure using weighted resource constraint
    - Mechanical properties of low-density open & closed cell foams based on tetradecahedron model of microstructure
    - Nano composites: parametric FE modeling of mechanical, electrical and thermal properties of Nano composite
    - Mechanical joining of composite materials: drilling of glass fiber-reinforced composites
- Mechanics of solids:
    - FE modeling of microscale structures with non-uniform material distribution - crystallites (non-linear material properties, large deformation and strain)
    - Sequence of damage events (delamination) occurring in the course of the low energy impact of carbon fiber composites
- Aviation:
    - Explosion resistance of the fuselage
    - Gyrocopter dynamics: prs, rotor braking, L/G

Research laboratory

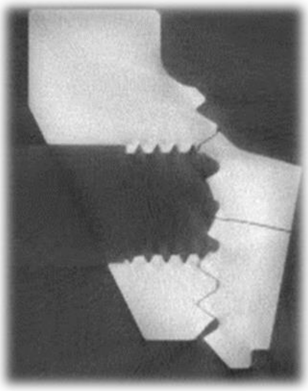
Laboratory of the Division of Strength of Materials and Structures
The Research Laboratory deals with testing materials, structural elements, and large structures. The laboratory uses works carried out to implement research projects and investments from other scientific research and industry. Modernization of the laboratory was finished in 2022, along with retrofitting with modern equipment, including X-ray tomograph, flaw detectors - ultrasonic (phase Array) and Eddy current, a system for optical deformation measurements (DIC) as well as CNC components and 3D printers for metal.
The laboratory provides its services mainly to companies from the aerospace and automotive industries. Among the current customers of the replacement laboratory are the State Aircraft Accident Investigation Principle, the Air Force Institute of Technology, and several companies from the small business sector.

Infrastructure

Modern equipment



Laboratory tests



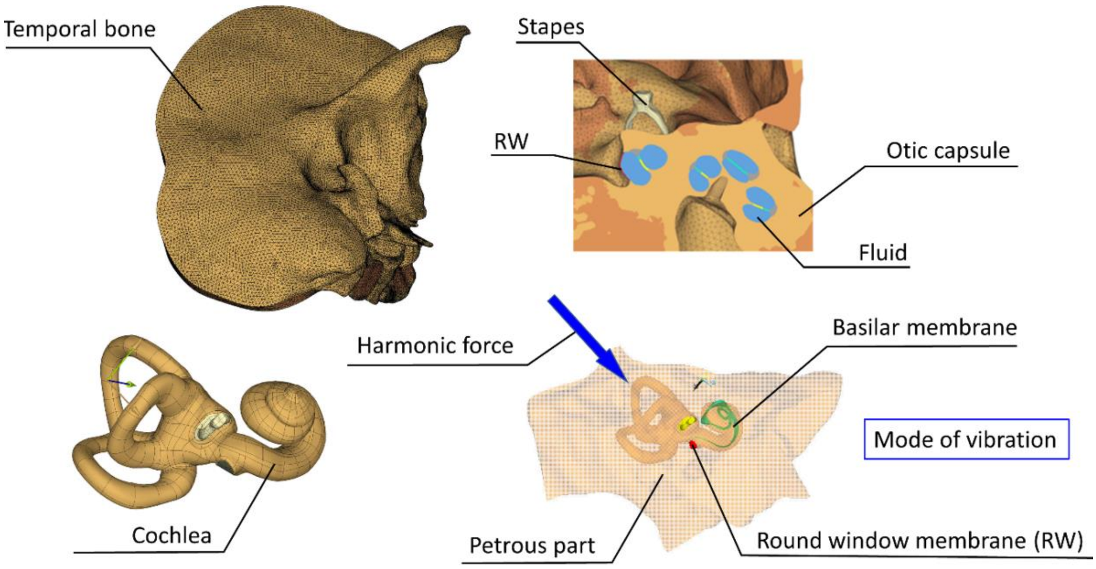
Crack at the propeller hub

Testing hyperelastic materials

Key research projects

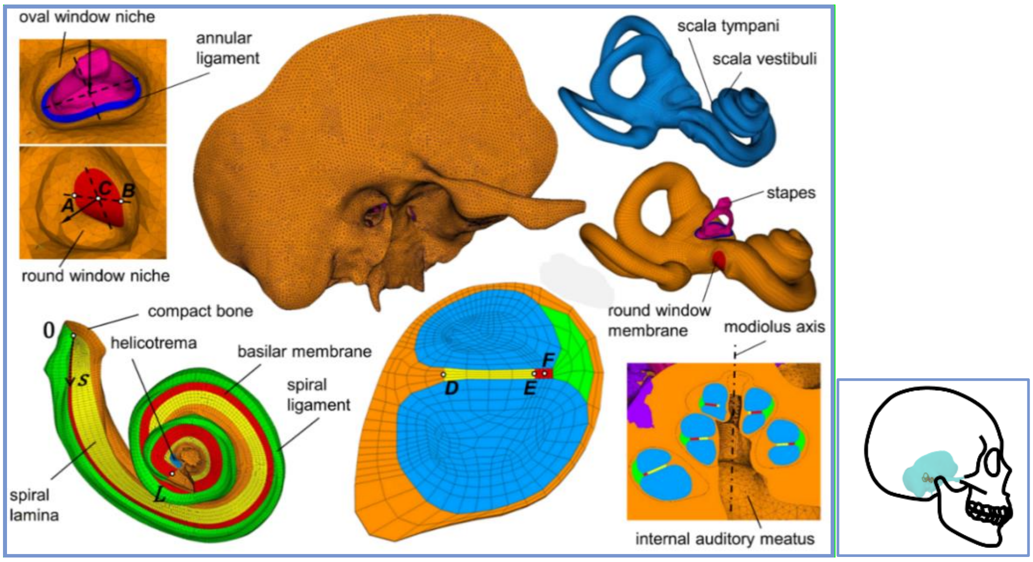
Bone Conduction Stimulation of the Temporal Bone with the Inner Ear

