EUROPEAN INSTITUTE
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IMPLEMENTATION OF INNOVATIONS

EXPERIENCE OF THE CZECH REPUBLIC

TECHNOLOGIES

EUROPEAN INSTITUTE FOR INNOVATION DEVELOPMENT

Implementation of Innovations in Technologies

Experience of the Czech Republic

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Contents

Part 1

Historical Evolution of the Technical Sciences and Technologies in the Czech Republic (1993–2025)

1993–2003: Post-Socialist Restructuring and the Search for a New Model

The first decade of the independent Czech Republic was for the technical sciences and technologies not a period of linear growth, but a phase of complex institutional recomposition. In 1993, the new republic inherited from the Czechoslovak period a substantial scientific and technical potential: a network of academic institutes, branch research institutes, engineering design schools, technical universities, and industrial enterprises capable of carrying out research and experimental design work. However, this potential was embedded in an economic logic that was rapidly collapsing after 1989 and was ultimately being restructured under the conditions of independent Czech statehood. Therefore, after 1993 the state faced a dual task: simultaneously to create its own national system for the governance of science and to adapt the research sphere to the market economy, privatisation, and European integration. Official documents of the Research and Development Council already show that in 1992–1994 the central theme became the elaboration of the very "fundamental concept" of research policy under new social and economic realities. In other words, at the beginning of the period the issue was not the fine-tuning of a functioning system, but the search for an answer to the question of which parts of the old structure should be preserved, which should be reformed, and which should be allowed to disappear. In the technical sciences this challenge was felt especially acutely, because it was precisely here that dependence on large-scale industry, long investment cycles, equipment, testing facilities, and stable government procurement was greatest. As a result, the period 1993–2003 should be regarded as a time of institutional survival, normative construction, and the gradual transfer of Czech engineering science from a post-socialist to a European framework.

The initial problem was that the Czech research system entered the 1990s with a relatively large but structurally distorted research sector. A significant share of applied research had previously been concentrated in branch and departmental institutes closely connected with state enterprises and the planned economy. After the collapse of the previous economic model, many of these institutes were either privatised, or lost stable demand for their developments, or found themselves compelled to change their profile rapidly. An official analytical document of 2002 directly recorded that, in the business sector, scientific outputs from institutes privatised in the early 1990s continued to appear, which means that the formal "disappearance" of the old system in reality often signified its redistribution into new organisational and legal forms. At the same time, the Czech Republic for a long time still retained an unusually high share of the state sector in R&D: in 1996 it accounted for 33.2% of those employed in research, as against 16.8% on average in the European Union. This indicates that market transformation did not lead to the immediate domination of business in the research sphere; on the contrary, state and academic structures continued for a long time to perform a stabilising function. Yet it was precisely this inertia that created internal tension: the country was already entering the logic of market competition and integration into the European

Union, while a significant part of its scientific and technical potential still existed in the organisational forms of the preceding period. Therefore, the first half of the stage under consideration was not a time of innovative acceleration, but a time of painful reassembly of the carriers of engineering knowledge.

A key symptom of this restructuring was the financial instability of science and technology. Government analytical materials of the early 2000s emphasised that the effect of the sharp reduction in public expenditure on R&D in 1990–1992 continued to be felt later as well—in terms of its share of GDP up to 1995, and in current prices at least until 1994. According to official calculations, in 1995 government expenditure on research and development fell to 0.336% of GDP. Then, after the adoption of the first governmental principles of research policy, recovery began, and by 2000 the figure had reached 0.6% of GDP—the highest level for the entire existence of the Czech Republic up to that point. However, a decline began again in 2001, and in 2002 there was a more noticeable downturn, which government documents directly linked to the prioritisation of short-term budgetary measures over long-term directions, among which research and development were included. Thus, Czech technical science lived in a stop-go regime: a downturn was followed by partial recovery, which was then followed by renewed contraction. For engineering disciplines such dynamics are particularly destructive, because they are less able than others to withstand interruptions in equipment provision, personnel trajectories, experimental design programmes, and infrastructural investment. Therefore, the early Czech evolution of the technical sciences was not simply underfunded; it was internally unstable in the temporal dimension, and this slowed both the modernisation of laboratories and the launch of new directions, as well as the ability of enterprises to commission medium- and long-term developments.

Despite this, the 1990s were not institutionally empty: it was precisely then that the basic framework of state governance of the scientific and technological sphere was formed. In 1992, a governmental council was established as a professional and advisory body in the field of scientific activity and the development of technologies. In 1995, the original regulatory framework was adjusted through Act No. 1/1995 Coll., and one of the most important innovations consisted in the introduction of the requirement of a public competition for the allocation of targeted state funds for R&D, as well as in the unification of terminology with OECD practices. In 1997, the government adopted new Principles of the Government for Research and Development, in which not only the general rules of support were described, but research policy was also directly linked to the forthcoming accession to the European Union. Moreover, these principles set the objective of regularly increasing direct state support so that by the time of accession to the European Union it would amount to not less than 0.7% of GDP, although this objective was subsequently not in fact achieved. In 1998, the document Principles of Scientific Policy of the Czech Republic at the Beginning of the 21st Century was prepared, and in 2000 the first National Research and Development Policy of the Czech Republic was adopted. This signified a qualitative shift: instead of fragmented budgetary administration, the state moved to the strategic language of policy, priorities, programmes, and evaluation. For the technical sciences, this was especially important, because without a programmatic logic it was impossible to reconnect basic research, applied tasks, and industrial needs.

A special place in this configuration was occupied by the Academy of Sciences of the Czech Republic. It was established by Act No. 283/1992 Coll. as the legal successor to the Czechoslovak Academy of Sciences, and in the 1990s its very existence became one of the central issues of Czech science policy. Official historical material of the Academy itself and a memorial text devoted to Rudolf Zahradník state directly that, in the 1990s, efforts were undertaken that threatened the very existence of the institution and of basic research as such, and that the leadership of the Academy played a decisive role in repelling them. Therefore, the academic sector in the early period of independence cannot be understood simply as a "remnant of the past": it became a mechanism for preserving research continuity under conditions in which a significant part of the branch applied sector had been disorganised by privatisation and changes of ownership. It was precisely through the Academy that schools in physics, chemistry, materials science, mathematics, a number of engineering-related natural-scientific fields, and, more broadly, the culture of the long cycle of fundamental work were preserved. But the Academy was also changing: requirements of evaluation, project competition, international comparability, and subsequent integration with universities were increasingly extended to it. Consequently, its historical role in 1993–2003 consisted not only in preserving the scientific core, but also in the gradual translation of this core into the language of a new, more competitive and internationally oriented model. For the technical sciences, this was critically important, because without such a basic core the subsequent development of laser physics, scientific instrumentation, materials science, or nanodirections in the 2000s would have been far less likely.

At the same time, the university segment was being strengthened, and this was, perhaps, the most important long-term institutional shift of the entire period. The analytical review of 2002 emphasised that the share of universities in total R&D expenditure in the Czech Republic had initially been one of the lowest among the countries compared, but at the end of the 1990s and the beginning of the 2000s it began to grow rapidly. Support for university research plans increased especially noticeably in 1999–2001, and it was precisely the universities that showed the greatest growth in institutional support among the main categories of recipients. However, this growth was contradictory: the same official documents recorded that university research plans were often small, fragmented, and insufficiently interconnected even within individual higher education institutions. That is, the universities were receiving an increasingly important role, but had not yet become fully mature research organisations in the Western European sense. Here, the decisive normative milestone was the Higher Education Act of 1998. The Act defined higher education institutions as "centres of education, independent knowledge and creative activity", enshrined academic freedoms, autonomy in the sphere of the aims of research and innovation activity, as well as the right of universities to develop international cooperation and interact with business and other legal entities. Thus, the Czech Republic laid the legal foundation for the transformation of technical universities from predominantly teaching institutions into fully fledged centres of research and innovation activity, although in practice this transition was only beginning.

This university transformation was closely connected with the broader reform of personnel training and human capital. The White Paper on Education of 2001 directly recommended not only the modernisation of the education governance system, but also the restructuring of the research and development institutes of the Ministry of Education, as well as the expansion of the university research base. For the technical sciences, this was of particular importance, because the engineering modernisation of the country depended not only on the preservation of old research collectives, but also on whether the Czech Republic would be able to reproduce a new generation of engineers, researchers, and specialists in applied development already within new institutional forms. A later OECD review of Czech higher education, retrospectively assessing this trajectory, noted that the role of higher education institutions in the sphere of R&D was steadily increasing and that they were increasingly expected not only to conduct research of a high standard, but also to transfer results into practice, as well as to cooperate with the business sector as a specific “third mission”. It is also important that the Higher Education Act of 1998 made possible the existence of private higher education institutions of university and non-university types. By the 2000s, this had already led to the emergence of a noticeable private segment, although in research and engineering training its role remained secondary compared with state and public universities. All this means that 1993–2003 became a period when technical science gradually ceased to be primarily the domain of academic institutes and branch research institutes and entered the university environment ever more visibly. But this process was still far from complete and carried within it a strong problem of fragmentation.

No less important a dimension of the stage was the Europeanisation of Czech science and technology policy. In December 1997, the Czech Republic applied for full association with the Fifth Framework Programme of the European Union, and already in 1998, the European Commission recorded that the government had approved a special policy document intended to create the basis for a national policy of research and technological development and thereby facilitate the country’s participation in the European programme. By 2000, the Czech Republic was already fully associated with the Fifth Framework Programme and the Euratom Framework Programme, and the necessary administrative structures and the system of National Contact Points had, in the Commission’s assessment, been established and were functioning. This circumstance was of far greater importance than mere access to calls for proposals. Through the framework programmes, the national contact points, harmonisation with the acquis, and the managerial requirements of the European Union, the Czech research system was learning to live by new rules: through transparent procedures, comparative evaluation, international consortia, project management, and thematic priorities. In the governmental analysis of 2002, there was already an explicit mention of the need for active participation in shaping the European Research Area and in preparing a new policy for 2003–2008. Consequently, even before accession to the European Union in 2004, Czech technical science began to change not only its sources of funding, but also its very organisational culture. This was a fundamental historical shift: national science was ceasing to be a relatively closed subsystem and was beginning to become a node within a larger European research area.

However, the new vector of the development of science and technology was formed not only “from above” through laws and European programmes, but also “from below” through industrial restructuring and foreign investment. The OECD Economic Survey 2003 emphasised that productivity in the Czech Republic as a whole remained comparatively low, although a powerful impulse came from the rapidly growing FDI sector, where enterprise productivity was approaching the levels of the investor countries. Over several years, total FDI inflows amounted to 9–12% of GDP, with the exception of 2003, and in 2002 state support was extended not only to the traditional manufacturing sphere, but also to strategic services and technological centres, including software development, high-technology services, and research and development centres. The OECD simultaneously recorded that this foreign-invested segment created on average about 20,000 net new jobs per year, considering direct and indirect effects. The territorial review of 2004 also highlighted the development of Science and Technology Parks, and Brno Technology Park even received the characteristic nickname “Czech Silicon Hill”. For the technical sciences, this was of extreme significance:

modernisation was increasingly proceeding not through the old departmental system, but through the linkage of universities, parks, technological centres, regional agencies, and transnational companies. At the same time, this model had a limitation: advanced technologies and managerial practices were entering the economy rapidly, but their diffusion across the broad layer of Czech SMEs was proceeding markedly more slowly. Therefore, the post-socialist modernisation of the technical sciences in the Czech Republic during this period was to a considerable extent FDI-mediated, that is, mediated by foreign capital and global production chains.

By the beginning of the 2000s, the Czech state attempted to turn this heterogeneous transformation into a more coherent policy model. In 2000, the National Research and Development Policy was adopted, after which the development of the National Research Programme and new instruments of programme funding began. A significant step was the creation of the Research Centres Programme, which by 2001 had already noticeably strengthened the consortial form of project implementation. The new model received its most mature normative expression in Act No. 130/2002 Coll., which entered into force on 1 July 2002. This Act clearly distinguished between targeted support and institutional support, included specific university research and international cooperation within the normative field, required budget proposals to be built on the basis of the National Research Programme and the National Research and Development Policy, and also strengthened the role of the Research and Development Council in shaping medium-term funding prospects. In other words, at the turn of 2002–2003, the Czech Republic for the first time obtained a relatively integral legal architecture of the research sphere, compatible with the European logic of programmes, competitions, evaluation of results, and transparent information systems. This was one of the greatest results of the first post-socialist stage. But even with the new law in place, structural weaknesses remained serious: business preferred short programmes with a rapid return on capital, indirect support for private research and development was practically absent, and early venture capital for high-technology entrepreneurship was minimal; in 2002, seed/start-up venture capital investment in the Czech Republic amounted to only 0.001% of GDP—the lowest figure among the countries included in the relevant comparison. Consequently, by the end of the stage the Czech Republic had already built the modern normative "skeleton" of the science and technology system, but had not yet created a fully functioning market of innovation-led growth around it.

In sum, the period from 1993 to 2003 should be assessed as a stage of state-institutional constitution of the technical sciences and technologies in the new Czech Republic. Its principal achievement was not the emergence of numerous breakthrough high-technology industries, but the prevention of the disintegration of the country's research core and the creation of the rules according to which this core could continue to develop. It was precisely in these years that roles were redistributed among the Academy of Sciences, universities, ministries, grant institutions, industry, and new agencies for business support. It was precisely then that Czech science and technology policy moved from reactive budgetary administration to the language of strategies, programmes, competitions, evaluation, and international integration. It was precisely during this period that the European framework—first as an external point of reference, and then as an almost internal norm—began to shape the country's managerial and research practices. However, the weaknesses of the stage were also fundamental: unstable funding, the unfinished transformation of the applied sector, weak early-stage innovation capital, not yet well-established links between universities and industry, and the unequal capacity of enterprises to absorb and commercialise knowledge. Therefore, the years 1993–2003 cannot be understood as a “lost decade”, but neither can they be described as a period of an already mature innovation economy. It was a decade of difficult adjustment, during which the Czech Republic sought, found, and partially consolidated a new model of scientific and technological development, on the basis of which, after 2004, movement towards more sustainable growth of infrastructures, applied programmes, and international competitiveness became possible.

2004–2013: European Integration and the Infrastructural Leap

The period from 2004 to 2013 became for the Czech Republic the second decisive stage in the post-socialist history of the technical sciences and technologies, because it was precisely then that the transition from a regime of institutional survival to a regime of purposeful expansion of research capacities was completed. If in the 1990s the state was primarily preserving the scientific and technical core from disintegration and searching for a new model of governance, then after accession to the European Union in May 2004 the Czech system of research and development began to be embedded in a far more capacious and demanding supranational framework. This meant a change not only in the sources of funding, but also in the very logic of the functioning of science: the programmatic approach, competitiveness, international partnership, infrastructural planning, and dependence on European evaluation standards all intensified. During the same period, the understanding was finally formed in the Czech Republic that, for a country with a powerful industrial base and a strong engineering tradition, it was not enough simply to support individual institutes or departments; it was necessary to create an integrated system capable of linking basic research, applied engineering, industrial needs, and regional development. It is precisely for this reason that the years 2004–2013 may be described as a decade of Europeanisation and the infrastructural materialisation of science policy. It was a time when, in the technical sciences of the Czech Republic, not only new documents and agencies began to emerge, but also real major facilities around which the entire scientific and technological geography of the country subsequently began to be reorganised. At the same time, modernisation proceeded unevenly: alongside the large-scale inflow of European funds, weak commercialisation, fragmented governance of innovation, and the still unstable capacity of science to be transformed into high added value remained. Nevertheless, it was during this period that the material and organisational foundation was laid on which, already in the 2010s and 2020s, the Czech Republic was able to build its most visible technological niches.

The first layer of this stage consisted of a new political and strategic architecture, constructed immediately after accession to the European Union. In official Czech documents, 2004 itself was explicitly designated as the moment when the basic conceptual documents of the new research and innovation policy were formed. These were, above all, the *National Research and Development Policy of the Czech Republic for 2004–2008*, the *National Innovation Policy of the Czech Republic for 2005–2010*, as well as two successive national research programmes—*National Research Programme I* (2004–2009) and *National Research Programme II* (2006–2011). The importance of these documents lay not only in the enumeration of priorities, but also in the linking of spheres that had previously been partially disconnected: science, innovation, industrial competitiveness, university policy, and European integration. If before this technical science in the Czech Republic had existed to a significant extent as the sum of individual institutes, budgetary flows, and sectoral practices, then after 2004 the state for the first time began insistently to describe it as a unified system oriented towards the formation of a knowledge economy. Already in the *Green Paper on Research, Development and Innovation in the Czech Republic* it was emphasised that the resources of the Structural Funds for 2007–2013 should become a means of transferring the country from a labour-intensive to a knowledge-intensive economy. Thus, the technical sciences began to be regarded not as an autonomous sector, but as an instrument of a broader transformation of the economy and state development. This turn was of fundamental importance precisely for engineering and technology, because it made it possible to justify major long-term investments in laboratories, computing capacities, experimental facilities, and high-technology personnel training.

One of the most important institutional shifts of this period was the legal and organisational restructuring of the research organisations themselves. An essential role here was played by *Act No. 341/2005 Coll. on Public Research Institutions*, as well as the related *Act No. 342/2005 Coll.*, which adjusted a number of associated normative acts. As official materials of the Ministry of Education show, these changes formed part of a broader process of aligning the Czech R&D system with European rules on state aid, competitive funding, property regimes, and organisational autonomy. The law on public research institutions created a legal form that was intended to provide research organisations with greater managerial flexibility, a more modern structure of property relations, and clearer rules for interaction with the state. It is especially important that, from 1 January 2007, the actual conversion of a number of organisations into public research institutions began, and a special transformation regime was also provided for the structures of the Academy of Sciences. This was not merely a technical legal reform. In practice, it involved the creation of an organisational framework suitable for participation in European programmes, the conclusion of consortium agreements, the operation of expensive infrastructure, and more flexible recruitment of personnel under conditions of growing international competition. For the technical sciences, this reform had an almost constitutional significance, because they depend more than others on complex ownership arrangements for equipment, on long-term programmes, and on clear rules for the distribution of responsibility between the institute, the state, and external partners. Therefore, the years 2005–2007 were a period not only of the adoption of new laws, but also of profound legal preparation for the future infrastructural leap.

In parallel, a deep Europeanisation of the Czech scientific environment was taking place through the EU Framework Programmes and the associated mechanisms of international cooperation. Already in the materials of the Ministry of Education from the late 2000s, it is evident how important the issue of ensuring the participation of Czech teams in the Sixth and then the Seventh Framework Programmes had become. The official guide to state support for R&D directly recorded that the amendment to *Act No. 130/2002 Coll.* through *Act No. 171/2007 Coll.* made it possible partially to co-finance, from national public funds, projects that had passed international evaluation and received support from the European Commission. This decision was highly significant, because it removed one of the key barriers to the participation of Czech organisations in European projects: the need to find national resources for co-financing and organisational support. Around the Framework Programmes, a special institutional infrastructure also developed—national contact organisations, the NINET network, the NICER information centre, and coordination with the participation of the Technology Centre of the Academy of Sciences. By 2013, the results of this Europeanisation had already become quite measurable: in the official analysis of the RVVI, 1,190 participations of Czech organisations in FP7 projects were recorded, as against 1,068 in FP6, while the financial success rate of applications from Czech teams amounted to 14.9%, which was the second-best result among the new Member States of the European Union. At the same time, state analysts honestly acknowledged a limitation as well: in terms of the volume of attracted funds per unit of total national R&D expenditure, the Czech Republic still belonged to the countries with a relatively low share of Framework Programme funding in overall research financing. Consequently, European integration did indeed strengthen the international presence of the technical sciences of the Czech Republic, but it had not yet turned them into a system equally competitive across all segments of European scientific cooperation.

By the middle of the stage, it had become evident that participation in European programmes and the updating of individual laws alone were insufficient: the country required a large-scale systemic reform of the governance of research and innovation. The response to this was the *Reform of the System of Research, Development and Innovation in the Czech Republic*, adopted in 2008. In the very first lines of the document, a programmatic objective was formulated: to create an innovation environment in which knowledge produced by science could be converted to a greater extent into economic value. Behind this formula stood the state's deep dissatisfaction with the existing system: excessively fragmented governance, excessively weak coordination between research policy and innovation policy, an overload of institutional compromises, low transparency in the distribution of funds, and an insufficient return on public investment. In the *Green Paper* of the same period, this problematique was developed even more broadly: the Czech Republic was conceptualised as a country already moving towards a knowledge-based economy, but still lacking a sufficiently integral mechanism for evaluation, prioritisation, and knowledge transfer. It was precisely for this reason that, at the turn of 2008–2009, the convergence of two previously partially separate languages of state policy took place—the language of research and the language of innovation. From that time onwards, governmental documents increasingly used not the pair "science and technology", but the combination "research, development and innovation". For the technical sciences, this was of fundamental importance: they were now expected not merely to produce results, but also to participate in the innovation chain—from laboratory to industry, from publication to prototype, from scientific centre to regional competitiveness. The reform thereby changed not only the rules, but also the normative conception of what in general should be regarded as successful modern engineering science.

The material expression of this reform was the establishment in 2009 of Technologická agentura České republiky (TA ČR)—an institution that very quickly occupied a central place in the new system of applied science. On the official page of TA ČR, it is stated directly that the agency was founded in 2009 on the basis of *Act No. 130/2002 Coll.* and that its establishment became one of the cornerstones of the fundamental reform of the Czech R&D system. Its most important function consisted in the concentration and simplification of state support for applied research and experimental development, which had previously been dispersed across numerous ministries and programmes. This decision had an obvious technological meaning: for engineering and industrially oriented fields, the presence of an operator capable not only of distributing grants, but also of constructing a clearer interface between companies, universities, and public research organisations, is especially important. Already in 2011, the OECD noted that the task of strengthening cooperation between enterprises and universities had been specifically delegated to the Czech technology agency. However, the same OECD simultaneously recorded that innovation policy as a whole remained highly fragmented and was channelled through several different institutions, while direct support measures, including those financed by EU Structural Funds, still predominated over indirect instruments. In other words, the establishment of TA ČR did not eliminate all the problems of the system, but it did, for the first time, create a specialised centre of gravity precisely for applied and use-oriented research activity. For the technical sciences, this meant institutional recognition of their special status as a sphere in which not only research as such, but also its delivery to a practical result, is critically important.

The most visible turn of the second stage is linked, however, not with agencies and not with laws, but with the unprecedented growth of investment ensured by European funds. In the official analysis of 2013, it was directly emphasised that 2011 and 2012 became exceptional years in terms of the overall increase in expenditure on research and development: over two years, the total volume of expenditure increased by 19.4 billion Czech crowns and reached 72.4 billion in 2012, while the share of R&D in GDP rose to almost 1.9%. The same analysis noted that total public expenditure on R&D, including EU funds and the financial mechanisms of Norway/EEA, reached 39.1 billion crowns, that is, 1.02% of GDP. A separate section of the analysis directly linked the growth of foreign funding sources with the deepening of integration into the European Research Area and emphasised that the EU Structural Funds created an important opportunity to modernise the infrastructural base of research and development, the educational system, human resources, and the innovative activity of business. After joining the EU, the Czech Republic first entered the shortened programme period of 2004–2006, and then fully entered the 2007–2013 cycle; by 2013, state analytics recorded that it was precisely this second framework that had become the principal investment platform for building new research and educational capacities. Thus, European funds ceased to be merely an external supplement to the national budget. They effectively turned into the principal driver of the material renewal of Czech technical science. Without them, this stage would probably have been limited to managerial reform; with them, however, it turned into a genuine infrastructural leap.

The central instrument of this leap was Operační program Výzkum a vývoj pro inovace (OP VaVpI), launched for the programme period 2007–2013. On the official page of the European Commission, it was indicated that the total budget of the programme amounted to approximately EUR 2.4 billion, of which around EUR 2.1 billion came from the European Regional Development Fund. A later assessment by the Commission clarified that, during the period, the amount was adjusted and the final allocation amounted to approximately EUR 2.2 billion, of which EUR 1.8 billion consisted of ERDF funds. It is also important that the programme was oriented towards the regions of the Czech Republic outside Prague, since the capital did not fall under the Convergence objective; thus, the very architecture of the funding stimulated a geographical redistribution of scientific and technological growth. According to the same assessment, eight new centres of excellence and forty regional research centres were created under OP VaVpI, while the main body of resources was directed precisely towards the infrastructure of Priority Axis 1 “European Centres of Excellence” and Priority Axis 2 “Regional R&D Centres”. It was here that the key historical turning point occurred: in the Czech Republic, the process began for the first time not merely of modernising existing institutes, but of building fundamentally new centres designed for an international level of equipment and research. For the technical sciences, this was especially important, because they benefit more than others from the concentration of expensive apparatus, shared facilities, interdisciplinary platforms, and large teams. OP VaVpI thus became not merely a financial programme, but a mechanism for the territorial and organisational recoding of the entire research system.

Alongside OP VaVpI, the shaping of a national strategy for large research infrastructures also played an important role. The official Czech roadmap for large research infrastructures was first prepared by the Ministry of Education in 2010 and was then updated in 2011. By its definition, this roadmap was constructed in accordance with the structure of the ESFRI Roadmap, that is, it was developed from the outset as a national instrument compatible with the European logic of defining priority research facilities. The significance of this step can hardly be overstated. For the first time, the Czech state recognised large research infrastructures as a special category of public policy requiring a separate selection procedure, international evaluation, long-term funding, and political approval at government level. This meant that major facilities—from laser and computing complexes to materials-science and nuclear installations—began to be perceived not as exceptional one-off projects, but as a systemic element of the national research ecosystem. For the technical sciences, such a transition was decisive, because in these fields the research level is increasingly determined not only by the quality of individual scholars, but also by the availability of world-class infrastructure. As a result, by the beginning of the 2010s the Czech Republic had moved from the rhetoric of modernising science to the practice of selecting and funding specific large facilities integrated into the European research space. In this sense, the 2010–2011 roadmap was not a bureaucratic appendix, but a strategic mechanism for the legitimation and ordering of the infrastructural state in science.

It was on this basis that projects began to emerge in the country that became symbols of the entire stage. CEITEC in Brno began operating in 2011, and on 6 June 2011 the European Commission approved funding for the centre in the amount of CZK 5.2 billion. CEITEC itself today describes itself as a cutting-edge infrastructure and research centre, but for the period under consideration another aspect is more important: it became one of the first Czech projects in which major infrastructure, an international кадровая policy, interdisciplinarity, and a regional strategy were combined within a single framework. ELI Beamlines underwent a preparatory phase with the support of the European Commission in 2007–2010, finally received the “green light” in 2011, and in the same year its funding was approved. The official Milestones section records April 2011 as the moment of project approval, August 2011 as the signing of the budget, and May 2013 as the start of the construction of the building. IT4Innovations, in turn, was established in 2011, joined PRACE in the same year, and launched the Anselm supercomputer in 2013. Taken together, these projects demonstrate the qualitative difference of the new stage from the previous one. The Czech Republic ceased to be a country that merely reformed regulatory acts and attempted to improve the governability of science, and became a country that was constructing physically tangible facilities of a European research class. It is especially important that all three examples represent different technological axes—advanced materials and life-science enabling technologies, extreme laser science, and supercomputing/HPC. This means that the infrastructural leap was not one-dimensional; it immediately created several platforms for the country’s future technological specialisation.

However, this leap was accompanied by serious contradictions as well. The European evaluation of OP RDI emphasised that the supported centres were initially required to ensure at least 30% of their income from contract research, because the European Union and the Czech managing authorities sought to achieve a closer link between the academic sector and business. But in 2013 the state-aid rules were changed, and the permissible threshold for contract research was reduced to 20%, which, in the Commission's assessment, seriously disrupted the logic of part of the projects and created legal uncertainty for the beneficiaries. This is particularly indicative for the technical sciences: it was precisely there that the centres naturally sought to work with industrial contracts, testing, prototyping, and applied commissions, but the normative framework did not always allow them to do so without the risk of losing compliance with the regime of non-economic activity. On the other hand, the Czech Republic itself had not yet fully overcome the fragmentation of innovation policy. In 2011, the OECD stated directly that innovation policy remained highly fragmented, despite the new institutions and the emphasis on indirect instruments such as guarantees and tax incentives. The official analysis of 2013 also recorded that the strengths of the Czech Republic lay in corporate investment in innovation and in the activity of innovative SMEs, whereas the weakest area remained the research system—especially in terms of the quality and openness of public research—as well as the use of intellectual property. In other words, European integration and infrastructural construction sharply strengthened the material base and the international visibility of the system, but did not automatically resolve the problem of how exactly that system was to transform knowledge into patents, licences, contracts, and sustainable technological business.

By the end of 2013, the Czech Republic had arrived at an ambivalent but, on the whole, historically very significant result. On the one hand, the country had achieved what it did not have in the 1990s: a new policy of major infrastructures, a specialised agency for applied research, a revised legislative framework, growing participation in the EU Framework Programmes, a noticeable rise in GERD, and centres of international level that were actually being built or had already been launched. In 2012, the National Priorities of Oriented Research, Experimental Development and Innovation were also approved, and in 2013 the updated National Research, Development and Innovation Policy for 2009–2015 with regard to 2020 already linked the prioritisation of applied research with the needs of society, the economy, and the new programme framework of the European Union. On the other hand, state analytical documents of the same period openly recorded structural limitations as well: a deterioration in overall competitiveness during the crisis period, the risk of the relocation of corporate R&D, weak positions in the sphere of intellectual assets, the very low role of venture capital, and the fact that Czech industrial competitiveness still relied above all on medium-high-tech and medium-low-tech activities rather than on high-technology added value. Therefore, the years 2004–2013 were not yet a time of a fully mature innovation economy. But neither were they merely an intermediate stage. This was the period when the Czech system of the technical sciences finally moved out of the logic of post-socialist stabilisation and entered the logic of European-integrated, infrastructure-rich, and strategically governed development. It is precisely for this reason that this stage should be regarded as the true moment of the institutional maturation of modern Czech engineering and technological science.

2014–2025: Consolidation, Frontier Technologies, and "Engineering Specialisation"

From 2014 onwards, the history of the technical sciences and technologies in the Czech Republic entered a qualitatively new phase. If the period from 2004 to 2013 had been a time of massive infrastructural construction and institutional re-equipment, then the years from 2014 to 2025 became a time of mastering the base that had been created, of its managerial consolidation, and of the clearer shaping of those directions in which the Czech Republic could lay claim not merely to participation in the European scientific and technological space, but to its own sustainable specialisation. During this period, the very character of development changed: instead of the logic of “creating centres and connecting to the EU”, the logic of “linking infrastructures, applied programmes, business, digitalisation, and export-oriented industry into a single system” became increasingly visible. It is precisely for this reason that, in official strategies and analytical documents of 2019–2025, the Czech Republic increasingly described itself not as a country of catch-up modernisation, but as a country seeking to use science, engineering competences, and new technologies as the core of national competitiveness. At the same time, this phase was not a period of problem-free triumph. On the contrary, it was precisely after the completion of the infrastructural leap that it became especially clear where the Czech Republic was genuinely strong and where its system remained limited: in applied engineering, private R&D, and medium- and high-technology industrial exports it appeared confident, whereas in venture financing, the depth of knowledge-intensive services, the scale of the digital transformation of business, and the educational base, structural weaknesses remained. Therefore, the years 2014–2025 are best understood as a phase of consolidation and selection, when the system built earlier began unevenly to develop into a model of engineering specialisation.

The beginning of this stage was closely connected with the transition to the new European programme framework for 2014–2020 and with the need to integrate the infrastructures already created into a more sustainable system for the reproduction of personnel, research, and innovation. The symbol of this transition became Operační program Výzkum, vývoj a vzdělávání (OP VVV), through which the Czech Republic directed more than EUR 2.76 billion from the EU budget to research, education, and related reforms. Unlike the previous period, when the priority had primarily been capital investment in facilities and equipment, the new programme was intended to connect infrastructure with human resources, the quality of research, international integration, and knowledge management. This is extremely important for understanding the technical sciences in the Czech Republic after 2014: the country began to realise that new centres in themselves did not yet create sustainable technological leadership if they were not accompanied by long-term measures for the development of research teams, international mobility, doctoral studies, network interaction, and organisational maturity. In effect, the Czech Republic moved from the stage of “construction” to the stage of “populating” infrastructures—with scientists, engineers, international partnerships, programmes of applied cooperation, and new managerial procedures. In such a configuration, the technical sciences were no longer regarded as a set of laboratories or institutes, but as part of a broader knowledge infrastructure linked simultaneously with industry, European cohesion policy, and national strategic documents. It is precisely for this reason that, from the middle of the 2010s onwards, the theme of coordination between science policy and innovation policy, as well as between national and regional support instruments, became increasingly prominent in the Czech Republic.

One of the key mechanisms of this coordination was the smart specialisation strategy—RIS3. The first version of the Czech Národní výzkumná a inovační strategie pro inteligentní specializaci was prepared in 2014, and in 2016 it received an updated and more operational form. Already in the documents of 2014 and 2016, RIS3 was described as an instrument for the effective targeting of European, national, regional, and private funds towards those areas capable of creating a long-term competitive advantage for the Czech Republic on the basis of knowledge and innovation. It is also significant that RIS3 was conceived from the outset as a multi-level system: the national level set the general framework, while regional strategies and platforms were to identify concrete points of growth, linking scientific organisations, firms, public administration, and sectoral networks. In the updated 2016 version, the mature logic of smart specialisation is already visible quite clearly: regular updates of the strategy, National Innovation Platforms, entrepreneurial discovery of opportunities, the tying of competitive calls to identified domains, and the Smart Akcelerátor instrument for the development of the regional innovation environment. This was the most important shift in comparison with the previous stage. The Czech Republic was now not merely funding science and technology, but was attempting to build a process of selection within which support for applied research, digitalisation, advanced manufacturing, ICT, transport, energy, and other directions was to rest on a systemic analysis of national advantages. For the technical sciences, this meant a transition from a general discourse of modernisation to a regime of structured specialisation.

Closely linked with RIS3 was another crucial line of the years 2014–2025—the transition to a new model of large research infrastructure as a long-term element of state policy. By this time, the Czech Republic already possessed CEITEC, ELI, IT4Innovations, and a number of other strong facilities, but it was precisely after 2014 that their systematic inclusion in the regime of international peer review, updated roadmaps, multiannual financial frameworks, and more stringent positioning within the European Research Area began. Official materials on the Cestovní mapa velkých výzkumných infrastruktur emphasise that, after the first versions of 2010 and 2011, the roadmap was updated in 2015, 2019, and then in 2023–2024, while international evaluation of Czech large infrastructures has been carried out by the Ministry of Education on the basis of international peer review since 2014. In the updated roadmap for 2023–2026, research infrastructures are directly described no longer merely as part of the R&I system, but as one of the components of the critical infrastructure of the state alongside energy, healthcare, and security. This is highly indicative of the mature stage of evolution. The Czech Republic ceased to regard large facilities as exceptional prestige projects and began to treat them as a permanent systemic resource on which scientific resilience, innovative capacity, and even national preparedness for crises depend. For the technical sciences, this meant definitive institutional maturity: their apparatus-based and computational base acquired a status comparable in significance with that of other strategic sectors.

On the basis of this, in 2014–2025 a distinctive spatial structure of Czech technical science finally took shape. Prague and the Central Bohemian Region strengthened their role as centres of governance, digital policy, AI coordination, and major international infrastructures such as ELI; Brno became an even more prominent pole of scientific instrumentation, electron microscopy, nano- and micro-engineering, materials science, and advanced inter-university cooperation; Ostrava consolidated its position as the country's principal national node of high-performance computing; Plzeň and Řež reinforced their positions in energy and nuclear engineering; the industrial belt around Mladá Boleslav, Plzeň, and Moravia remained the base of automotive and mechanical-engineering technological competence. At the same time, the most important feature of the mature phase consists in the fact that territorial technological poles increasingly relied not on a single institute or enterprise, but on complexes: universities, academic institutes, research centres, industrial R&D divisions, regional agencies, and EU infrastructures. It was precisely in this format that the Czech Republic began to build its "engineering specialisation". It was less oriented than the leading Western European countries towards large-scale platform-based digital corporations or towards the dominance of knowledge-intensive services, but it used its strengths in applied physics, complex scientific instrumentation, manufacturing automation, industrial robotics, materials science, and transport technologies much more actively. As a result, by the middle of the 2020s the Czech technological map had already become markedly polycentric, yet at the same time internally integrated through RIS3, large infrastructures, sectoral strategies, and nationwide digital documents.

A key turn in the middle of the stage was connected with the realisation that, for the Czech Republic, it was not sufficient simply to remain a country of strong industry and solid applied R&D. It was necessary to formulate a response to the global agenda of the Fourth Industrial Revolution. It was precisely in this context that, on 24 August 2016, the government approved the document Iniciativa Průmysl 4.0. Its officially formulated long-term objective consisted in preserving and strengthening the competitiveness of the Czech Republic under the conditions of the mass advance of the Fourth Industrial Revolution. In the same year, 2016, the government also approved the implementation of BIM as one of the instruments for the digitalisation of construction practice, appointing the Ministry of Industry and Trade as the guarantor of its promotion. These decisions meant that digital modernisation began to be perceived not as a narrow theme of the IT sector, but as a horizontal challenge for the entire engineering economy—from mechanical engineering and logistics to construction, energy, and public infrastructure. It is also important that the Czech version of Industry 4.0 was from the outset deeply “engineering-oriented”: the emphasis was placed not so much on consumer digital platforms as on production systems, cyber-physical complexes, automation, data, standardisation, and new workforce competences. This corresponds well to the country’s overall trajectory: the Czech Republic sought not to replace its industrial foundation with a digital one, but to digitalise and strengthen precisely its industrial and engineering foundation. In this lay one of the most important historical distinctions between 2014–2025 and the earlier phases.

The next major turning point fell in 2018–2019, when the digital and innovation agenda acquired a supra-sectoral strategic status. In 2018, the Digitální Česko framework was adopted, and in 2019 the Inovační strategie České republiky 2019–2030 was approved. The latter became one of the central documents of the entire late phase and directly declared the ambition of bringing the country into the ranks of Europe’s innovation leaders by 2030. The text of the strategy fixed nine strategic pillars, and the rhetoric of the document is markedly more confident and ambitious than the language of the preceding reforms. This was no longer a strategy of stabilisation and not merely a strategy of catch-up modernisation, but a strategy of technological self-assertion. Yet what is especially important is not the slogan, but the substantive turn: innovation policy begins to be interpreted as interministerial, cross-sectoral, and connected not only with science, but also with talent attraction, English-language master’s and PhD programmes, the startup and spin-off environment, digital statehood, industrial transformation, and the country’s international reputation as a Country for the Future. Thus, the technical sciences and technologies finally became in the Czech Republic not an object of narrowly professional policy, but a central element of the national development project. This is precisely the moment when “engineering specialisation” moved from the level of expert analysis and became a state narrative.

In the same year, 2019, the Czech Republic was one of the first countries in the European Union to approve a Národní strategie umělé inteligence. The official resource of the Ministry of Industry and Trade already emphasises that, in 2019, the country became one of the first in the

European Union to adopt its own national AI strategy. The initial ambition consisted in making the Czech Republic a model European country in the field of AI and in creating a hub for cooperation between scientists and developers, especially in sectors with a high degree of engineering and applied intensity. It is of fundamental importance that the Czech AI agenda was formed not in isolation from industry, but in conjunction with RIS3, Digitální Česko, HPC, cybersecurity, digital public services, and applied testbeds. It is precisely for this reason that AI in the Czech Republic for a long time developed predominantly not as a consumer-tech narrative, but as part of a broader system of advanced manufacturing, computational science, and public-sector digital transformation. In 2024, this line was updated: the government approved the Národní strategie umělé inteligence České republiky 2030. Consequently, by the end of the period under consideration, AI was no longer in the Czech Republic an experimental direction of the future, but had turned into an established layer of national technological policy embedded in the system of broader digital and research priorities. In the context of historical evolution, this means that by the middle of the 2020s the Czech Republic had begun to institutionalise not only the classical engineering disciplines, but also frontier digital technologies.

No less important a feature of the late stage was the final consolidation of the dominant role of business in the Czech system of research and development. By 2024, according to data from the Czech Statistical Office, total expenditure on R&D had reached CZK 146.9 billion, or 1.82% of GDP, while more than CZK 93 billion had been financed from business sources, and the share of business resources exceeded 60% of all expenditure. This shows that the mature Czech model of the technical sciences became to a considerable extent corporate-engineering in character. Unlike countries where the principal driver of the innovation system is the venture ecosystem or the state megaproject sector, in the Czech Republic it is precisely enterprises—often embedded in international value chains—that play the decisive role in maintaining research intensity. This picture is also confirmed by the European Innovation Scoreboard 2025: the country remains a Moderate Innovator, but demonstrates strong positions in public-private co-publications, in exports of medium- and high-tech products, and also in certain indicators of digital skills. At the same time, the same EIS 2025 records its weaknesses: venture capital expenditure, the share of the population with tertiary education, and labour productivity. Therefore, the mature stage of 2014–2025 cannot be described as a transition to unconditional innovation leadership. Rather, it is the consolidation of a model in which applied engineering, industrial R&D, and the export of technologically sophisticated products are strong, but in which the ecosystem of radically new companies, high-risk capital, and broader digital entrepreneurial dynamism still remains insufficiently developed.

It is precisely in this context that the strategies of the 2021+ period acquire particular significance. The National Research, Development and Innovation Policy 2021+ became a document that already proceeded directly from the need to overcome the gap between the research sphere and the application sphere. Its text emphasises the desirability of moving the Czech Republic from the group of moderate innovators to the group of innovation leaders, but at the same time acknowledges the insufficient long-term cooperation between the research sphere and the application sphere. The strategy places emphasis on the coordination of providers of RDI support, the support of mobility, international cooperation, the identification of projects with application potential, and the more systematic use of the results of fundamental research in company innovation. This is characteristic precisely of the mature phase: the country’s problem no longer consisted in the absence of basic infrastructure or strategies as such, but in how to make the entire system operate with greater coherence, effectiveness, and international impact. The updated National RIS3 Strategy 2021–2027 develops the same logic. It states directly that, despite the presence of strong organisations and infrastructures, the quality and effectiveness of public R&D can still be improved, while the digitalisation of companies and the public sector continues to lag behind. As a result, at the turn of the 2020s Czech policy spoke less about the "construction of the system" and more about increasing its internal coherence, efficiency, and capacity for transfer. Historically, this is the principal sign of consolidation.

In the later segment of the stage, new zones of technological priority also took shape with particular clarity. One of these became cybersecurity. The National Cyber Security Strategy of the Czech Republic for the period from 2021 to 2025 already formulated one of its basic visions as Resilient Society 4.0, emphasising that ensuring cybersecurity requires not only technical, but also diplomatic, legal, educational, and organisational measures. Another line is semiconductors. On 10 October 2024, the government approved the National Semiconductor Strategy, directly linking it to the European Chips Act and to the ambition of making the Czech Republic an important player in chip production, above all in those segments where it has genuine potential. At the same time, at the level of digital policy, the country's embedding in pan-European programmes continued: the Ministry of Industry and Trade coordinates participation in the Digital Europe Programme, directed towards HPC, AI, cybersecurity, and digital skills. All these steps show a characteristic feature of the mature phase: the Czech Republic defines priorities less and less simply by ministerial affiliation and increasingly groups them around technological stacks—digital infrastructure, computing, AI, cybersecurity, semiconductors, and advanced manufacturing. This is no longer the logic of classical sectoral industrial policy, but the logic of frontier ecosystems, albeit developed on the basis of a strong industrial country rather than a post-industrial platform economy.

The pandemic and post-pandemic context further intensified this restructuring. The National RIS3 Strategy 2021–2027 states directly that the crisis caused by Covid-19 significantly affected the orientation of the strategy and strengthened the search for new innovative solutions from the point of view of long-term resilience. The updated roadmap of large research infrastructures for 2023–2026 emphasises that the ecosystem of research infrastructures should be regarded as part of critical infrastructure, since it strengthens the capacity of the system to respond immediately to sudden threats and crises. In turn, the Digital Decade 2025 Country Report on the Czech Republic states that the country has achieved strong results in digital skills and nationwide 5G coverage, but still lags behind in the deployment of very high-capacity networks and in the digital transformation of businesses. This combination is highly indicative. It means that, in the 2020s, the Czech Republic already possessed a sufficiently mature foundation to shift the discussion of technologies from the level of individual projects to the level of resilience, preparedness, and strategic capability. But at the same time it became clear that infrastructural and engineering strength does not automatically translate into an even digital modernisation of the entire economy. Thus, the end of the 2014–2025 stage is characterised not only by an expansion of priorities, but also by a more honest recognition of the internal limitations of the model that has been created.

In sum, the period from 2014 to 2025 should be assessed as the time when the Czech system of the technical sciences and technologies first acquired a sustainably distinguishable profile. It was no longer simply a post-socialist system catching up with the West through reforms and European funds. But neither did it become a copy of Western European innovation economies, where venture ecosystems, global digital platforms, and a large-scale market of knowledge-intensive services dominate. The Czech Republic built its own model: strong research infrastructures, the growing role of international peer review and strategic roadmaps, the dominance of business financing of R&D, the high weight of industrial and medium-/high-technology exports, the active promotion of Industry 4.0, AI, cybersecurity, and semiconductors, as well as a constant attempt to link all this through RIS3 and nationwide strategies. At the same time, chronic limitations remained—weak venture capital, a deficit in tertiary education compared with the best countries of the European Union, limited productivity of knowledge transfer, and insufficient depth of the digital transformation of business. Therefore, the mature phase of Czech technological evolution is best defined as a phase of consolidated engineering specialisation. It was precisely in this phase that the Czech Republic found not a universal innovation formula, but its own path: reliance on industry, applied science, world-class infrastructures, and selective frontier directions capable of strengthening the country's already existing engineering base.

Part 2

An Expanded Characterisation of the Contemporary Stage of the Development of the Technical Sciences in the Czech Republic

The Contemporary Model: Strong Business R&D and Applied Engineering

The contemporary model of the development of the technical sciences in the Czech Republic is defined above all by the fact that its research system relies decisively on the business sector, and not only on state institutions or universities. According to data from the Czech Statistical Office, in 2024 gross domestic expenditure on research and development reached CZK 146.9 billion, which corresponded to 1.82% of GDP, and more than CZK 93 billion of this amount was financed from business sources. At the same time, around CZK 95 billion of R&D was performed in the business sector, that is, almost 65% of all expenditure on research and development in the country. This means that the contemporary Czech model, in structural terms, is not simply mixed, but specifically business-centred, in which companies act not as an auxiliary, but as the principal institutional carrier of engineering and research activity. In quantitative terms, this is confirmed by the personnel structure as well: of 86.9 thousand persons employed in R&D in full-time equivalent, 51,740 were in the business sector, whereas the government sector accounted for 13.7 thousand and higher education for 20.8 thousand. In other words, in the Czech Republic contemporary technical science is organised in such a way that its largest working arena is not only the laboratories of the academy and universities, but above all the research divisions of companies. From this follows the character of the technological model itself: it is oriented not towards an abstract increase in publication activity, but towards the solution of concrete engineering tasks connected with products, processes, components, testing, and industrial implementation. The statistical methodology of the Czech Statistical Office itself explicitly records that the business sector is concentrated chiefly on applied research and experimental development, and that the results of its activity are especially closely connected with innovations in the form of new or improved products and services.

An important conclusion follows from this structure: the contemporary Czech Republic is neither a classical "academia-centred" innovation system of the Western European type nor a model based on the dominance of start-ups and venture funds. On the contrary, the Czech research system in technical fields has grown around a mature manufacturing economy, closely embedded in European and global value chains. In its Economic Survey 2025, the OECD emphasises that the central problem for the country remains the slowdown in productivity growth after the global financial crisis and the effective halt of productivity convergence after the pandemic. Within this logic, science and technology are considered not in isolation, but as a key instrument for reviving productivity and business dynamism. Yet the path to this revival is sought by the Czech Republic above all not through a large-scale platform-based digital economy, but through strengthening the innovation capacity of enterprises, improving the links between business and the research sphere, and better targeting R&D support for young and small firms. Consequently, the current Czech model proceeds from the assumption that science must be embedded in the productive fabric of the country. Hence the special role of the engineering disciplines: it is precisely they that most organically link knowledge, industrial design, testing cycles, the digitalisation of production, and exportable products. In other words, applied engineering in the Czech Republic is not a peripheral part of the scientific system, but its actual centre of gravity. In this lies the principal distinction of the contemporary Czech model from models in which technical science is built primarily around fundamental university clusters or around rapidly growing start-up ecosystems.

This type of organisation of science is historically based on the industrial structure of the Czech economy. Even in contemporary analytical OECD documents, the Czech Republic continues to be described as one of the most distinctly manufacturing economies in Europe, deeply integrated into global value chains and especially sensitive to the quality of links between foreign investors, local suppliers, and the national research system. The 2024 OECD report on linkages between FDI and SMEs in the Czech Republic proceeds directly from the assumption that the innovation and productivity effects of foreign investment depend on how effectively the channels of the diffusion of knowledge, technologies, and skills function between transnational corporations and local companies. In this context, the Czech model of business R&D is not confined to the internal laboratories of large firms; it includes an entire system of technological spillovers, in which major foreign and national manufacturers, suppliers, regional SMEs, universities, and applied centres form a complex ecosystem. It is indicative that the OECD links the potential of productivity and innovation spillovers precisely with the quality of inter-firm cooperation, partnerships, and value-chain relationships. This is especially important for the Czech Republic, because a large part of its industrial strength is concentrated in sectors where research is rarely fully autonomous: in the automotive industry, electronics, component engineering, transport engineering, precision instrumentation, and advanced materials. Thus, the contemporary business-oriented model of Czech science functions as a system of applied knowledge within supply chains, and not as an autonomous high-technology sector detached from the real industrial environment. In this sense, its strength lies not in maximum scientific "breadth", but in the deep linkage between production and research.

This linkage is especially clearly visible in those directions in which the Czech Republic has managed to create a dense co-existence of enterprises, engineering teams, and technical universities. For example, CzechInvest directly states that the country is a highly competitive location for the placement of R&D facilities, and that local technical universities are accustomed to cooperating with global OEMs and providing services in the field of research, development, and testing. The same official material lists Volkswagen, Robert Bosch, Valeo, ZF Engineering, and Honeywell as companies that have placed their centres of competence in the Czech Republic and employ thousands of qualified engineers there. This configuration shows that the Czech model of applied engineering is based not only on national companies and not only on foreign subsidiaries, but on their interaction with the local educational and research base. This is highly characteristic of a mature, but not venture-dominant, innovation regime. Instead of building the economy around a multitude of rapidly growing digital start-ups, the Czech Republic strengthens already existing engineering chains through R&D centres, testing, design engineering, material validation, embedded development, and industrial services. That is precisely why the term "applied engineering" here is not stylistic, but structural: R&D in the Czech Republic often represents not fundamental science located far from production, but a research-intensive extension of industry itself. For a country with a strong export specialisation, this offers a major advantage: scientific results are more easily integrated into real products and technological processes. At the same time, however, this makes the system more dependent on the condition of international production chains, external demand, and the strategies of large corporations.

Government strategy in recent years has consciously supported precisely this configuration. The *National Research, Development and Innovation Policy 2021+* explicitly identifies among the key areas of development not only the governance and funding of the system, the quality and international excellence of RDI, but also cooperation between the research and application spheres and the enhancement of the innovation potential of the Czech Republic. This is highly symptomatic. The state does not proceed from the assumption that it is sufficient simply to improve fundamental research and then the market will itself find a way to use it. On the contrary, the very formulation of the objectives indicates that the systemic problem is seen in the weak or insufficiently dense link between the production of knowledge and its practical use. In this context, the contemporary Czech model of strong business R&D appears simultaneously both as an achievement and as a political norm that needs to be further strengthened. RIS3 2021–2027 fixes the same logic even more firmly: the strategy defines its task as the effective direction of European, national, and local resources towards support for oriented and applied research and innovation in selected priority areas capable of giving the Czech Republic a long-term competitive advantage on the basis of the use of knowledge and innovation. Thus, the applied, sectoral, and use-oriented character of the Czech model is not a side effect of the structure of the economy; it is also fixed at the level of strategic documents. It is precisely here that one can see that state policy and the actual structure of the economy in the Czech Republic have, to a considerable extent, converged in the same direction.

At the same time, the Czech model should not be understood as the complete subordination of science to the interests of business in a narrow sense. Rather, it is a more complex system in which companies act as the largest performers and financiers of R&D, while the state and the universities perform a supporting, coordinating, and personnel function. In 2024, the state and university sectors together still accounted for around 34% of domestic expenditure on research and development, while higher education and the government sector together concentrated more than 34 thousand R&D FTE. This means that business dominance has not destroyed the public research base. On the contrary, the Czech system functions as a model of the division of labour: public structures retain a significant part of the fundamental and academic potential, whereas the business sector turns this, together with its own developments, into applied solutions and production innovations. It is especially important here that the statistical methodology of the Czech Statistical Office includes, within the income of the government and higher-education R&D sector, not only budgetary appropriations, but also income from contract research, royalties and licence fees from the use of intangible research results. This shows that the public sector in the Czech system has long since ceased to be conceived as wholly autonomous from the application sphere. Consequently, the contemporary Czech model is not a binary scheme of “the state versus business”, but a system in which applied engineering serves as an interface between the public research base and corporate technological implementation. Historically, it was precisely such a configuration that enabled the Czech Republic to absorb relatively successfully the infrastructural investments of the 2000s and 2010s without losing its connection with the productive economy.

The strength of this model lies in the fact that it provides quite a high degree of commercial and productive realisability of scientific results. The European Innovation Scoreboard 2025 places the Czech Republic in the group of Moderate Innovators, but at the same time identifies among the country's relative strengths public-private co-publications, digital skills of the population above the basic level, and the share of foreign doctoral students. Even more indicative is the fact that among the Czech Republic's highest-ranked indicators are exports of medium and high-tech products, high-tech imports from outside the EU, and non-R&D innovation expenditures. Taken together, this suggests that the country is especially effective not so much in creating an entirely new radical knowledge economy, as in its ability to embed technological knowledge in export-oriented industry, to import complex technological components, to process them within national production chains, and to strengthen the innovation process not only through formal R&D, but also through investment in implementation, adaptation, and modernisation. This is precisely the typical characteristic of an applied-engineering model. It produces fewer symbolic effects of "innovation leadership" in the ranking sense, but often yields a more stable productive result. Therefore, the Czech system may appear less impressive in terms of the overall innovation index than more venture-oriented economies, yet be very strong in that zone where knowledge is transformed into real components, machines, assemblies, materials, transport solutions, security systems, and production processes.

However, the same model also has internal limitations, which are especially noticeable precisely because the rest of its structure is already sufficiently mature. EIS 2025 identifies among the Czech Republic's relative weaknesses venture capital expenditures, population with tertiary education, and labour productivity. OECD 2025, in turn, states directly that, in order to revive productivity, it is necessary to target business support for R&D more effectively at small and young firms, to develop capital markets, and to strengthen links between business and science. Of particular importance is the OECD's conclusion that state support for business R&D in the Czech Republic is comparatively limited and is to a significant extent focused on direct forms of support. This means that the business-centred model is strong where large engineering companies, international value chains, and mature applied divisions already exist, but it provides a weaker stimulus for the emergence of new technological firms with a high-risk profile. Hence the chronic limitation of the start-up ecosystem and the risk that the system will be effective in modernising the already existing industrial structure, but slower in creating radically new technological niches. In other words, business R&D in the Czech Republic is powerful, but rather asymmetrical: it works better for deepening and refining the engineering base than for the rapid birth of new breakthrough markets. This does not make the model weak, but it does determine its historical type. The Czech Republic today is a country of a strong applied engineering economy, and not a country of a venture-driven technological revolution.

Of particular significance for understanding this asymmetry is the question of the diffusion of knowledge within the economy. The OECD, in its report on FDI-SME linkages, emphasises that foreign firms and global production networks can generate substantial productivity and innovation spillovers, but that this requires not only the investments themselves, but also working diffusion channels and sufficient absorptive capacity of local companies. The report notes separately that the digital gap between large and small firms in the Czech Republic is especially visible in supplier and customer management technologies, such as CRM and ERP, which are often a precondition for the inclusion of SMEs in the supply chains of large transnational companies. Moreover, the OECD points out that foreign affiliated companies in the Czech Republic import almost half of their intermediate inputs, and this means that local spillovers are not automatic. From this it follows that the Czech model of strong business R&D must be assessed not only by the scale of corporate expenditure on research, but also by the extent to which these forms of knowledge and standards spread to the lower levels of the economy. If the main share of the benefit is concentrated in large enterprises and their nearest suppliers, then even a high volume of R&D will not ensure the full modernisation of the entire productive fabric. This is precisely why themes such as Smart Specialisation, innovation diffusion, regional platforms, and business-science cooperation occupy such an important place in official Czech policy. The contemporary model works most successfully where, around large enterprises and centres, there are trained engineering personnel, strong universities, applied institutes, and digitally mature suppliers. Where these elements are weaker, the model begins to reproduce structural unevenness of development.

No less important is the fact that the very engineering nature of the Czech model influences the character of innovation outcomes. In countries with a strong platform economy, innovativeness is often measured by the number of rapidly growing digital companies, the volume of venture financing, or global tech brands. In the Czech Republic, by contrast, the most important technological results often manifest themselves in something different: in stronger product quality, process optimisation, advanced manufacturing, design and testing capacities, export competitiveness in medium- and high-technology segments, and also in the ability to retain complex production chains in such areas as mobility, precision engineering, instruments, cybersecurity-enabling infrastructure, materials, and industrial automation. That is precisely why contemporary Czech technical science should not be judged solely through the general innovation rank. Its real strength is revealed in the fact that a significant part of R&D is not isolated in a laboratory or purely academic mode, but from the outset is oriented towards the productive and engineering cycle. The Czech Statistical Office methodologically records that the business sector is concentrated precisely on applied research and experimental development, that is, on forms of activity that are maximally close to implementation. RIS3, in turn, directs resources precisely into those areas where knowledge and innovation can create a long-term competitive advantage. And the OECD views the problem not as a deficit of business activity itself, but as the need to make the ecosystem around it more productive and more inclusive for young firms and science. All this taken together makes it possible to define the contemporary Czech model as a production-embedded system of engineering knowledge in which scientific quality and practical application are not opposed to one another, but are structurally joined.

In sum, the contemporary model of the development of the technical sciences in the Czech Republic may be described as a model of strong business R&D resting on applied engineering, industrial chains, and a coordinating state strategy. Its quantitative base is expressed in the dominance of companies in the financing and performance of R&D, in the high share of corporate employment of researchers, in the large number of enterprises systematically engaged in research and development, and in the integration of R&D into the export-oriented productive economy. Its qualitative base consists in the predominance of applied research and experimental development, in close ties with technical universities, in the location of corporate centres of competence, in orientation towards engineering-intensive sectors, and in the political support of collaboration between research and application spheres. Its principal strength is the ability to turn knowledge into real engineering solutions, to support the competitiveness of the productive economy, and to develop those technological niches in which the Czech Republic already possesses an industrial and personnel base. Its principal limitation is the comparatively weak capacity to generate a large-scale flow of new risk-intensive firms, rapidly to increase venture capital, and to spread innovation dynamism evenly across the whole economy. Consequently, the contemporary stage of the development of the technical sciences in the Czech Republic cannot be characterised either as a purely industrial model of the past or as a post-industrial digital model in the narrow sense. It is a mature engineering-applied system of a European middle power, strong in the depth and connectedness of productive knowledge, but more restrained in radical innovative breadth. It is precisely this combination that defines the present-day face of Czech technical science.

Strengths: Medium- and High-Technology Exports, Engineering Niches, and International Cooperation

One of the principal strengths of the contemporary stage in the development of the technical sciences in the Czech Republic is not an abstractly high “level of innovativeness” across all possible parameters, but a very clear concentration of advantages in several interrelated areas. This refers above all to a powerful export base of medium- and high-technology industry, to a number of engineering niches in which the Czech Republic possesses genuinely notable European and global positions, and to comparatively dense international cooperation, primarily within the European Research Area. According to the *European Innovation Scoreboard 2025*, the Czech Republic is among the three best EU countries in exports of medium- and high-tech products and reaches 114.7% of the EU average for this indicator. At the same time, the country demonstrates good dynamics in public-private co-publications and in the growth of international publications, as well as confident results in sales of new-to-market and new-to-firm innovations. All this indicates a very important circumstance: the strengths of the contemporary Czech scientific and technological model lie above all where knowledge is materialised in products, components, engineering systems, and production processes, and not only in patent statistics or venture activity. Therefore, the present stage of Czech technological development should be assessed not according to a template of “leadership in everything”, but according to the country’s ability to retain and strengthen precisely those segments where scientific, engineering, and industrial logic are joined most densely. In this sense, exports, niche competences, and international cooperation form three mutually complementary pillars of one and the same model.

The structural basis of this model remains an unusually strong industrial base. The Czech profile in *EIS 2025* directly shows that the share of employment in manufacturing amounts to 25.3% as against 15.6% on average in the EU; in other words, this is a much more industrialised economy than that of most European partners. This picture is also confirmed by the long-term statistical surveys of the Czech Statistical Office: after accession to the EU, foreign trade became the principal factor of the country’s economic growth, while motor vehicles, machinery and equipment, electrical equipment, fabricated metal products, and computer, electronic and optical products occupied a central place in the structure of exports. According to CSO data, in 2023 motor vehicles accounted for more than a quarter of Czech goods exports, while around 80% of goods exports were directed to EU countries. Such a structure means that the strength of the Czech Republic lies not only in the existence of individual technology companies or research centres, but also in the capacity of the entire productive economy steadily to produce export-competitive engineering products. For the technical sciences, this is fundamentally important, because it is precisely such an economic fabric that creates stable demand for materials engineering, product development, industrial software, testing, digital control systems, precision components, and transport technologies. Put simply, contemporary Czech science receives serious support in the form of an economy that genuinely needs complex engineering solutions and knows how to use them commercially. This is what makes the country's export strength not an external consequence, but an internal part of its scientific and technological model.

This strength is most clearly manifested in the segment of high-tech trade. The Czech Statistical Office records that in 2024 Czech exports of high-tech goods exceeded CZK 548 billion and accounted for 11.8% of the country's total goods exports. Imports of high-tech goods reached CZK 703 billion, which also shows the considerable scale of the country's inclusion in global technological chains. Particularly indicative is the distribution by category: the largest export subgroups remain computers and office machines, and electronics and telecommunications. In 2024, exports of computers and office machines reached CZK 183 billion, having increased by 37% compared with 2023, while exports of electronics and telecommunications amounted to CZK 169 billion, having increased by 9%. It is also important that around 62% of Czech high-tech exports were directed to EU countries, whereas only one third of high-tech imports came from the EU, which underlines the dual role of the Czech Republic: on the one hand, as a European export hub, and on the other, as a country actively using global, including Asian, technological supplies. From a scientific and technological point of view, this configuration is advantageous because it combines European market embeddedness with access to global technological components and allows Czech enterprises to specialise in the integration, refinement, engineering adaptation, and production of final or intermediate products of high complexity. It is precisely for this reason that the high export of medium- and high-tech products in the Czech case reflects not only the strength of trade, but also the maturity of the applied engineering base.

However, the export strength of the Czech Republic is not equal to the simple quantity of exported goods. Much more important is the fact that behind these indicators stands a stable ability to turn engineering knowledge into productive advantages. *EIS 2025* emphasises that the Czech Republic reaches 109.9% of the EU average in sales of new-to-market and new-to-firm innovations, while its companies are increasingly bringing new process and product solutions to the market. This confirms that exports in the Czech case rely not only on traditional industrial inertia, but also on the renewal of the goods and processes themselves. At the same time, the OECD draws attention to the fact that the Czech innovation system functions better in the manufacturing sphere than in knowledge-intensive services, and that productivity remains weaker than the strong export results might suggest. From this follows an important analytical conclusion: the strengths of the Czech Republic today lie above all in technologically intensive manufacturing, and not in the equally high development of all parts of the innovation economy. That is, the country is especially successful where the scientific result is embedded in a machine, a component, an electronic system, a production line, a transport solution, or a digital control complex. Such specialisation does not make the model narrow in a negative sense; on the contrary, it allows the country to occupy stable positions in those sectors where competition is determined by engineering depth, quality of execution, and industrial discipline. Yet this also explains why the export power of the Czech Republic does not always automatically translate into comparable strength in the sphere of platform services, large-scale venture capital, or global digital brands.

The second major advantage of the contemporary Czech Republic is connected with the presence of several engineering niches in which it has managed to achieve an internationally visible concentration of competences. Here the issue is no longer simply strong industry in general, but those directions in which the country possesses a combination of scientific infrastructure, a personnel school, industrial application, and international visibility. These niches include, above all, laser and photonic technologies, electron microscopy and scientific instrumentation, nanotechnologies and nanomaterials, supercomputing, transport automation, as well as part of nuclear and power engineering. A particular feature of the Czech profile is that these niches rarely exist in isolation. They are usually formed as local ecosystems in which research centres, university groups, companies, open-access infrastructures, and international partners are simultaneously present. It is precisely because of this that the country is able not to disperse its limited resources across a very broad spectrum of directions, but to achieve considerable depth in selected segments. The OECD, in its report on innovation diffusion, directly shows that one of the Czech Republic's strengths is the comparatively high propensity of innovative SMEs to cooperate, while international, inter-firm, and university-industry channels play a significant role in the transfer of knowledge. Consequently, the engineering niches of the Czech Republic are not accidental successes of individual organisations, but broader nodes of cooperation and specialisation.

The Czech profile in photonics, supercomputing, and scientific instrumentation is especially expressive in this respect. ELI Beamlines in Dolní Břežany is officially positioned as a site of ultra-intense and high-power lasers for particle acceleration, plasma physics, and related research, that is, the Czech Republic possesses an infrastructure working directly at the frontier of contemporary laser science. In parallel, IT4Innovations in Ostrava operates the Karolina supercomputer with a theoretical peak performance of 15.7 PFlop/s and with separate capacities for cloud services, HPC simulations, large dataset processing, and AI computations. This means that the Czech Republic possesses not only experimental but also computational platforms capable of supporting the most demanding engineering and scientific tasks. Finally, a powerful cluster of electron microscopy has taken shape in Brno, and Akademie věd České republiky stated directly in 2025 that around one third of the world production of electron microscopes is connected precisely with this city. Such a combination—extreme light infrastructure, national supercomputing capacity, and a globally visible instrumentation cluster—is exceptionally rare in countries of a comparable scale. It shows that the strengths of the Czech Republic are not confined to the production of "good industrial goods", but also include research-engineering platforms of a very high level. It is precisely such platforms that then become a support both for fundamental science and for applied industrial uses.

The Czech profile in the field of nanotechnologies and nanomaterials is no less indicative. CzechNanoLab officially describes itself as an open-access infrastructure providing an interconnected system of instruments and expertise in nanoscience—from the preparation of nanostructures to their functionalisation, characterisation, and theoretical description. For the contemporary technological model, this is especially important, because open infrastructure makes it possible to connect academic researchers, applied groups, and industrial users on a single platform. Even more expressive is the case of Elmarco and Nanospider technology: the company defines it as a patented needle-free electrospinning technology ensuring uniformity and throughput, suitable for industrial scale manufacturing. In other words, the Czech Republic has managed not only to develop nanoresearch as a scientific direction, but also to bring one of its key developments to the level of an industrial technology. For small and medium-sized European countries, it is precisely this transition from laboratory knowledge to a production-applicable solution that usually proves the most difficult. The Czech experience shows that the country is especially strong where research depth is combined with engineering refinement, the possibility of scaling, and a clear industrial application. This once again confirms that its technological advantages are neither purely scientific nor purely productive in character, but arise at the intersection of these two logics.

The third important group of strengths relates to transport, systems, and heavy engineering. CzechInvest emphasises that the Czech Republic is a highly competitive location for the creation of R&D facilities, while local technical universities have an established practice of cooperating with global OEMs and providing services in the field of research, development, and testing. In the same official profile, Volkswagen, Bosch, Valeo, ZF Engineering, and Honeywell are named as companies that have located their centres of competence in the Czech Republic. This shows that automotive and mobility engineering here is strong not only in production terms, but also in research terms. In parallel, in the railway sphere the country demonstrates a high technological ambition: Ministerstvo dopravy records that, from January 2025, ETCS covered 622 km of main lines, monitored around 50,000 trains per month, and, after the first month of operation, the system showed reliability above 99%. Even more notable was the AŽD EDITA project, which the company officially presented as the first autonomous passenger train in Europe in real operation. If to this one adds the stable positions of ŠKODA JS, which describes itself as one of the leaders of European nuclear engineering, it becomes clear that Czech strengths cover not only “light” digital and laboratory technologies, but also complex, capital-intensive, and system-critical engineering complexes. It is precisely this ability to retain competences in complex transport and energy engineering that makes the technological profile of the country more resilient and less dependent on the conjuncture of individual digital markets.

The third pillar of the contemporary Czech model is international cooperation. Here it is important immediately to emphasise that the internationality of the Czech Republic has two levels. The first is the embeddedness of its industry in European and global supply chains, which gives access to orders, technologies, standards, and external demand. The second is the participation of scientific and engineering teams in European programmes and research infrastructures. According to data from Technologické centrum Praha, Czech organisations participate in approximately 6.2% of Horizon Europe projects. A similar level of participation has been recorded in a number of other European programmes; in particular, in Digital Europe Czech organisations reported 102 participations in 46 projects, of which 15 were in the role of coordinators. The most visible participants named are Masarykova univerzita, České vysoké učení technické v Praze, Vysoká škola báňská—Technická univerzita Ostrava, Vysoké učení technické v Brně, and CESNET. These figures are important not in themselves, but as an indication that international cooperation in the Czech Republic has not an elitist-symbolic, but a fairly broad institutional character. It actively involves not only metropolitan academic structures, but also technical universities, specialised research organisations, and applied networks. Consequently, international cooperation functions for the Czech Republic not as an external embellishment, but as one of the principal mechanisms for renewing competences and consolidating its engineering niches in the pan-European context.

This international openness is especially important because it strengthens those advantages that already exist within the country. EIS 2025 records growth in international publications and public-private co-publications, while the OECD draws attention to the fact that the quality of innovation diffusion in the Czech Republic depends to a considerable extent on channels of cooperation—within the country, between regions, and through external partnerships. In other words, international cooperation is valuable for the Czech Republic not only because it brings European grants or access to consortia. It performs a deeper function: it helps to transform a strong, yet in places rather closed, productive and engineering base into a more open system capable of learning faster, comparing itself with best practices, and raising its own technological standard. In this sense, Czech international cooperation is closely linked with the development of engineering niches. ELI, IT4Innovations, CzechNanoLab, the Brno microscopy cluster, the Horizon Europe and Digital Europe programmes—all these are elements of one and the same logic, in which local competence is strengthened through international connection, while international participation acquires meaning thanks to local engineering depth. It is precisely this logic that makes the strengths of the Czech Republic relatively sustainable. It does not guarantee leadership in all directions, but it does allow the country to preserve competitiveness where industrial culture, the research base, and international cooperation coincide in vector.

In sum, the strengths of the contemporary Czech Republic may be defined as an engineering model supported by exports, organised around niches, and internationally connected. Its strength lies in the ability to rely on the very high weight of manufacturing, to embed research in production chains, to maintain several engineering specialisations of European level, and constantly to nourish them through international cooperation. Its principal advantages are not universality and not the broadest possible innovation profile, but high effectiveness in those technological segments where precision, infrastructure, engineering discipline, long-term personnel, and close cooperation between firms and scientific organisations are required. It is precisely for this reason that the contemporary Czech Republic appears especially convincing in the export of medium- and high-tech products, in instrumentation and infrastructure niches, in transport and industrial engineering, and also in European scientific and technological programmes that require genuine research and organisational capability. In the future, it is these strengths that will continue to determine its comparative advantages in relation to other Central European states. But they also define the framework of the entire model: the country is strong above all where knowledge can be technologically embodied, institutionally supported, and embedded in an export-oriented economy. This is the most accurate characterisation of its current stage of development in the aspect of strengths.

Weaknesses and Limitations

For all the evident strengths of the contemporary Czech model of the development of the technical sciences, it remains a system with rather clearly expressed limitations. Moreover, it is precisely the maturity of this model that makes it possible to see its weaknesses especially clearly. When a country already possesses a strong industrial base, notable engineering niches, major research infrastructures, and a high share of corporate R&D, the question shifts from the simple accumulation of resources to the quality of their transformation into sustainable innovation-led growth. And it is here that it becomes evident that the Czech system operates unevenly: it is strong in applied engineering and in the industrial integration of knowledge, but acts less confidently where radical innovation dynamics, developed capital markets, broad entrepreneurial digitalisation, mass training of highly qualified personnel, and even spatial diffusion of innovation are required. The European Innovation Scoreboard 2025 directly classifies among the Czech Republic’s relative weaknesses venture capital expenditures, population with tertiary education, and labour productivity. The same conclusions are confirmed by the OECD and by European digital reviews. Consequently, the weaknesses of the Czech model are not reducible to a single shortage of resources. They are structural in character and affect the financial, educational, digital, territorial, and institutional logic of the functioning of the system. It is precisely for this reason that the contemporary stage of the development of the technical sciences in the Czech Republic should be characterised not as a completed success story, but as a model with convincing achievements and, at the same time, with internal limits that are difficult to eliminate.

The first and, perhaps, most systemic limitation is the insufficient depth of innovation financing, especially at the high-risk and early stages of technological entrepreneurship. According to the European Innovation Scoreboard 2025, the indicator of venture capital expenditures for the Czech Republic amounts to only 37.8% of the EU average in the current cross-section, while among the strongest recent declines it is venture expenditures that are directly named. This is a highly important signal. It means that the country, despite its developed engineering base and strong corporate R&D, still experiences a shortage of the type of capital that is especially important for the rapid growth of new technological firms, spin-off companies, deep-tech ventures, and the commercialisation of radically new solutions. The OECD Economic Survey 2025 formulates the same problem in broader terms: in order to increase the innovation capacity of the Czech economy, it is necessary to develop capital markets, better target support for business R&D towards young and small firms, and strengthen the start-up ecosystem. Consequently, the contemporary Czech model finances research inside already existing large companies and production chains comparatively well, but supports less effectively the emergence of new players capable of changing the structure of the market itself. This is not merely a financial shortcoming. This limitation affects the character of the country’s entire innovation dynamic: the system modernises the existing industrial base better than it generates new technological trajectories on a large scale. As a result, the Czech Republic remains strong in engineering-intensive sectors, but less convincing in that part of the innovation economy where risk, speed, flexibility, and access to capital at the early stages play the decisive role.