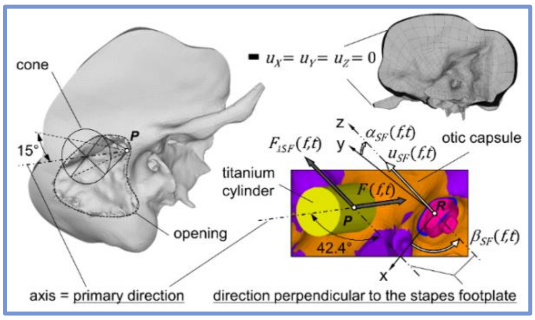
PBS3/B7/25/2015: "Development of an innovative method of direct stimulation of the inner ear by bone conduction" performed by the consortium WUM-PW-Aurismed S.A.- Signovia International sp. z o.o., 2015-2019.

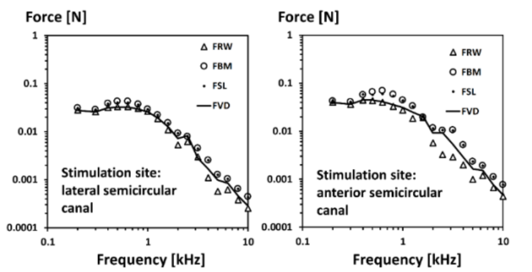


The subject of numerical analysis was a three-dimensional model of the temporal bone, published in [2] and shown in the figure. The finite element model has well-reconstructed structures of cortical and trabecular parts and included the cochlea, semicircular canals, annular ligament, round window membrane, basilar membrane, spiral lamina, spiral ligament, perilymph fluid, helicotrema, and a titanium cylinder representing the bone conduction implant, which was attached to the otic capsule bony surface above the lateral semicircular canal. Other parts of the inner ear, such as the balance receptors, Reissner's membrane, tectorial membrane, organ of Corti, and the cochlear duct, were not included. Hence, the passive linear behavior of BM was assumed. The middle and outer ear structures, such as the tympanic membrane, malleus, incus, and the middle-ear ligaments and muscles, were not included, except the stapes. Consequently, only two of the five possible BC sound pathways were considered: the inertia of the perilymph fluid and compression of the cochlear walls. The inertia of the middle-ear ossicles was partially considered in the model with a movable stapes. In contrast, the otosclerotic condition on the annular ligament existed in the model with an immobilized stapes, where the ligament was replaced with a cortical bone. The RW membrane and cortical bone were assumed as viscoelastic, with the storage and loss moduli defined as functions of frequency. Other solid tissues were modeled as linear isotropic. Some properties of the BM and SL were defined as functions of the spatial coordinates and frequency. The cochlear fluid was assumed as viscous and compressible. The dynamic viscosity of the fluid was considered only for vibration damping The cochlea in the model was validated based on the experimental data.

FE modeling of bone conduction in the human ear
displacements in the bone, selection of the excitation force





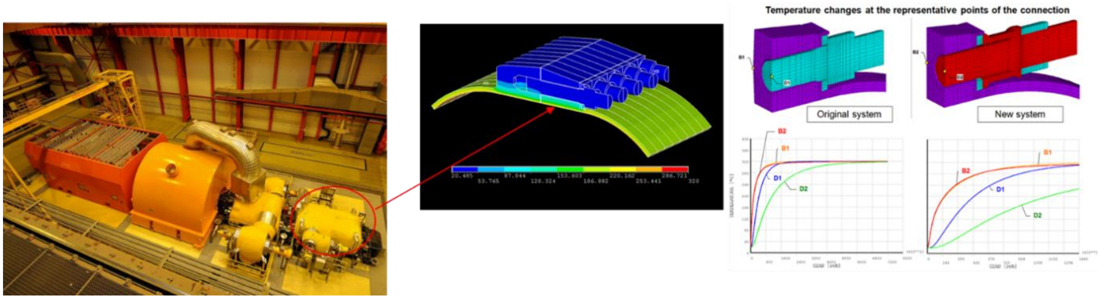


The subject of the work was to develop a method of direct stimulation of the inner ear fixed in place of the otic capsule to improve hearing with minimal stimulator energy and to find design assumptions for a new type of implant utilizing the bone conduction pathway.