The second major limitation is connected with the educational and personnel base, above all with the insufficient share of the population with tertiary education and with the weakening of interest in part of the engineering fields. EIS 2025 classifies population with tertiary education among the weakest indicators of the Czech Republic in the pan-European comparison. But even more important is the internal structure of this limitation. The Education and Training Monitor 2025 for the Czech Republic shows that engineering, manufacturing and construction are steadily losing popularity relative to other fields of study: whereas in 2015 these fields accounted for 59.2% of all STEM fields, in 2023 they accounted for only 44.6%. The Czech Statistical Office records the same problem even more sharply: at the end of 2022, around 37,000 students were studying in technical specialisations, which was 11,000 fewer than in 2017, while the share of students in technical fields among all university students fell from one quarter in 2001 to 12% in 2022. This is one of the most serious challenges for a country whose technological model is based on applied engineering. In other words, the Czech Republic has a strong industrial and research base, but at the same time faces the risk of the gradual narrowing of its own personnel reserve precisely in those fields that nourish this base. Yes, the growth of interest in ICT partially compensates for this decline, but it does not fully offset it, because an industrial economy needs not only programmers and data specialists, but also designers, materials scientists, engineers of production systems, specialists in equipment, transport technology, and electronics. Thus, the personnel limitation of the contemporary Czech model consists not simply in the number of educated people, but in the changing balance itself between the types of knowledge on which the country's industrial-engineering specialisation rests.

Closely connected with this is also the problem of the qualitative alignment of skills with the demands of contemporary technological development. The OECD, in its report on innovation diffusion, emphasises that labour force shortages and skills mismatches are frequently identified as the single most important hurdle for innovation diffusion in Czechia. The same document states that the country's further movement up the value chain requires more "skills of the future", while the shortage of qualified labour is becoming a systemic barrier to innovation diffusion. This observation is especially significant because the issue concerns not only a shortage of top researchers or IT talent. The problem affects a broader layer of employees capable of working with digital production systems, automation, new materials, data, quality control, and the integration of complex solutions into business processes. Under the conditions of the Czech economy, where innovation largely takes place within enterprises and production chains, the shortage of such competences affects the whole system more severely than in economies where the principal innovation driver is concentrated in narrow technological clusters. Moreover, the OECD also points to regional variations: some Czech regions are effectively in a low-skilled equilibrium, where high business demand for low skills is combined with their high availability, which hinders the transition to a more complex model of growth. Consequently, the personnel problem of the Czech Republic is not only the number of graduates, but also the depth of the structural mismatch between the country's technological ambitions and the skills configuration of its labour market.

The third limitation is the slowdown in productivity and the incomplete innovation return from the scientific and technological base that has already been created. The OECD Economic Survey 2025 emphasises that productivity growth in Czechia slowed significantly after the global financial crisis and stalled after the pandemic, leaving a sizeable productivity gap with the OECD average of around 20%. This is one of the most serious signals for a country that has invested heavily in research infrastructure, applied programmes, and corporate R&D. If the economy preserves a strong export base and a relatively high weight of industry, but at the same time does not ensure comparable productivity growth, this means that a gap exists within the system between technological potential and its macroeconomic realisation. EIS 2025 directly includes labour productivity among the Czech Republic's relative weaknesses, while the Regional Innovation Scoreboard 2025 shows that, even within the country, differences in this indicator between regions are large: Prague appears significantly stronger, whereas a number of other regions remain substantially lower both in overall innovation performance and in productivity. It follows from this that the Czech model of the technical sciences is able to generate competences, support exports, and modernise individual segments of industry, but does not always translate this potential equally successfully into broad-based productivity gains. In a mature innovation system, it is precisely this translation that becomes the principal criterion of effectiveness. Therefore, the productivity problem is not an external economic background, but an internal indicator of the limited nature of the current scientific and technological model.

The fourth major weakness relates to the digital transformation of business. Despite the noticeable successes of the Czech Republic in 5G coverage, AI policy, and a number of digital skills, the Digital Decade 2025 Country Report assesses the overall picture as mixed. The executive summary states directly that Czechia still lags in the rollout of very high-capacity networks (VHCNs) and the digital transformation of businesses. Moreover, the report records that Czech SMEs face barriers to adopting digital technologies, while the country's target recommendations include the expansion of support for the digital transformation of SMEs, especially in relation to AI, cloud, and data analytics. At the infrastructural level, the problem is also expressed clearly: in 2024, VHCN coverage stood at 53.91% as against 82.49% on average in the EU, and in sparsely populated areas at only 10.04% as against 61.89% in the EU. From the point of view of enterprise adoption, the gap is likewise evident: cloud computing was used by around 35.23% of firms, data analytics by 19.49%, and AI by 11.26%, and in all these areas the Czech Republic lags behind the European average values. This is especially important for a country whose innovative strength is based on industry. If the production economy does not undergo a sufficiently deep digital transformation, then even a strong engineering base and corporate R&D will have a limited effect. In other words, the Czech Republic is strong in engineering, but not always equally strong in the pervasive digital modernisation of enterprises, especially small and medium-sized ones. In the long term, it is precisely this gap that may become one of the principal factors limiting further movement up the technological ladder.

The fifth weakness is the unevenness of innovation development across regions. Formally, the Czech Republic is a comparatively small country, and this may create the illusion of the spatial compactness of its innovation system. However, both the OECD and the Regional Innovation Scoreboard show that the differences between regions are noticeable. RIS 2025 demonstrates that, for example, Jihovýchod has an innovation index of 89.1 relative to the EU base, whereas Severovýchod has 71.6, Moravskoslezsko 73.6, and Střední Morava 73.8. The OECD, in its report on innovation diffusion, emphasises that the scope for innovation diffusion from FDI varies across regions and that some parts of the country have much weaker framework conditions. The same report states that public and private activities are often largely disconnected, that innovation support is complex, and that regional ecosystems are unequally equipped with knowledge-intensive intermediaries, science parks, accelerators, and cluster anchors. It is particularly indicative that the OECD separately points to regions where the absence of science parks or the weakness of accelerators is perceived as a real brake on innovation development. Consequently, the contemporary Czech system of the technical sciences is not a genuinely homogeneous national system. It represents rather a network of strong poles—Prague, Brno, Ostrava, and certain industrial zones—and weaker spaces where innovation diffusion proceeds more slowly. For a country with a high weight of industry, this is an important risk, because technological development requires not only strong centres, but also a sufficient ability to spread innovation across the whole productive fabric.

The sixth limitation is connected with the complexity and fragmentation of innovation support. The OECD, in its report on innovation diffusion, writes directly that the innovation support system is complex, while government support measures are generally perceived as cumbersome, procedurally difficult and time-consuming, especially for smaller enterprises. This observation is especially important because it concerns not the volume of funds as such, but the ability of firms and research organisations actually to use the support instruments. In a business-centred model, where innovation must circulate constantly between companies, universities, applied centres, and state programmes, support that is too complex and cumbersome becomes an independent barrier. It affects SMEs especially strongly, because they do not possess large administrative teams and are less able to bear lengthy procedures, high transaction costs, and uncertainty of requirements. As a result, support may work quite well for already mature large actors, but less well for those who need it most from the point of view of growth in innovation dynamics. That is, the system reproduces its own asymmetry: strong actors remain strong, while weaker ones are more difficult to integrate into innovation processes. For the contemporary Czech Republic, this is one of the most sensitive problems, because its strategic documents constantly emphasise precisely better targeting, stronger linkages, and wider diffusion. If, however, the support instruments remain too complex, then the very mechanism of widening the innovation base begins to operate more slowly.

The seventh limitation is the comparatively weak zone of intellectual assets, entrepreneurial dynamism, and commercialisation. The OECD, in its report on innovation diffusion, notes that the Czech Republic performs well below the EU average in intellectual assets—patents, designs, trademarks—as well as in opportunity-driven entrepreneurship. EIS 2025, although it records strong national results in exports and in certain innovation sales, does not place the Czech Republic among the leaders in those blocks that are connected with the financing of high-risk innovation and the creation of new technological companies. It follows from this that the country is more comfortable in a regime of engineering exploitation of knowledge than in a regime of mass entrepreneurial creation of knowledge-based assets. This is a highly important distinction. In the first case, the issue is the ability to improve existing products and processes, retain the competitiveness of the productive economy, and gradually deepen engineering niches. In the second, it is the ability to generate new markets, new technological platforms, new rapidly growing companies, and new forms of monetising intellectual capital. The contemporary Czech Republic is clearly stronger in the former than in the latter. This is precisely why its innovation profile appears mature, but at the same time somewhat conservative: it is stable, productively connected, and technologically rich, yet does not always generate sufficient breadth of radical commercialisation and entrepreneurial renewal.

Finally, the eighth limitation concerns strategic ambition and the pace of adaptation. The Digital Decade 2025 Country Report notes that Czechia shows a low level of ambition in its contribution to the Digital Decade, with only 43% of its national targets fully aligned with EU 2030 targets. This does not mean an absence of strategies: on the contrary, the Czech Republic has strong documents on AI, semiconductors, cybersecurity, RIS3, and Research Policy 2021+. But this observation shows that a gap remains between the existence of strategies and the degree of their goal-setting ambition. This is especially significant under conditions in which technological competition in Europe and the world is accelerating, while the window of opportunity for medium-sized countries is determined to a considerable extent by the speed of decision-making and the scale of the concentration of resources. If a country acts too cautiously, scales digital infrastructure too slowly, or sets less ambitious benchmarks, it risks consolidating itself in the status of a strong, yet still “second-line”, European technological economy. For the Czech Republic, such a risk is real precisely because its model is already strong enough to aspire to more, but not yet powerful enough unconditionally to set the rules of the game in key frontier areas. Thus, one of the limitations of the contemporary stage is not the deficit of policy as such, but the deficit of a sufficiently rapid and large-scale transition from engineering maturity to fuller innovation leadership.

In general, the weaknesses and limitations of the contemporary Czech model may be reduced to one general conclusion. The Czech Republic has built a very strong system of applied engineering, industrial R&D, and niche technological specialisation, but this system has not yet become a fully balanced innovation ecosystem. Its weak zones—venture financing, the personnel base, productivity, the digital transformation of SMEs, regional heterogeneity, the complexity of support instruments, and the limited breadth of intellectual assets—indicate that the country stands on the boundary between a mature industrial-engineering model and a more advanced knowledge-driven economy. In other words, the principal problem of the Czech Republic today does not lie in the absence of scientific and technological capacity, but in the fact that this capacity is not yet realised equally deeply across the whole system and not always in its most dynamic forms. It is precisely this that defines the limits of the contemporary stage of its technical development.

Regional Structure: Several Powerful Technological Poles

The contemporary system of the technical sciences in the Czech Republic has a distinctly polycentric, yet at the same time uneven, spatial structure. It is not built around a single centre that completely dominates the rest of the territory, but neither does it constitute a uniformly distributed network of equally strong scientific and technological nodes across the country. Rather, it is a configuration in which several powerful poles concentrate the principal mass of research infrastructures, university competences, corporate R&D, international links, and high-technology services, whereas a significant part of the remaining space is involved in innovation processes weaklier and fragmentarily. The OECD directly emphasises that innovation activity in the Czech Republic differs spatially and that regional systems possess unequal capacities for the absorption, diffusion, and commercialisation of knowledge. The Regional Innovation Scoreboard 2025 shows the same picture in quantitative form: Prague remains the only Czech region with the status of a strong innovator, whereas most of the others belong to various categories of moderate innovators. From this alone it is clear that the regional structure of the contemporary stage is not a secondary background. It itself constitutes one of the principal characteristics of the Czech technological model. It is precisely through regional poles that the country organises its strengths, and through regional gaps that it encounters its limitations. Therefore, an analysis of contemporary technical science in the Czech Republic is impossible without an understanding of how its institutions, infrastructures, personnel, and sectoral specialisations are distributed geographically.

At the top of this spatial hierarchy stands Prague, which in the Czech technological system performs the role of the principal managerial, academic, international, and partly research centre. RIS 2025 records for Prague a regional innovation index at the level of 110.1 relative to the EU average in 2025, while the OECD separately emphasises that Prague is the only region in the country classified as a strong innovator. Its advantages are especially noticeable in such parameters as the share of the population with tertiary education, international scientific publications, and public expenditure on R&D. And this is only to be expected: the capital concentrates the largest universities, a significant part of the national bodies governing RDI, network organisations, international representations, and an entire layer of knowledge-intensive services, which is less developed in the rest of the Czech Republic. Prague also functions as the principal node of international scientific integration, as is evident from the very high values of international scientific co-publications. At the same time, it is characteristic of the Czech model that the capital region dominates not so much as a production site, but rather as a node of coordination, human capital, and service and academic infrastructure. Within the national system, this makes Prague not only the strongest region, but also a region of a special type: there, scientific and technological development is connected not only with industrial engineering, but also with a broader concentration of intellectual and managerial resources. However, the leadership of the capital does not negate the fact that an important part of Czech applied engineering is already developing not in Prague itself, but in neighbouring and other specialised poles.

It is precisely for this reason that Prague should more accurately be considered not in isolation, but in conjunction with Střední Čechy / Central Bohemia, where some of the country's most significant research facilities are located. RIS 2025 shows that Central Bohemia lags noticeably behind Prague in terms of the innovation index —73.8 relative to the EU average—but in the country's real technological geography it plays a far more significant role than might be assumed from a single aggregate indicator. It is here, in Dolní Břežany, that ELI Beamlines is located; the official resource of the centre directly states that the municipality of Dolní Břežany in the Central Bohemian Region was chosen as the site for the research complex, while the facility itself is situated approximately 10 km south of Prague. Moreover, it is precisely the Czech Republic that hosts in Dolní Břežany the statutory seat of ELI ERIC, which turns the Prague–Central Bohemian node into a European centre of extreme laser science. The same orbit also includes Řež, where ÚJV Řež and the research and engineering infrastructure associated with it operate in the fields of energy, nuclear technologies, and radiopharmaceuticals. Taken together, this creates a special configuration: Prague provides the concentration of universities, international networks, and the public sector, while Central Bohemia provides the location of major experimental and applied facilities, for which the capital itself would be too confined and organisationally more difficult. As a result, it is the Prague–Central Bohemian pairing that forms the largest national node of advanced research infrastructure, combining science, governance, internationality, and the spatial possibility of placing large installations. This is one of the key axes of the entire contemporary technological geography of the Czech Republic.

The second pole—and, in a number of directions, the most substantively dense one—is the South-East / Jihovýchod, that is, above all Brno and the broader South Moravian research environment. RIS 2025 records for this macro-region an innovation index of 89.1 relative to the EU average—markedly below Prague, but substantially above most of the rest of the country. At the same time, in certain structural indicators Jihovýchod appears especially strong: the level of tertiary education there is clearly above the national average, the indicators of international co-publications are also high, and both public and business expenditure on R&D are among the best in the country. This corresponds very well to the real role of Brno as the second scientific and technological centre of the Czech Republic. CEITEC directly positions itself as a cutting-edge research infrastructure founded on the cooperation of six partners, while CEITEC Brno University of Technology has, since 2011, been described as a key part of the modern infrastructure for advanced nanotechnology, advanced materials and cybernetics. Brno itself is described by CEITEC as the second largest city in the Czech Republic and a vibrant cultural and academic centre, where universities, international companies, scientific institutes, and start-ups coexist side by side. It is precisely here that the specificity of the Czech model is especially clearly visible: Brno is not simply the "second city of the country", but rather the second technological capital, in which ties between materials science, nano- and micro-engineering, cybernetics, medical technologies, electron microscopy, and an entrepreneurial engineering environment are particularly dense. In essence, if Prague is stronger as a centre of governance, international scientific visibility, and the public sector, then Brno is stronger as a concentrator of specialised engineering depth.

The particular strength of Brno and South Moravia lies in the fact that scientific and technological functions form a genuine cluster there, rather than simply a set of neighbouring organisations. This is especially evident in the field of electron microscopy, where the Academy of Sciences of the Czech Republic stated directly in 2025 that Brno is associated with approximately one third of world production of electron microscopes. Nearby are located CEITEC, the research groups of Masarykova univerzita and Vysoké učení technické v Brně, companies producing complex equipment, international technological branches, and service teams. The OECD, in its report on FDI and SME linkages, even uses South Moravia as one of the special cases of regional analysis, which in itself shows that this is not an ordinary region, but a territory where interactions between foreign investment, local SMEs, and the innovation system are especially clearly observable. Unlike the Prague–Central Bohemian node, which in many respects operates as a national centre of governance and large infrastructures, Brno is stronger as a pole of concentrated applied complexity. It is there that those directions are concentrated which require long laboratory traditions, expensive equipment, interdisciplinarity, and a close transition from research to instrument, device, or material. It is precisely for this reason that the South-East of the Czech Republic plays in the contemporary system the role not merely of the second most important region, but of the central node of the country's engineering specialisation. In many directions it does not so much complement Prague as functionally balance it, creating for the Czech Republic a second heavy core of scientific and technological development.

The third major pole is Moravskoslezsko / the Moravian-Silesian Region, centred on Ostrava. In aggregated rankings, it does not appear as strong as Prague or Jihovýchod: RIS 2025 gives it an index of 73.6 relative to the EU average, which is close to Střední Čechy and below the leading Czech regions. Yet its strategic role in the contemporary system is much greater than this general index would suggest. It is precisely here that the IT4Innovations National Supercomputing Center is located, officially defining itself as the country's leading national centre in the fields of HPC, HPDA, quantum computing, and AI, while the Karolina supercomputer remains the country's principal computing resource. The centre's own contact information directly indicates its location in Ostrava, based at VŠB—Technical University of Ostrava. This makes the Moravian-Silesian Region a key Czech node of computational infrastructure and data-intensive research. Yet its significance is broader than computing alone. RIS 2025 shows that the region has a very high value for the indicator exports of medium and high technology products—136.8 relative to the EU average—as well as notable dynamics in international scientific co-publications. This points to an interesting combination: a region with a heavy industrial legacy and a complex socio-economic structure is gradually being transformed into a more modern node where digital computing capacities, industrial transformation, and international research activity are combined. Thus, Ostrava / Moravskoslezsko represents a distinctive type of technological pole within the Czech system—neither capital-academic nor instrument-laboratory based, but computational-industrial.

A fourth notable pole is Jihozápad / the South-West, above all associated with Plzeň and its broader engineering environment. In RIS 2025, this macro-region has an innovation index of 73.0 relative to the EU average, that is, it belongs to the group of moderate innovators and formally trails Prague and Jihovýchod. However, in substantive terms its role is determined not by the overall aggregate, but by its specialisation in several highly specific fields. The University of West Bohemia stresses that it is among the most successful scientific and technological universities in the Czech Republic, while its New Technologies Research Centre (NTC) positions itself as a research centre working with green technologies, advanced and quantum materials, smart vehicles, and related fields. At the same time, Plzeň remains a major node of nuclear engineering thanks to ŠKODA JS, which explicitly describes itself as one of the leaders of the European nuclear sector and builds its profile on three pillars—engineering, production, and service—across the full life cycle of a nuclear power plant. At the regional level, this creates a characteristic combination: university applied research, materials and green technologies on the one hand, and heavy high-technology industrial engineering on the other. South-West Czechia therefore cannot be regarded as a periphery. Rather, it is a specialised pole in which the energy, materials-science, and mechanical-engineering components are especially strong. On the overall map of the country, it performs the role of a powerful, though more narrowly profiled, West Bohemian engineering centre.

The combination of these poles shows that the regional structure of Czech technical science is organised not according to a crude centre-periphery scheme, but according to a scheme of functional differentiation. Prague and Central Bohemia form a complex of governance, international academic visibility, and major infrastructures. South Moravia and Brno concentrate instrumental, nano- and micro-engineering, materials-science, and biomedically oriented complexity. The Moravian-Silesian Region provides national computational capacity and part of the country's industrial-transformation capability. The South-West, with Plzeň and its surrounding engineering environment, strengthens the country in the logic of energy, nuclear engineering, and advanced materials. Such a structure has two advantages. First, it reduces the national system's excessive dependence on a single city. Second, it allows individual poles to develop specialisations that naturally correspond to their university, industrial, and infrastructural base. But it also has a reverse side: coordination between these poles requires a much more complex policy than in a compact, one-dimensionally centralised system. It is precisely for this reason that RIS3, the national roadmaps for infrastructures, and mechanisms of programme coordination are so important for the Czech Republic. Without them, polycentricity could easily turn into fragmentation.

However, beyond these strong poles the Czech regional map becomes markedly less favourable. The OECD directly points out that Karlovy Vary and Ústí nad Labem belong to the weaker innovation zones; their below-average results are largely explained by comparatively low R&D intensity and weaker provision of R&D personnel both in higher education and in business. The same report emphasises that part of the Czech regions remain under weaker framework conditions, while the supporting innovation infrastructure—science parks, accelerators, cluster anchors—is unevenly distributed. RIS 2025 likewise shows a noticeable gap between the leading poles and the weaker regions: for example, the index of Jihovýchod is 89.1, whereas Severovýchod stands at 71.6, Střední Morava at 73.8, Moravskoslezsko at 73.6, while Prague reaches 110.1. This means that the polycentric structure of the Czech Republic nevertheless remains hierarchical. The strong poles are not only strong in themselves, but also differ substantially from the less dynamic parts of the country in human capital, the intensity of public and private R&D, international cooperation, and innovation density. In such a configuration, scientific and technological policy faces a dual task: to support the already formed centres of excellence and at the same time to prevent an excessively large spatial gap that would weaken the national system as a whole.

In this connection, the question of the diffusion of knowledge from the strong poles into the broader regional fabric of the country acquires particular significance. The OECD repeatedly emphasises that Czech innovation policy should be directed not only towards the creation of high-level nodes, but also towards improving the mechanisms for the transfer of knowledge, technologies, and skills between large companies, universities, SMEs, and regions. It is precisely for this reason that the regional structure of contemporary Czech technical science cannot be understood solely through a list of strong centres. It is also important to consider the extent to which these centres function as sources of the diffusion of innovation. So far, the picture remains mixed. In some cases—e.g., in the South Moravian environment—dense interaction is observed between research organisations, international firms, and regional innovation actors. In others, spillovers remain limited, and strong centres function rather as local islands of high competence. This, however, is typical of countries of medium scale with a strong industrial base: the advanced poles themselves emerge comparatively quickly, whereas the channels of their influence on weaker territories take longer to build. Consequently, the contemporary regional structure of the Czech Republic is not a completed map of a stably balanced technological space, but an ongoing process in which powerful poles have already been created, while the mechanisms of their full national effect are still continuing to take shape.

In sum, the contemporary regional organisation of the technical sciences in the Czech Republic may be defined as a system of several strong technological poles with differing functional specialisations and with noticeable interregional asymmetry. Prague dominates as a centre of governance, high-level human capital, and international academic integration; the Prague–Central Bohemian zone reinforces this leadership through major infrastructures such as ELI and Řež; Brno and South Moravia act as the principal arena of instrumental, nano- and micro-engineering, materials-science, and cluster-based technological complexity; Ostrava and the Moravian-Silesian Region provide the country with computational capacity and part of its high-technology export potential; Plzeň and the West Bohemian environment concentrate energy, advanced materials, and heavy engineering competence. Beyond these nodes, the innovation map becomes weaker and more uneven. Therefore, the regional structure is at once both a strength and a vulnerability of the Czech technological model. It makes the country polycentric and resilient to excessive concentration, but it requires constant coordination, support for diffusion, and targeted work with regions that lag behind the leading centres. It is precisely in this balance between powerful poles and spatial unevenness that one of the key characteristics of the contemporary stage in the development of the technical sciences in the Czech Republic resides.

Part 3

Electron Microscopy and Scientific Instrumentation

General Characterisation

Electron microscopy and scientific instrumentation occupy a special place in the contemporary Czech Republic, because here the country has achieved not merely notable successes in a particular field of research, but has formed a fully-fledged technological cluster of international standing. Unlike many other fields, in which the Czech Republic is strong primarily as a user or integrator of foreign solutions, in electron microscopy it acts simultaneously as a developer, manufacturer, researcher, and exporter of complex equipment. That is why this field should be considered not narrowly, as part of materials science or solid-state physics, but as an independent segment of national scientific and technological specialisation. Its contemporary profile has been formed at the intersection of a long historical tradition, a strong engineering school, a successful post-socialist transformation, and a high density of cooperation among academic institutes, universities, and companies. It is especially important that, in the Czech case, the issue is not only the manufacture of the microscopes themselves, but also the development of adjacent competences: electron optics, vacuum technology, detectors, micromechanics, control software, analytical attachments, sample-preparation systems, and integrated research workflows. Thus, electron microscopy in the Czech Republic is not a single industry, but a complex scientific and engineering ecosystem in which instrumentation, applied physics, materials science, biomedicine, and industrial analytics are closely intertwined. That is why, in characterising the contemporary stage, it is necessary to speak not of the “sphere of instruments” in the narrow sense, but of a system of high-precision research engineering, one of the most mature in the country.

The key geographical centre of this system is Brno, which in the contemporary Czech Republic effectively performs the role of the capital of electron microscopy. According to data from Akademie věd České republiky and CEITEC, roughly one third of the world’s production of electron microscopes is today associated with Brno, while the urban ecosystem itself brings together research institutes, universities, manufacturing companies, and users of the equipment. This is not rhetorical exaggeration, but an indication of a concentration of competences in one place that is extremely rare in Europe. In Brno, major microscope manufacturers, academic teams engaged in the development of methods and the component base, open core facilities, and numerous groups applying these instruments in materials science, microstructural analysis, biomedicine, cryo-EM, nanotechnologies, and industrial diagnostics are all present simultaneously. Such density creates a typical cluster effect: engineers and researchers move between companies and universities, students are incorporated into applied projects, and laboratories become platforms for the testing of new solutions and new modes of instrument use. As a result, Brno functions not simply as a place where enterprises are located, but as a space of constant circulation of knowledge, personnel, and technologies. It is precisely this that makes the Czech model especially strong: here the manufacture of instruments and their research application develop within one and the same regional circuit, rather than being split between different countries or sectors.

At the same time, the contemporary Czech electron-microscopy school rests on a much longer historical tradition than the period 1993–2025 alone. In its official historical account, Delong Instruments notes that, in 1948, a team was formed in Czechoslovakia to create the first electron microscope, and one of the participants in that team was Armin Delong. It is with this line that the early formation of the Czechoslovak school of electron-optical instrumentation is associated. For the contemporary stage, not only the historical primacy itself is important, but also the fact that this tradition was not broken after 1989. On the contrary, the post-socialist transformation allowed it to assume new organisational forms: part of the legacy passed into private companies, part into academic institutes and university structures, and part was embedded in international corporate networks. According to TESCAN, the company emerged in Brno in 1991 on the basis of the engineering legacy of former Tesla specialists, while the Brno environment itself was already characterised at that time as a globally respected centre of electron optics. Consequently, the contemporary Czech specialisation in electron microscopy was not created from scratch in the 2000s or 2010s. It grew out of a historically accumulated engineering culture, but managed to pass through market adaptation and transform itself from a post-socialist legacy into an internationally competitive cluster. It is precisely this combination of continuity and transformation that constitutes one of the principal features of the overall characterisation of the field.

After 1993, the development of this field followed a model that is highly typical of the Czech Republic as a whole, but which manifested itself especially successfully here: a strong national engineering tradition was combined with global integration. This is most clearly visible in the example of two major manufacturing lines. On the one hand, TESCAN remained a company with Czech roots and headquarters in Brno, transforming itself into an international supplier of solutions for research and industrial microscopy. The company emphasises that it now operates in more than 80 countries and develops not only classical SEM platforms, but also FIB-SEM, micro-CT, 4D-STEM, and automated multimodal workflows. On the other hand, global corporate presence was also strengthened in Brno: Thermo Fisher Scientific states that its Brno site carries out the development and manufacture of focused ion- and electron-beam microscopes, X-ray and optical emission instruments, while the local company page directly describes the Brno technological division as the largest electron microscope manufacturing site in the world and refers to more than 1,200 specialists. Taken together, this means that the Czech field developed not as a closed national school, but as an open system in which local tradition, private capital, international markets, and global technological standards reinforced one another. It is precisely because of this that electron microscopy in the Czech Republic has retained not a museum-like, but a living and expanding character.

An important feature of the contemporary stage lies in the fact that Czech electron microscopy has long since moved beyond the classical division into “the instrument” and “the user of the instrument”. Today it develops as a field of scientific instrumentation in the broad sense, in which value is created along the whole chain—from the electron-optical scheme and mechanics to software, automation, analytical modules, integration with X-ray and spectroscopic methods, as well as the development of ready-made workflows for specific industries. This is especially clearly visible in the official TESCAN portfolio: the company positions its systems as solutions for materials science, semiconductors, batteries, life science, and geoscience, and the issue is not only the obtaining of images, but also failure analysis, nano-prototyping, TEM sample preparation, non-destructive 3D analysis, structural and chemical degradation studies, and automated mineralogy. In this logic, the microscope ceases to be merely a "research window" into the micro- and nano-world. It becomes a complex platform for diagnostics, development, quality control, engineering analysis, and production optimisation. For the Czech Republic, this is of fundamental importance, because it is precisely this type of scientific instrument that is naturally embedded in its broader model of applied engineering. Consequently, electron microscopy here is strong not only as an instrument of fundamental science, but also as a segment of the advanced instrumentation industry, closely linked with industry, semiconductors, battery technologies, new materials, and biomedicine.

No less substantial is the academic component of this field. In the contemporary Czech Republic, electron microscopy is supported not only by companies, but also by a number of research centres that develop methods, train specialists, and create new fields of instrument application. Ústav přístrojové techniky AV ČR in Brno has a separate Department of Electron Microscopy, within which teams are officially distinguished for biomedicine, surface microscopy and spectroscopy, microscopy and microanalysis, microscopy for materials science, environmental electron microscopy, and electron optics. The very structure of this institute already shows how multi-layered the field has become: it brings together not one discipline, but a set of specialised research zones linked by a common engineering and instrumental foundation. Ústav fyziky materiálů AV ČR, for its part, singles out a separate direction, Electron Microscopy and Advanced Analysis of Materials, which underlines the role of electron microscopy as a key method in contemporary materials diagnostics. CEITEC develops core facilities open to internal and external users from academia and industry, and also possesses high-level microscopes, including Titan Krios for high-throughput cryo-electron microscopy. Thus, the Czech model of electron-microscopy specialisation rests not only on the manufacture of equipment, but also on a strong research demand that continually supports the development of methods, the training of personnel, and the emergence of new applied tasks. It is precisely this that distinguishes a sustainable cluster from a simple manufacturing node.

A very important sign of the maturity of this field is its open and service-oriented infrastructuralisation. In the contemporary Czech Republic, electron microscopy is increasingly organised through shared facilities, booking systems, open access, and inter-institutional platforms. CEITEC directly emphasises that its core facilities are equipped with high-end instrumentation, were financed through national and European projects, and are accessible to internal and external users from academia and industry at national and international levels. A similar logic was also evident in 2025 at the opening of the new Centre of Electron Microscopy in Brno on the basis of Ústav fyziky materiálů AV ČR: Akademie věd České republiky emphasised that the new facility would operate according to an open-access model, serve researchers, master's students, and doctoral candidates, and expand academic cooperation throughout the region. This circumstance is especially important for the general characterisation of the field, because it shows a shift from the earlier model of "each institute with its own equipment" to a more modern model of distributed infrastructure. In such a system, electron microscopy becomes not a local resource of a particular laboratory, but a common research service that can be used in different areas—from metallurgy and defectoscopy to molecular biology and the analysis of cultural artefacts. For the Czech Republic, this organisational form is extremely advantageous: it increases the efficiency of the use of expensive instruments, deepens interdisciplinarity, and strengthens links among academia, universities, and industrial users. That is why contemporary scientific instrumentation in the country is developing not only as the manufacture of equipment, but also as the production of infrastructural accessibility.

In substantive terms, this field in the Czech Republic is moving increasingly towards multimodality and technological hybridisation. The issue is no longer a simple dichotomy of TEM and SEM, but an expanding set of interconnected platforms: FIB-SEM, STEM, cryo-EM, micro-CT, correlative microscopy, in-situ analysis, automated nanocharacterisation, advanced detectors, and digital analytical data-processing chains. TESCAN directly promotes solutions combining high-precision milling, high-resolution imaging, automation, non-destructive 3D analysis, and multimodal nanocharacterisation. Thermo Fisher, for its part, includes the Brno site in a manufacturing and development system in which electron- and ion-beam microscopes are combined with X-ray and spectrometric instruments. In the academic sector, this is complemented by the development of cryo-EM, environmental electron microscopy, and advanced analysis of materials. Such hybridisation reflects a broader global shift, but in the Czech Republic it has special significance because it coincides with the strengths of the national economy: complex instrumentation, materials, industrial diagnostics, semiconductors, batteries, and biomedical applications. In other words, the field is becoming less and less “a single technique” and increasingly a platform-based engineering domain capable of serving numerous technological markets and research tasks. This makes electron microscopy and scientific instrumentation one of the most universal and at the same time one of the most highly specialised parts of contemporary Czech science.

Another important feature of the general characterisation lies in the close connection of the field with personnel training and the regional innovation environment. In its description of life and science in Brno, CEITEC emphasises that the city is a vibrant cultural and academic centre with several universities, research organisations, international companies, and start-ups, which creates a dynamic environment for research, networking, and collaboration. In practice, this means that electron microscopy in the Czech Republic develops within a space where students, doctoral candidates, engineers, researchers, and industrial practitioners constantly intersect. It is precisely such a human framework that makes the reproduction of the school possible. No less important is the educational function of the centres themselves: the new Centre of Electron Microscopy in Brno, according to Akademie věd České republiky, will also serve the training of master’s students and doctoral candidates, while companies involve graduates of regional universities directly in the development and manufacture of instruments. Consequently, the general characterisation of the field must also take into account the fact that it is embedded in a sustainable regional market of competences and does not exist solely on the basis of one-off large projects. This is especially important for 1993–2025, because the post-socialist transformation was successfully completed here precisely because the industrial line and the educational line did not diverge permanently, but managed to meet again in a new institutional form.

In sum, electron microscopy and scientific instrumentation in the contemporary Czech Republic should be characterised as one of the most mature, complex, and internationally competitive directions of the national technical sciences. Its specificity lies in the rare convergence of several factors: historical depth, a strong engineering tradition, a successful post-socialist transformation, a dense regional concentration in Brno, close cooperation between companies and academia, a developed open-access infrastructure, and the ability continually to expand the field of application of the instruments. This direction simultaneously produces instruments, develops methods, trains specialists, serves industry, and supports fundamental and applied research. That is why it is not merely one of the strengths of the Czech Republic, but a model example of how the country's broader logic of "strong business R&D and applied engineering" operates. Unlike fields in which Czech achievements depend chiefly on a single infrastructure or a single industry, electron microscopy rests on an entire ecosystem of complementary organisations and markets. Owing to this, it demonstrates high resilience and a capacity for renewal. Within the whole history of the technical sciences of the Czech Republic in 1993–2025, this direction may be regarded as one of the most convincing examples of how a national engineering school was not only preserved, but also transformed into a global technological resource.

Achievements and Their Characterisation

The principal achievement of the Czech Republic in the field of electron microscopy and scientific instrumentation lies in the fact that the country has managed to transform a distinct scientific and engineering tradition into a fully-fledged global cluster. In contemporary Europe, there are few examples in which the development, manufacture, research application, and personnel reproduction of so complex a class of equipment are concentrated in one city at the same time. Brno has become precisely such an example. In 2025, Akademie věd České republiky stated directly that around one third of the world's production of electron microscopes is associated with Brno, while the regional Data Report 2025 specifies the same thesis in economic terms: more than 2,800 employees in microscopy-focused companies and over EUR 1.1 billion in revenue of electron microscope manufacturers in 2023. In essence, this means that the Czech Republic has achieved not only scientific recognition, but also industrial concentration on a global scale. It is also important that this result is not limited to a single firm. It rests on the combination of several manufacturing companies, academic institutes, university groups, and open-access infrastructures. Therefore, the first and most significant achievement should be formulated as the formation in Brno of a globally significant, economically sustainable, and technologically multi-level cluster of electron microscopy. For a country on the scale of the Czech Republic, this is a result of exceptional importance, because it secures for it not a peripheral, but a system-forming role in the international scientific and instrumental ecosystem.

The second achievement is connected with the fact that the Czech Republic not only preserved the historical legacy of electron optics, but successfully transformed it under post-socialist conditions. The history of Ústav přístrojové techniky AV ČR shows that the Czechoslovak school of electron-optical instrumentation began to take shape as early as the middle of the twentieth century: it was here that the first domestic prototype of an electron microscope and then the first serially produced instrument, BS 241, were created. TESCAN, for its part, emphasises that it emerged in Brno in 1991—already as a company of the new market period—on the basis of the local school of electron beams and the engineering culture of the region. Delong Instruments directly links its origin with the line of Armin Delong and points to the continuity of the development of electron-optical solutions since the beginning of the 1990s. As a result, the Czech Republic proved to be one of the few post-socialist countries that managed not to lose a complex instrumental tradition after the transition to the market, but to turn it into an internationally competitive sector. This achievement has not only historical, but also methodological significance: it shows that an engineering school can survive an institutional rupture if it is deeply enough rooted in personnel, technologies, and local productive culture. In this case, the success did not consist in the simple conservation of the past, but in its adaptation to new forms of ownership, global competition, and new technological standards. Therefore, the second achievement may be defined as the successful market reincarnation of the Czechoslovak school of electron optics in the contemporary Czech Republic.