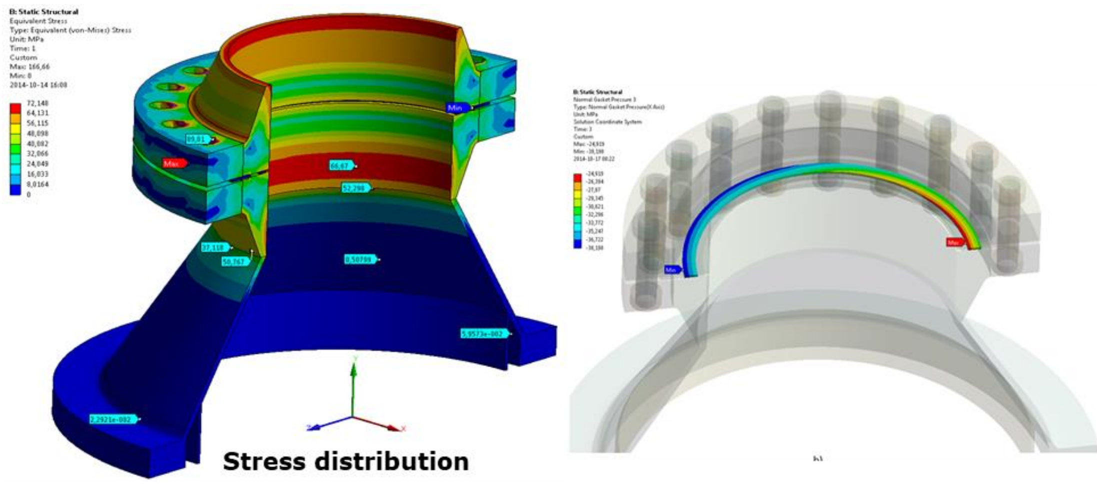
Harmonic analysis of the FEM model was a tool to determine displacements of the temporal bone caused by the implant vibrations.
The effectiveness of bone conduction stimulation depended on the force amplitude as a function of frequency, which caused a similar response in the cochlea of the inner ear as for the displacement applied on the stapes. For the optimal direction of stimulation, the forces were the smallest in the analyzed frequency range (0.4 to 10 kHz).

Design and stress analysis of high presser components

Power engineering is one of the most important field for division of strength of materials and structures. Team supported and worked on several project in that area focusing on high pressure components as piping, valves, vessels, reactors, heat exchangers and boilers. The team worked on projects aimed at improving existing structure or emergency support for quick repair of components to ensure the maintenance of installation including gasket tightness issues. Team has experience in both modeling and concept of new design solution. Furthermore team is able to support project in area of reverse engineering finding the root cause of failure.



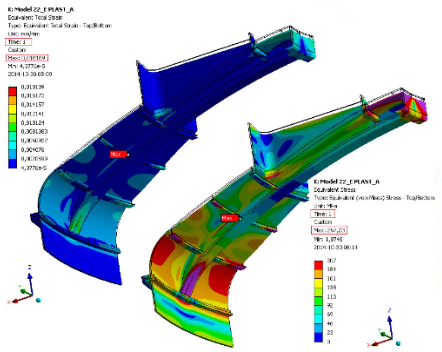
Steam leakage problem of HP power turbine casing (860MWatts at Lagisza Power Plant)



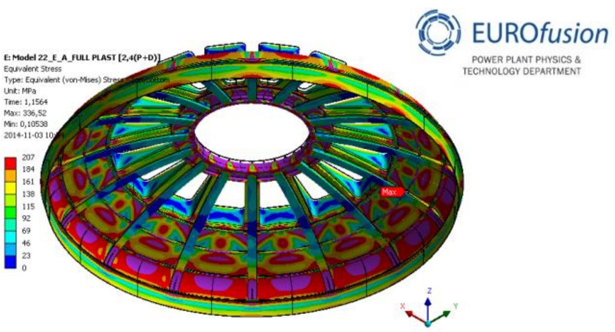
Quench heat exchanger (model include nonlinear gasket – tightness improvements)

Design of DEMO fusion reactor structure (2014-2022)

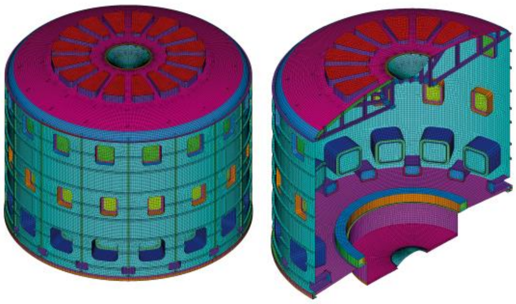
As part of the EUROfusion program (as part of the work in the Joint European Program of the EURATOM Community), calculation (design and research) work was carried (2014-2022) aimed at determining the concept of the structure and fastening of the vacuum tank (cryostat) of the DEMO reactor and its biological shield. The DEMO reactor (DEMOnstration Power Station) is an experimental tokamak nuclear fusion reactor in the conceptual phase, designed on the model of the smaller ITER reactor under construction in Cadarache (France).



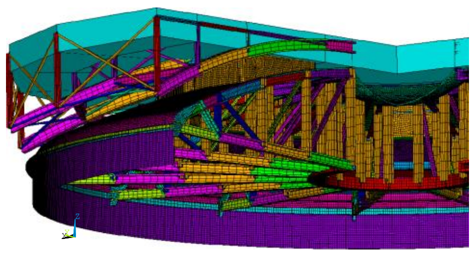
Plastic Collapse in 1/16 Model



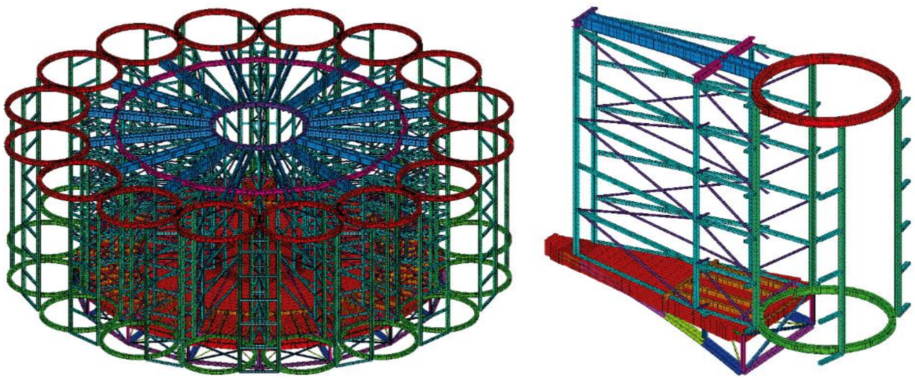
Plastic Collapse in FULL Model



FEM model of the entire cryostat



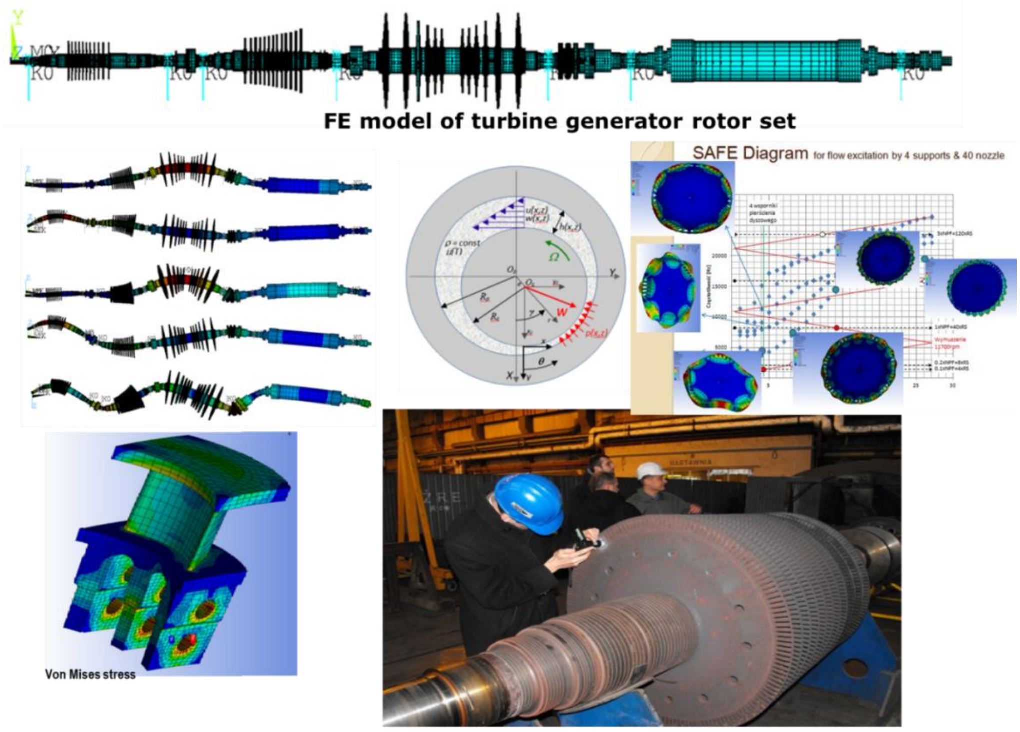
Design of cryostat roof and bioshield



Contamination protection structure

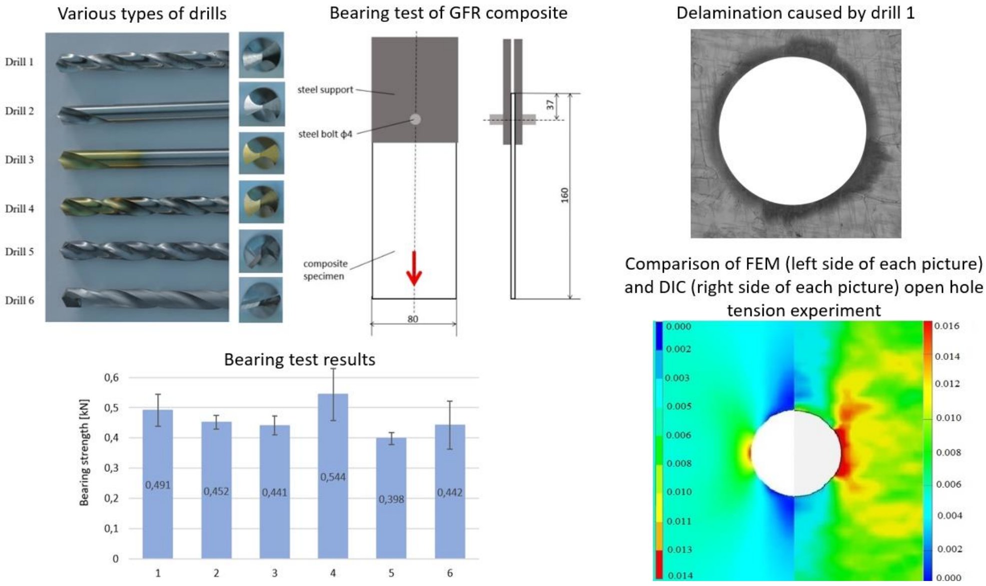
Strength of turbo machinery components

Team had a chance to work on several R&D projects in filed on turbo machinery. It allowed team to gain experience in both stator and rotor side including creep, fatigue and cracking problems. Several analysis of dynamic behavior of rotors has been performed and verified by tests. As part of the interests, knowledge in the field of bearings is also developed. In addition to the rotors, the team also worked on components such as nozzles and shrouds.