The third major achievement was the development of indigenous Czech manufacturers of scientific instruments, above all TESCAN and Delong Instruments, which did not dissolve into the global market, but retained Czech engineering agency. TESCAN officially states that it operates in more than 80 countries and supplies not only scanning electron microscopes, but also FIB-SEM, micro-CT, 4D-STEM, and integrated working solutions for science and industry. This means that the Czech Republic has achieved a presence not only in the traditional SEM segment, but also in the more complex zones of the contemporary instrumentation ecosystem. Delong Instruments, for its part, maintains a far more niche, but equally important, specialisation: low-voltage transmission electron microscopes, Schottky electron guns, OEM solutions, and custom electron-optical components. Particularly significant here is Delong's product strategy—the creation of compact and tabletop low-voltage TEM systems combining TEM, STEM, SEM, and electron diffraction in one device. Such a line does not compete directly with the heaviest high-end segment, but it opens another important market: the democratisation of access to electron microscopy, the lowering of the entry threshold, and the widening of the use of microscopy in laboratories where a classical TEM would be too expensive, too large, or too complex. Thus, the third achievement of the Czech Republic consists in the fact that it preserved national players in scientific instrumentation and was able to secure for them different, yet internationally distinguishable, product niches.

The fourth achievement is the integration of Brno into global chains of production and development of world-leading equipment. Here the issue concerns above all the Brno division of Thermo Fisher Scientific. Independent descriptions of the sector and of the local production base emphasise that it is precisely in Brno that the company designs, develops, assembles, and tests advanced electron microscopes, supplying them to customers throughout the world. On Thermo Fisher's career page for the Czech Republic, it is separately stated that the Brno site is the largest electron microscope manufacturing facility in the world and employs more than 1,200 people; on the corporate resource devoted to manufacturing sustainability, Brno is directly designated as an electron microscope manufacturing site. For the Czech Republic, this achievement has a double meaning. On the one hand, the country has become embedded in the global production architecture of a high-technology class of equipment. On the other hand, this is not passive participation in the form of cheap assembly, but deep involvement in development, engineering fine-tuning, testing, and the manufacture of complex scientific systems. In other words, the Czech role here is not the role of a peripheral workshop, but the role of a fully-fledged technological node. Therefore, the fourth achievement may be defined as the successful embedding of Czech electron microscopy in the global high-end instrumentation market without the loss of local engineering depth.

The fifth important achievement relates to the sphere of open research infrastructure and scientific service. CEITEC emphasises that it possesses core facilities equipped with high-end instrumentation and accessible not only to internal users, but also to external researchers and industrial partners at national and international levels. Particularly indicative here is Titan

Krios—one of the key platforms of high-throughput cryo-electron microscopy. In 2025, Akademie věd České republiky also presented the new Centre of Electron Microscopy in Brno as an open-access facility intended for the work of researchers, master's students, doctoral candidates, and partners in academic cooperation. This means that the Czech Republic has achieved not only the manufacture of microscopes, but also the creation of an environment in which expensive instruments become a shared scientific resource rather than the privilege of a narrow group of laboratories. For contemporary science, this is critically important: the cost of high-end EM equipment is such that, without shared facilities and carefully designed access, even strong universities cannot use it fully. In the Czech case, it has proved possible to build such an infrastructural model in which the instrumentation cluster is simultaneously nourished by a large number of users, while the users are supported by locally accessible equipment and engineering assistance. Consequently, the fifth achievement is the transformation of electron microscopy into an element of national open research infrastructure, and not merely into a branch of instrument manufacture.

The sixth achievement is connected with methodological innovations, above all in the field of environmental electron microscopy and work with difficult, weakly conductive, wet, and biological samples. Ústav přístrojové techniky AV ČR officially states that its Environmental Electron Microscopy group continues a tradition of more than twenty years associated with the development of scanning electron microscopy in a gaseous environment and systems for the registration of signal electrons. On another page of the institute, it is stated directly that ESEM makes it possible to observe non-conductive objects without the application of a metallic or carbon coating and to preserve wet samples close to their natural state. This is a methodologically very important achievement, because one of the classical problems of electron microscopy consists in the strong artificiality of sample preparation. The closer microscopy can come to the "natural" state of a material or biological object, the wider the range of its applications and the higher the scientific value of the data. In the Czech case, the issue is not the passive use of another party's technology, but the development of its own detectors, operating modes, and engineering solutions for difficult observation conditions. Consequently, the sixth achievement of the Czech Republic is its contribution to the expansion of the methodological basis of electron microscopy itself, especially in those cases where classical vacuum and preparative regimes were insufficient. This strengthens not only national science, but also the international reputation of the Czech school as a school capable of developing new modes of observation, and not merely of manufacturing instruments.

The seventh achievement may be designated as the transition from "individual microscopes" to platform-based multimodal analytics. The contemporary portfolios of TESCAN and other Brno actors show that Czech instrumentation is already working not only in the logic of classical SEM/TEM, but within the broader architecture of multimodal workflows. In the TESCAN product line, solutions for FIB-SEM tomography, TEM sample preparation, micro-CT, 4D-STEM, automation of analysis, battery degradation studies, semiconductor failure analysis, and advanced materials characterisation are separately highlighted. This is a very important achievement, because the contemporary market for scientific instruments is becoming less and less interested in a "single instrument" and increasingly in an integrated system that makes it possible to conduct research from sample preparation and visualisation to three-dimensional reconstruction, chemical correlation, and automatic data processing. The Czech Republic has managed to integrate itself precisely into this higher logic, rather than remaining a manufacturer of classical mono-instruments. As a result, the national cluster of electron microscopy becomes significant not only for academic science, but also for semiconductors, battery technologies, pharmaceuticals, metallurgy, geosciences, and industrial quality control. Therefore, the seventh achievement should be understood as the transition of Czech scientific instrumentation into a phase of complex, multimodal, and sector-oriented analytical platforms.

The eighth achievement relates to the institutional shaping and international positioning of the Brno microscopy ecosystem as a single brand. In 2022, CEITEC directly declared its ambition to strengthen Brno's position on the global electron microscopy map, and in 2024 it emphasised that, together with Thermo Fisher Scientific, TESCAN, and Delong Instruments, Brno is simply "the centre of electron microscopy". The regional Data Report 2025 adds to this not only marketing, but also organisational elements: the launch of the Brnoregion Microscopy platform in 2024, the growth of international visibility, and links with university programmes and the formation of STEM personnel. At first glance, this achievement may appear merely image-related, but in reality, it has highly practical significance. Contemporary high-technology clusters compete not only through instruments and contracts, but also through their ability to attract students, doctoral candidates, engineers, international partners, companies, and research projects. When a region begins to be perceived as a world capital of a particular technological field, this creates a self-sustaining effect of attraction. For the Czech Republic, which as a whole is not a giant scientific power in terms of scale, such cluster brands are especially valuable. Consequently, the eighth achievement is the transformation of Brno electron microscopy into an internationally recognisable technological brand serving science, industry, education, and regional development simultaneously.

Taken together, all these achievements show that the success of the Czech Republic in electron microscopy and scientific instrumentation has not an isolated, but a multi-level character. The country has succeeded in creating a global cluster, preserving a historical engineering school, developing its own national manufacturers, embedding itself in the global high-end instrumentation economy, creating an open-access infrastructure, contributing to methodological innovations, moving towards multimodal solutions, and institutionally shaping all this as a sustainable regional and national specialisation. That is why this field occupies a special place in the contemporary Czech Republic. It is not simply one of the branches, but an exemplary case of how, in the Czech model, industry, science, engineering, education, and international cooperation are combined. Within the whole history of the technical sciences of the Czech Republic after 1993, electron microscopy and scientific instrumentation may be regarded as one of the most convincing achievements altogether—in depth, in sustainability, and in international visibility.

Leading Figures and Their Publications

In contemporary Czech electron microscopy and scientific instrumentation, it is possible to distinguish several figures of different generations who together form the historical and substantive framework of the field. This group includes, first, the founder of the Brno and Czechoslovak school of electron microscopy, Armin Delong; second, representatives of the key line of low- and very-low-energy electron microscopy—above all Ilona Müllerová and Luděk Frank; third, the leader of the Czech school of environmental electron microscopy, Vilém Neděla; and, finally, a representative of the newer wave of instrumental and methodological developments, Ivo Konvalina, associated with detectors, low-energy spectroscopy, and contemporary STEM-in-SEM modes. Taken together, these names make it possible to see not only the personal composition of the field, but also its internal evolution: from the foundation of the school and classical electron optics to very-low-energy SEM, then to ESEM, and subsequently to a new generation of hybrid and quantitative analytical solutions.

Armin Delong

The scientist is a foundational figure in the whole of Czech electron microscopy. It is he who is regarded as the founder of electron microscopy in Czechoslovakia and as the scholar whose work created the long Brno tradition that survived both the socialist period and the post-socialist transformation. For the contemporary Czech Republic, the significance of Delong lies not only in his historical primacy, but also in the fact that he established the very model of combining science, engineering, and instrumentation. Through his line there subsequently grew both Ústav přístrojové techniky AV ČR and Delong Instruments, as well as the whole later identity of Brno as a world centre of electron-microscope equipment. Even in the post-Soviet and post-socialist period, his name continued to function as a symbol of continuity: from the early national school to low-voltage microscopy and compact TEM solutions.

Leading works:

1. Delong, A. (1980). Early History of Electron Microscopy in Czechoslovakia. In P. W. Hawkes (Ed.), *The Beginnings of Electron Microscopy* (pp. 63–79). New York: Academic Press.
2. Delong, A., & Lencová, B. (2021). Early history of electron microscopy in Czechoslovakia. In P. W. Hawkes (Ed.), *Advances in Imaging and Electron Physics* (Vol. 220, pp. 127–152). Academic Press. https://doi.org/10.1016/bs.aiep.2021.08.006
3. Frank, L., Müllerová, I., & Delong, A. (1994). Microscopy with slow electrons. *Czechoslovak Journal of Physics*, *44*, 195–238. https://doi.org/10.1007/BF01694486
4. Delong, A., Hladil, K., & Kolařík, V. (1994). A low voltage transmission electron microscope. *European Microscopy and Analysis*, *27*, 13–15.

Ilona Müllerová

The scientist is one of the central figures of the contemporary Brno school of electron microscopy, especially in the field of low-energy and very-low-energy scanning electron microscopy. If Delong laid the foundation of the school, then Müllerová became one of its principal architects in the late and post-socialist periods, when the field began to develop no longer only as classical electron optics, but also as a methodologically innovative area. Her work played a major role in the development of cathode-lens approaches, very-low-energy imaging, signal collection physics, and scanning transmission low-energy electron microscopy. In essence, Müllerová's publications show very clearly how the Czech school moved from a general instrumental tradition to a highly specialised contemporary methodology that gave Brno international recognition precisely in low-energy EM.

Leading works:

1. Müllerová, I., & Lenc, M. (1992). The Scanning Very-Low-Energy Electron Microscope (SVLEEM). In A. Boekestein & M. K. Pavićević (Eds.), *Electron Microbeam Analysis. Mikrochimica Acta Supplement* (Vol. 12). Vienna: Springer. https://doi.org/10.1007/978-3-7091-6679-6_16

2. Müllerová, I. (2001). Imaging of specimens at optimized low and very low energies in scanning electron microscopes. *Scanning*, *23*(6), 379–394. https://doi.org/10.1002/sca.4950230605
3. Müllerová, I., & Konvalina, I. (2009). Collection of secondary electrons in scanning electron microscopes. *Journal of Microscopy*, 236(3), 203–210. https://doi.org/10.1111/j.1365-2818.2009.03189.x
4. Müllerová, I., Hovorka, M., Konvalina, I., Unčovský, M., & Frank, L. (2011). Scanning transmission low-energy electron microscopy. *IBM Journal of Research and Development*, *55*(4), 2:1–2:6. https://doi.org/10.1147/JRD.2011.2156190

Luděk Frank

The scientist is another key figure of the Brno school, especially in its theoretical and methodological dimension. His role is particularly visible where electron microscopy goes beyond the limits of the standard instrumental regime and turns into a finely tuned physics of the interaction of slow electrons with matter. It was Frank who, to a significant degree, helped to shape the intellectual depth thanks to which the Czech school of low-energy electron microscopy became visible in the international literature. His publications include both review and conceptual texts, as well as works on very-low-energy SEM, cathode-lens systems, and fields/charge in electron-microscopy regimes. Within the contemporary Czech model of scientific instrumentation, Frank is important above all as a figure linking the physics of the method with the engineering realisation of the instrument.

Leading works:

1. Frank, L. (2002). Advances in scanning electron microscopy. *Advances in Imaging and Electron Physics*, *123*, 327–373. https://doi.org/10.1016/S1076-5670(02)80069-6
2. Frank, L., Hovorka, M., Konvalina, I., Mikmeková, Š., & Müllerová, I. (2011). Very low energy scanning electron microscopy. *Nuclear Instruments and Methods in Physics Research Section A*, *645*, 46–54. https://doi.org/10.1016/j.nima.2010.12.214
3. Frank, L., Hovorka, M., Mikmeková, Š., Mikmeková, E., Müllerová, I., & Pokorná, Z. (2012). Scanning Electron Microscopy with Samples in an Electric Field. *Materials*, *5*(12), 2731–2756. https://doi.org/10.3390/ma5122731
4. Frank, L., Müllerová, I., & Delong, A. (1994). Microscopy with slow electrons. *Czechoslovak Journal of Physics*, *44*, 195–238. https://doi.org/10.1007/BF01694486

Vilém Neděla

The scientist is the leading figure of the Czech school of environmental electron microscopy and one of the most recognisable contemporary Czech researchers in the international ESEM literature. His works are especially significant because they extend the classical limits of electron microscopy: instead of analysing only dry, stable, and well-prepared samples, Neděla and his group develop methods for studying wet, living, thermodynamically sensitive, and biological objects under conditions as close as possible to natural ones. This makes his contribution not simply “one more application of SEM”, but an important extension of the methodological basis of electron microscopy itself. In the context of the contemporary Czech Republic, Neděla represents the line in which instrumentation, electron optics, thermodynamic control, and biological applications are combined into a single research regime.

Leading works:

1. Tihlaříková, E., Neděla, V., & Shiojiri, M. (2013). In situ study of live specimens in an environmental scanning electron microscope. *Microscopy and Microanalysis*, *19*(4), 914–918. https://doi.org/10.1017/S1431927613000603
2. Neděla, V., Tihlaříková, E., & Hřib, J. (2015). The low-temperature method for study of coniferous tissues in the environmental scanning electron microscope. *Microscopy Research and Technique*, *78*(1), 13–21. https://doi.org/10.1002/jemt.22439
3. Závacká, K., Neděla, V., Tihlaříková, E., Šabacká, P., Maxa, J., & Heger, D. (2022). ESEM Methodology for the Study of Ice Samples at Environmentally Relevant Subzero Temperatures: "Subzero ESEM". *Microscopy and Microanalysis*, *28*(1), 196–209. https://doi.org/10.1017/S1431927621013854
4. Neděla, V., Tihlaříková, E., Cápal, P., et al. (2024). Advanced environmental scanning electron microscopy reveals natural surface nano-morphology of condensed mitotic chromosomes in their native state. *Scientific Reports*, *14*, 12998. https://doi.org/10.1038/s41598-024-63515-9

Ivo Konvalina

The scientist represents a newer generation of Czech electron microscopy, associated with quantitative detection, the modelling of electron trajectories, energy filtering, low-energy spectroscopy, and STEM-in-SEM approaches. His publications show especially clearly how the Brno school is moving from the classical electron-optical tradition towards a more digital, quantitative, and analytically integrated model of instrumentation. His works are important not only for improving image quality, but also for a more precise understanding of how exactly the signal is formed and how it can be used for new modes of analysing materials and fine structures. In the contemporary Czech system, Konvalina represents the direction in which the instrument ceases to be only a visualisation device and increasingly becomes a complex measurement platform.

Leading works:

1. Konvalina, I., & Müllerová, I. (2006). The trajectories of secondary electrons in the scanning electron microscope. *Scanning*, *28*(5), 245–256. https://doi.org/10.1002/sca.4950280501
2. Konvalina, I., Mika, F., Krátký, S., Materna Mikmeková, E., & Müllerová, I. (2019). In-Lens Band-Pass Filter for Secondary Electrons in Ultrahigh Resolution SEM. *Materials*, *12*(14), 2307. https://doi.org/10.3390/ma12142307
3. Konvalina, I., Daniel, B., Zouhar, M., Paták, A., Müllerová, I., Frank, L., Piňos, J., Průcha, L., Radlička, T., Werner, W. S. M., & Mikmeková, E. M. (2021). Low-Energy Electron Inelastic Mean Free Path of Graphene Measured by a Time-of-Flight Spectrometer. Nanomaterials, *11*(9), 2435. https://doi.org/10.3390/nano11092435
4. Konvalina, I., Paták, A., Zouhar, M., Müllerová, I., Fořt, T., Unčovský, M., & Mikmeková, E. M. (2021). Quantification of STEM Images in High Resolution SEM for Segmented and Pixelated Detectors. *Nanomaterials*, *12*(1), 71. https://doi.org/10.3390/nano12010071

If one sums up the personal composition of the field, the genealogy of the school is clearly visible in Czech electron microscopy. Delong provides the foundation and historical identity; Müllerová and Frank bring the Brno school to the international level in the field of slow- and very-low-energy electron microscopy; Neděla extends it towards environmental and native-state microscopy; Konvalina represents a newer phase in which the method becomes even more quantitative, digital, and analytically complex. Such a sequence is especially important for the Czech Republic: it shows that this field does not rest on one outstanding figure of the past, but possesses internal continuity and a capacity for renewal. It is precisely this that makes electron microscopy and scientific instrumentation one of the most stable and strongest directions of contemporary Czech technical science.

Part 4

High-Performance Computing, AI, and Robotics

General Characterisation

High-performance computing, artificial intelligence, and robotics in the contemporary Czech Republic form not three isolated fields, but a single technological linkage that developed in response to the needs of the industrial economy, the digitalisation of the state, and the country's involvement in European research programmes. It is precisely in this that the first and principal feature of the Czech model consists. Unlike those countries where AI grew primarily as an extension of the platform internet economy or the consumer-tech sector, in the Czech Republic it was from the very beginning closely connected with computing infrastructure, industrial automation, cybernetics, production planning, machine vision, systems verification, and the digital transformation of applied sectors. Therefore, the contemporary state of this field should be described not as the history of a "separate AI", but as the formation of an integrated ecosystem of computing, intelligent systems, and robotised production. This ecosystem rests on several key nodes: IT4Innovations in Ostrava as the national centre of HPC, CIIRC CTU in Prague as the core of robotics, cybernetics, and industrial AI, RICAIP as a Czech-German platform for advanced industrial production, as well as on the state strategies Industry 4.0, Digital Czechia, and National Artificial Intelligence Strategy. As a result, by 2025 the Czech Republic had arrived at this point not as a country that had joined the global AI fashion by chance, but as a country that had embedded HPC, AI, and robotics in its own model of industrial modernisation. It is precisely this that determines the overall profile of the field at the contemporary stage.

The first supporting component of this model is high-performance computing. IT4Innovations National Supercomputing Center in Ostrava officially defines itself as the leading Czech centre in the fields of HPC, HPDA, AI, and QC, serving both academic and industrial teams. This means that in the Czech Republic computing infrastructure is regarded not as an auxiliary service for abstract science, but as a technological base for a broad range of applications—from the modelling of materials and engineering processes to the processing of large datasets and artificial-intelligence tasks. The Karolina system, acquired within EuroHPC, became a symbol of this phase: according to IT4Innovations itself, after its installation in 2021 it entered TOP500 and Green500, which underlined not only its computing power, but also its energy efficiency. Even more important is the institutional function of IT4Innovations. Through the National Competence Centre in HPC, the centre acts as a single national point of coordination and dissemination of competences in the field of supercomputing and data analysis for science, industry, and the public sector. Thus, the Czech Republic did not simply acquire one strong supercomputer, but created a national architecture of access, training, consultation, and the transfer of HPC competences. For the characterisation of the contemporary stage, this is critically important, because it is precisely such an architecture that makes computing power part of the real economy, and not only a rare resource for a narrow group of researchers.

The second component is artificial intelligence as a state-defined technological field. In 2019, the Czech Republic became one of the first EU countries to adopt a national AI strategy, and in

July 2024 the government approved its updated version—*National Artificial Intelligence Strategy of the Czech Republic 2030*. The Ministry of Industry and Trade directly indicates that the new strategy is built around seven interconnected areas: AI in R&D&I, AI education and expertise, AI skills and labour market, ethical and legal aspects, security aspects, AI in industry and business, and AI in public administration and public services. The very structure of this strategy already shows the character of the Czech approach. Artificial intelligence is regarded here not as a narrow theme of software companies, but as a horizontal technology that should simultaneously strengthen the competitiveness of the economy, increase the efficiency of the state, and reinforce societal resilience. OECD, in its country note 2025, records the same logic: the Czech Republic is strengthening AI infrastructure through HPC and cloud development, regarding it as a basis for research, public services, and cross-sectoral collaboration. Consequently, contemporary AI in the Czech Republic is not only a scientific topic and not only a corporate instrument, but a politically institutionalised cross-cutting technology embedded in the state and research agenda.

The third component is robotics and cybernetics, which in the Czech system have above all an industrial orientation. CIIRC CTU, founded in 2013 as a university institute of the Czech Technical University, officially states among its key fields automatic control and optimisation, robotics, artificial intelligence, computer vision, machine learning, software systems design, and decision/diagnostic systems. At the same time, the description of the institute emphasises not only the scientific, but also the applied character of its work: CIIRC is intended to connect research with university teaching and with the needs of industrial and clinical practice. An additional detail is provided by the historical page of CIIRC: it was precisely the team led by Vladimír Mařík that prepared the document *National Initiative Industry 4.0*, approved by the government in 2016. From this it is clear that Czech robotics developed not as a peripheral engineering specialism, but as part of a broader programme of industrial digital transformation. It rests on the traditions of cybernetics, control systems, and mechatronics, but in its contemporary form it increasingly operates in conjunction with AI, machine vision, collaborative robotics, planning and scheduling, and cyber-physical manufacturing systems. As a result, robotics in the Czech Republic is above all robotics for Industry 4.0, and not primarily service, consumer, or entertainment robotics.

It is precisely at this point that HPC, AI, and robotics converge through the system of testbeds and experimental infrastructures. The Testbed for Industry 4.0 at CIIRC CTU is officially defined as an open unique research and experimental workplace, the largest in Central and Eastern Europe, created for the development and testing of solutions for smart factories. The site of the centre particularly emphasises that the Testbed covers the entire innovation cycle—from the validation of purely scientific hypotheses and new experiments to the transfer of technologies and practices to industry. This is an extremely important characteristic. It means that in the contemporary Czech Republic robotics and AI are developed not only in articles, algorithms, or prototypes, but in an environment where they can be tested at the level of real production flow, integrated machines, logistics, human-machine interaction, and digital control. In this logic, the testbed becomes the central organisational link between the university, the research laboratory, and the manufacturing enterprise. For the Czech model, this is especially organic, since it places its emphasis not on abstract digital innovativeness, but on deployable technology. Hence the overall character of the field: HPC–AI–robotics in the Czech Republic is not a set of disconnected high-technology disciplines, but a unified experimental and applied circuit.

The next important element of the overall characterisation is international embeddedness. RICAIP officially describes itself as an international distributed centre of excellence, founded on the strategic partnership of two Czech and two German research institutes and oriented towards robotics and artificial intelligence for distributed manufacturing in the Industry 4.0 environment. This definition itself already shows that Czech robotics and industrial AI are developing not in national isolation, but as part of a cross-border scientific and engineering ecosystem. Even more importantly, RICAIP is constructed not as a purely research consortium, but as a distributed testbed core linking Prague, Brno, Ostrava, and German centres. This means that internationality here has an operational character: it is embedded in shared infrastructures, educational trajectories, applied projects, and services for industry. In analytical terms, this is one of the key strengths of the Czech Republic. A medium-scale country could hardly on its own achieve the same level of robotics and AI infrastructure as the largest EU states, but thanks to partnership architectures it strengthens its own competences and secures for itself the role of an important Central European node in the field of industrial AI. Consequently, the contemporary Czech model of HPC–AI–robotics has from the outset a European, and not only a national, scale.

To this same international framework belongs the participation of the Czech Republic in Digital Europe instruments, above all through EDIH CTU and AI-MATTERS. EDIH CTU represents a major European Digital Innovation Hub in the field of AI and machine learning, oriented towards providing trustworthy AI/ML services for industry, health, transport, and energy, as well as for public-sector organisations. AI-MATTERS, in turn, is part of the European network of testing and experimentation facilities and is aimed at increasing the resilience and flexibility of the manufacturing sector through AI, robotics, and intelligent autonomous systems. On the CIIRC site it is directly stated that, in the Czech Republic, this initiative brings together CIIRC CTU, CEITEC BUT, and VŠB-TUO, and that its task is to give SMEs and technology companies access to state-of-the-art infrastructure and testing and validation services. This is a very important feature of the overall characterisation of the field. The Czech Republic does not limit itself to having strong scientific groups and several infrastructures. It is systematically building bridges between advanced technologies and small and medium-sized business, using pan-European instruments. As a result, the contemporary stage in the development of HPC, AI, and robotics in the Czech Republic may be described as a phase in which frontier technologies are increasingly being translated into formats of accessible services, tests, and demonstrations for a broader range of enterprises.

If one looks at this field in a broader comparative context, the most accurate characterisation of it will be industrially oriented digital intellectualisation. Such a conclusion is an analytical interpretation based on official and international sources. The Ministry of Industry and Trade links AI with competitiveness, state efficiency, and societal resilience. CIIRC and RICAIP are directly focused on smart factories, distributed manufacturing, robotics, and cybernetics. IT4Innovations emphasises the application of HPC and AI for academia, industry, and society. OECD, in its 2025 country note on the implementation of the European AI plan, separately highlights for the Czech Republic the strengthening of AI infrastructure through HPC and cloud development, support for start-ups and innovation hubs, as well as cross-sectoral collaboration. From the combination of these sources it follows that the Czech model differs from more “platform-based” digital economies. Its core consists of computing power, the industrial application of AI, robotised and cybernetic systems, as well as infrastructures for testing and validation. In other words, in this field the Czech Republic is stronger as a country of industrial intelligence than as a country of pure consumer AI.

Spatially, this ecosystem is organised around several clearly defined nodes. Ostrava concentrates national computing power through IT4Innovations. Prague acts as the centre of cybernetics, robotics, AI design, and testbeds through CIIRC CTU, the National Centre for Industry 4.0, and related initiatives. Brno enters the system through CEITEC, the RICAIP Brno testbed, and participation in AI-MATTERS. Such a configuration is highly indicative of the contemporary Czech Republic as a whole: technological leadership is built not on one metropolis, but on several specialised poles, each of which performs its own function. At the same time, the connectedness between them is ensured not only by political documents, but also by joint projects, European programmes, shared testbeds, and infrastructural consortia. It is precisely this multi-node structure that allows the Czech Republic to maintain a balance between scientific depth, engineering applicability, and national-scale coordination. Therefore, the overall characterisation of this field must necessarily include its spatial form as well: it is a network system of several mutually complementary centres, and not a single cluster.

In sum, high-performance computing, artificial intelligence, and robotics in the contemporary Czech Republic should be defined as one of the most dynamic and strategically significant directions of the technical sciences, but at the same time as a direction with a clearly recognisable national profile. Its principal distinction lies in the close link of frontier digital technologies with the industrial economy, computing infrastructure, and applied cybernetics. This is neither a purely academic nor a purely market model. It is a hybrid system in which state strategy, university institutes, testbeds, European programmes, supercomputing, and industrial partners interact constantly. From 2013 to 2025, the Czech Republic succeeded in turning this field into one of the key channels of its own technological modernisation. It did not become a universal leader in Europe across all indicators, but it built a very recognisable and strong specialisation: HPC-backed AI and robotics for advanced manufacturing, public services, and cross-sectoral digital transformation. It is precisely this formula that constitutes the most accurate overall characterisation of this field at the contemporary stage.

Achievements

The principal achievements of the Czech Republic in the field of high-performance computing, artificial intelligence, and robotics cannot be reduced to a single institute or a single successful programme. What has taken shape here is a multi-level system of results in which computing infrastructure, industrial testbed sites, state AI policy, cross-border centres of competence, and services for the implementation of technologies in business and the public sector have gradually reinforced one another. That is why the contemporary state of the field should be described not through a single “breakthrough”, but through several interrelated achievements, each of which strengthened a particular level of the system: infrastructural, institutional, applied, international, and translational. As a result, the Czech Republic has been able to transform HPC, AI, and robotics from a set of promising themes into one of the most dynamic blocks of national technical science.

The first and most obvious achievement was the creation of a national core of high-performance computing on the basis of IT4Innovations. The centre itself officially positions itself as the leading Czech RDI hub in the fields of HPC, HPDA, AI, and quantum computing, serving both academic and industrial teams. The key symbol of this achievement became the Karolina supercomputer, acquired within the framework of the EuroHPC Joint Undertaking and put into operation in 2021. According to IT4Innovations, in its launch year Karolina ranked 69th in the global TOP500 ranking, 19th in Europe, and 8th in Green500 for energy efficiency. For the Czech Republic, this was not merely a prestigious infrastructural object, but a qualitative leap: the country obtained a computing platform capable of supporting complex simulations, data-intensive science, and the rapidly growing segment of AI workloads. By 2025, this development had already produced a further result: Czech AI Factory (CZAI) was approved in the Czech Republic, and its computing core is to become the new AI-optimised supercomputer KarolAIna. This shows that Karolina did not remain a one-off investment, but became the foundation for the next generation of infrastructure. Thus, the first achievement may be defined as the transition of the Czech Republic from the status of a user of distributed European computing resources to the status of a country with its own HPC and AI infrastructural core.

The second important achievement was that Czech HPC infrastructure was transformed into a system of broad access and the dissemination of competences, rather than remaining an elite resource for a narrow circle of researchers. IT4Innovations emphasises that its computing capacities are provided to research groups from the Czech Republic and from abroad, as well as to industrial users. Through the National Competence Centre in HPC, the centre performs the function of a national point of support for supercomputing and data analysis, assisting organisations in training, consultation, and the effective of computing resources. It is precisely this service and educational superstructure that constitutes a major achievement, because otherwise even a strong supercomputer remains an infrastructure with limited impact. In the Czech case, a more mature model was created: the computing centre became simultaneously a technological resource, an educational platform, and a transfer channel for industry. As a result, high-performance computing in the Czech Republic ceased to be only part of “big science” and entered the broader circulation of engineering and applied tasks. This is especially important for a country where AI and digital industry are developing not apart from production, but in conjunction with it. Therefore, the second achievement should be understood as the institutionalisation of HPC not only as capacity, but also as a national competence.

The third major achievement is connected with the creation of the Testbed for Industry 4.0 at CIIRC CTU. On the official page of the centre, this facility is defined as an open unique research and experimental site, the largest of its kind in Central and Eastern Europe. What is important is not only this definition, but also the way in which the testbed is conceptualised: it serves for the development and testing of innovative solutions for fully integrated industrial production and smart factories and covers the entire innovation cycle—from the verification of a scientific hypothesis to the transfer of technology into industrial practice. For the Czech Republic, this achievement is of fundamental importance because it gave the country an environment in which AI, robotics, digital twins, industrial communication, and advanced control systems can be tested not in laboratory abstraction, but in an almost real production configuration. It is precisely this that transforms robotics from a research theme into an instrument of industrial transformation. Moreover, the testbed has proved to be an important organisational bridge between university science, industrial companies, and European projects. Consequently, the third achievement is the creation of a large-scale experimental infrastructure for industrial AI and robotics, capable of working as a translational mechanism from science to production.

The fourth achievement was the formation of RICAIP as an international distributed centre of excellence in the field of advanced industrial production. The official materials of RICAIP and CIIRC emphasise that the centre connects testbeds in Prague, Brno, and Saarbrücken and is focused on modular distributed production and production as a service. The 2022 annual report of RICAIP describes this project as a Centre of Excellence for AI and Industry 4.0, and also records that it was precisely in 2022 that critical progress was achieved in building the shared infrastructure and international cooperation. It is important here to grasp the scale of the result. The Czech Republic did not merely join an international consortium. It became one of its central sites. This strengthened the national system in several dimensions at once: it expanded access to cross-border infrastructures, increased research visibility, provided access to the German industrial and research environment, and consolidated the role of Prague and Brno as nodes within a pan-European robotised manufacturing ecosystem. For a country of medium scale, such an achievement is especially significant, because it sharply increases the return on its own investments in robotics and digital production. Therefore, the fourth achievement is correctly defined as the international institutionalisation of Czech robotics and industrial AI through a cross-border centre of excellence.

The fifth achievement was the creation of a sustainable national platform for digital industrial transformation associated with the National Centre for Industry 4.0 and the ecosystem of partners around CIIRC. Although the centre functions not as a classical grant structure, but as a networked platform, its role in the contemporary Czech Republic is extremely great. CIIRC materials from 2023–2025 show that, around the National Centre for Industry 4.0, a practical environment has been formed in which university researchers, technology suppliers, financial partners, network operators, engineering firms, and European innovation communities are brought together. At exhibitions and open demonstrations, this ecosystem presents not separate “technologies for the sake of technologies”, but complete solutions for flexible modular production, energy management, data-driven optimisation, industrial 5G, digital twins, and the implementation of smart manufacturing practices. This is a highly important type of achievement: it is less visible than the launch of a supercomputer, but it has great significance for the real economy. It means that the Czech Republic has acquired not only research capacity, but also an organised mechanism for bringing digital and robotic solutions to industrial users. For a country with a powerful manufacturing base, it is precisely such a mechanism that has long-term value. Consequently, the fifth achievement may be designated as the formation of a practical ecosystem of industrial digitalisation, linking research, demonstration, consultation, partnerships, and implementation.

The sixth achievement is the political and strategic institutionalisation of AI. The approval of the first National Artificial Intelligence Strategy in 2019, and then the adoption of the updated NAIS 2030 in July 2024, became an important result not only for digital policy, but for the whole of Czech technical science. The Ministry of Industry and Trade emphasises that the 2030 strategy reflects the latest technological developments, trends, and political initiatives and is structured around seven areas—from AI in R&D and AI education to AI in business, public administration, and security. The Digital Decade 2025 country report directly calls the updated NAIS 2030 the cornerstone of Czechia’s digital ambitions. This is a highly important formulation: it means that artificial intelligence has ceased to be a set of scattered initiatives and has been embedded in nationwide strategic goal-setting. For the Czech Republic, this achievement is especially significant because it made it possible to link AI with broader themes—industrial digitalisation, public services, data infrastructure, ethics, security, and education. As a result, the field acquired not only a scientific and applied, but also a stable political dimension. Therefore, the sixth achievement is the transformation of AI into an officially coordinated priority of national technological development.

The seventh achievement was the creation of channels for the democratisation of access to AI and digital technologies for SMEs and the public sector. The most important here are EDIH CTU and AI-MATTERS. EDIH CTU is officially described as a major European Digital Innovation Hub in the Czech Republic in the field of AI and Machine Learning, which transfers trustworthy AI/ML services to industry, health, transportation, energy, and public administration and is oriented towards SMEs, small mid-caps, and public sector organisations. AI-MATTERS, in turn, creates unified access to testing and experimentation facilities across EU states and, in the Czech node, brings together testbeds in Prague, Brno, and Ostrava. It is especially important that, in 2025, CIIRC directly emphasised that, thanks to this network, it is possible to offer Czech and foreign clients industrial AI and intelligent robotics services at a significantly more affordable price, with access to high-end technology and experts. This means that the Czech Republic has taken a step from strategies and infrastructures to a practical implementation service. For a contemporary technological system, this is one of the most mature achievements, because it is precisely through such mechanisms that frontier technologies cease to be the concern only of large players and begin to work for a much broader circle of companies. Consequently, the seventh achievement may be defined as the creation of a service infrastructure for the implementation of AI and robotics for the SME economy and the public sector.

The eighth achievement is connected with the fact that the Czech Republic has succeeded in making HPC–AI–robotics one of the recognisable Central European technological profiles, rather than simply a set of internal programmes. At the end of 2025, CIIRC summed up the year as a period of strong scientific results, international successes, and major projects in the fields of artificial intelligence, robotics, and cybernetics. On the same page, it was emphasised that EDIH CTU secured Horizon Europe funding for another three years, while the projects and services of the centre received the AI Award in the category of public administration. Although this is already a result from the end of the period under consideration, it clearly shows the overall outcome of the development of the 2010s and the first half of the 2020s: the Czech Republic reached a level at which its infrastructures and platforms are recognised not only within the country, but also in European mechanisms of selection, funding, and professional recognition. For a medium-sized country, such international verification is especially important. It confirms that the achieved results are not merely a national narrative, but achievements recognised and supported in the broader European space. Therefore, the eighth achievement should be formulated as the consolidation of international visibility and trust in the Czech ecosystem of HPC, AI, and robotics.