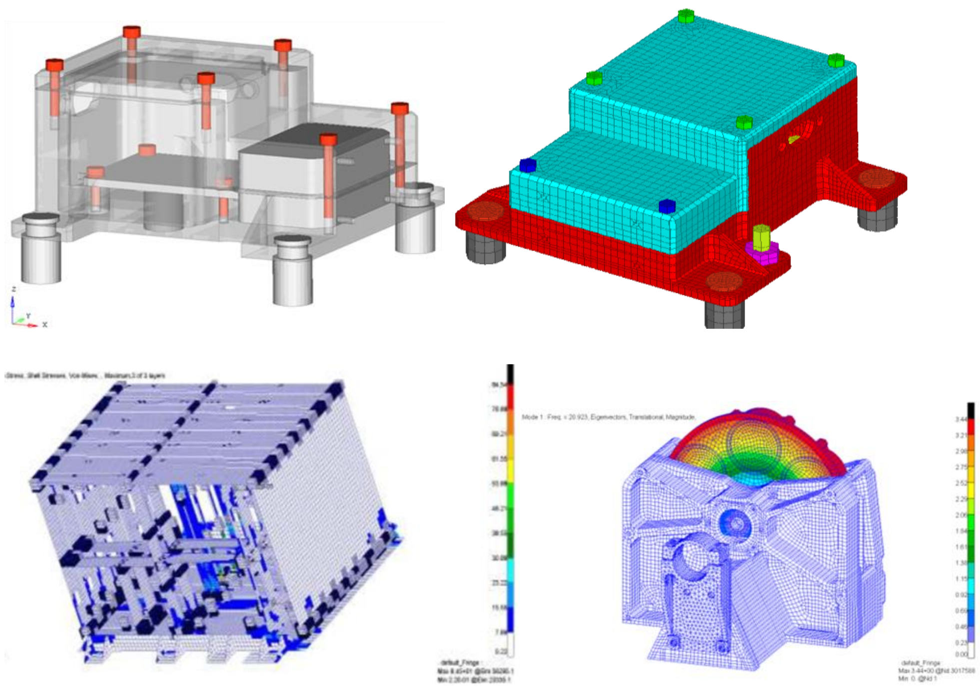
Mechanical joining of composite materials: Drilling of glass fiber reinforced composites

As drilling holes is necessary for bolted joining of composite materials, quality of the holes is one of key factors influencing strength of the joints. Therefore, a research has been made to select the drill material which assures the best hole quality in glass fiber-reinforced composite. Six drills made of different materials have been chosen: plain high speed steel (HSS) (drill 1), HSS with 5% addition of cobalt (drill 2), HSS with 5% addition of cobalt with titanium coating (drill 3), HSS with titanium coating (drill 4), cemented carbide (drill 5) and HSS tipped with tungsten carbide (drill 6). The quality of the holes has been assessed and bearing strength of holes made with use of each drill has been measured. The best results have been achieved for HSS drill with titanium coating. The research was funded by Internal Faculty Grant No. MEiL-847/2019 in Warsaw University of Technology, Faculty of Power and Aeronautical Engineering.



Instruments for space missions of the European Space Agency (ESA)

Mechanical objects of very high complexity were analyzed to meet the requirements of space standards (ECSS). The procedure involved many analysis types: thermomechanical, self-vibration, frequency response, random loads, shock loads, and bolt connection analysis.



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12. Bachmann C., Marek Piotr: **Engineering concept of the VNS - a beam-driven tokamak for component testing.** *Fusion Engineering and Design*, vol. 211, 114796, 2025. DOI: 10.1016/j.fusengdes.2024.114796
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Division of Mechanics

Research Interests

The Division of Mechanics conducts research in a wide range of areas related to flight mechanics, vehicle motion modelling, and the analysis of aeronautical systems. The team's primary research activities focus on flight dynamics, mathematical identification of aircraft and flight processes, as well as the numerical modelling of aerodynamic phenomena.

Researchers within the Division investigate the dynamics and control of various aerial platforms, including fixed-wing and rotary-wing aircraft, unmanned aerial vehicles (UAVs), and rockets. They also develop advanced control methods and algorithms to improve the performance, stability, and autonomy of these systems and support parameter estimation for aerospace systems. The Division's work also extends to the study of wind turbine systems, where advanced computational fluid dynamics (CFD) methods are applied to optimize aerodynamic performance and energy efficiency.

Recent activities include the exploration of solar energy harvesting during flight operations, the use of UAVs to carry out diverse mission profiles, and the study of novel flight concepts such as entomopters—bio-inspired micro air vehicles that combine mechanics and aerodynamics in unique ways. Artificial intelligence methods are also being introduced as a new research direction, supporting the development of future modelling and control approaches.

Through a combination of theoretical modelling, simulation, and experimental validation, the Division contributes to advancing modern aerospace technologies and supporting the development of innovative flight systems.

Research Laboratories

Aerial Robotic Systems Lab

The Aerial Robotic Systems Lab is specializing in developing robotic aerial systems to address the challenges of safe drone usage in urban and complex, hard-to-reach rural environments. The laboratory integrates multiple branches of robotics, encompassing aerial, reconfigurable, soft, and wearable robotics, complemented by AI, computer vision, machine learning, and perception algorithms. The laboratory strongly emphasize facilitating safe and easy human-robot interaction for the convenience of users.

Strategic infrastructure monitoring drone *Package transporting drone*

The laboratory is equipped with the following:

- Machines and tools for drone prototype construction: Grinders, Screwdrivers, Angle grinder, High-speed grinder, HEPA vacuum cleaner, Table saw, 3D printer, Bench drill, Tool cart, Vise, Air compressor, Workbench, etc.
- Devices for electronic prototyping: Soldering station, Hot air station, Oscilloscope, Quartz preheater, Power supply, Ultrasonic cleaner.
- Microphones for studying noise emitted by drone propulsion systems.
- Test bench (dynamometer) for measuring the efficiency of drone propulsion systems.

Mechanics Lab

The laboratory equipment used in the Department of Mechanics also includes also other specialized and high-class devices, such as:

- The HP Z4 G4 workstation - a high-performance computing platform designed for demanding engineering and simulation tasks. It provides excellent reliability and processing power for numerical simulations.
- Computational Cluster for CFD/FEM Calculations Workstation - A specialized high-performance computing workstation forming part of a cluster for CFD (Computational Fluid Dynamics) and FEM (Finite Element Method) simulations. It provides the processing power necessary for complex numerical analyses and large-scale engineering computations.

Hi-speed Workstation

- Speedgoat Simulation Computer - A high-performance simulation computer designed for real-time testing and hardware-in-the-loop (HIL) simulations. It enables precise validation of control algorithms and dynamic system models under realistic conditions.

Speed goat station

- The HIKMICRO Mini2 V2 is a modern USB-C thermal imaging camera designed for Android smartphones. Its compact, durable aluminum housing and high thermal sensitivity (<40 mK) allow for accurate detection of temperature differences even in small areas, making it perfect for technical inspection and maintenance applications.

- The HIKMICRO M20W 256×192 is a versatile high-resolution thermal imaging camera ideal for examining a wide range of objects. It enables precise temperature measurements and visualization of heat distribution, making it suitable for research and diagnostics.

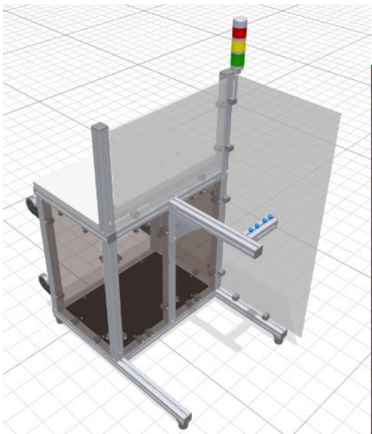
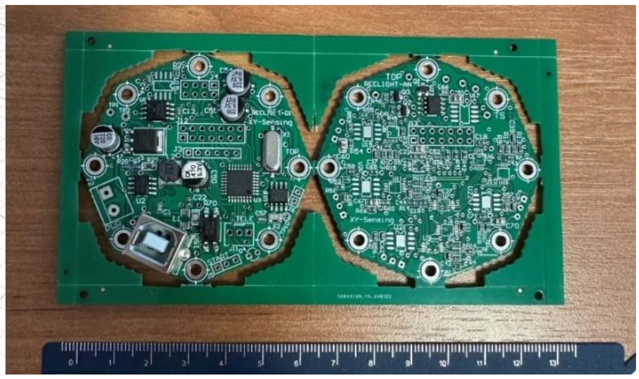
HIMIKRO thermal camera

- The test stand for the analysis of tail rotor blade vibrations enables the determination of natural frequencies and mode shapes, visualization of nodal lines, and detailed frequency-domain analysis. It provides valuable insights into the dynamic behavior of rotor components, supporting advanced research and optimization of such systems.

Key research projects

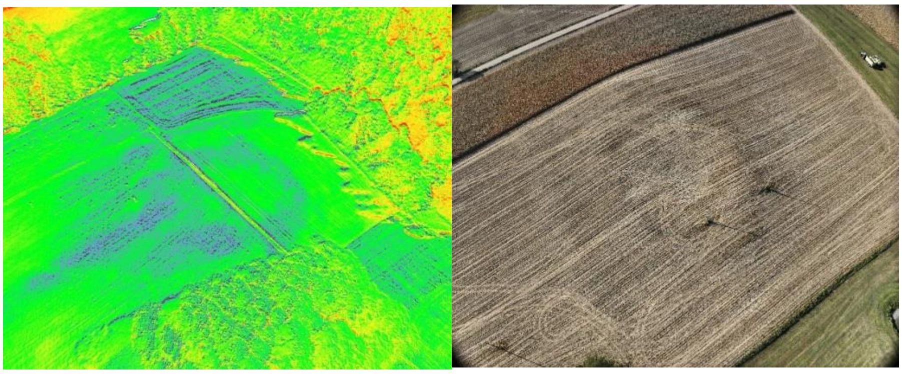
Innovative Navigation Support System for Rapidly Rotating Objects

The project aims to develop an innovative navigation support system for rapidly rotating objects such as missiles and drones. The system is based on the prediction of navigation data using algorithms that analyze changing environmental conditions during motion. Its core concept involves a low-cost measurement unit equipped with a set of sensors detecting various types of electromagnetic radiation (visible, infrared, and ultraviolet light). The developed system enables the determination of rotation-channel navigation data that remain fully resistant to both intentional and unintentional interference with satellite navigation systems.



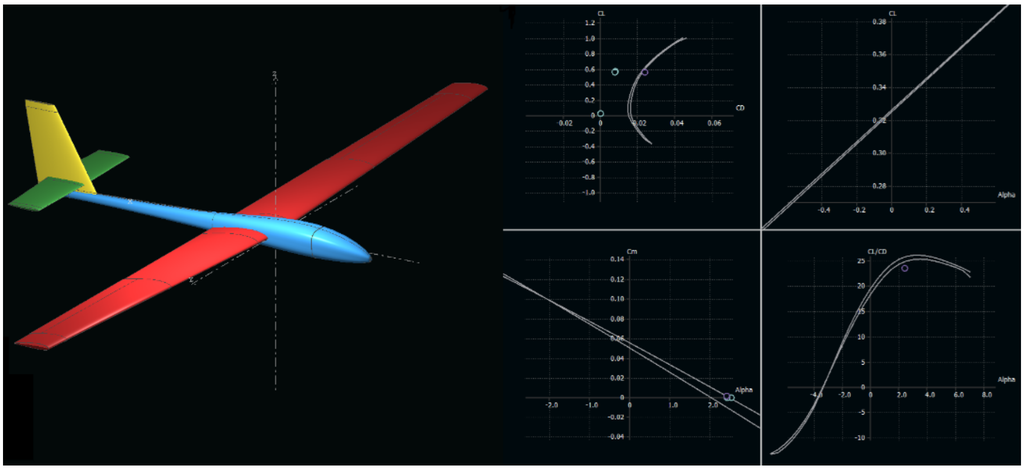
Satellite and Aerial Image Analysis System for Agriculture and Archaeology