Taken together, these achievements show that the contemporary development of high-performance computing, AI, and robotics in the Czech Republic has a deeply systemic character. The country has created a world-class computing core, transformed it into a national competence platform, built the largest industrial testbed in the region, joined a cross-border centre of excellence, shaped a national ecosystem of industrial digitalisation, politically established AI as a strategic priority, and created mechanisms of practical access to these technologies for business and the state. That is why this field occupies a special place in contemporary Czech technical science. It is one of the most convincing examples of how the Czech Republic can combine scientific infrastructure, applied engineering, European cooperation, and service-based implementation in the real economy.

Leading Figures and Their Publications

Within the Czech ecosystem of high-performance computing, artificial intelligence, and robotics, it is possible to distinguish several figures who represent different, yet interconnected, lines of development within the field. Vladimír Mařík embodies industrial cybernetics, multi-agent systems, and the logical framework of Industry 4.0; Michal Pěchouček represents contemporary applied AI, game-theoretic and multi-agent reasoning, and the strategic institutionalisation of artificial intelligence; Petr Holub represents the line of HPC, network, and e-infrastructure, without which mature computational science is impossible; Tomáš Krajník represents robotics of long-term autonomy, robot vision, and spatio-temporal intelligence for robots. Taken together, these researchers show that the Czech model in this sphere is built not around a single discipline, but around an entire spectrum of links between computation, intelligent algorithms, industrial implementation, and autonomous systems.

Vladimír Mařík

The scientist is one of the key figures of Czech scientific and technological modernisation in the fields of cybernetics, intelligent manufacturing, and multi-agent systems. In the contemporary Czech Republic, he is associated not only with fundamental and applied developments, but also with the institutional shaping of the Industry 4.0 agenda: it was precisely the team associated with him and CIIRC CTU that prepared the Czech *National Initiative Industry 4.0*, while Mařík himself appears as the Scientific Director of CIIRC CTU and a recognised international authority, additionally confirmed by his status as an IEEE Life Fellow. His contribution is especially important because he helped to translate multi-agent and holonic approaches from academic theory into the language of real manufacturing, decentralised control, and smart manufacturing systems.

Leading works:

1. Pěchouček, M., & Mařík, V. (2008). Industrial deployment of multi-agent technologies: Review and selected case studies. *Autonomous Agents and Multi-Agent Systems*, *17*(3), 397–431. https://doi.org/10.1007/s10458-008-9050-0
2. Mařík, V., Vrba, P., Hall, K. H., & Maturana, F. P. (2005). Rockwell Automation agents for manufacturing. In *Proceedings of the 4th International Joint Conference on Autonomous Agents and Multiagent Systems: Industrial Applications Track* (pp. 107–113). ACM. https://doi.org/10.1145/1082473.1082812
3. Mařík, V., Vrba, P., & Leitão, P. (Eds.). (2011). Holonic and Multi-Agent Systems for Manufacturing. In *Proceedings of the 5th International Conference on Industrial Applications of Holonic and Multi-Agent Systems*. Berlin; Heidelberg: Springer. https://doi.org/10.1007/978-3-642-23181-0
4. Camarinha-Matos, L. M., Afsarmanesh, H., & Mařík, V. (Eds.). (1998). *Intelligent Systems for Manufacturing*. Boston, MA: Springer.

Michal Pěchouček

The scientist represents a newer, but already fully mature, phase of Czech AI. He is the Director of the AI Center at the Faculty of Electrical Engineering CTU in Prague, and the official profile of the centre emphasises that he is the author of more than 400 peer-reviewed publications and one of the most prominent researchers in the fields of computer science, AI, planning, and security-related decision systems. Unlike Mařík, who is associated to a greater extent with industrial cybernetics as an architecture of production, Pěchouček embodies the Czech turn towards contemporary applied AI: game theory, multi-agent planning, cyber defence, resource allocation, secure reasoning, and AI applications in complex adversarial environments. His figure is especially important for understanding how the Czech AI school linked academic rigour with real applied scenarios.

Leading works:

1. Pěchouček, M., & Mařík, V. (2008). Industrial deployment of multi-agent technologies: Review and selected case studies. *Autonomous Agents and Multi-Agent Systems*, *17*(3), 397–431. https://doi.org/10.1007/s10458-008-9050-0
2. Tožička, J., Jakubův, J., Komenda, A., & Pěchouček, M. (2016). Privacy-concerned multiagent planning. *Knowledge and Information Systems*, 48(3), 581–618. https://doi.org/10.1007/s10115-015-0887-7
3. Durkota, K., Lisý, V., Bošanský, B., Kiekintveld, C., & Pěchouček, M. (2019). Hardening networks against strategic attackers using attack graph games. *Computers & Security*, *87*, 101578. https://doi.org/10.1016/j.cose.2019.101578
4. Mařík, V., Pěchouček, M., Štěpánková, O., & Lažanský, J. (2000). ProPlanT: Multi-agent system for production planning. *Applied Artificial Intelligence*, *14*(7), 727–760. https://fel.cvut.cz/cs/fakulta/lide/762-michal-pechoucek/publikace

Petr Holub

The scientist represents, for the Czech Republic, the direction without which the mature development of HPC, data-intensive AI, and contemporary distributed digital infrastructures would be impossible. The official profile of Masaryk University shows that he heads the BioMedAI / CERIT-SC division, teaches courses in high-performance computing, GPU programming, and computer networks, while his research and organisational activity is linked with network-centric collaborative systems, advanced infrastructures, and data-intensive computing. His role is especially important because the Czech computational ecosystem rests not only on the supercomputers themselves, but also on networked, distributed, and multimedia solutions that make possible collaborative work with big data, visualisation, and high-speed information transfer. In this sense, Holub represents the more infrastructural and systemic layer of Czech HPC culture.

Leading works:

1. Hutanu, A., Allen, G., Beck, S. D., Holub, P., Kaiser, H., Kulshrestha, A., Liška, M., MacLaren, J., Matyska, L., Paruchuri, R., Prohaska, S., Seidel, E., Ullmer, B., & Venkataraman, S. (2006). Distributed and collaborative visualization of large data sets using high-speed networks. *Future Generation Computer Systems*, *22*(8), 1004–1010. https://doi.org/10.1016/j.future.2006.03.026
2. Holub, P., Rudová, H., & Liška, M. (2011). Data transfer planning with tree placement for collaborative environments. *Constraints*, *16*(3), 283–316. https://doi.org/10.1007/s10601-011-9106-7
3. Kabát, M., David, V., Holub, P., & Pulec, M. (2016). High-performance forward error correction: Enabling multi-gigabit flows and beyond on commodity GPU and CPU hardware in presence of packet loss. *Future Generation Computer Systems*, *54*, 326–335. https://doi.org/10.1016/j.future.2015.04.007

4. Holub, P., Matela, J., Pulec, M., Jirman, M., Chmelar, D., & others. (2012). UltraGrid: Low-latency high-quality video transmissions on commodity hardware. In *Proceedings of the 20th ACM International Conference on Multimedia* (pp. 1457–1458). ACM. https://doi.org/10.1145/2393347.2396519

Tomáš Krajník

The scientist is one of the most notable figures of contemporary Czech robotics, especially in the fields of long-term autonomy, robot vision, and aerial robotics. The official profile of the Artificial Intelligence Center CTU Prague directly identifies these fields as his key research interests. Unlike Mařík and Pěchouček, who work primarily with the architectures of intelligent systems and agent-based approaches, Krajník represents robotics as a problem of long-term autonomous behaviour in a changing environment. His works are especially important for understanding how the Czech school translates AI into embodied systems: mobile robots, service robotics, spatio-temporal learning, and adaptation to the human and natural rhythms of the environment. This is no longer simply "robots as devices", but robots as carriers of long-term intelligent adaptation.

Leading works:

1. Krajník, T., Fentanes, J. P., Santos, J. M., & Duckett, T. (2017). Fremen: Frequency map enhancement for long-term mobile robot autonomy in changing environments. *IEEE Transactions on Robotics*, *33*(4), 964–977. https://doi.org/10.1109/TRO.2017.2665664
2. Kunze, L., Hawes, N., Duckett, T., Hanheide, M., & Krajník, T. (2018). Artificial Intelligence for Long-Term Robot Autonomy: A Survey. *IEEE Robotics and Automation Letters*, *3*(4), 4023–4030. https://doi.org/10.1109/LRA.2018.2860628
3. Krajník, T., Přeučil, L. (2010). Simple, yet stable bearing-only navigation. *Journal of Field Robotics*, *27*(5), 511–533. https://imr.ciirc.cvut.cz/uploads/Papers-pdfs/Krajnik10jfr.pdf
4. Molina, S., Cielniak, G., Krajník, T., & Duckett, T. (2018). Modelling and predicting rhythmic flow patterns in dynamic environments. In *Towards Autonomous Robotic Systems* (Lecture Notes in Artificial Intelligence, Vol. 10965, pp. 135–146). Springer. https://doi.org/10.1007/978-3-319-96728-8_12

If the leading figures of this field are considered together, the internal division of labour within the Czech school becomes clearly visible. Mařík defines the architecture of industrial cybernetics and agent systems for manufacturing; Pěchouček strengthens the line of contemporary applied AI, planning, and security; Holub represents the infrastructural and computational foundation of distributed digital science; Krajník embodies the robotic dimension of AI as a problem of long-term autonomy. Taken together, they show that the Czech ecosystem of HPC, AI, and robotics is strong precisely because of its connectedness: here computation, intelligent algorithms, manufacturing, networks, and autonomous systems develop not separately, but within a unified engineering and research logic.

Part 5

Cybersecurity and Network Technologies

General Characterisation

Cybersecurity and network technologies in the contemporary Czech Republic represent not a narrow branch of IT, but a fully-fledged strategic direction of the technical sciences, formed at the intersection of state security, internet infrastructure, applied informatics, university research, and the commercial development of protective solutions. Its contemporary profile took especially clear shape in the 2010s and 2020s, when the digitalisation of the economy, the state, and critical infrastructure sharply increased the importance of network resilience, threat detection, incident response, cryptography, personnel training, and the secure administration of network services. In the Czech case, this direction is distinguished by the fact that it develops simultaneously in several modes: as a sphere of state coordination and strategic planning, as an environment of practical response services and internet operations, as a university research and educational platform, and as a segment of applied technological solutions, some of which have gained international recognition. Therefore, cybersecurity in the Czech Republic should be understood not only as a set of protective tools, but as a complex ecosystem of digital resilience in which state institutions, CSIRT teams, DNS developers, university laboratories, and commercial firms form an interconnected system.

The first defining feature of this direction is its high strategic status in state policy. The National Cyber Security Strategy of the Czech Republic for the period 2021–2025 directly emphasises that ensuring cybersecurity today "goes far beyond technology alone" and requires a comprehensive approach, including political, economic, social, legal, educational, and other instruments. The strategy separately notes that the Czech Republic and its institutions have for many years been targets of cyber espionage, and that the use of cyberspace to promote the foreign-policy interests of states has intensified. This means that, in the Czech context, cybersecurity is from the outset conceived not as secondary technical support for digitalisation, but as part of the general architecture of national resilience. That is why this direction in the contemporary Czech Republic is closely connected not only with IT sectors, but also with issues of international law, public administration, the protection of sensitive information, cryptographic policy, and the resilience of critical systems. Such a formulation of the task gives cybersecurity a special weight within the Czech system of the technical sciences: it belongs simultaneously both to the engineering disciplines and to the broader field of state security.

The second important characteristic is the presence of a strong specialised state centre of coordination. This role is performed by NÚKIB—National Cyber and Information Security Agency. According to the Report on the State of Cyber Security in the Czech Republic for 2024, it is NÚKIB that coordinates the assessment of the fulfilment of the Action Plan to the National Strategy 2021–2025 and participates, as a responsible or cooperating subject, in the implementation of 101 out of the 105 tasks of the plan. The same report shows that, in 2024, NÚKIB handled 268 cyber incidents, while the document itself identifies the key trend of the year as an increase in the number of incidents combined with a decrease in their severity. This combination is especially important for the general characterisation of the field. It shows that the Czech system is not merely recording threats, but is gradually increasing the maturity of its processes of observation, classification, prioritisation, and response. In analytical terms, this means that cybersecurity in the Czech Republic is developing not only as a scientific or technological field, but also as an operational managerial system capable of combining strategy, monitoring, normative frameworks, and incident-management practice.

The third characteristic feature of the Czech model is its hybrid institutional architecture, in which state functions are combined with the activity of technical and semi-autonomous infrastructural actors. Particularly indicative in this respect is the linkage of NÚKIB, CSIRT.CZ, and CZ.NIC. The official CSIRT.CZ page directly states that it is the National CSIRT of the Czech Republic, operated by the domain registry CZ.NIC under public contract with the National Cyber and Information Security Agency. CZ.NIC, in turn, defines itself as an association that not only manages the .cz domain registry and the MojeID service, but also engages in cybersecurity, support for internet infrastructure, the development of internet applications, and educational initiatives. Such an architecture is unusual and, in a certain sense, very strong: part of the key national cyber functions is embedded not only in the bureaucratic vertical, but also in the environment of technically oriented infrastructure operators. This allows the Czech system to remain closer to real network practices, standards, incidents, and communities of internet operators. As a result, cybersecurity here develops as a synthesis of public authority and engineering internet governance, and not as a purely departmental sphere.

The fourth important layer of the field is the university and research cyber environment, within which Masaryk University stands out in particular. The official research profile of the university reports that the Institute of Computer Science has been engaged with cyber-threat issues since 2007 and is home to key projects and infrastructures, including CERIT-SC, CSIRT-MU, and KYPO. The KYPO Cyber Range Platform is described as a flexible, scalable, and complex virtual environment for cyber education, developed since 2013 and already used for teaching in several courses at Masaryk University and for the training of cybersecurity specialists. The MUNI KYPO Portal also emphasises a broader mission: the formation of a cyber-secure digital society through the preparation of future experts and practice-oriented education. Taken together with the research projects of the Cybersecurity Laboratory, this shows that, in the Czech Republic, cybersecurity is institutionalised not only as security operations, but also as a sustainable academic discipline with a strong educational and experimental base. This is especially important for the contemporary stage, because the shortage of personnel is one of the general problems of the whole European cyber sphere, and it is precisely such platforms that create a long-term personnel reserve.

The fifth feature of the Czech direction is its strong connection with network technologies and basic internet infrastructure, and not only with the protection of end devices and corporate networks. This line is especially clearly visible through the solutions of CZ.NIC and the Knot ecosystem. The official resources of Knot DNS and Knot Resolver describe them respectively as a high-performance authoritative DNS server and a modern resolver implementation designed for scalability, resiliency, and flexibility. On the CZ.NIC support page it is directly stated that KNOT is open-source software used for running DNS services, while the organisation itself emphasises its mission to strengthen the internet infrastructure of the Czech Republic and beyond. This linkage is extremely indicative. It means that the Czech cyber ecosystem is strong not only in responding to threats, but also in developing the basic network components on which the resilience and security of domain and resolver infrastructure depend. In a broader sense, this makes it possible to classify the Czech Republic among those countries where cybersecurity develops not only as a “protective” discipline, but also as the engineering of a trusted network. For the contemporary stage, this is especially important, because an increasing number of threats are connected precisely with DNS, routing, resolvers, infrastructural dependencies, and supply-chain risks in basic network services.

The sixth component of the general characterisation is connected with the international and European embeddedness of the Czech cyber sphere. The NÚKIB report for 2024 records the agency’s participation in an international project submitted within Horizon Europe, as well as the continuation of cooperation on the CHESS project, aimed at strengthening regional innovation excellence in cybersecurity. CSIRT.CZ, for its part, emphasises its external links and tasks as a point of contact for the international CERT/CSIRT community. Masaryk University links the development of KYPO with the European strategy of digital sovereignty and the shortage of cybersecurity specialists in Europe. This means that the Czech model does not close itself within national needs and is not exhausted by the protection of its own systems. It is built as part of a broader European ecosystem of trust, norm-setting, training, research, and operational interaction. For a country of medium scale, this is critically important: it is precisely international cooperation that enables the Czech Republic to update methods rapidly, integrate into standards, and strengthen its own technological and educational platforms. Therefore, contemporary Czech cybersecurity should be regarded as a Europeanised national system, and not as an exclusively internal sector.

Finally, the seventh important feature of the field lies in the fact that it brings together public security, infrastructural open-source development, and the commercial cyber ecosystem. At the commercial level, the symbol of Czech international visibility remains the Avast line: the company’s official material recalls that Avast was founded in Prague in 1988 and became one of the most prominent global brands in the field of mass digital protection; the current corporate page emphasises that Avast now operates as part of Gen and continues to position itself around the idea of safe digital life. Even if contemporary Czech cybersecurity is not reducible to a single company, this line itself is important as a historical and reputational marker: the Czech Republic is known not only for state and academic initiatives, but also as the homeland of a globally recognisable consumer-security brand. Taken together with NÚKIB, CZ.NIC, CSIRT.CZ, Masaryk University, and KYPO, this shows that the Czech direction is distinguished by an extraordinarily broad institutional range—from the internet registry and the DNS stack to educational cyber ranges and a commercial antivirus history. It is precisely this breadth that makes it one of the most integral digital-technological directions of the contemporary Czech Republic.

In sum, cybersecurity and network technologies in the contemporary Czech Republic should be characterised as a mature, multi-level, and strategically institutionalised field of the technical sciences, in which state coordination, national CERT/CSIRT mechanisms, the development of basic internet infrastructure, university research and training, open-source network solutions, and a commercial line of international scale are combined. The strength of the Czech model lies precisely in this composition: here cybersecurity is not detached from network engineering, and state strategy is not detached from real technical communities and educational platforms. Therefore, the field in the Czech Republic develops not as a secondary service of digitalisation, but as one of the key means of ensuring the resilience of digital modernity itself—from the state and critical infrastructure to universities, DNS services, professional training, and everyday user security.

Achievements

The principal achievement of the Czech Republic in the field of cybersecurity and network technologies lies in the fact that, within a comparatively short historical period, the country succeeded in building an integral and multi-level system of digital resilience, rather than limiting itself to a set of scattered projects. This system includes state strategic governance, national incident-response mechanisms, a strong university school, developed training and exercise platforms, indigenous solutions in the sphere of basic internet infrastructure, and commercially successful technologies of international standing. As a result, Czech cybersecurity has become not a peripheral adjunct to digitalisation, but an independent field of technical sciences and practices, connected simultaneously with national security, network engineering, software platforms, and personnel training. It is precisely this that distinguishes the Czech Republic from states in which cybersecurity is either almost entirely absorbed by the departmental sector or, on the contrary, remains primarily a matter of the private market. In the Czech case, a more mature balance has been achieved between public coordination, infrastructural engineering, and the applied research environment. Therefore, the achievements of this field should be considered not as the sum of individual successes, but as elements of a single strategically interconnected model.

The first and most fundamental achievement should be regarded as the creation of a mature national system of cyber governance and threat monitoring concentrated around NÚKIB. The National Cyber and Information Security Agency became in the Czech Republic not merely a regulator, but the central node of strategic, normative, and operational governance in this sphere. The European Cybersecurity Competence Centre directly states that NÚKIB is the central administrative authority for cybersecurity, the protection of classified information in ICT systems, and cryptographic protection, and that it was established in 2017 on the basis of a special law. The NÚKIB report for 2024 already shows a mature stage in the development of this model: the agency coordinates the implementation of the National Strategy 2021–2025, participates in the fulfilment of almost all the tasks of its action plan, and at the same time maintains a systematic register and assessment of cyber incidents. It is especially indicative that, in 2024, a record volume of incidents for the Czech Republic was registered—268—yet NÚKIB itself emphasises the continuing decline in the severity of consequences for the third year in a row, together with the presence of only one very significant incident. This means that the Czech system has learned not only to see more threats, but also to work more effectively with their consequences. Thus, the first achievement may be defined as the institutionalisation of cybersecurity at the level of a fully-fledged state system of situational awareness, coordination, and adaptive response.

The second major achievement is the formation of a national CERT/CSIRT response model based on interaction between public authority and the engineering internet community. The official CSIRT.CZ page states directly that it is the National CSIRT of the Czech Republic, operating on the basis of a public contract with a state authority and fulfilling the role of the National CERT team in accordance with the Cybersecurity Act. What is important here is not only the status itself, but also the institutional design: in the Czech Republic, the national CSIRT function is implemented through an environment closely connected with the infrastructural operator CZ.NIC, and not exclusively through a classical ministerial subdivision. Such an arrangement creates a very substantial advantage. Incident response, the exchange of technical information, interaction with network operators, and the maintenance of trust within the internet community take place in a more flexible and technically rooted environment than is usually the case in fully departmental systems. Owing to this, the Czech model combines the legal legitimacy of a state mandate with the practical competence of infrastructural operators. Consequently, the second achievement of the Czech Republic consists in the fact that it created a functional national CERT/CSIRT model embedded both in the legal system of the state and in the real architecture of internet operations.

The third achievement relates to the development of indigenous basic-level network technologies, above all through the ecosystem of CZ.NIC, Knot DNS, and Knot Resolver. CZ.NIC defines itself as an association that manages the .cz domain and at the same time engages in cybersecurity, internet infrastructure, application development, and educational projects. Knot DNS is officially described as a high-performance authoritative-only DNS server supporting the key functions of contemporary DNS, while Knot Resolver is described as a caching DNS resolver scalable from large farm infrastructures to home routers. In practice, this means that the Czech Republic did not confine itself to importing ready-made network products, but developed its own open-source tools for one of the most sensitive zones of digital infrastructure—the domain and resolver environment. Under conditions in which DNS resilience is the foundation for a vast number of internet services, such an achievement has not a local, but a systemic character. It is especially important as well that these solutions exist as living, updated, and widely used projects, and not as academic prototypes. Therefore, the third achievement may be defined as the creation in the Czech Republic of its own set of infrastructurally significant network technologies operating in support of the security, reliability, and sovereignty of internet services.

The fourth most important achievement is connected with the KYPO Cyber Range platform, which has become one of the best-known Czech contributions to European cyber-educational and cyber-training infrastructure. The official KYPO site directly describes it as the first European open-source cyber range, proven in practice, with the purpose of boosting the resilience of digital society. It also emphasises that the platform has already been used for training students in several courses at Masaryk University and for the training of cybersecurity specialists. Additional material from the CONCORDIA project clarifies that KYPO has been developed by Masaryk University since 2013, is built on many years of experience in conducting cyber defence exercises, and was released in open-source format in 2020. This achievement is especially significant because it places the Czech Republic in an internationally visible position not merely as a user of cyber platforms, but as their developer. The open nature of KYPO is also of fundamental importance: it makes practice-oriented cyber training accessible to universities and organisations that cannot afford expensive commercial cyber range solutions. Thus, the fourth achievement of the Czech Republic is the creation of a scalable, open, and internationally significant platform for cyber training and cyber exercises, possessing value far beyond the country itself.

The fifth achievement consists in the fact that the Czech Republic succeeded in turning cybersecurity into a sustainable university research and educational specialisation, and not merely into a set of professional courses. Masaryk University directly indicates that its research activity in this field covers protection against phishing and malicious data collection, automation of penetration testing, detection of botnets and malware, cryptanalysis, and anomaly detection in encrypted traffic. A separate Cybersecurity Laboratory also operates, positioning itself as an expert laboratory across a wide range of themes and supporting projects directed towards the development of cybersecurity knowledge and skills, hands-on training, and the automation and adaptivity of educational processes. This means that the Czech cyber sphere is built not only on operational security and infrastructure, but also on a scientific environment capable of constantly producing new knowledge, testing methods, and training specialists. For the long-term resilience of the field, this is critically important: only the presence of such an environment allows the country not to depend entirely on external solutions and imported personnel. Consequently, the fifth achievement is the formation in the Czech Republic of a research-and-educational cyber school with a strong experimental, methodological, and personnel base.

The sixth achievement is connected with European and international cooperation, which has given the Czech cyber sphere additional scale and political weight. The NÚKIB report for 2024 records that the agency participated in international projects within Horizon Europe and also continued work on the CHESS project, aimed at strengthening regional innovation excellence in cybersecurity. At the level of political and strategic leadership, the Czech Republic is also visible through the so-called Prague Proposals: a special document of 2021, published by NÚKIB, invited governments to support the Prague Proposals on Cyber Security of Emerging and Disruptive Technologies and directly referred to the need for the exchange of expert knowledge, joint research, and the strengthening of collective resilience. Even if the Prague Proposals are not themselves a "technology" in the narrow sense, they represent an important achievement at the institutional level. Here the Czech Republic appears not only as an executor of European cyber policy, but also as one of the forum-centres in which norms, approaches, and recommendations for the international community are formulated. Consequently, the sixth achievement may be defined as the emergence of Czech cybersecurity at the level of active participation in a pan-European and international norm-setting and collaborative cybersecurity ecosystem.

The seventh achievement relates to the creation of a recognisable commercial line of Czech digital protection, the historical symbol of which became Avast. The official Avast blog recalls that the company was founded in Prague in 1988 by Eduard Kučera and Pavel Baudiš, while the official brand page today continues to position Avast as part of the broader Gen group working on the digital freedom and security of users. Although contemporary Czech cybersecurity is by no means exhausted by this company, its significance in the overall history of the field is considerable. Avast became one of the first internationally recognisable Czech brands in the digital sphere and demonstrated that products of global scale can emerge from the Czech engineering and software environment. Moreover, the Avast line itself connected the country's scientific and technological reputation with mass digital security, and not only with narrowly professional markets. Therefore, the seventh achievement is most correctly understood as the formation of an internationally visible commercial cyber brand that strengthened the reputation of the Czech Republic as a producer of protective digital solutions.

The eighth achievement is a more general, but very important, result: the combination within one national system of three levels of cybersecurity—infrastructural, educational, and operational. This achievement is not reducible to a single institute, but is clearly visible from the whole Czech field. At the infrastructural level, CZ.NIC, Knot DNS, and Knot Resolver operate; at the operational level, NÚKIB and CSIRT.CZ; at the educational and research level, Masaryk University, KYPO, and the Cybersecurity Laboratory. Such a combination creates a rare effect. The country gains not only mechanisms of protection and response, but also its own technological tools, as well as a system for the training and reproduction of personnel. As a result, the Czech cyber sphere possesses far greater resilience than one in which only one of these levels is present. For the contemporary stage of development, this is perhaps the deepest achievement of all: the Czech Republic has created not simply a set of strong projects, but a functionally complete national cyber ecosystem capable of protecting, training, developing, and interacting internationally at the same time. It is precisely this that makes cybersecurity and network technologies one of the most advanced digital directions of contemporary Czech technical science.

Leading Figures and Their Publications

In contemporary Czech cybersecurity and network technologies, several figures representing different levels of the system are especially prominent: Pavel Čeleda and Jan Vykopal represent the university school of applied cybersecurity, cyber ranges, and cyber education at Masarykova univerzita; Martin Husák represents the line of network security, situational awareness, forecasting, and network-traffic analysis; Martin Rehák represents the direction of behavioural threat analysis, intrusion detection, and AI/ML for network defence; Libor Peltan represents the infrastructural-network line of CZ.NIC, where the key results are expressed above all in DNS/DNSSEC standards and the practical engineering of internet infrastructure. Taken together, these researchers and developers show that the Czech school is strong not only in the operational response to incidents, but also in training, the scientific analysis of network data, intelligent defence, and the development of basic internet technologies.

Pavel Čeleda

The scientist is one of the central figures of Czech academic cybersecurity. His profile at Masarykova univerzita shows a stable linkage of three directions: network security operations, cybersecurity training, and practice-oriented education. He is especially important for the Czech school because he connects the classical line of intrusion detection and situational awareness with the newer line of adaptive cybersecurity education and the cyber-range ecosystem. It is precisely through his works that one can clearly see how cybersecurity in the Czech Republic developed from the analysis of high-speed network traffic towards more complex models of forecasting, triage, and specialist training.

Leading works:

1. Rehák, M., Pěchouček, M., Bartoš, K., Grill, M., Čeleda, P., & Krmíček, V. (2008). CAMNEP: An intrusion detection system for high-speed networks. *Progress in Informatics*, *5*, 65–74. https://www.nii.ac.jp/pi/n5/5_65.pdf
2. Husák, M., Komárková, J., Bou-Harb, E., & Čeleda, P. (2019). Survey of Attack Projection, Prediction, and Forecasting in Cyber Security. *IEEE Communications Surveys & Tutorials*, *21*(1), 640–660. https://doi.org/10.1109/COMST.2018.2871866
3. Sadlek, L., Yamin, M. M., Čeleda, P., & Katt, B. (2025). Severity-Based Triage of Cybersecurity Incidents Using Kill Chain Attack Graphs. *Computers & Security*, *155*, 104476. https://www.muni.cz/lide/206086-pavel-celeda/publikace
4. Vykopal, J., Švábenský, V., Lopez Jr., M. T., & Čeleda, P. (2025). Cybersecurity Study Programs: What’s in a Name? In *Proceedings of the 56th ACM Technical Symposium on Computer Science Education* (SIGCSE 2025). https://www.muni.cz/lide/206086-pavel-celeda/publikace

Jan Vykopal

The scientist is one of the most important figures of the Czech school of cyber exercises, cyber ranges, and hands-on cybersecurity education. His official profile at Masarykova univerzita directly emphasises that he is concerned not only with cybersecurity itself, but also with research into how it is best taught. This makes him an especially characteristic representative of the Czech model: within it, personnel training and experimental educational infrastructure are regarded as an inseparable part of cybersecurity. Through Vykopal's publications, one can clearly trace the transition from classical teaching-by-lab to adaptive learning environments, data-driven analysis of trainees, and a more systematic model of cyber-range pedagogy.

Leading works:

1. Šeda, P., Vykopal, J., Švábenský, V., & Čeleda, P. (2021). Reinforcing Cybersecurity Hands-on Training With Adaptive Learning. In *2021 IEEE Frontiers in Education Conference* (FIE). IEEE. https://www.muni.cz/en/research/publications/1783806
2. Vykopal, J., Šeda, P., Švábenský, V., & Čeleda, P. (2023). Smart Environment for Adaptive Learning of Cybersecurity Skills. *IEEE Transactions on Learning Technologies*, *16*(3), 443–456. https://doi.org/10.1109/TLT.2022.3216345
3. Švábenský, V., Vykopal, J., Čeleda, P., & Kraus, L. (2022). Applications of Educational Data Mining and Learning Analytics on Data from Cybersecurity Training. *Education and Information Technologies*, *27*(9), 12797–12826. https://www.muni.cz/en/people/98724-jan-vykopal/publications
4. Vykopal, J., Švábenský, V., Lopez Jr., M. T., & Čeleda, P. (2025). Cybersecurity Study Programs: What's in a Name? In *Proceedings of the 56th ACM Technical Symposium on Computer Science Education* (SIGCSE 2025). https://www.muni.cz/en/people/98724-jan-vykopal/publications

Martin Husák

The scientist represents within the Czech school above all the direction of network situational awareness, attack forecasting, network-traffic analysis, and operational knowledge engineering for cybersecurity. His profile at Masarykova univerzita and his list of publications show that he is one of the key figures of the newer phase of Czech cyber science, in which network security is supplemented by attack forecasting, cyber knowledge graphs, passive fingerprinting, and decision support for incident management. In the context of the Czech model, this is especially important because Husák stands at the intersection of the academic analysis of network data and the real tasks of the SOC/CSIRT environment.

Leading works:

1. Husák, M., Komárková, J., Bou-Harb, E., & Čeleda, P. (2019). Survey of Attack Projection, Prediction, and Forecasting in Cyber Security. *IEEE Communications Surveys & Tutorials*, *21*(1), 640–660. https://doi.org/10.1109/COMST.2018.2871866
2. Husák, M., Bartoš, V., Sokol, P., & Gajdoš, A. (2021). Predictive Methods in Cyber Defense: Current Experience and Research Challenges. *Future Generation Computer Systems*, *115*, 517–530. https://doi.org/10.1016/j.future.2020.10.006
3. Matta, L., & Husák, M. (2021). A Dashboard for Cyber Situational Awareness and Decision Support in Network Security Management. In *2021 IFIP/IEEE International Symposium on Integrated Network Management (IM)* (p. 1753376). IEEE. https://www.muni.cz/en/research/publications/1753376

4. Laštovička, M., Husák, M., Velan, P., Jirsík, T., & Čeleda, P. (2023). Passive Operating System Fingerprinting Revisited. *Computer Networks*, *229*, 109782. https://doi.org/10.1016/j.comnet.2023.109782

Martin Rehák

The scientist is one of the most prominent figures of the Czech line of behavioural threat analysis, intrusion detection, malware analytics, and the application of machine learning to network security. His professional trajectory links České vysoké učení technické v Praze, Cognitive Security, Cisco Cognitive Threat Analytics, and later-stage AI security entrepreneurship. That is precisely why he is especially indicative for the Czech model: through him one can see how university research in the field of network anomaly detection and malware behaviour was translated into commercially and technologically significant products. His works belong to the most representative outputs of the Czech school of network analytics and AI-driven cyber defence.

Leading works:

1. Rehák, M., Pěchouček, M., Bartoš, K., Grill, M., Čeleda, P., & Krmíček, V. (2008). CAMNEP: An intrusion detection system for high-speed networks. *Progress in Informatics*, *5*, 65–74. https://www.nii.ac.jp/pi/n5/5_65.pdf
2. García, S., Uhlíř, V., & Rehák, M. (2014). Identifying and Modeling Botnet C&C Behaviors. In *Proceedings of the 1st International Workshop on Agents and CyberSecurity* (pp. 1–8). ACM. https://doi.org/10.1145/2602945.2602949
3. Stiborek, J., Pevný, T., & Rehák, M. (2018). Multiple Instance Learning for Malware Classification. *Expert Systems with Applications*, *93*, 346–357. https://doi.org/10.1016/j.eswa.2017.10.036
4. García, S., Grill, M., Stiborek, J., & Zunino, A. (2014). An Empirical Comparison of Botnet Detection Methods. *Computers & Security*, *45*, 100–123. https://doi.org/10.1016/j.cose.2014.05.011

Libor Peltan

The scientist represents within the Czech cyber ecosystem the more infrastructural-network line associated with CZ.NIC, DNS/DNSSEC, and the standardisation of basic internet technologies. In his case, the most significant results are expressed not so much in classical journal articles as in standards-track RFCs, IETF drafts, and engineering documents, which is typical of the field of DNS infrastructure. For the characterisation of the Czech direction, this is important because it shows that, in the Czech Republic, cybersecurity develops not only at the level of SOC, malware analysis, and cyber ranges, but also as a contribution to the fundamental resilience of internet infrastructure. Through the figure of Peltan, one can clearly see the transition from a national operator of the internet environment to a fully-fledged participant in the international standardisation of DNS.

Leading works:

1. van Dijk, P., Peltan, L., Surý, O., Toorop, W., Monshouwer, C. R., Thomassen, P., & Sargsyan, A. (2023). *DNS Catalog Zones*. RFC 9432. RFC Editor. https://doi.org/10.17487/RFC9432
2. van Dijk, P., Peltan, L., Surý, O., Toorop, W., & Vandewoestijne, L. (2020). *DNS Catalog Zones*. Internet-Draft draft-ietf-dnsop-dns-catalog-zones-00. IETF.
3. Peltan, L. (2023, July 25). *RFC 9432: DNS Catalog Zones*. CZ.NIC Blog.

4. Peltan, L. (2025, October 7). *DNSSEC Validation as Part of Signing Pipeline*. DNS-OARC 45 presentation.

If one looks at the figures of this field as a whole, several stable lines of development are clearly distinguishable in the Czech Republic: the university school of cyber training and cyber ranges (Čeleda, Vykopal), the research line of network analytics and forecasting (Husák), the applied line of AI/ML for network and malware security (Rehák), and the infrastructural-network line of DNS/DNSSEC and internet standardisation (Peltan). Taken together, they show that Czech cybersecurity is strong not because of one fashionable theme, but precisely because of its systemic completeness: from educational platforms and incident triage to network monitoring, malware behaviour, DNS engineering, and international standards.

Part 6

Automotive Engineering and Industry 4.0

General Characterisation

Automotive engineering and Industry 4.0 in the contemporary Czech Republic do not form two independent narratives, but a single technological field in which a historically strong production base was gradually saturated with digital, robotised, and data-driven solutions. It is precisely in this way that this field should be understood at the present stage. The Czech Republic does not simply preserve the automotive industry as a major sector of the economy; it is consistently transforming it into a space of engineering development, testing, automation, software-hardware integration, and industrial digitalisation. Therefore, automotive engineering in the Czech case is no longer only the design of vehicles and the manufacture of components, but a much broader system including R&D centres, technical universities, testing and simulation capacities, robotised lines, digital twins, Industry 4.0 standards, and complex supply chains. From this follows the principal feature of the Czech model: it is not built around one automotive brand or one technological platform, but develops as a production-engineering ecosystem in which major OEMs, first-tier suppliers, software-engineering teams, and research organisations act in an interconnected manner. It is precisely this that makes the field one of the most system-forming for the contemporary technical science of the Czech Republic.

The first defining feature of the field is the extremely high weight of the automotive sector in the country's industrial structure. According to AutoSAP, in 2024 the Czech Republic produced 1,452,881 passenger vehicles, while more than 93% of output was directed to external markets; in the sector, according to the same association, around 140,874 people are employed in member companies, and the average wage in the sector significantly exceeds the average level in other industries. These figures are important not merely as industrial statistics. They show that, in the Czech Republic, automotive engineering has a critical mass sufficient for the constant reproduction of engineering competences, demand for applied research, and long technological chains. The OECD, in its 2025 review, also states directly that integration into global value chains, especially downstream activities in the automotive sector, was one of the principal drivers of productivity growth in the pre-crisis period. Consequently, the contemporary development of automotive engineering in the Czech Republic rests not on a narrow niche, but on a very deep industrial base that generates constant demand for design, digital, materials-science, and production innovations.

The second important feature of the field is the transition from the model of a "production country" to the model of a country of automotive R&D. CzechInvest directly emphasises that the Czech Republic is a very competitive location for establishing R&D facilities, while local technical universities are accustomed to cooperating with global OEMs and suppliers in the field of research, development, and testing. The same official material names Volkswagen, Robert Bosch, Valeo, ZF Engineering, and Honeywell as companies that have located their global centres of excellence here and employ thousands of qualified engineers. An additional CzechInvest page on mobility specifies that the Czech mobility sector concentrates more than 5,000 R&D workers, around 20% of all private investment in research and development, while the private sector annually invests more than 12 billion Czech crowns in research and development in this field. This means that contemporary automotive engineering in the Czech Republic has long since moved beyond the traditional notion of assembly production. It is constructed as a sector in which design, testing, validation, software integration, lighting systems, drivetrain solutions, industrial electronics, and other engineering subsystems form an independent layer of research activity. It is precisely for this reason that the automotive field in the Czech Republic should be described as an R&D-intensive branch of industrial engineering, and not as an industry of mass assembly.

The third characteristic is connected with the fact that Czech automotive engineering does not exist in isolation, but as part of the broader logic of industrial digital transformation, fixed in the national Industry 4.0 initiative. The Ministry of Industry and Trade states that the government approved the Initiative Industry 4.0 in August 2016, while the document itself includes measures relating to investment, standardisation, applied research, cybersecurity, logistics, and standardisation. This is of fundamental importance for the characterisation of the field. In the Czech case, Industry 4.0 was not added to the automotive sector as a fashionable digital term. It became a way of rethinking the entire engineering logic of industry—from the organisation of production flow to the design of supply chains and requirements for personnel. Therefore, automotive engineering and Industry 4.0 in the Czech Republic develop as mutually reinforcing elements: the automotive sector provides real scale and applied demand, while Industry 4.0 provides the conceptual and technological framework for the transition from classical mechanical engineering to cyber-physical production systems. As a result, contemporary Czech automotive engineering is increasingly defined not only by mechanics and materials, but also by data, automation, machine integration, flexible logistics, and digital production management.

The fourth feature of the field is its pronounced systemic linkage with technical universities and engineering education. CzechInvest directly notes that nine technical universities and more than 25,000 students participate in the Czech mobility sector, while the universities themselves are used by international companies as partners in development, testing, and engineering services. This is important for several reasons. First, the field receives sustainable personnel support. Second, universities act not only as educational institutions, but also as a link in the R&D chain: places where laboratories, testing sites, joint projects, and engineering teams are formed. Third, it is precisely through university-industry interaction that Industry 4.0 in the Czech Republic acquires a practical rather than a declarative character. In other words, digital transformation and automotive engineering are connected not only at the level of factories, but also at the level of specialist training, prototype development, and the testing of materials and control algorithms. This makes the field more resilient than it would be if it depended only on corporate investment without an educational and research base.

The fifth characteristic feature is the extremely deep embeddedness of the field in export-oriented European value chains. AutoSAP records that more than 93% of passenger cars produced in the Czech Republic in 2024 were exported. The OECD in 2025 separately warns that any shocks in the German automotive sector may have direct consequences for Czech car manufacturing, while in the Economic Outlook 2025 it indicates that external trade uncertainty and restrictions affect investment and exports especially strongly precisely through automotive supply chains. On the one hand, this integration is the greatest strength of the Czech model: it provides market scale, technological standards, major demand for components, and constant inclusion of the country in transnational engineering processes. On the other hand, it shows that the general characterisation of the field must also take into account a high degree of external dependence. Czech automotive engineering develops under conditions in which decisions on platform, standards, supplies, and demand are often taken outside the country. Therefore, indigenous centres of engineering competence and indigenous digital production capacities are of great importance here: it is precisely they that enable the Czech Republic to be not only a productive appendage of the chain, but also its intellectual and engineering participant.

The sixth feature of the field is its strongly private-investment character. The CzechInvest page on the mobility sector emphasises that around 20% of all private R&D investments in the Czech Republic are concentrated precisely here. This makes automotive engineering and Industry 4.0 one of the principal zones in which business not merely uses ready-made technologies, but itself finances research development. For the contemporary Czech Republic, this is especially indicative, because in the previous sections it was already evident that the whole national model of the technical sciences gravitates towards strong business R&D. In the automotive sphere, this is manifested in the most concentrated form. Here applied research, experimental development, validation engineering, automation, and process optimisation become an everyday part of the activity of companies, and not an exception. It is precisely for this reason that this field cannot be described only as the "sphere of transport technologies". It is one of the central arenas in which the Czech model of applied engineering as a whole is formed. Through it one can see especially clearly how knowledge is transformed into products, components, lines, algorithms, and standardised industrial solutions.

The seventh important feature is the high sensitivity of the field to technological transition, above all to electromobility, digital production platforms, and new regulatory regimes. AutoSAP, in its priorities for the period 2024–2029, states directly that its key objective is to preserve the Czech Republic as an attractive place for innovation and the development of new business opportunities, that is, the sector itself is aware that it has entered a phase of structural shift. At the level of general characterisation, this means that automotive engineering and Industry 4.0 in the Czech Republic are not in a static state of maturity, but in a state of constant adaptation. Unlike the era when competitiveness depended chiefly on the quality of mechanical production and labour costs, today it is increasingly determined by flexibility in the sphere of software-defined functions, industrial data, automation, supply-chain resilience, energy efficiency, and the ability rapidly to reconfigure production. Therefore, the contemporary field should be understood as a transitional, yet already highly organised, system in which the traditional mechanical-engineering core is gradually being reformatted to meet the requirements of Europe's digital and ecological transformation.

The eighth and perhaps most generalising characteristic lies in the fact that automotive engineering and Industry 4.0 in the Czech Republic represent an exemplary field of the merger of classical industrial competence and new digital modes of production. The automotive sector gives the country scale, discipline, demand for engineering personnel, and embeddedness in global chains. Industry 4.0 gives the conceptual framework for the transition to smart factories, digital data, cybersecurity, robotised logistics, and applied research. Together they form not merely an industry, but one of the principal supports of contemporary Czech technical science. It is precisely here that the difference between the Czech Republic and those countries where digitalisation develops predominantly in service and platform sectors is especially clear. The Czech model remains deeply industrial, but it is precisely for this reason that digital modernisation acquires within it an especially practical and engineering-rich character. As a result, this field may be defined as the central segment of Czech production-engineering modernisation, in which the historical strength of mechanical engineering is combined with the contemporary principles of Industry 4.0.

Achievements

The principal achievement of the Czech Republic in the field of automotive engineering and Industry 4.0 lies in the fact that the country has succeeded in transforming a traditionally strong manufacturing sector into a technologically intensive, research-supported, and digitally transformable system, rather than remaining merely a site of large-scale serial assembly. This achievement is especially visible precisely in the historical perspective of 1993–2025. If, in the first post-socialist decades, the Czech Republic was above all preserving its industrial base and integrating itself into European value chains, then by the 2020s it had already emerged as one of the key automotive powers of Europe, with a developed engineering, supply, and digital infrastructure. Therefore, the achievements of this field must be considered not only through output volumes, but also through the transition to a more complex model in which production, research and development, robotisation, digital twins, testing, and industrial analytics mutually reinforce one another. It is precisely this that distinguishes contemporary Czech automotive engineering from the earlier phase of its development.

The first and most obvious achievement is the preservation and expansion of production scale at the level of one of Europe’s leading automotive sites, despite supply-chain crises, energy fluctuations, and technological transition. AutoSAP records that, in 2025, 1,445,776 passenger cars were produced in the Czech Republic, which was only 0.5% below the record level of 2024 and remained the second-best result in history; more than 92.5% of the cars produced were directed to export markets. In 2024, for its part, the country reached a record output of 1,452,881 passenger cars, while exports exceeded 1.35 million units. This achievement is important not only as an indicator of scale. It shows that the Czech engineering and production system was able to withstand the simultaneous pressure of several factors: the transition to electrification, changes in demand on European markets, rising energy costs, and the need to renew model ranges. Under such conditions, maintaining output at the level of 1.4 million cars is already not simply industrial inertia, but the result of the high technological and organisational adaptability of the sector. Therefore, the first achievement should be defined as the maintenance of the Czech automotive industry at the level of a pan-European production core even during a phase of structural transition.

The second major achievement is the transition from manufacturing specialisation to a dense engineering and research ecosystem of automotive R&D. CzechInvest states directly that the Czech Republic has become a very competitive location for establishing R&D facilities, while companies such as Volkswagen, Robert Bosch, Valeo, ZF Engineering, and Honeywell have placed their global centres of excellence here and employ thousands of qualified engineers. On the more general mobility-sector page, the same institution notes that more than 5,000 R&D workers are employed in this sphere, that it accounts for around 20% of all private investment in research and development in the country, and that the private sector invests more than 12 billion Czech crowns annually in mobility R&D. For the contemporary Czech Republic, this is a fundamental result. It means that the automotive sector no longer functions as the manufacturing “end” of an international chain, but includes a substantial layer of design, testing, software-engineering, and research functions. In other words, the country has managed to transform automotive production into an automotive engineering ecosystem. This is one of the most important signs of the technological maturation of the sector.

The third achievement is the institutional shaping of Industry 4.0 as a state framework for industrial transformation. The Ministry of Industry and Trade emphasises that the Initiative Industry 4.0 was approved by the government in August 2016 and included measures in the areas of investment, applied research, standardisation, logistics, cybersecurity, and regulation. The significance of this step lies not only in the appearance of yet another strategic document. The Czech Republic was one of the first countries in Central Europe to construct industrial digitalisation as an integral state programme directly linked to the real sectors of the economy, above all mechanical engineering, automation, and automotive value chains. This was especially important for automotive engineering, because it is precisely this field that is most sensitive to changes in production architectures, human-machine interaction, data traceability, robotisation, and the flexibility of supply chains. Thus, the third achievement of the Czech Republic lies in the fact that it did not wait for the spontaneous digitalisation of industry, but created an institutional framework for its acceleration and coordination.

The fourth achievement was the creation of the Testbed for Industry 4.0 at CIIRC CTU as the largest experimental site of this kind in Central and Eastern Europe. The official description of the testbed states that it is a unique research and experimental environment for testing innovative solutions and processes for smart factories, and that it makes it possible to verify Industry 4.0 processes prior to their introduction into real-world manufacturing. The significance of this facility for the Czech Republic is difficult to overestimate. It gave the country not merely a demonstration centre, but a fully-fledged experimental infrastructure in which digital production, flexible robotisation, augmented and virtual reality, intelligent logistics, production data, and the integration of software-hardware systems can be modelled and tested. For the automotive sector, where the cost of error in the introduction of new production regimes is exceptionally high, such testbed sites are especially valuable. They make it possible to transfer part of the engineering risk from the real factory into a controlled experimental environment. Therefore, the fourth achievement should be understood as the creation of a national laboratory of industrial digitalisation working for the real manufacturing sector.

The fifth achievement is the development of the international distributed infrastructure of RICAIP, which raised Czech industrial engineering and Industry 4.0 to the level of a Central European centre of excellence. RICAIP officially defines itself as an international distributed research centre of excellence founded on the partnership of two Czech and two German institutes and oriented towards intelligent and secure solutions for distributed manufacturing in the Industry 4.0 environment. In its annual report for 2022, the centre emphasises the development of research infrastructure for testing and validating advanced manufacturing technologies, including artificial intelligence, robotics, and cyber-physical systems, while the 2023 report already states that the testbeds in Prague and Brno are fully operational and that the focus has shifted to distributed production demonstrators. This means that the Czech Republic achieved not only the internal institutionalisation of Industry 4.0, but also the international verification of its technological course. Thanks to RICAIP, the country became not merely a user of German or pan-European solutions, but one of the site-centres where such solutions are developed, tested, and demonstrated. Consequently, the fifth achievement is the transformation of the Czech Republic into a cross-border experimental node of advanced industrial production and distributed manufacturing.

The sixth achievement is connected with the formation of a practical ecosystem for the implementation of Industry 4.0, and not only its research or demonstration base. In materials from 2023–2024, CIIRC shows that, around the National Centre for Industry 4.0 and its partners, a platform has been formed in which KUKA, Siemens, T-Mobile, DEL, Deprag, Smart Informatics, and financial and industrial partners jointly demonstrate and discuss concrete smart solutions, consultations, and workshops for companies. In practice, this means that Industry 4.0 in the Czech Republic has moved beyond laboratories and strategies and has begun to operate as a channel for the dissemination of know-how across the real sector. For an economy in which manufacturing companies and complex supply chains predominate, such a service-and-implementation function is fundamental. Without it, digitalisation remains the concern of individual large players. With it, however, a mechanism emerges that allows medium-sized and smaller companies to assess their digital maturity, test solutions, and gradually enter the new technological regime. Therefore, the sixth achievement may be defined as the creation of an organisational environment for the practical dissemination of Industry 4.0 approaches across the Czech industrial fabric.

The seventh important achievement is the advancement of electrification as an engineering and manufacturing transition, and not merely as a market trend. AutoSAP shows that, during 2025, the share of electric and plug-in vehicles in Czech production grew noticeably: already by the end of the first ten months of 2025, 235,207 electric vehicles had been produced in the country, while their share in passenger-car production had reached 19.4%. In individual production nodes, the transformation proceeded even more rapidly: by the end of 2025, Hyundai in Nošovice was producing electrified vehicles with a share of 23.8% in its national production, while Toyota announced the launch of a new battery electric vehicle in Kolín. Even if the transition has not yet been completed and is accompanied by high costs, the very fact of such a shift is already an important achievement. It shows that the Czech sector is not merely defending legacy production, but is beginning to restructure its model and technological contour for the new generation of transport. For automotive engineering, this means the expansion of competences in power electronics, thermal management, battery integration, new assembly logic, and the digital control of production. Therefore, the seventh achievement of the Czech Republic is the entry of the automotive sector into a phase of real industrial electrification, fixed in production figures and investment decisions.

The eighth achievement lies in the fact that automotive engineering and Industry 4.0 in the Czech Republic have succeeded in becoming the synthetic core of the whole production-technological modernisation of the country. This is already a conclusion of a higher order, but it rests on the totality of facts: on the scale of output, on the concentration of private R&D, on the participation of nine technical universities and more than 25,000 students in the mobility ecosystem, on the operation of the region's largest testbed, on the international infrastructure of RICAIP, and on accelerating electrification. As a result, it was precisely the automotive sector that became the field in which the general Czech model of applied engineering manifested itself most clearly: a strong production base, a close connection with research and development, active digitalisation, cooperation between universities and companies, as well as integration into European technological and market processes. Therefore, the contemporary Czech Republic may quite justifiably be described as a country in which automotive engineering and Industry 4.0 have formed the principal laboratory of national industrial transformation.

Leading Figures and Their Publications

In Czech automotive engineering and Industry 4.0 today, seven figures are especially prominent, representing different yet interconnected lines of development within the field. Vladimír Mařík, Pavel Vrba, Pavel Burget, and Zdeněk Hanzálek embody the Czech school of industrial cybernetics, intelligent manufacturing, robotic cells, industrial communication, and digital factories. Jan Macek, Oldřich Vítek, and Josef Morkus represent the specifically automotive engineering line—internal combustion engines, 0D/1D and 3D CFD modelling, powertrain engineering, electrification, and sustainable mobility. Taken together, they show that the Czech model in this area is built not around a single discipline, but around the deep integration of mechanical engineering, digital control, industrial communication, simulation, and sustainable mobility.

Vladimír Mařík

The scientist is a central figure in the Czech line of Industry 4.0, industrial cybernetics, and intelligent manufacturing. His role is important not only because of the large number of publications, but also because it was precisely through him that the agenda of smart manufacturing, multi-agent systems, and digital industrial transformation was institutionally shaped in the Czech Republic. In the Czech context, Mařík is not simply a scholar in the field of AI, but one of the architects of the very logic of the transition from traditional mechanical engineering to intelligent factory systems. His figure is especially important for the section on automotive engineering and Industry 4.0 because it is precisely, who helps to connect applied cybernetics with real production chains, robotic lines, and distributed production control.

Leading works:

1. Pěchouček, M., & Mařík, V. (2008). Industrial deployment of multi-agent technologies: Review and selected case studies. *Autonomous Agents and Multi-Agent Systems*, *17*(3), 397–431. https://doi.org/10.1007/s10458-008-9050-0
2. Mařík, V., Vrba, P., Hall, K. H., & Maturana, F. P. (2005). Rockwell Automation agents for manufacturing. In *Proceedings of the 4th International Joint Conference on Autonomous Agents and Multiagent Systems* (pp. 107–113). ACM. https://doi.org/10.1145/1082473.1082812
3. Mařík, V., Vrba, P., & Leitão, P. (Eds.). (2011). Holonic and Multi-Agent Systems for Manufacturing. In *HoloMAS 2011 Proceedings*. Springer. https://doi.org/10.1007/978-3-642-23181-0
4. Camarinha-Matos, L. M., Afsarmanesh, H., & Mařík, V. (Eds.). (1998). *Intelligent Systems for Manufacturing*. Springer.

Pavel Vrba

The scientist is one of the key figures of the Czech school of agent-based manufacturing control, semantic manufacturing systems, and distributed industrial intelligence. His publications are especially important because they show the transition from the theory of multi-agent systems to real applications in manufacturing, including reconfigurable manufacturing and industrial control. In the contemporary Czech Republic, Vrba stands at the intersection of academic industrial informatics and the practical digitalisation of production systems. For the theme of Industry 4.0, he is especially significant as a researcher who developed the language of distributed, semantically enriched, and service-oriented production control.

Leading works:

1. Vrba, P., Radakovič, M., Obitko, M., & Mařík, V. (2011). Semantic technologies: Latest advances in agent-based manufacturing control systems. *International Journal of Production Research*, *49*(5), 1483–1496. https://doi.org/10.1080/00207543.2010.518746
2. Vrba, P., Mařík, V., Siano, P., Leitão, P., Zhabelova, G., Vyatkin, V., Cecati, C., & Strasser, T. (2014). A review of agent and service-oriented concepts applied to intelligent energy systems. *IEEE Transactions on Industrial Informatics*, *10*(3), 1890–1903. https://bibliotecadigital.ipb.pt/bitstreams/df320f1d-e913-46ea-958e-cf0de0e2fb40/download
3. Vrba, P., & Mařík, V. (2005). Simulation in agent-based control systems: MAST case study. *IFAC Proceedings Volumes*, *38*(1), 74–79. https://doi.org/10.3182/20050703-6-CZ-1902.01508
4. Hall, K. H., Staron, R. J., & Vrba, P. (2005). Experience with Holonic and Agent-Based Control Systems and Their Adoption by Industry. In *Holonic and Multi-Agent Systems for Manufacturing* (pp. 1–10). Springer. https://doi.org/10.1007/11537847_1

Pavel Burget

The scientist represents a newer phase of Czech applied Industry 4.0 engineering, closely associated with the Testbed for Industry 4.0, RICAIP, and the optimisation of robotic manufacturing cells. The official profile of the Testbed at CIIRC states directly that he has headed this infrastructure since 2016, and that his research interests include industrial communication and control systems, the optimisation of robotic manufacturing cells, and discrete event systems. His significance for the contemporary Czech Republic lies in the fact that he works not only within a scientific logic, but also within the logic of testbed-based transfer, that is, in a space where algorithms and optimisation are verified on real or quasi-real industrial configurations.

Leading works:

1. Bukata, L., Šůcha, P., Hanzálek, Z., & Burget, P. (2017). Energy Optimization of Robotic Cells. *IEEE Transactions on Industrial Informatics*, *13*(1), 92–102. https://doi.org/10.1109/TII.2016.2626472
2. Burde, V., Martinez Lema, D. S., Zeman, V., Kahlert, L., Jochman, T., & Burget, P. (2023). Automatic Workspace Calibration Using Homography for Pick and Place. In *2023 IEEE 19th International Conference on Automation Science and Engineering* (CASE). https://doi.org/10.1109/CASE56687.2023.10260601
3. Hradecky, P., Janu, V., Burget, P., Jochman, T., & Becker, T. (2023). Description and Evaluation of Production Goals. *IFAC-PapersOnLine*, *56*(2), 2982–2988. https://doi.org/10.1016/j.ifacol.2023.10.1423
4. Hanzálek, Z., Burget, P., & Šůcha, P. (2009). Profinet IO IRT Message Scheduling. In *21st Euromicro Conference on Real-Time Systems*. IEEE. https://doi.org/10.1109/ECRTS.2009.18

Zdeněk Hanzálek

The scientist is one of the most prominent Czech specialists in real-time scheduling, industrial communication, and manufacturing-systems scheduling, that is, in those areas that are critical for Industry 4.0 and for contemporary automotive electronics and industrial automation. His personal page directly identifies him as an internationally recognised expert in scheduling for computer and manufacturing systems. For the Czech context, this is especially important, because Industry 4.0 requires not only robots and data, but also highly reliable synchronisation of computation, network exchange, and technological operations. It is precisely in this zone that Hanzálek's work is especially representative.

Leading works:

1. Hanzálek, Z., Burget, P., & Šůcha, P. (2009). Profinet IO IRT Message Scheduling. In *21st Euromicro Conference on Real-Time Systems*. IEEE. https://doi.org/10.1109/ECRTS.2009.18
2. Minaeva, A., Akesson, B., Hanzálek, Z., & Dasari, D. (2018). Time-Triggered Co-Scheduling of Computation and Communication with Jitter Requirements. *IEEE Transactions on Computers*, *67*(1), 115–129. https://dl.acm.org/doi/abs/10.1109/TC.2017.2722443
3. Bukata, L., Šůcha, P., Hanzálek, Z., & Burget, P. (2017). Energy Optimization of Robotic Cells. *IEEE Transactions on Industrial Informatics*, *13*(1), 92–102. https://doi.org/10.1109/TII.2016.2626472
4. Hanzálek, Z., & Jurčík, P. (2010). Energy Efficient Scheduling for Cluster-tree Wireless Sensor Networks with Time-Bounded Data Flows: Application to IEEE 802.15.4/ZigBee. *IEEE Transactions on Industrial Informatics*, *6*(3), 438–450. https://doi.org/10.1109/TII.2010.2050144

Jan Macek

The scientist is one of the key figures of contemporary Czech automotive engineering, engine engineering, and powertrain research. On the page of the National Centres of Competence of the CTU Faculty of Mechanical Engineering, he is listed as a solver of the Josef Božek Centre of Vehicles for Sustainable Mobility, while the publication and project environment around him shows a stable linkage among classic engine engineering, simulation, sustainable mobility, and vehicle electrification. Unlike researchers of the purely digital line, Macek represents the thermo-mechanical core of the Czech automotive school, which in the 2000s and 2010s was gradually extended towards hybrid and electric platforms. For the contemporary Czech Republic, his figure is important because through it one can see that automotive engineering in the country continues to remain a strong scientific field rather than dissolving completely into software-driven mobility.

Leading works:

1. Macek, J., Vítek, O., Srinivasan, S., & Tanner, F. X. (2008). 1-D Modeling of Transient Engine Operations Using Data Generated by a CFD Code. *SAE Technical Paper*, 2008-01-0357. https://doi.org/10.4271/2008-01-0357
2. Vítek, O., Macek, J., Poetsch, C., & Tatschl, R. (2016). Knowledge Transfer from Detailed 3-D CFD Codes to System Simulation Tools — CCV Modeling in SI Engine. MECCA Journal of Middle European Construction and Design of Cars, 14(1). https://doi.org/10.1515/mecdc-2016-0002
3. Vítek, O., Macek, J., Doleček, V., Syrovátka, Z., Pavlovic, Z., Priesching, P., & Tap, F. (2021). Application of Advanced Combustion Models in Internal Combustion Engines Based on 3-D CFD LES Approach. *Acta Polytechnica*, *61*(SI), 14–32. https://doi.org/10.14311/AP.2021.61.0014

4. Macek, J., & Morkus, J. (2017). Optimum Limits of Motor Vehicle Driving. In *XLVIIIth Conference of Czech and Slovak Combustion Engine Research* (pp. 111–124). Technical University of Liberec. https://kniholib.cz/arl-li/en/detail-li_us_cat-0666990-Optimum-limits-of-motor-vehicle-driving/

Oldřich Vítek

The scientist represents the strongest contemporary Czech line in the numerical modelling of internal combustion engines, combustion modelling, cycle-to-cycle variability, and simulation-based engine development. His name is especially important in connection with projects at CTU Prague, where the classical engine school was combined with advanced CFD and system simulation approaches. Within contemporary Czech automotive engineering, it is precisely through Vítek that one can clearly see how the field is moving away from purely empirical calibration towards a physics-based, data-enhanced, and multi-scale simulation model. This makes him one of the key figures not only in the theme of engines, but also in the broader transition of Czech automotive engineering to a digitally enriched engineering workflow.

Leading works:

1. Vítek, O., Macek, J., Poetsch, C., & Tatschl, R. (2016). Knowledge Transfer from Detailed 3-D CFD Codes to System Simulation Tools — CCV Modeling in SI Engine. *MECCA Journal of Middle European Construction and Design of Cars*, *14*(1). https://doi.org/10.1515/mecdc-2016-0002
2. Vítek, O., Macek, J., Doleček, V., Syrovátka, Z., Pavlovic, Z., Priesching, P., & Tap, F. (2021). Application of Advanced Combustion Models in Internal Combustion Engines Based on 3-D CFD LES Approach. *Acta Polytechnica*, *61*(SI), 14–32. https://doi.org/10.14311/AP.2021.61.0014
3. Hatschbach, P., Vítek, O., & Tichánek, R. (2021). In-Cylinder Flow Characterization Using Vorticity Based Parameters. *MECCA Journal of Middle European Construction and Design of Cars*, *19*(1), 31–42. https://doi.org/10.14311/mecdc.2021.01.03
4. Macek, J., Vítek, O., Srinivasan, S., & Tanner, F. X. (2008). 1-D Modeling of Transient Engine Operations Using Data Generated by a CFD Code. *SAE Technical Paper*, 2008-01-0357. https://doi.org/10.4271/2008-01-0357

Josef Morkus

The scientist is one of the notable figures in the Czech line of electromobility, hybrid drivetrains, and sustainable vehicle mobility, associated with CTU Prague and the Josef Božek Centre. His significance lies in the fact that he represents not classical engine engineering as such, but the transitional zone between conventional automotive engineering and electrified mobility. Through his publications and engineering developments, one can clearly see how the Czech automotive school entered the discussion of hybridisation, the energy consumption of electric buses, and broader vehicle electrification. For the contemporary Czech Republic, this is especially important, because it is precisely such researchers who ensure continuity between traditional automotive know-how and new mobility.

Leading works:

1. Sivkov, O., Novak, J., Musalek, L., Morkus, J., & Novak, M. (2020). Drivetrain Modelling and Parameter Calculation for an Electric Bus with Fixed or 2-Speed Gearbox.

International Journal of Electric and Hybrid Vehicles, *12*(3), 229–252. https://doi.org/10.1504/IJEHV.2020.110088

2. Novak, M., Novak, J., Morkus, J., & Sivkov, O. (2019). Energy Consumption Calculation of an Electric Bus with a Variable or Fixed Gearbox. In *IECON 2019 – 45th Annual Conference of the IEEE Industrial Electronics Society* (pp. 2670–2675). IEEE. https://doi.org/10.1109/IECON.2019.8926683
3. Morkus, J. (2016). Trends in the Development of Hybrid Drives. *MECCA Journal of Middle European Construction and Design of Cars*, *14*(2). https://doi.org/10.1515/mecdc-2016-0006
4. Macek, J., & Morkus, J. (2017). Optimum Limits of Motor Vehicle Driving. In *XLVIIIth Conference of Czech and Slovak Combustion Engine Research* (pp. 111–124). Technical University of Liberec. https://kniholib.cz/arl-li/en/detail-li_us_cat-0666990-Optimum-limits-of-motor-vehicle-driving/

If these names are considered together, the internal balance between two lines of development is clearly visible in Czech automotive engineering and Industry 4.0. The first is the digital-industrial line running through Mařík, Vrba, Burget, and Hanzálek: smart factories, agent systems, robotic cells, scheduling, industrial communication, and distributed manufacturing. The second is the automotive-engineering line represented by Macek, Vítek, and Morkus: engines, powertrains, simulation-based development, hybridisation, and transport electrification. It is precisely the combination of these two lines that creates the contemporary Czech profile of this field: not simply a strong automotive industry and not simply an abstract Industry 4.0, but an engineering-intensive system in which the digital factory and transport technology develop as parts of one technological whole.

Part 7

Aircraft Manufacturing

General Characterisation

Aircraft manufacturing in the contemporary Czech Republic represents not a peripheral segment of mechanical engineering, but one of the most integrated and technologically intensive branches of national industry. Its significance is determined not only by historical tradition, but also by the fact that the country still retains a capability that is rare for a medium-sized European state: the ability to cover almost the entire production contour of aviation technology—from aircraft and engine design to testing, certification, maintenance, and flight training. According to CzechInvest materials, more than 120 specialised companies are active in the Czech aerospace sector and more than 21,000 specialists are employed there, which in itself already indicates the existence of a sustainable sectoral ecosystem rather than a few isolated factories. CzechTrade, for its part, directly emphasises that the Czech Republic is among the few countries capable of producing an aircraft entirely on its own territory, and at the same time belongs to the very narrow circle of states able to develop and manufacture aviation engines. This combination is especially important, because it is precisely what distinguishes a technologically autonomous aviation country from a jurisdiction embedded only in the assembly or outsourcing of individual components. In the Czech case, the aviation sector combines military and civil lines, light aviation and more complex programmes, manned platforms and unmanned systems, serial production and experimental design activity. Therefore, aircraft manufacturing here should be understood as a strategic high-technology specialisation serving exports, defence resilience, engineering employment, and international cooperation at the same time. Already at this level, it is clear that the contemporary Czech model is not built around a single “national corporation”, but rests on a distributed network of manufacturers, research centres, educational institutes, regulatory bodies, and specialised clusters.

After the dissolution of Czechoslovakia in 1993, Czech aircraft manufacturing did not disappear, but passed through a profound structural recomposition. Its basis lay not so much in mass post-socialist privatisation as such, but in the ability of individual enterprises and engineering schools to preserve their technological core and then embed themselves in new export and certification regimes. It is characteristic that the largest players in the sector rely on very long production memories: in 2024, AERO Vodochody marked one hundred years since the beginning of production of the Aero A-22 aircraft, Aircraft Industries emphasises more than 80 years of aviation activity, and Evektor states that it was founded in 1991 and had already begun aircraft design in 1992. These lines are important not merely as the marketing biographies of companies, but as indicators that continuity of design culture, production discipline, and sectoral self-awareness has been preserved in the Czech Republic. However, the contemporary sector is organised differently from the late-socialist period: it is far more export-oriented, more dependent on international certification, more deeply integrated into global supply chains, and more widely distributed among specialised niches. In other words, after 1993 Czech aircraft manufacturing preserved its identity not through the reproduction of the old industrial model, but through a transition to a more flexible, multi-nodal, and market-adapted architecture. Within it, some companies retained the role of OEM manufacturers of complete aircraft, others became high-precision suppliers of units and systems, and still others became testing and research organisations. Therefore, the historical resilience of the sector in the Czech Republic is explained not by the scale of the domestic market, which is objectively limited, but by the depth of engineering specialisation and the ability constantly to translate accumulated competence into new organisational forms.

The contemporary sectoral structure of Czech aircraft manufacturing is especially clearly visible through the diversity of end platforms. CzechTrade identifies as the first basic segment the manufacture of complete aircraft: aircraft for local and regional transport, training and light combat aircraft, sporting and agricultural machines, ultralight aircraft, and gliders. In this group, the Czech Republic is simultaneously present in several market niches, which in itself increases the resilience of the sector. AERO Vodochody remains the country's largest aircraft manufacturer and develops a line of its own military and training platforms; in 2024 the company continued the roll-out of the L-39NG programme, renamed L-39 Skyfox, and also expanded deliveries to foreign customers and to the Czech state pilot-training system. Aircraft Industries, for its part, concentrates on the transport and regional niche around the L 410 family: the enterprise reports that, since 1969, more than 1,200 such aircraft have been produced, and almost one third of them are still operated in more than 60 countries worldwide. The light-aviation line is represented, among others, by ZLIN AERO and Evektor, where competences in training, sporting, and light-aircraft platforms, as well as in aircraft design for the international small-aviation market, are especially visible. It is also important that the ultralight category is strong in the Czech Republic, and sectoral materials describe it as one of the most dynamic forms of national aviation development. As a result, the sector does not close itself within one product type, but combines trainer-combat aircraft, regional turboprop machines, light aircraft, ultralights, and the increasingly visible UAV segment. It is precisely this multi-segment character that makes Czech aircraft manufacturing more adaptable to fluctuations in world demand than a model based only on one major serial product.

No less important is the second line of the sector—the production of components, subsystems, and large assemblies for world aviation programmes. CzechTrade directly states that Czech companies supply components for Airbus, Boeing, Embraer, Bombardier, Sikorsky, CASA, and Eurofighter, that is, they participate not only in their own national programmes, but also in international industrial cooperation at the highest level. This means that a significant part of Czech value in aviation is created not in the form of producing a fully national aircraft, but in the form of integration into global production chains as a reliable supplier of high-precision and certified products. A good example here is AERO Vodochody: in its annual report for 2024, the company reports a substantial expansion of cooperation with Embraer on the C-390 Millennium transport aircraft programme and with Airbus on the manufacture of wing leading edges for the A220. Such a profile is especially characteristic of countries with a strong engineering school and comparatively limited domestic demand: they develop their own flagship platforms, but at the same time strengthen their positions as industrial partners of global OEMs. For the Czech Republic, this is strategically advantageous because it diversifies risk, opens access to international quality standards, and creates demand for precision mechanics, composites, avionics, and digital production support. At the same time, such a model requires the constant updating of certification practices, equipment, software infrastructure, and supply-chain management competences. Therefore, contemporary Czech aircraft manufacturing should be characterised not simply as “aircraft production”, but as a complex set of interconnected competences in which the manufacture of end platforms coexists with deep subcontracting and tier-supplier specialisation. In this sense, the sector increasingly operates according to the logic of networked manufacturing rather than that of a classically isolated national factory.

A special place in the Czech aviation ecosystem is occupied by engine building and the manufacture of specialised aviation systems. For assessing the sector, this is of fundamental importance, because the ability to develop an engine, power unit, APU, or environmental control system constitutes a higher level of industrial maturity than aircraft assembly alone. CzechTrade emphasises that the Czech Republic belongs to the elite circle of states able to develop and manufacture aviation engines; PBS Velká Bíteš and GE Aviation Czech are named there as the key actors. PBS states on its official resource that it develops and manufactures turbine engines, APUs, and ECS for aviation-equipment manufacturers from more than 40 countries worldwide and possesses EASA type certifications DOA, POA, and MOA. GE Aviation Czech, for its part, defines itself as the country’s largest centre for the design and manufacture of turboprop engines, while GE materials on investment in the Czech Republic show that, after the acquisition of Walter assets in 2008, Prague was turned into the headquarters of the new Turboprop Center of Excellence. Thus, the Czech aviation sector rests not only on an airframe-design school, but also on its own propulsion line, both in a national and in an internationally corporate form. This substantially increases the country’s technological autonomy and expands its role in global value chains: engines and auxiliary systems create greater added value than ordinary metalworking operations. In addition, it is precisely engine building that directly links classical manned aviation with new platforms—UAVs, light aircraft, specialised equipment, and, potentially, hybrid-electric solutions. Consequently, the engine in the Czech model is not a peripheral segment, but one of the most important supporting pillars of sectoral competence.

The preservation and development of so complex an industry would have been impossible without a powerful research and testing infrastructure. In this regard, VZLU AEROSPACE has central significance, defining itself as the national centre of research, development, and testing in the aerospace industry and emphasising its mission of providing scientific support and innovative solutions to industry. The official VZLU page lists unique research capacities: high-speed and low-speed wind tunnels, rigs for full-scale strength and fatigue testing, materials-science laboratories, engine laboratories, and other infrastructural elements directly linked with the development and certification of aviation technology. This means that the Czech sector possesses not only manufacturers, but also a national base for the testing, verification, and support of new products. The role of cluster structures is also substantial. Czech Aerospace Cluster, founded in 2010, brings together aviation companies and educational institutions, and on its website shows the scale of the cooperative environment: thousands of aircraft manufactured, thousands of workers, hundreds of millions of euros in aggregate turnover, and dozens of innovation projects. The cluster emphasises that its members develop R&D, testing, certification, and special technologies, while a separate page on projects directly links its activity with the internationalisation, innovation, and enhancement of the competitiveness of Czech aviation. Finally, state-supported applied programmes provide an institutional superstructure over this infrastructure, including the National Competence Centre for Aeronautics and Space with the support of TA ČR, in which the Faculty of Mechanical Engineering of Brno University of Technology is indicated as the leading participant. All this makes it possible to speak of Czech aircraft manufacturing as a research-backed industry, that is, an industry in which experimental production, testing, applied science, and the certification contour are closely intertwined.