The project aims to develop an innovative system for analyzing satellite and aerial images (from aircraft and UAVs) to support agriculture and archaeological research. The system will enable consortium partners to advance AI-based technologies and prepare a commercial product that enhances crop safety, environmental sustainability, and economic efficiency. Image analysis will form the basis for predicting the occurrence of diseases and pests in crops, as well as for comprehensive assessment of crop condition and quality for major Polish crops. Machine learning solutions developed in the project will improve both the consortium's software tools and the monitoring, management, and productivity of agricultural processes. The resulting system will be capable of diagnosing threats to crops from diseases, pests, and adverse weather conditions.



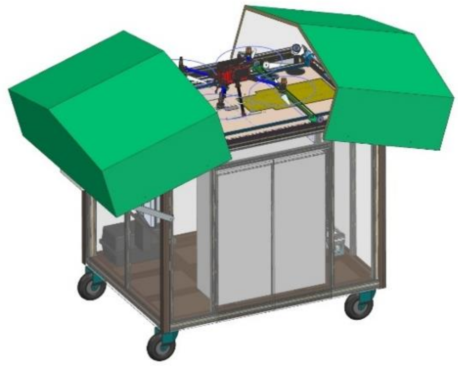
Development of a Simulation Model of a Solar-Powered Unmanned Aircraft

The project focuses on developing a generic simulation model of a small solar-powered unmanned aircraft of the LALE (Low Altitude, Long Endurance) class. The research explores the potential of solar energy to extend flight endurance and reduce the environmental impact of UAV operations. A dedicated solar radiation model is being developed using system identification techniques and high-resolution commercial solar data. The project supports sustainable development by promoting renewable energy use and minimizing emissions and material consumption associated with physical prototyping.



Innovative Automatic Railway Infrastructure Monitoring System Using Artificial Intelligence and Unmanned Aerial Vehicles (UAVforRail)

The aim of the UAVforRail project is to develop an advanced system that automatically identifies faults and potential hazards in railway traction infrastructure. By integrating artificial intelligence with unmanned aerial vehicles, the solution enables real-time monitoring, early detection of irregularities, and improved maintenance efficiency. The project contributes to enhancing railway safety, reliability, and operational effectiveness through the application of cutting-edge AI and drone technologies.



Safe and Quiet Drones for Urban Applications

The project focuses on developing drone technologies that enhance safety and reduce noise levels, enabling their broader use in urban environments. Conventional drones often produce significant noise from propellers and pose risks due to exposed rotors, limiting their use for direct delivery to recipients or for indoor inspections. This research aims to design and optimize drones with improved acoustic performance and enhanced protection features, supporting their safe and efficient operation in densely populated and confined spaces.

Universal Inertial Navigation Unit (IMU) for Missile Guidance and Control Systems

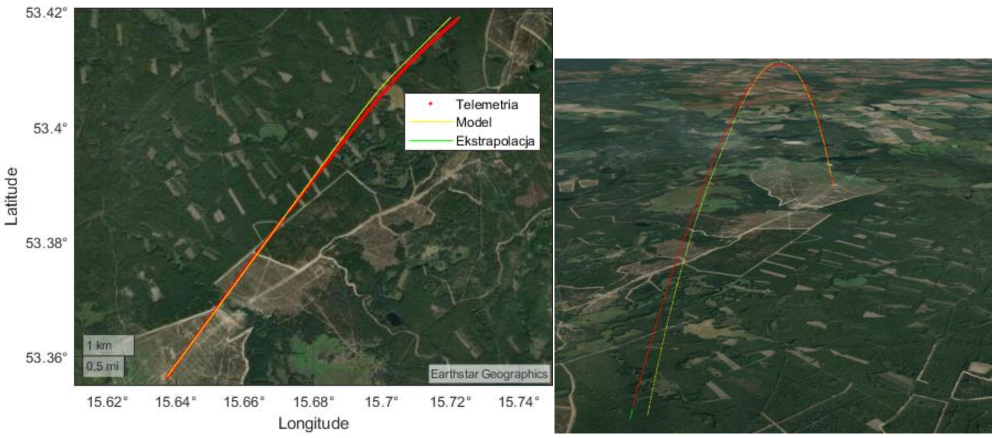
The project aimed to develop a new inertial dead-reckoning navigation module (IMU) for missile control and guidance at Technology Readiness Level VI. Its main objective was to design a professional IMU built exclusively with MEMS sensors, verifying the feasibility of using only MEMS accelerometers. Laboratory and field tests were conducted to assess prototype advantages and limitations. The project enabled cost-effective, large-scale IMU production in Poland using imported MEMS components, later replaced with domestic ones. Since no missile-grade inertial navigation systems were previously produced in Poland, this development was crucial for creating accurate, independent missile control technologies.