No less indicative is the way in which personnel reproduction for the aviation sector is organised in the Czech Republic. The training of specialists here is not reduced to a single department or one region, but is distributed among several strong educational nodes with different sectoral orientations. At the level of the Czech Technical University in Prague, the Aerospace Engineering programme at the Faculty of Electrical Engineering is taught in parallel in Czech and in English and is presented as a combination of aeronautics and astronautics with electronics and informatics. At the same time, the Faculty of Mechanical Engineering of CTU offers the master's programme Aeronautics and Astronautics, directly oriented towards the training of engineers for aerospace, research and development, and air transport, and linked with pan-European qualification requirements. In Brno, an analogous systemic role is played by the Institute of Aerospace Engineering at BUT, which combines training in Professional Pilot and Aerospace Technology with contract research, laboratory testing, commercial services, and the participation of students in real projects. The military dimension is supported by the University of Defence, where the Department of Aviation Technology operates within the Faculty of Military Technology. It is also indicative that Aircraft Industries not only manufactures aircraft, but also operates an Aviation High School, that is, it literally embeds the personnel contour within the industrial organisation. Such a linkage of universities, military education, applied centres, and corporate training means that the Czech aviation industry reproduces not only designers, but also pilots, technicians, specialists in operation, testing, aerodrome technologies, avionics, and maintenance. This is one of the reasons why the sector in the Czech Republic appears institutionally mature: its competences are distributed across the whole chain of "education—design—production—testing—operation", rather than being concentrated only in final manufacturing.

However, contemporary aircraft manufacturing is not only production enterprises and universities, but also a developed regulatory and infrastructural environment of civil aviation. The Czech Ministry of Transport, on its page devoted to air transport, lists the key civil aviation organisations of the country: Prague Airport, Air Navigation Services of the Czech Republic, the Civil Aviation Authority, the Aeronautical Research and Test Institute, the Aeronautical Amateur Association, and other specialised structures. The Czech State Safety Programme of 2022 shows that the national aviation safety system is built as a coordinated contour between the Ministry of Transport, CAA, ANS CR, LAA CR, the Air Accidents Investigation Institute, and a number of other bodies operating within European and international obligations. It is especially noteworthy that the same document directly records the absence of fatal accidents in commercial air transport in the modern history of the Czech Republic. This does not mean the absence of risks, but it does indicate a high degree of institutionalisation of safety governance. ANS CR also plays an important role in this architecture as the operator of air navigation services, working within the logic of the Single European Sky and performance management. Civil infrastructure likewise demonstrates recovery and growth: Prague Airport reported that, in 2024, it handled 16,353,522 passengers, ensured 134,609 take-offs and landings, and offered direct connections to 181 destinations. It is also important for the contemporary sector that, since 31 December 2020, a pan-European regulatory framework for unmanned aircraft systems has been in force in the Czech Republic, while the CAA publishes special regimes, geographical zones, and rules for cross-border operations. All this shows that

Czech aircraft manufacturing develops within a mature aviation environment in which manufacturing, operation, safety, air navigation, and unmanned regulation are mutually coordinated.

The most characteristic feature of the contemporary stage is the entry of Czech aviation into new technological niches without abandoning its classical production core. One of these niches is unmanned aerial systems. VZLU singles out UAS as an independent direction of services and competences, including design, the development of composite structures, hardware and software, and propeller-rotor solutions, which shows that the unmanned line is already regarded not as a side activity, but as a fully-fledged engineering specialisation. A symbol of the market maturity of this niche became Primoco UAV: in March 2025, the company reported obtaining both NATO military certification and EASA authorisation within the Light UAS Operator Certificate framework for its One 150 aircraft, which sharply strengthened its position on the international market. Another important vector is linked with digitalisation and the transition to Industry 4.0 within the aviation manufacturing enterprises themselves. In its annual report for 2024, AERO specifically noted the introduction of the IFS ERP and Siemens Teamcenter PLM systems as a step towards the digitalisation of processes from development and production to the supply chain. At the same time, cluster organisations emphasise the international orientation of innovation work: Czech Aerospace Cluster projects are aimed at the internationalisation of participants, the development of R&D, and the enhancement of competitiveness. Taken together, this shows that contemporary Czech aviation does not live solely by virtue of historical brands, but attempts to translate traditional engineering strength into a regime of digital production, dual-use solutions, UAV certification, and more complex project cooperation. Therefore, in the 2020s the sector should be described as a mature, but not static, system: it simultaneously preserves classical platforms such as the L-39 and the L 410 and enters those fields where the future of aviation will be determined by certification, software, automation, composites, and unmanned capability.

If one sums up, aircraft manufacturing in the contemporary Czech Republic is not simply one branch of mechanical engineering, but a multi-level national technological system in which historical continuity, export specialisation, applied science, testing infrastructure, European regulation, and personnel reproduction are combined. Its strength lies not in a gigantic domestic market and not in the dominance of a single manufacturer, but in the rare combination of a full engineering chain and flexible niche specialisation. The Czech Republic simultaneously produces its own aircraft, engines, and aviation systems, participates in international programmes as a supplier of components, maintains national research and certification capacities, and forms a multi-channel system of specialist training. At the same time, the sector increasingly depends on its ability to maintain compliance with EASA and NATO standards, to digitalise production processes, to develop dual-use segments, and to scale up international cooperation. Within Central Europe, this makes the Czech Republic one of the most visible aviation-engineering countries, especially in the fields of light aircraft, training aircraft, commuter turboprops, propulsion niches, MRO, testing, and UAVs. At the same time, structural challenges remain: the limited scale of national demand, dependence on export markets, the need for constant technological renewal, and ever tougher global competition. But it is precisely against the background of these limitations that the Czech model appears especially convincing, because it shows how a medium-sized country can retain aviation sovereignty not through quantitative gigantism, but through the quality of engineering specialisation, the density of cooperation, and institutional coherence. Therefore, in the overall picture of the technological development of the Czech Republic, aircraft manufacturing should be regarded as one of the most integrated and strategically significant industries of the contemporary period.

Achievements

For the contemporary Czech Republic, achievement in aviation does not consist only in the release of a new aircraft or in the growth of one company's turnover. Much more important is the fact that, since 1993, the country has managed to pass from post-socialist adaptation to the position of one of the most integral aviation centres of Central Europe. This has found expression in the preservation of a full industrial cycle, the development of its own line of aircraft, the retention of engine-building competences, inclusion in global supply chains, the creation of a national testing and research base, and entry into new niches, above all in the segment of unmanned systems. It is especially important that these results were achieved not under conditions of a gigantic domestic market, but within the logic of an export-oriented, highly specialised, and certification-intensive industry. Therefore, the achievements of the Czech Republic in aircraft manufacturing should be assessed simultaneously according to several parameters: technological autonomy, international recognition of products, export integration, research depth, personnel reproduction, and the capacity for modernisation in response to new requirements of NATO, EASA, and the global market. Taken together, it is precisely these parameters that show that Czech aircraft manufacturing in 1993–2025 did not merely survive, but strengthened its status as one of the most effective high-technology branches of national industry. In other words, the achievements of Czech aviation consist not in an isolated "successful case", but in the formation of a sustainable model combining national platforms, international cooperation, and technological evolution.

The first and, perhaps, most fundamental achievement of the contemporary Czech Republic was the preservation and institutional renewal of the aviation industry as a full-profile system. For a state of medium scale, this in itself is already a rare result. According to CzechInvest, more than 120 specialised companies operate in the Czech aerospace sphere and more than 21,000 professionals are employed there, while the country itself belongs to the group of seven states in the world possessing the capacity to develop and manufacture aviation engines. CzechTrade additionally emphasises that the Czech Republic remains one of the few countries capable of producing an aircraft entirely on its own territory and at the same time continues to supply products and components to global leaders of the sector. In the context of post-socialist transformation, this is especially significant, because the issue is not the preservation of individual brands in a symbolic form, but the real retention of production, engineering, and certification depth. In the 1990s, many states of Central and Eastern Europe lost the ability for such a complex reproduction of aviation competence, whereas the Czech Republic managed not only to preserve this potential, but also to translate it into a market-adapted, export-oriented structure. Thus, the first achievement should be regarded precisely as the overcoming of the structural disintegration of the sector after 1993 and the transformation of the historical legacy into a contemporary competitive platform. Without this, neither new aircraft, nor engine programmes, nor modern training and testing complexes could have emerged. In practical terms, it was precisely this systemic resilience that created the basis for all subsequent Czech aviation successes.

The second major achievement of the Czech Republic was the creation, certification, and market introduction of the new generation jet trainer L-39 Skyfox, previously known as the L-39NG. This achievement has not only engineering, but also symbolic significance, because it was precisely the Skyfox programme that demonstrated that the Czech Republic is capable not merely of modernising the legacy of past decades, but of developing a contemporary platform meeting the requirements of present-day air forces. Aero states directly that this aircraft became one of the first machines certified under the new international military standards EMAR 21 and EMACC. In 2024, the company obtained the type certificate for the training version of the L-39 Skyfox, intended for the training of pilots according to NATO standards, while in August of the same year Vietnam, as the first customer, successfully completed the Site Acceptance Test of six delivered aircraft. By the end of 2024, Aero had delivered all 12 ordered machines to Vietnam, and in February 2025 the first two Skyfox aircraft were officially handed over to the state enterprise LOM PRAHA for the training of Czech pilots for flying fifth-generation aircraft. This achievement acquires particular significance from the fact that the Skyfox programme relies on approximately 600 subcontractors, of whom around 400 are located in the Czech Republic, so that the issue is not simply the success of one factory, but a large-scale technological multiplier within national industry. In addition, the aircraft is embedded in a contemporary training system with a virtual training environment, new avionics, a HOTAS architecture, and a ground-training complex, which makes it not simply a platform, but an element of an integral training solution. Therefore, the achievement of Skyfox exists simultaneously on several levels: it is both a new national aviation product and an export success, a modernisation of domestic military training, and confirmation that Czech aircraft manufacturing retains highly complex competences in the segment of advanced jet trainers.

The third important achievement of the contemporary Czech Republic was not simply the preservation, but the qualitative renewal of the L 410 family in the form of the L 410 NG project. For Czech aircraft manufacturing, this is especially indicative because success here is connected not with a jet military trainer, but with a multi-purpose regional turboprop aircraft demanded in an entirely different market niche. Aircraft Industries states that development of the L 410 NG began in 2010 and that serial production started in 2018. The new version received a redesigned wing with an integrated fuel tank, increased range and endurance, a payload increase of 500 kg, the GE H85-200 engine, a new propeller, and an integrated Garmin 3000 avionics system. The company also emphasises that the aircraft is certified in the transport category under EASA, FAA, and FATA regulations, which means that it has passed through a complex international airworthiness-recognition framework. Of particular value is the fact that Czech industry did not limit itself to maintaining the older L 410 version, but carried out a genuine generational modernisation of the platform, while preserving its strengths — STOL capabilities, operation in hot climates and at high altitude, suitability for severe operating conditions, and the multi-purpose character of its use. In conditions in which the niche of 19-seat commuter aircraft remains difficult and competitive, the very fact of maintaining the serial programme and its technological renewal should be regarded as a serious result. This testifies to the capacity of the Czech Republic not only to sustain heritage aircraft in operation, but also to rethink them through the use of new design, materials-science, and digital solutions. Thus, the L 410 NG project consolidated the Czech Republic's status as one of the few European manufacturers continuing to develop its own platform in the segment of regional turboprop aviation.

The fourth achievement should be recognised as the deep integration of Czech aviation enterprises into global production chains and the transformation of this integration into a source of technological and financial growth. It is important to emphasise that the issue here is not secondary outsourcing, but work with programmes of world level. CzechTrade states directly that Czech companies supply components and assemblies for Airbus, Boeing, Embraer, Bombardier, Sikorsky, CASA, and Eurofighter. The clearest example is AERO Vodochody, which in 2024 expanded industrial cooperation with Embraer on the C-390 Millennium transport-aircraft programme. According to Aero's official materials, the agreement increased the Czech share of participation in production and fixed an increase in output from four sets in 2024 to twelve sets annually in subsequent years. In parallel, the company reported that production of wing leading edges for the Airbus A220 was to more than triple within three years, and that, in response to the growth of orders, new employees had been hired and the largest IT investment in Aero's history had been launched for the digitalisation of development, production, and supply chain management. The result of this transformation was the best financial performance in the company's modern history: by the end of 2024, revenue exceeded 6 billion Czech crowns, adjusted EBITDA reached 821 million crowns, and net profit amounted to 102 million crowns. This makes it possible to say that Czech aircraft manufacturing has achieved not only engineering, but also commercial validation of its solutions. In other words, one of the key achievements of the Czech Republic was the transformation of national aviation competence into a sustainably monetisable export force embedded in international programmes of the highest level.

The fifth major achievement of the Czech Republic was the retention and development of engine building as an independent branch of the aviation industry. For a country of this size, this is an exceptionally important indicator of technological maturity. CzechInvest emphasises that the Czech Republic belongs to the very narrow circle of states capable of developing and manufacturing aviation engines. In this sphere, the contemporary Czech model is built around two complementary lines. The first is connected with GE Aviation Czech: after acquiring Walter Engines, GE chose the Czech Republic as the headquarters of its Turboprop Center of Excellence, announcing the creation of a centre for the development, testing, and manufacture of turboprop engines and the creation of more than 500 new jobs. GE also confirmed the receipt of EASA engine certifications for the H75 and H85 engines, while the present Czech GE Turboprop site defines itself as a centre for the design, development, manufacture, and servicing of H-Series engines. The second line is represented by PBS Velká Bíteš, which possesses DOA, POA, and MOA certifications, TC and ETSO certifications for turbine engines and APUs, as well as military approval under EMAR 21. Particularly indicative is the history of the TJ100 engine, which received EASA type certification as the first jet power unit of its kind certified for use on gliders; at the same time, PBS is developing a family of engines for light aviation and UAVs, including the TP100. Taken together, this means that the Czech Republic in 1993–2025 did not lose the propulsion component of aviation sovereignty, but managed to embed it both in international corporate programmes and in national niche developments. For the aviation sector, this is one of the most serious achievements, because it is precisely engine building that ensures high added value, a long product life cycle, and a particular depth of engineering specialisation.

The sixth achievement of the Czech Republic was entry into the ranks of European leaders in certain areas of unmanned aviation and the certification practice associated with it. The clearest example here is Primoco UAV. In March 2025, the company officially announced that it had become the first UAV manufacturer simultaneously to obtain NATO military certification and EASA authorisation within the Light UAS Operator Certificate framework for its One 150 aircraft. Moreover, the company states that the One 150 remains the only UAV in its class certified under the NATO STANAG 4703 standard, which gives users the possibility of immediate deployment in NATO countries without additional prolonged approvals. In its investor materials, Primoco emphasises that by 2025 more than 200 One 150 aircraft had already been produced and were being operated on four continents for infrastructure monitoring, border and coastline surveillance, calibration of airport systems, and other military and civil missions. No less important is the fact that VZLU AEROSPACE is also active in the unmanned segment, continuing in 2025 the free-flight testing of the MiYa project, previously awarded the title Visionary of the Year 2024. In this case, the achievements of the Czech Republic consist not only in the very fact of having national UAV projects, but in the capacity to pass the strictest procedures of demonstrating airworthiness, safety, and operational usability in shared airspace. For a sector in which, in many countries, developments remain at the level of prototypes and demonstrators, this is a sign of particular technological maturity. Thus, in the 2020s Czech aircraft manufacturing achieved a notable result in the transition from classical manned aviation to dual-use and unmanned segments, without losing engineering and certification rigour.

The seventh achievement should be regarded as the transformation of Czech aviation from a manufacturing industry into a complex training-and-research ecosystem operating in conjunction with NATO and with an orientation towards the fifth generation of combat aviation. Here the central role is played by the Pardubice Flight Training Center of LOM PRAHA. In 2021, NATO officially selected this centre as one of the first two campuses of the NATO Flight Training Europe initiative, which in itself means high international recognition of the level of Czech aviation training. In 2024, VR Group, a subsidiary of LOM PRAHA, obtained the Type Certificate for the L-39NG/Skyfox simulator as a Flight Training Device Level 2 under the international CS-FSTD(A) regulation, and in February 2025 the first two L-39 Skyfox aircraft were delivered to Pardubice for the basic and advanced training of pilots of the Czech Air Force. Aero and LOM PRAHA directly link this modernisation with preparation for the transition to the F-35 and for broader participation in NATO training programmes. An additional level of this achievement was the inclusion of Czech industry in F-35 industrial cooperation: in May 2024, the Ministry of Defence of the Czech Republic reported the signing of an agreement between LOM PRAHA and Lockheed Martin, as well as subsequent projects involving PBS Velká Bíteš and other Czech partners. As a result, the Czech Republic received not merely new aircraft, but a broader architecture—aircraft, simulator, training doctrine, NATO compatibility, infrastructure modernisation, and industrial cooperation with the F-35 programme. Such integration of the training, industrial, and military-technological lines represents one of the most important achievements of recent years, because it shifts national aviation from the mode of separate production to the mode of strategically embedded allied competence. For a country that in the 1990s was still resolving the tasks of post-socialist adaptation, this transition has fundamental significance.

Finally, the general concluding achievement of the Czech Republic in aircraft manufacturing should be regarded as the formation, by 2025, of a model of aviation development that is rare for a European country of medium size, combining completeness of competences with adaptation to new technological conditions. The Czech Republic has not become a global giant in terms of output volume, but has achieved a result that is, perhaps, more complex: it has preserved the ability to produce its own aircraft of different classes, retained engine building, embedded itself in the international programmes of Airbus and Embraer, advanced in unmanned certification, created research and testing infrastructure, and linked its aviation with long-term NATO training projects. In practical terms, this means that the Czech aviation industry can no longer be described as a “legacy of the past” maintained through historical inertia. On the contrary, it functions as an active high-technology system in which legacy is converted into innovation. It is especially important that a significant part of these successes fell precisely in the 2010s and the first half of the 2020s, that is, in a period when the global aviation environment became tougher, certification requirements more complex, and competition sharper. Therefore, the achievements of the Czech Republic in aircraft manufacturing have not only national, but also pan-European significance as an example of how a comparatively small country can retain aviation subjecthood through engineering quality, institutional cooperation, and export specialisation. Against this background, it may be confidently stated that aircraft manufacturing remains one of the most successful and strategically significant technological branches of the contemporary Czech Republic. And it is precisely in this capacity that it should be regarded in the general picture of the development of Czech technical sciences and high-technology industry in 1993–2025.

Leading Figures and Their Publications

When moving from the general characterisation of the industry to the personal level, it is important to consider that contemporary Czech aircraft manufacturing develops neither around a single figure nor within a single institution. It is most productively considered as a network of research and engineering schools in which Vysoké učení technické v Brně, České vysoké učení technické v Praze, and the laboratories, testing groups, and design teams associated with them are especially prominent. Therefore, this section highlights not simply well-known names, but those figures who simultaneously meet three criteria: institutional leadership, sustained publication activity, and a link to specific technological directions—aircraft structures, aviation systems, safety, fatigue and damage tolerance, flight control, avionics, and UAVs. This selection is representative rather than exhaustive, since industry also includes strong engineers with a less visible public academic profile. However, it is precisely those figures who are present in official university and research resources with substantial publication lists that make it possible best to trace the evolution of Czech aeronautical thought in 1993–2025. Within this selection, it is especially evident that, after 1993, continuity was preserved in the Czech Republic not only in production, but also in scientific and pedagogical schools. Some figures act as architects of the industry’s institutional stability, others as developers of particular technological directions, and still others as carriers of a new generation of the digital, unmanned, and sensor-oriented turn in aviation. It is precisely in this combination that the genuine maturity of the national aviation system is manifested.

One of the central figures of the entire post-socialist stage of Czech aircraft manufacturing should be regarded as Antonín Píštěk. The history of Letecký ústav Vysokého učení technického v Brně directly records that, after the transformation of faculty departments into institutes in 1993, it was he who became the first director of the newly created institute. Importantly, his role was not limited to academic administration: the university pages of the VUT 001 Marabu and VUT 051 Ray projects present him as chief designer and the ideological initiator of experimental platforms linking manned and unmanned aviation, as well as classical aircraft construction and electric propulsion. In this sense, Píštěk is a transitional figure between professor, designer, and organiser of sectoral cooperation. His publications reflect this breadth especially well. On the one hand, there are works on the design and technological realisation of his own aircraft programmes, above all the article by Píštěk and Popela, "The VUT 100/200 General Aviation Aircraft Family: Project and Realization". On the other hand, there are texts on training and aviation simulation technologies, such as Janíček and Píštěk, "Technological Trends in Simulation Technology in Aviation & Pilot Training" and Píštěk and Janíček, "Training Aspects of Implementation of the JAR Regulations in the Czech Republic". Finally, his profile also includes a more specialised structural-strength line, for example the work "Analytical Method for Limit Load Capacity Calculation of Thin-Walled Aircraft Structures", as well as the UAV-related publication "VUT 001 Marabu: Design Philosophy and Realization of an Experimental Aircraft Supporting UAV Applications in Civil Sector". Thanks to this, Píštěk is rightly perceived as one of the key figures who ensured the institutional and substantive continuity of the Czech aviation school after 1993.

If Píštěk symbolises the long line of institutional and design formation, then Jiří Hlinka reflects the transition of the Czech aviation school towards the more complex agenda of aircraft systems, safety assessment, reliability engineering, and the integration of modern airborne technologies. His official profile at Vysoké učení technické v Brně shows that he combines leadership of the faculty with the teaching of subjects in aircraft on-board systems, reliability and maintainability of aircraft, maintenance, and aeronautical instrumentation. The project page additionally demonstrates his involvement in directions connected with haptic feedback for aviation safety, modular control and diagnostic systems of aircraft engines, and international research cooperation. Hlinka's publication profile is especially valuable because it unites classical airworthiness logic with new technological challenges. Among his most representative works are the article by Hlinka, Kostial, and Horpatzka, "Application of Enhanced Methods for Safety Assessment of FADEC", in which powerplant safety is examined through an updated assessment toolkit, and the earlier work by Hlinka and Trefilová, "Identification of Major Safety Issues for Futuristic Personal Plane Concept", which shows an interest in prospective forms of personal air mobility. His role in the article by Šplíchal, Píštěk, and Hlinka, "Dynamic Tests of Composite Panels of an Aircraft Wing", is also significant, as he is included in the structural and experimental line of research. In recent years, Hlinka has also found himself at the centre of UAS safety, as evidenced by the work by Balážová et al., "Enhancing UAS Safety through Building-Induced Dangerous Zones Prediction: Concept and Simulations". Taken together, this makes him one of the most notable figures in that part of Czech aviation science which links engineering design, operational reliability, and system safety.

Antonín Píštěk

The scientist is one of the key figures of the post-socialist stage of Czech aircraft manufacturing, above all in the Brno line of aircraft design, experimental aircraft development, and institutional continuity. His particular significance is determined by the fact that, after the transformation of departments into institutes in 1993, it was he who became the first director of Letecký ústav Vysokého učení technického v Brně, that is, he stood at the origins of the new organisational form of the aviation school already under the conditions of the independent Czech Republic. At the same time, he acted not only as an academic leader, but also as a designer and ideological initiator of experimental platforms, which is especially clearly visible in the VUT 001 Marabu and VUT 051 Ray projects. The official pages of these projects directly associate his name with the conceptual design of Marabu and with the position of chief designer in the Ray electric-aircraft programme. Through this figure, it is especially clear how the Czech aviation school combined classical aircraft construction, early UAV concepts, electric propulsion, and the university engineering environment. Therefore, Píštěk is not simply one of the senior professors of the sector, but precisely the figure through whom the transfer of competences passed from traditional aeronautical engineering to newer forms of aviation experimentation and applied research.

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Jiří Hlinka

The scientist is one of the most notable figures of the contemporary Czech aviation school in the fields of aircraft systems, safety assessment, reliability engineering, and applied aerospace technologies. His significance is connected with the fact that he represents not so much the purely structural line as the systemic and certification branch of aircraft manufacturing, without which neither modern powerplants, nor complex on-board systems, nor the transition to unmanned aviation are possible. The official pages of Vysoké učení technické v Brně show him as dean of Fakulta strojního inženýrství, a lecturer in subjects relating to aircraft systems and reliability, and also a participant in key projects—from VUT 001 Marabu to the VUT 051 Ray electric aircraft. In publication terms, Hlinka is especially important because he brings together the safety of FADEC, futuristic aircraft concepts, UAS safety, and the broader problem of system dependability. Thus, he represents that line of Czech aircraft manufacturing in which engineering design is closely linked with normative logic, risk analysis, and the enhancement of operational reliability. For the contemporary Czech Republic, this is especially important, because it is precisely such researchers who form the bridge between aircraft engineering in the narrow sense and the broader architecture of airworthiness, certification, and operational safety.

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Jaroslav Juračka

The scientist is one of the central figures of the contemporary Brno school in the fields of aircraft structures, experimental testing, composite structures, and aerostructural capability. His official profile at Vysoké učení technické v Brně shows a long trajectory from technical worker and head of the Aircraft Test Laboratory to director of a division and leader of projects within the National Competence Centre for Aeronautics and Space. It is fundamentally important that Juračka combines institutional leadership, applied structural-strength expertise, and direct involvement in the development of testing infrastructure. His research and organisational activity is connected with structural strength, airworthiness, certification, composite structures, and applied experiments on aircraft structures. Through him it is especially clear how the Czech aviation school maintains continuity between laboratory testing, software-supported strength analysis, and industrially relevant aerostructural validation. It is precisely for this reason that Juračka should be regarded as one of the leading figures in that segment of Czech aircraft manufacturing which is responsible for the real engineering soundness of the structure, and not only for its conceptual design.

Leading works:

1. Juračka, J. (2017). Specifics of Aerostructures Experimental Testing. In *Engineering Mechanics 2017* (pp. 46–49). Prague: Czech Academy of Sciences. https://www.vut.cz/en/people/jaroslav-juracka-2356/publikacni-vysledky
2. Juračka, J., Chlebek, J., & Hodaň, V. (2021). Bird strike as a threat to aviation safety. In *Transportation Research Procedia* (Vol. 59, pp. 281–291). Elsevier. https://www.researchgate.net/publication/356881008_Bird_strike_as_a_threat_to_aviation_safety
3. Juračka, J., Červenka, M., Horák, M., & Šplíchal, M. (2022). Trend Monitoring of Turboprop Engines. In *33rd Congress of the International Council of the Aeronautical Sciences, ICAS 2022* (Vol. 6, pp. 4389–4407). https://www.vut.cz/en/people/miroslav-splichal-17696/publikacni-vysledky

4. Juračka, J., & Hübnerová, Z. (2024). Fuel Consumption Monitoring of Turboprop Engine. In *ICAS 2024 Proceedings*. https://www.icas.org/icas_archive/icas2024/data/papers/icas2024_0708_paper.pdf
5. Cejpek, J., & Juračka, J. (2016). Modifications of a Simple I-Beam and Its Effects on the Stress State. *Aviation*, *20*(4), 168–172. https://doi.org/10.3846/16487788.2016.1227538

Miroslav Šplíchal

The scientist is a notable figure in the Czech line of operational safety, human factors, landing-support systems, engine monitoring, and UAV-related operational integration. His official publication profile at Vysoké učení technické v Brně shows a sustained trajectory from research on risk management and airport safety in the 2000s to later works on pilot errors during landing, electric-powered aircraft, turboprop-engine monitoring, and workload assessment in real flight. Thus, Šplíchal represents not so much the design branch as the operational-safety branch of aircraft manufacturing. For the contemporary Czech Republic, this is especially important, because the development of the aviation sector depends not only on new aircraft and engines, but also on how safety, pilot support, operational monitoring, and the integration of new platforms into airspace are arranged in practice. Through his publications, one can clearly see the gradual expansion of Czech aviation science from the classical logic of airport and flight safety towards the more contemporary logic of human-machine support, small-turboprop monitoring, and unmanned operation in non-segregated airspace. Therefore, Šplíchal rightly occupies a place among the leading figures of contemporary Czech aviation precisely as a representative of applied operational aviation research.

Leading works:

1. Šplíchal, M., Červenka, M., & Juračka, J. (2023). Engine Condition Monitoring on Small Single Engine Turboprop. *Aircraft Engineering and Aerospace Technology*, *95*(9), 1335-1343. https://doi.org/10.1108/AEAT-09-2022-0249
2. Šplíchal, M. (2018). Pilot Errors during Landing Manoeuvres and Possible Ways to Reduce Them. In *New Trends in Civil Aviation* (pp. 129–132). Netherlands: CRC Press/Balkema. https://www.vut.cz/en/people/miroslav-splichal-17696/publikacni-vysledky
3. Šplíchal, M. (2019). Reduction in the Pilot's Stress during the Landing Maneuver by Providing Accurate Height Information. In *Research and Education in Aircraft Design 2018* (pp. 23–30). Brno. https://www.vut.cz/en/people/miroslav-splichal-17696/publikacni-vysledky
4. Šplíchal, M., & Finda, J. (2010). Design and Equipment of VUT 001 Marabu Unmanned Aerial Vehicle for Operation in Non-Segregated Airspace. *Aviation*, *14*, 24–32. https://www.vut.cz/en/people/miroslav-splichal-17696/publikacni-vysledky
5. Šplíchal, M. (2012). Perspectives of Electric Powered Airplane. In *INAIR 2012* (pp. 119–125). Žilina: EDIS. https://www.vut.cz/en/people/miroslav-splichal-17696/publikacni-vysledky

Martin Hromčík

The scientist is one of the leading figures of Czech aviation science at the intersection of flight control, aeroelasticity, morphing structures, and advanced control systems. His profile at České vysoké učení technické v Praze shows a stable connection with Fakulta elektrotechnická and Katedra řídicí techniky, as well as participation in the broader digital and cybernetic line of aerospace research. It is precisely such researchers who are especially important for the contemporary Czech Republic, because they move the national aviation school from the plane of classical mechanical structure into the plane of adaptive control, distributed propulsion concepts, flexible structures, and integrated cyber-physical aerospace systems. Hromčík's publications demonstrate the logic of this transition especially well: from controller design for a flexible BWB aircraft to morphing trailing-edge demonstrators, aeroelastic wing control, and new concepts of aircraft controllability through high-lift propellers. Thus, he represents the most contemporary cybernetic-aeronautical branch of Czech aircraft manufacturing, in which calculation and geometry are no longer the only decisive elements, but algorithms, adaptability, and the controllability of complex aerodynamically flexible systems.

Leading works:

1. Haniš, T., & Hromčík, M. (2011). Lateral Flight Dynamic Controller for Flexible BWB Aircraft. In *Proceedings of the 18th International Conference on Process Control* (pp. 333–337). Bratislava: Slovak University of Technology. https://fel.cvut.cz/cs/fakulta/lide/745-martin-hromcik/publikace
2. Svoboda, F., & Hromčík, M. (2019). Construction of the Smooth Morphing Trailing Edge Demonstrator. In *Proceedings of the 22nd International Conference on Process Control* (pp. 136–139). IEEE. https://doi.org/10.1109/PC.2019.8815050
3. Svoboda, F., Hromčík, M., & Šika, Z. (2021). Adaptive Control Design for the Aeroelastic Wing. In *Proceedings of the 23rd International Conference on Process Control* (pp. 225–228). IEEE. https://doi.org/10.1109/PC52310.2021.9447451
4. Belák, J., Beňo, D., & Hromčík, M. (2023). Aircraft Controllability through High-Lift Propellers. In *Proceedings of the 24th International Conference on Process Control* (pp. 78–83). Bratislava: Slovak University of Technology. https://doi.org/10.1109/PC58330.2023.10217691

Martin Šipoš

The scientist is a notable figure of the contemporary Czech aviation and avionics school in the fields of inertial navigation, sensor calibration, avionics, integrated modular avionics, and signal processing. The official resources of České vysoké učení technické v Praze and Katedra měření directly characterise him as a member of the Navigation group of the Laboratory of Aircraft Instrumentation Systems, while the list of his courses includes Integrated Avionics, Integrated Modular Avionics, Aircraft Avionics, and related subjects. This makes him an important representative of that part of Czech aircraft manufacturing in which the tasks of the precision of on-board measurements, orientation, navigation, and digital information architecture are addressed. Scientifically, his works show a sustained interest in the calibration of inertial sensors, GNSS-aided inertial navigation, magnetometer and accelerometer calibration, and the hardware base for heavy-lift drones. For the contemporary Czech Republic, this is fundamentally important, because it is precisely such a sensor-and-avionics line that ensures the transition from classical aviation technology to more complex digital, autonomous, and unmanned platforms. Thus, Šipoš represents the direction in which Czech aviation science is embedded in the global logic of smart avionics and measurement-driven aerospace systems.

Leading works:

1. Šipoš, M., Pačes, P., Roháč, J., & Nováček, P. (2012). Analyses of Triaxial Accelerometer Calibration Algorithms. *IEEE Sensors Journal*, *12*(5), 1157–1165. https://doi.org/10.1109/JSEN.2011.2167319
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3. Roháč, J., Hansen, J. M., Alam, M., Šipoš, M., Johansen, T. A., & Fossen, T. I. (2017). Validation of Nonlinear Integrated Navigation Solutions. *Annual Reviews in Control*, *43*, 91–106. https://doi.org/10.1016/j.arcontrol.2017.03.006
4. Šipoš, M., Roháč, J., & Nováček, P. (2012). Improvement of Electronic Compass Accuracy Based on Magnetometer and Accelerometer Calibration. *Acta Physica Polonica A*, *121*(4), 945–949. https://doi.org/10.12693/APhysPolA.121.945
5. Carev, V., Roháč, J., Šipoš, M., & Schmirler, M. (2021). A Multilayer Brushless DC Motor for Heavy Lift Drones. *Energies*, *14*(9), 2504. https://doi.org/10.3390/en14092504

Petr Augustin

The scientist is one of the most representative figures in the Czech line of fatigue analysis, crack propagation, damage tolerance, and structural life assessment of aircraft. His profile at Vysoké učení technické v Brně shows a stable connection with Letecký ústav, while his publication trajectory shows a systematic specialisation precisely in those questions that lie at the basis of aircraft life prediction and structural integrity. For the contemporary Czech Republic, this is especially important, because the aviation sector here rests not only on the creation of new platforms, but also on the competent assessment of service life, operational history, and the behaviour of loaded structural elements. Augustin's works cover fatigue life analysis of ageing aircraft, simulation of crack growth in wing spars, fatigue optimisation of the L 410 NG, and fractographic reconstitution of fatigue crack growth. This means that he represents that branch of Czech aviation science which makes possible service-life extension, evidence-based certification decisions, and a more precise assessment of the residual life of structures. Taken together, his contribution should be regarded as one of the key ones for maintaining the engineering reliability and operational validity of Czech aviation technology.

Leading works:

1. Augustin, P. (2018). Fatigue Life Analysis of Aging Aircraft Based on Previous Service Usage. In V. Socha, L. Hanáková, & A. Lališ (Eds.), *New Trends in Civil Aviation* (pp. 133–138). London: CRC Press. https://www.fme.vutbr.cz/en/veda/publikace/detail/149781
2. Augustin, P. (2019). Simulation of Fatigue Crack Propagation in the Wing Main Spar Flange. In *Research and Education in Aircraft Design 2018*. Brno: Brno University of Technology. https://dspace.vut.cz/items/be36cdd7-5750-47d7-ae8d-9bbe4042dfed
3. Katrňák, T., Augustin, P., & Vlček, D. (2016). Fatigue Analyses and Optimization of L 410 NG Aircraft. *Letecký zpravodaj*, *2016*(2), 39–41. https://www.fme.vutbr.cz/veda/publikace/detail/132022
4. Kunz, J., Kovářík, O., Lauschmann, H., Siegl, J., & Augustin, P. (2010). Fractographic Reconstitution of Fatigue Crack Growth in Integrally Stiffened Panels. *Procedia Engineering*, *2*(1), 1711–1720. https://doi.org/10.1016/j.proeng.2010.03.184

Robert Popela

The scientist is a notable figure in the Czech line of aerodynamics, CFD for aerospace, aircraft design, propeller-related aerodynamics, and autonomous flying systems. His official teaching profile at Vysoké učení technické v Brně shows a broad coverage of subjects: Aerodynamics I, Aerodynamics II, CFD for Aerospace, Space Structures Design, Aeroplane Propellers, Aircraft Design, and Autonomous Flying Systems. This indicates that Popela represents not a narrowly specialised field, but a broader aerodynamic and design block of the contemporary Czech aviation school. Scientifically, his works link aerodynamic optimisation, winglet design, business-jet wing analysis, general-aviation aircraft development, and an interest in UAV-related concepts. It is especially indicative that his name is associated with the VUT 100/200 General Aviation Aircraft Family programme, where the ability of the Czech academic environment to create real aviation platforms rather than only computational models is clearly visible. Therefore, Popela should be regarded as one of the leading figures of that branch of Czech aircraft manufacturing in which classical aerodynamics has long since been combined with CFD, optimisation, and autonomous-flight-oriented design thinking.