Autonomous UAV Docking and Charging Station for Environmental Monitoring

The project developed mobile and stationary versions of a docking and charging station for unmanned aerial vehicles (UAVs), serving as an autonomous hub for monitoring forested and agricultural areas. The system integrated a landing pad, protective shelter, charging unit, and a renewable energy subsystem with solar-tracking photovoltaic panels and energy storage. It enabled autonomous or remotely supervised monitoring tasks such as wildlife counting, pest detection, fire risk assessment, and precision agriculture operations. The station managed UAV missions automatically using GPS RTK and visual navigation, with optional remote human supervision.

Development of a gasodynamic control module for missile precise guidance

The project developed, manufactured, and tested a gas-dynamic control module and precision guidance demonstrator for a rocket projectile. The system used a cluster of small rocket thrusters as actuators integrated with navigation and control electronics. Navigation combined inertial measurement units with the GALILEO positioning system to support operation at supersonic flight speeds. Flight trials demonstrated improved flight-path accuracy and hit probability, enabling reductions in salvo size and corresponding operational costs for combat units.

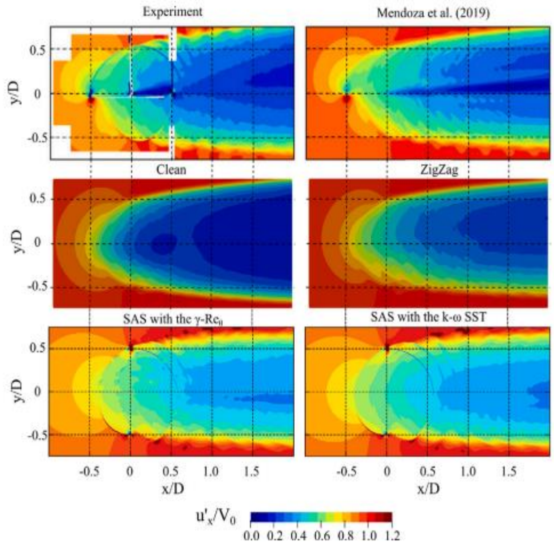


Advanced Autonomous Drone Swarm Technology for the Digital Protection of Critical Infrastructure, On-Demand Inspection Applications, and Innovative Creative Entertainment

The project aims to develop and implement the concept of a controlled “Starling Swarm” — a network of autonomous drones designed to restore communication and Internet access in areas affected by disasters or warfare. Inspired by vision of distributed connectivity, the swarm operates as a dynamic, reconfigurable network of aerial nodes acting as mobile access points. This innovative system enhances crisis response capabilities, enabling rapid deployment, flexible coordination, and resilient communication in emergency and post-disaster environments.

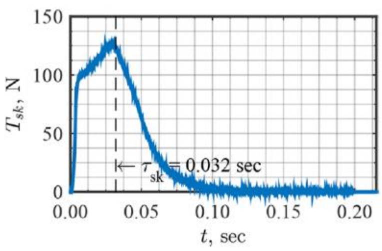
Boundary Layer Effect on the Vertical-Axis Wind Turbine Blades on Wind Energy Conversion

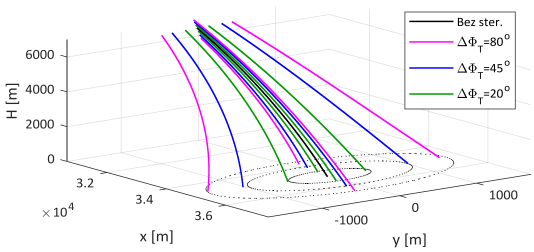
Large-scale wind turbines require preliminary laboratory-scale investigations in wind tunnels. The rotor blades operating at small scale work in a completely different flow regime than those of megawatt-class turbines. To ensure that the flow obtained under laboratory conditions more accurately reflects the real flow conditions of offshore wind turbines, boundary-layer turbulization techniques are often employed, such as using zigzag tapes. The action of the tape promotes early laminar-to-turbulent transition and removes laminar separation bubbles, but at the same time significantly alters the geometry of the aerodynamic wake behind the rotor.



Projectiles control system technology development

The project advanced national competencies in rocket control systems design and guidance technologies through work on 122 mm and 208 mm missiles. Activities included modification of control, stabilization, and navigation algorithms, together with system-identification tasks aimed at verifying the feasibility of identifying such vehicles from range trials. To this end, various types of input excitation signals and control strategies were tested and evaluated to determine which measurement regimes allow reliable parameter estimation. The program comprised task-specific efforts covering algorithm updates and model-identification analyses for each calibre, supporting the design and verification of both electric and gas-dynamic actuator solutions applicable across rockets of varying ranges.





Relevant achievements

The Division of Mechanics actively participates in numerous research and development projects, many of which have been recognized with prestigious awards both within the Warsaw University of Technology and beyond. Among recent achievements, the GAMS control module, co-designed by the Division, received the Second-Class Award in the “Innovative Product” category at the MSPO 2025 International Defence Industry Exhibition in Kielce. Earlier recognitions include a Gold and Silver Medal at the International Invention and Innovation Fair INTARG 2020, as well as the President of the Polish Patent Office Award.

Staff members of the Division are also authors of patents, including the System for Stabilizing the Trajectory of a Projectile with Aerodynamic Control (PL 242077) and Mechanical Control (PL 242078). In addition, the Division is actively involved in organizing “Mechanics in Aviation”, the oldest and largest aviation conference in Poland, fostering knowledge exchange and innovation in aerospace engineering.

International Defence Industry Exhibition and Innovation Fair Awards

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Project within Regional Operational Funds of Mazowian Voivodeship lounched in 2019

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