Leading works:

1. Píštěk, A., & Popela, R. (2007). The VUT 100/200 General Aviation Aircraft Family: Project and Realization. *Proceedings of the Institution of Mechanical Engineers*, *Part G: Journal of Aerospace Engineering*, *221*(2), 193–197. https://doi.org/10.1243/09544100JAERO126
2. Popela, R., Zikmund, P., Vaněk, F., & Kouřil, M. (2007). The Methodology of Winglet Aerodynamic Design for Ul and VLA Aircraft. *Letecký zpravodaj*, *2007*(3), 52–55. https://www.fme.vutbr.cz/veda/publikace/detail/43911
3. Popela, R., & Doupník, P. (2010). Response Surface Method Application to Transonic Business-jet Wing Optimization. *Letecký zpravodaj*, *2010*(1), 23–27. https://www.czaerospace.eu/en/2010-01-34.html
4. Zikmund, P., & Popela, R. (2015). Airliner-UAV Flight Formation in Climb Regime. *World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, *9*(10), 1661–1666. https://www.fme.vutbr.cz/veda/publikace/detail/117958
5. Zikmund, P., & Popela, R. (2013). Wake Vortex Gliding as a New Propulsion Concept for UAVs. *Letecký zpravodaj*, *2013*(2), 14–16. https://www.vut.cz/en/people/robert-popela-2529/publikacni-vysledky

Part 8

Semiconductors and Electronics

General Characterisation

Semiconductors and electronics in the contemporary Czech Republic constitute not a narrow auxiliary segment of industry, but one of the key technological platforms on which the country's export competitiveness, its participation in European value chains, and its capacity to move towards more complex forms of industrial development rest. At the same time, the Czech model does not coincide with the image of a state possessing giant full-scale foundries across the entire spectrum of microelectronics. Its strength lies elsewhere: in the combination of a historically formed manufacturing base, a strong engineering school, applied microelectronics, power semiconductors, measuring and electronic equipment, chip design, as well as a developed research infrastructure in the field of micro- and nanotechnologies. It is precisely for this reason that the contemporary Czech Republic is more accurately described not as a "small country without its own electronic agency", but as a specialised European node in the semiconductor and electronics value chain. It is indicative that, already in 2024, the country's government approved the National Semiconductor Strategy, while in the European Digital Decade country report 2025 Czechia is directly characterised as a country seeking substantially to strengthen its strategic positioning in the semiconductor sector. The same European document notes that the strategy sets the goal of sharply increasing national manufacturing capacities and mobilising a large body of qualified specialists by 2029. This means that, in the 2020s, the semiconductor and electronics sector in the Czech Republic definitively ceased to be perceived as merely part of general mechanical engineering and was moved into the category of strategic technological priorities. Already at the level of state policy, it is evident that the country regards microelectronics, chip design, and electronic systems as a foundation for future industrial sovereignty, the green transition, and the digital economy.

Historically, this branch in the Czech Republic rests on a long trajectory that extends much deeper than the period after 1993. In 2025, CzechInvest directly spoke of seventy years of development of the semiconductor industry in the country, while contemporary Rožnov pod Radhoštěm remains a symbol of this continuity. It is especially important that the post-socialist transformation did not destroy the branch, but changed its organisational form. In place of centralised socialist electronics, there arose a more flexible, export-oriented, and institutionally distributed system linked with international companies, national research centres, and universities. The example of onsemi in Rožnov pod Radhoštěm is indicative: CzechInvest recalls that the company has operated there since 2003, while the enterprise itself emerged through the merger of Tesla Sezam and Terosil, that is, new global corporate forms were literally embedded in an old Czech technological territory. As a result, the contemporary branch is not wholly "imported" from outside, as sometimes occurs in countries into which a foreign investor has simply arrived. In the Czech case, it is far more accurate to speak of a preserved and reformulated technological legacy which, in the 21st century, was incorporated into global semiconductor and electronics networks. Therefore, the development of the sector after the breakup of Czechoslovakia should be characterised as a process not of loss, but of complex institutional conversion: from late-socialist electronics to a market-embedded system of microelectronic manufacturing, design, measuring technology, and research infrastructure.

In structural terms, the Czech electronics industry is substantially broader than semiconductor fabrication proper. This is clearly visible in the sectoral panorama of the Ministry of Industry and Trade, where section CZ-NACE 26 includes not only electronic components and boards, but also computers, communication equipment, consumer electronics, measuring and navigation instruments, electromedical equipment, optics, and related sub-sectors. According to this panorama, already in the 2018 structure the most substantial segment within CZ-NACE 26 was instruments and appliances for measuring, testing and navigation, while among the notable players were ON Semiconductor Czech Republic, Foxconn, Wistron, Inventec, Continental Automotive Czech Republic, FEI Company, TESCAN, and Meopta. This matters not only as a historical snapshot of the sector, but also as an indication of its internal heterogeneity: the Czech electronics industry is not reducible to the production of one type of component. Contemporary foreign-trade statistics confirm that this base remains macroeconomically significant. According to the Czech Statistical Office, in 2024 exports of high-tech goods in the subgroup computers-office machines reached CZK 183 billion, while exports of electronics and telecommunications amounted to CZK 169 billion; at the same time, around 62% of high-technology exports were directed to EU countries. At the same time, import dependence remains high, since, according to the same statistics, the EU share in high-technology imports was substantially lower, while a significant proportion of supplies came from non-European sources. Consequently, contemporary Czech electronics should be understood as a strong export and manufacturing platform, but a platform embedded in global supply chains and not yet possessing full autonomy across all technological links.

If one turns to the semiconductor core itself, the state strategy of the Czech Republic formulates it quite specifically. The Ministry of Industry and Trade directly stated that the country’s greatest potential is linked above all with power electronics, the design of integrated circuits, and the manufacture of highly complex equipment necessary for chip production. This is an extremely characteristic formulation, because it shows that the Czech Republic is not trying artificially to present itself as a new universal world leader of the semiconductor industry, but is concentrating on those links in the chain where a real industrial and research base already exists. The European Digital Decade 2025 report supplements this picture by recording that the national strategy envisages a 300% increase in manufacturing capacity by 2029 and the mobilisation of 9,000 qualified specialists. Here the word “mobilise” is especially important: the issue is not only the construction of new facilities, but also the restructuring of the whole system of competences, personnel training, commercialisation, and links between research and industry. In other words, Czech semiconductor policy is built not around a single factory, but around the idea of a semiconductor ecosystem as a combination of manufacturing, IP design, advanced equipment, human capital, and public support instruments. In this respect, the Czech model is closer to the logic of a specialised European hub than to the model of a self-sufficient national superpower in the manner of the United States, Taiwan, or South Korea. But it is precisely such specialisation that makes it realistic: it rests on genuinely existing strengths, and not on declarative ambitions without an industrial foundation.

The manufacturing core of the contemporary Czech semiconductor sector remains Rožnov pod Radhoštěm and the onsemi complex associated with it. In 2024, the company officially announced its intention to create in the Czech Republic a vertically integrated silicon carbide facility for advanced power semiconductors, and the declared multi-year investment was identified at up to USD 2 billion. The importance of this project extends far beyond one region. onsemi directly states that the issue is the creation of a Central European supply chain for energy-efficient solutions oriented towards electric transport, renewable energy, and AI data centres, while its existing operations in the Czech Republic already include the growth of silicon crystals, silicon and silicon carbide wafers, and a silicon wafer fab. In 2025, the Ministry of Industry and Trade clarified that, for the expansion of the production of SiC wafers with epitaxial layer, a decision had already been taken to grant an investment incentive of CZK 567 million, while the key phase of the project envisages investment of tens of billions of Czech crowns and hundreds of new jobs. The European Commission then approved a Czech state-aid scheme for onsemi amounting to EUR 450 million, while CzechInvest reported that the new plant is expected to become the first facility of this type in the European Union. Taken together, Rožnov pod Radhoštěm should be regarded not simply as an old industrial centre, but as a possible nucleus of a new advanced power semiconductor cluster of European significance. It is precisely here that one most clearly sees how traditional Czech microelectronics is being linked with the new markets of electric mobility, clean energy, and computing infrastructure.

However, the contemporary Czech semiconductor system is built not only around a major investor, but also around new coordination institutions. A key event was the creation in 2025 of the Czech Semiconductor Centre in Brno. Brno University of Technology emphasises that this centre is intended to connect academia and industry, facilitate chip development for small companies and start-ups, provide mentoring, financial advice, and access to pilot lines, and also become part of the European network of centres of competence. Shortly after the launch of the centre, CTU Prague additionally noted that it had already succeeded in creating a service catalogue, establishing links with foreign partners, and offering companies participation in a pan-European design platform. At this level, it is especially important that the matter concerns not a purely academic institution, but an interface platform between development, industry, and public policy. In parallel, the Czech National Semiconductor Cluster is active, positioning itself as the country's main industrial contact node in the semiconductor value chain and bringing together leading universities, companies, suppliers, start-ups, and innovation centres. The cluster itself emphasises that it works within the logic of the EU Chips Act, IPCEI, design and IP development, and integration into European networks. Thus, by 2025 the Czech Republic had acquired not merely a set of scattered players, but the beginnings of an institutionally formed semiconductor governance layer, which is one of the most important signs of the maturity of the sector.

The research base of Czech electronics and microelectronics is also much deeper than may appear at first glance. One of its principal supporting nodes is CzechNanoLab, a distributed large research infrastructure with sites in Brno and Prague. On the infrastructure's page, it is directly stated that CEITEC Nano possesses a nanofabrication laboratory with an 800 m^2 cleanroom of class 100 and more than 35 items of technological and analytical equipment designed to work with everything from small substrates to 150-millimetre wafers; the principal area of application of this base is electronics, optics, and MEMS. The same infrastructure includes nanocharacterisation, structural analysis, electron microscopy, molecular beam epitaxy, MOVPE, lithographic structuring, and laboratories for spintronics and optospintronics.

A separate CEITEC page emphasises that, at Brno University of Technology, intensive research on semiconductor technologies and chips is conducted simultaneously at several faculties and at CEITEC BUT itself. In addition, one of the CEITEC research groups describes work on nanolithography, quantum point contacts, SETs, spintronics systems, dielectric and semiconductor nanodots and nanowires, that is, in those areas which connect microelectronics with the deeper nano- and quantum agenda. As a result, the Czech model of the electronics branch rests not only on applied manufacturing and design, but also on a research infrastructure capable of supporting materials science, device fabrication, nanocharacterisation, and prototyping. This is especially important because it is precisely such a base that enables the country not only to produce goods, but also to participate in shaping the next generation of technologies.

The Czech Republic's educational contour also remains a strong point, without which its present ambitions in the semiconductor sector would be scarcely realistic. The master's programme in Microelectronics at Brno University of Technology is directly oriented towards the training of engineers in the theory, design, and technology of integrated circuits, electronic systems, and devices, including computer-aided simulation, PCB design and manufacture, surface mounting, testing, and measuring technology. In 2025, the same university launched the new programme "Chip Design and Modern Semiconductor Technologies", which the university described as unique for the Czech environment and directly linked with an acute shortage of personnel: according to the head of the programme, the country requires up to three thousand specialists in this area. In parallel, the Department of Microelectronics at CTU in Prague demonstrates a very broad set of research topics: sensor applications, new diodes, generic devices, planar waveguides, MEMS simulations, testing of ICs, new semiconductors, nanostructures, and energy harvesting. An additional page on the department's partnerships shows long-term cooperation both with Czech universities and institutes of the Academy of Sciences and with industrial partners, including ASICentrum, ON Semiconductor Rožnov, Cadence, ST Microelectronics, and other organisations. All this means that personnel training in the Czech Republic is not limited to abstract courses in electronics, but is built in close connection with real design, fabrication, testing, and industry-collaboration workflows. That is precisely why personnel here act not as an external constraint, but as one of the bearing structures of the branch. In the long term, the capacity to expand this human-capital pipeline matters no less than the volume of investment in particular factories.

Finally, an important feature of the contemporary Czech Republic is the presence of a notable fabless and design-oriented layer which complements manufacturing microelectronics and renders the sector internally more modern. ASICentrum in Prague has existed since 1992 as the design centre of EM Microelectronic and, since 2001, has participated in the development of advanced ultra-low-power low-voltage analog-digital integrated circuits; later, embedded software, mobile-device applications, and wireless communication were added to this. Codasip, for its part, defines itself as Europe's leading RISC-V company and builds its business around customisable processors, processor design automation, and custom compute, which places the Czech Republic in the strategically important area of architecture and IP competence. Even more indicative is the example of Tropic Square, a Prague fabless semiconductor company, which in February 2025 announced the launch of its secure element TROPIC01 as the first generation of an openly architected tamper-proof security chip. These examples mean that the Czech electronics and semiconductor sector is no longer reducible to wafer production, electronics assembly, or classical components. It includes low-power IC design, open secure hardware, the RISC-V ecosystem, and the architectural-software level of semiconductor development. Therefore, the general characterisation of the sector in the contemporary Czech Republic must take account of several layers at once: industrial fabrication, power semiconductors, embedded electronics, chip design, security chips, nanofabrication, and research infrastructure. It is precisely this multilayered nature that makes the Czech model especially interesting: the country does not possess everything, but it has a sufficiently large number of high-quality nodes to be a genuinely significant European player.

In its final form, semiconductors and electronics in the contemporary Czech Republic constitute a highly specialised and rapidly institutionalising technological system. Its strengths are historical continuity, a powerful node of power semiconductors in Rožnov pod Radhoštěm, a developed electronics industry beyond chips proper, a deep research base, the formation of new centres of competence, and the presence of European-level design-oriented companies. Its limitations are likewise quite evident: dependence on external supplies in a number of high-technology positions, the absence of a universal full-spectrum foundry base, and a pronounced personnel shortage, which the Czech Republic itself officially acknowledges. But it is precisely the combination of these strengths and weaknesses that makes the branch analytically interesting. The Czech Republic is not a world hegemon in semiconductors, but neither is it merely a sales market or an assembly site. Rather, it is turning into a specialised European semiconductor-and-electronics hub in which manufacturing, development, measuring technology, nanoinfrastructure, exports, and state strategy meet. Therefore, in the overall picture of the development of contemporary technologies in the Czech Republic, this direction should be assessed as one of the most promising and strategically charged at the turn of the 2020s.

Achievements

It is important to identify precisely those results that make it possible to speak of the achievements of the contemporary Czech Republic, and not merely of the existence of an industry. In the Czech case, achievement in this sphere means not only the appearance of a new enterprise or an individual laboratory. Much more important is the fact that the country has managed to combine the historical depth of the electronic sector, production modernisation, advancement into more complex links of the semiconductor value chain, the formation of design-oriented companies, and the creation of new national institutions of coordination. Therefore, Czech successes in the field of semiconductors and electronics should be assessed simultaneously in several dimensions: industrial, research, institutional, personnel, and export. Such an approach is especially important because the Czech Republic is not a universal “chip superpower”, but has achieved notable results precisely as a specialised European player. In effect, its model shows that a medium-sized country can preserve and expand its agency in microelectronics not only through scale, but also through precise specialisation, high-quality infrastructure, and the ability to integrate itself into European and global technological chains. This is precisely the principal logic of the achievements of the Czech Republic in 1993–2025: it did not create the industry from scratch, but translated an inherited electronic and microelectronic base into a more mature, modern, and strategically comprehended form.

The first fundamental achievement should be recognised precisely as the fact that the Czech Republic managed to preserve its semiconductor-electronics specialisation after the dissolution of Czechoslovakia and, in the 2020s, to raise it to the level of an official strategic priority. The very fact that, in 2025, Czech Semicon Days was presented as an event marking 70 years of development of the semiconductor industry in Czechia already testifies to the deep historical continuity of the sector. However, something else is more important: in October 2024, the Czech government approved the National Semiconductor Strategy, stating directly that the country possesses real potential to become an important player in chip production at least at the European level. The Ministry of Industry and Trade specifically highlighted the areas in which Czech potential is strongest: power electronics, the design of integrated circuits, and highly sophisticated equipment for chip production. This means that the achievement of the Czech Republic consists not only in preserving the industry, but also in the fact that the state, for the first time, formally defined it as an object of purposeful industrial policy. In other words, semiconductors were transferred from the regime of an “important but fragmented industrial topic” into the regime of a long-term national priority connected with technological sovereignty, higher added value, and new industrialisation. For a Central European country that in the 1990s was still resolving the tasks of post-socialist adaptation, this should be regarded as a very serious institutional achievement.

The second and most visible achievement was the transformation of Rožnov pod Radhoštěm into one of the most important European nodes of advanced power semiconductors. In June 2024, Onsemi announced plans to create in the Czech Republic a state-of-the-art, vertically integrated silicon carbide manufacturing facility with multi-stage investments of up to USD 2 billion. It is fundamentally important that this project is not being built on an empty site: the company emphasised that its existing operations in the Czech Republic already include crystal growth, silicon and silicon carbide wafer manufacturing, and a silicon wafer fab. Moreover, at the moment of the announcement, the Rožnov site was already capable of producing more than three million wafers annually, including more than one billion power devices. This means that the achievement of the Czech Republic consisted not merely in attracting a foreign investor, but in the transition from a historical microelectronic centre to a site capable of claiming a key role in the formation of a Central European supply chain for SiC-based power devices. Under the conditions of the global race for energy-efficient semiconductors for electric vehicles, renewable energy, and AI data centres, such a transition has not a local, but a pan-European significance. Therefore, the modernisation of Rožnov is not a private success of one corporation, but one of the largest industrial results of the contemporary Czech Republic in the semiconductor sphere.

The third important achievement was that the Czech Onsemi project received not only industrial, but also full political and economic consolidation at the level of the European Union. In November 2025, the European Commission approved a Czech state-aid measure amounting to EUR 450 million for the new semiconductor manufacturing facility of Onsemi in Rožnov. CzechInvest directly stated that the new fab is intended to become the first facility of its kind in the European Union, while the investor itself is expected to contribute around EUR 1.64 billion. This moment is especially significant because it transforms the Czech case from a national investment project into a recognised element of European semiconductor resilience policy. In essence, this is a rare case in which the Czech Republic appears not as a peripheral executor of decisions taken in other EU countries, but as the site of one of the most notable projects of Europe’s new chip policy. In addition, such support confirms that Czech specialisation in power semiconductors was perceived as corresponding to the aims of the European Chips Act and to the broader task of strengthening European technological autonomy. Consequently, the achievement of the Czech Republic here lies not only in the plant itself, but also in the international recognition of the fact that precisely Czech territory and the Czech industrial base are suitable for the localisation of a strategically important segment of European microelectronics.

The fourth achievement of the Czech Republic was the formation of a notable fabless and processor-design layer, which is especially important for a country that does not possess numerous full-scale fabs of world level. One of the oldest examples here is ASICentrum in Prague, founded in 1992 and functioning as the design centre of EM Microelectronic; since 2001 it has participated in the development of advanced ultra-low-power low-voltage analogue-digital integrated circuits, and later expanded into embedded software, mobile applications, and wireless communication. But the newer Czech success represented by Codasip is especially important. The company itself defines itself as Europe's leading RISC-V company with a global presence and emphasises that its technology is already used in billions of chips. In March 2025, Codasip was selected to develop a high-end RISC-V general-purpose processor within the framework of the DARE project—a major European initiative worth EUR 240 million, oriented towards the creation of a European compute stack for high-performance and energy-efficient RISC-V processors and accelerators. This means that the Czech Republic has achieved a serious result not only in manufacturing, but also in one of the most strategically sensitive zones of contemporary microelectronics—processor IP, custom compute, and European digital autonomy. For a small country, such a level of participation in RISC-V and HPC-oriented architecture development is an unquestionable achievement.

The fifth achievement should be recognised as the emergence in the Czech Republic of a genuinely innovative direction in hardware security chips, embodied in the company Tropic Square. In February 2025, the company announced the launch and general availability of its first product, TROPIC01, which was presented as the industry's first open-architecture tamper-proof secure element. It is substantial that this is not simply another security chip, but specifically auditable and open secure hardware designed for use in IoT devices, crypto wallets, digital identity devices, and hardware authenticators. Already in March 2025, TROPIC01 received notable international recognition at Embedded World 2025, where Tropic Square reported a double victory—in the safety & security category and in the best in show format. Even more indicative is the fact that, in October 2025, the company announced the integration of TROPIC01 into Trezor Safe 7, calling this the first case of the deployment of an open and auditable security chip in a mass-market consumer device. At the analytical level, this is an extraordinarily important result: the Czech Republic demonstrated an ability not only to produce components for other people's supply chains, but also to create its own innovative solution at the intersection of semiconductors, cybersecurity, and open hardware. It is precisely achievements of this kind that move national electronics from the regime of production participation into the regime of technological authorship.

The sixth major achievement was the consolidation of research infrastructure capable of serving not only academic science, but also the real needs of the semiconductor and nanoelectronics ecosystem. By the middle of the 2020s, CEITEC and CzechNanoLab already function not as a set of scattered laboratories, but as a national technological base with European visibility. In 2020, CzechNanoLab received the highest possible evaluation in the national system for assessing large research infrastructures, while the CzechNanoLab+ project became the most successful in the corresponding grant competition, with a score of 78 out of 80 and full funding in the amount of CZK 361 million for equipment modernisation.

CEITEC also plays a key role in the EuroNanoLab consortium and acts as a sought-after participant in Horizon 2020 and Horizon Europe projects. It is especially important that, at Brno University of Technology, this infrastructure is already directly incorporated into the semiconductor pipeline: CEITEC Nano provides cleanrooms and state-of-the-art equipment for training students in microelectronics and in the new programme Chip Design and Modern Semiconductor Technologies, while the research groups themselves work in beyond-CMOS areas, including magnonics as a potentially more energy-efficient platform of future computing. Consequently, the Czech Republic has achieved not only an industrial, but also a scientific-infrastructural result: a research base has been formed in the country that is capable simultaneously of supporting current microelectronics and of seeking solutions for the post-CMOS future. For a national technological system, this is one of the deepest types of achievement.

The seventh achievement was the institutional assembly of the Czech semiconductor ecosystem in 2025 around new coordination structures. The launch of the Czech Semiconductor Centre in Brno became an important milestone, because the centre was conceived not as a purely academic site, but as an interface structure between academia, industry, and public support instruments. The official description of the centre emphasises that it is intended to facilitate chip development for small and start-up companies, offer mentoring, financial advice, and access to pilot lines, and also become part of a broader European network of centres. Only a few months after its launch, Brno University of Technology reported that the CSC had already succeeded in creating a team, establishing project-management rules, preparing a service catalogue, exceeding a number of annual target indicators, and entering into negotiations with international partners. In parallel, the Czech National Semiconductor Cluster was also strengthening: according to FEEC BUT, by spring 2025 it united 42 members—universities and companies—and was regarded as an important instrument for changing the industrial and educational landscape of the country. In this same context, the growth of interest in microelectronics education is especially remarkable: according to the same FEEC data, the number of applications to the corresponding programmes increased by 25% in comparison with previous years. All this makes it possible to regard 2025 as the moment when the Czech semiconductor sector reached a new stage of maturity: it began to exist no longer as the sum of individual players, but as a coordinated ecosystem.

Finally, another important achievement should be recognised in the fact that Czech electronics and ICT-related manufacturing confirm their macroeconomic significance not only through strategies and investment announcements, but also through real foreign-trade statistics. According to the Czech Statistical Office, in 2024 Czech exports of ICT goods reached CZK 336 billion and accounted for 7.2% of the country's total exports of goods. In the same statistics, the most significant subgroups of high-tech goods remain computers-office machines and electronics-telecommunications, while exports of the first of these in 2024 increased by 37% compared with 2023 and reached CZK 183 billion. These data do not prove full technological sovereignty, but they do confirm that the electronic and microelectronic contour of the Czech Republic already has real economic weight and is capable of materialising in a sustainable export result. If this is combined with the Rožnov SiC expansion, the growth of design companies, the CSC, CzechNanoLab, and the new strategy, the overall picture becomes quite definite. The principal achievement of the Czech Republic in 1993–2025 was the transformation of semiconductors and electronics from an important but fragmented legacy into a rapidly institutionalising system of European level, which already possesses its own strong manufacturing, research, and architectural niches. It is precisely for this reason that this branch should be regarded as one of the most promising and strategically significant in the contemporary Czech Republic.

Leading Figures and Their Publications

When moving from the general characterisation of the sector to the personal level, it is important to bear in mind that the contemporary Czech school of semiconductors and electronics is not concentrated in a single centre. It develops as a distributed network of research and engineering nodes, in which the Prague school around CTU, the Brno school around Brno University of Technology and CEITEC, as well as the broader industrial-university environment associated with design, power semiconductors, nanoelectronics, microsystems, and advanced instrumentation are especially prominent. Therefore, this section highlights not merely well-known names, but those figures who reflect the strongest lines of the contemporary Czech Republic within the semiconductor and electronics value chain: power devices, integrated circuits, analogue and mixed-signal design, microsystems, nanofabrication, and semiconductor nanostructures.

This selection is representative rather than exhaustive in character. Many more strong engineers and scholars are active in Czech industry and the research environment, yet it is precisely these figures who are especially visible in official university, research, and professional resources. Some of them represent the power-semiconductor and device-physics branch; others embody analogue and mixed-signal integrated circuits, low-voltage design, microsystems, and sensor electronics; still others represent nanoelectronics, nanofabrication, and advanced semiconductor materials at the nanoscale. It is precisely in the combination of these clusters that the maturity of the contemporary Czech semiconductor-electronics school is manifested.

Taken together, the figures considered here make it possible to see that the contemporary Czech Republic in the field of semiconductors and electronics rests not on an accidental set of individual researchers, but on a reproducible intellectual body. Pavel Hazdra and Jan Vobecký represent above all the line of power semiconductor devices and defect engineering. Jiří Jakovenko, Jiří Háze, and Fabian Khateb embody the Czech school of integrated circuits, mixed-signal systems, microsystems, and low-voltage electronics. Tomáš Šikola and Michal Urbánek represent nanoelectronics, nanofabrication, and advanced semiconductor-related nanostructures. It is precisely through such figures that one sees most clearly how the Czech Republic, in 1993–2025, translated the historical legacy of electronics into a more contemporary and strategically shaped semiconductor ecosystem.

Pavel Hazdra

The scientist is one of the key figures of the contemporary Czech line of power semiconductor devices, radiation effects in semiconductors, and wide-bandgap electronics. His significance is determined not only by his scientific productivity, but also by his institutional position: he heads the Department of Microelectronics at CTU in Prague and simultaneously leads the Electron Device Group. Official CTU resources emphasise that his group works at the intersection of carrier lifetime control, defects in semiconductors, silicon carbide devices, and advanced power electronics. It is especially through Hazdra's publications that one can see how Czech microelectronics entered one of the most strategically important zones of contemporary semiconductor science—4H-SiC power devices, radiation hardness, and defect engineering. For the contemporary Czech Republic, this is especially important, because power semiconductors lie at the foundation of energy-efficient industry, transport, and power electronics.

Leading works:

1. Hazdra, P., Smrkovský, P., Vobecký, J., & Mihaila, A. (2021). Radiation resistance of high-voltage silicon and 4H-SiC power p-i-n diodes. *IEEE Transactions on Electron Devices, 68*(1), 202-207. https://doi.org/10.1109/TED.2020.3038713
2. Hazdra, P., Smrkovský, P., & Popelka, S. (2021). Radiation defects and carrier lifetime in 4H-SiC bipolar devices. *Physica status solidi (a), 218*(23), 2100218. https://doi.org/10.1002/pssa.202100218
3. Hazdra, P., & Popelka, S. (2019). Displacement damage and total ionisation dose effects on 4H-SiC power devices. *IET Power Electronics, 12*(15), 3910–3918. https://doi.org/10.1049/iet-pel.2019.0049
4. Hazdra, P., & Vobecký, J. (2019). Radiation defects created in n-type 4H-SiC by electron irradiation in the energy range of 1–10 MeV. *Physica status solidi (a), 216*(19), 1900312. https://doi.org/10.1002/pssa.201900312
5. Hazdra, P., & Popelka, S. (2018). Optimization of SiC power p-i-n diode parameters by proton irradiation. *IEEE Transactions on Electron Devices, 65*(10), 4483–4489. https://doi.org/10.1109/TED.2018.2866763

Jan Vobecký

The scientist is one of the most authoritative figures of the Czech power-semiconductor school and, more broadly, of the whole of contemporary Czech microelectronics. His particular significance is confirmed not only by academic publications, but also by the industrial dimension of his career: the Faculty of Electrical Engineering at CTU has emphasised that he was inducted into the ISPSD Hall of Fame, and that his research made it possible to bring the parameters of diodes and thyristors to the limits of physical possibility; his name is associated with fast commutation diodes and high-voltage thyristors used in HVDC transmission lines worldwide. This makes Vobecký a rare example of a researcher whose work is simultaneously deeply scientific and directly materialised in global power electronics. For the contemporary Czech Republic, such a figure is especially important, because he demonstrates the capacity of the national school to move from the university environment into globally significant industrial power-device applications.

Leading works:

1. Vobecký, J. (2021). Impact of defect engineering on high-power devices. *Physica status solidi (a), 218*(23), 2100169. https://doi.org/10.1002/pssa.202100169
2. Vobecký, J., & Hazdra, P. (2007). Radiation-enhanced diffusion of palladium for a local lifetime control in power devices. *IEEE Transactions on Electron Devices, 54*(6), 1521–1526. https://doi.org/10.1109/TED.2007.896384
3. Hazdra, P., & Vobecký, J. (2019). Radiation defects created in n-type 4H-SiC by electron irradiation in the energy range of 1–10 MeV. *Physica status solidi (a), 216*(19), 1900312. https://doi.org/10.1002/pssa.201900312

4. Vobecký, J., Stiegler, K., Bellini, M., & Meier, U. (2017). New generation large area thyristor for UHVDC transmission. In *PCIM Europe 2017: International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management*. https://pcim.mesago.com/content/dam/messefrankfurt-mesago/pcim/2023/documents/pdf/download/PCIM_Europe_2017_Proceedings_Table_Of_Content.pdf

Jiří Jakovenko

The scientist is one of the most prominent figures of the Prague school of microsystems, analogue integrated systems, MEMS design, and reliability modelling. Official CTU resources describe him as a professor in the Department of Microelectronics, deputy head of the department, and vice-dean of the faculty, while his scientific profile is directly associated with analogue integrated circuit design, MEMS design, and reliability modelling. It is especially through his publications that one can see how the Czech microelectronics school expanded from classical microsystems and IC design towards detector electronics, robust analogue layout, LDO regulators, and reliability-oriented design. That is why Jakovenko represents that important branch of contemporary Czech electronics which connects semiconductor devices with practical circuit architecture, design automation, and application-driven mixed-signal electronics.

Leading works:

1. Buryánec, L., Petenyi, S., Bille, G., Ribellino, C., & Jakovenko, J. (2023). Programmable 1 A ultra-low dropout LDO regulator for high-resolution camera sensors. *Microelectronics Journal, 139*, 105899. https://doi.org/10.1016/j.mejo.2023.105899
2. Vančura, P., Gečnuk, J., Jakovenko, J., Janoška, Z., Jirsa, J., Kafka, V., Korchak, O., Kostina, A., Lednický, D., Marčišovská, M., Marčišovský, M., & Tomášek, L. (2022). A low power asynchronous column-parallel 10-bit analog to digital converter with a high input impedance. *Journal of Instrumentation, 17*, T05016. https://doi.org/10.1088/1748-0221/17/05/T05016
3. Vančura, P., Jakovenko, J., Kotě, V., Vacula, P., & Kubačák, A. (2020). Spatial systematic mismatch assessment of pre-arranged layout topologies. *Solid-State Electronics, 170*, 107822. https://doi.org/10.1016/j.sse.2020.107822
4. Kotě, V., Kubačák, A., Vacula, P., Jakovenko, J., & Husák, M. (2018). Automated pre-placement phase as a part of robust analog-mixed signal physical design flow. *Integration, the VLSI Journal, 63*, 18-30. https://doi.org/10.1016/j.vlsi.2018.04.018
5. Jakovenko, J., Formánek, J., Perpiñà, X., Jordà, X., Vellvehí, M., Werkhoven, R. J., Kunen, J., Bancken, P., Bolt, P. J., & Husák, M. (2013). Design methodologies for reliability of SSL LED boards. *Microelectronics Reliability, 53*(8), 1076–1083. https://doi.org/10.1016/j.microrel.2013.02.017

Jiří Háze

The scientist is one of the key figures of the contemporary Brno line of analogue integrated circuits, mixed-signal design, and microelectronic education. His official profile at Brno University of Technology records his status as Head of the Department of Microelectronics, while his teaching load includes Microelectronics in English, Modern Microelectronic Systems, Analogue Integrated Circuits, and Design of Analog Integrated Circuits. Institutionally, his significance is even greater, because it is precisely through such figures that the Brno school connects research, curriculum modernisation, and chip-design training. Public materials from FEEC BUT also emphasise his role in expanding personnel training in chip design and semiconductor technology. It is especially through Háze's works that one can see how the Czech microcircuit-design school is moving towards low-power ASICs, analogue front-ends, delta-sigma modulators, and FDSOI-based circuits.

Leading works:

1. Kledrowetz, V., Fujcik, L., Prokop, R., & Haze, J. (2024). Asynchronous delta-sigma modulator in 28 nm FDSOI technology. *Engineering Science and Technology, an International Journal, 57*, 101821. https://doi.org/10.1016/j.jestch.2024.101821
2. Kledrowetz, V., Prokop, R., Fujcik, L., & Haze, J. (2023). A fully differential analog front-end for signal processing from EMG sensor in 28 nm FDSOI technology. *Sensors, 23*(7), 3422. https://doi.org/10.3390/s23073422
3. Kledrowetz, V., Fujcik, L., Prokop, R., & Háze, J. (2020). A 1 V 92 dB SNDR 10 kHz bandwidth second-order asynchronous delta-sigma modulator for biomedical signal processing. *Sensors, 20*(15), 4137. https://doi.org/10.3390/s20154137
4. Pavlík, M., Háze, J., & Kledrowetz, V. (2012). Design of the 12-bit Delta-Sigma modulator using SC technique for vibration sensor output processing. *Radioengineering, 21*(1), 246–252. https://www.radioeng.cz/fulltexts/2012/12_01_0246_0251.pdf

Fabian Khateb

The scientist is one of the most prominent figures of the contemporary Czech school of low-voltage low-power analogue integrated circuits. His official profile at BUT shows a sustained presence in international journals at the level of *IEEE Access*, *IEEE Transactions on Circuits and Systems*, *IEEE Transactions on Very Large-Scale Integration Systems*, *Microelectronics Journal*, and *IET Circuits, Devices & Systems*. In more substantive terms, this means that Khateb represents precisely that part of Czech electronics which is not limited to local applied developments, but is integrated into the global research conversation around ultra-low-voltage analogue design, biomedical analogue front-ends, and energy-efficient circuit topologies. For the contemporary Czech Republic, this is especially important, because such a line of research links microelectronics with practical edge devices, biomedical electronics, and battery-constrained systems.

Leading works:

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2. Khateb, F., Kumngern, M., Kulej, T., & Ranjan, R. K. (2023). 0.5 V multiple-input multiple-output differential difference transconductance amplifier and its applications to shadow filter and oscillator. *IEEE Access, 11*, 31212–31227. https://doi.org/10.1109/ACCESS.2023.3260146
3. Nako, J., Psychalinos, C., Khateb, F., & Elwakil, A. S. (2024). Bilinear double-order filter designs and application examples. *IEEE Access, 12*, 14040–14049. https://doi.org/10.1109/ACCESS.2024.3357092
4. Khateb, F., & Kulej, T. (2018). Guest editorial: Low voltage low power integrated circuits and systems. *IET Circuits, Devices & Systems, 12*(6), 669–670. https://doi.org/10.1049/iet-cds.2018.5519

Tomáš Šikola

The scientist is one of the central figures of the Czech nanoelectronics and semiconductor nanostructures line. CEITEC directly presents him as Research Group Leader of the Fabrication and Characterisation of Nanostructures direction, while descriptions of the group emphasise work on nanolithography, advanced planar materials and devices, nanostructures for nanoelectronics, nanophotonics and sensing, as well as ultrathin films and nanostructures of wide-bandgap semiconductors such as GaN and AlN. Additional CEITEC materials also separately note his historical role in the development of semiconductor-related research and instrumentation in Brno after his move from Tesla Brno. Thus, Šikola represents that direction of Czech semiconductor science in which micro- and nanoscale fabrication competence is joined with the study of new semiconductor structures and functional nanosystems.

Leading works:

1. Rothman, A., Bukvišová, K., Itzhak, N. R., Kaplan-Ashiri, I., Kossoy, A. E., Sui, X., Novák, L., Šikola, T., Kolíbal, M., & Joselevich, E. (2022). Real-time study of surface-guided nanowire growth by in situ scanning electron microscopy. *ACS Nano, 16*(11), 18757–18766. https://doi.org/10.1021/acsnano.2c07480
2. Rothman, A., Maniš, J., Dubrovskii, V. G., Šikola, T., Mach, J., & Joselevich, E. (2021). Kinetics of guided growth of horizontal GaN nanowires on flat and faceted sapphire surfaces. *Nanomaterials, 11*(3), 624. https://doi.org/10.3390/nano11030624
3. Maniš, J., Kolíbal, M., Dubrovskii, V. G., Blumtritt, H., Šikola, T., & Mach, J. (2022). Low temperature 2D GaN growth on Si(111) 7 × 7 assisted by electron beam. *Nanoscale Advances*. https://pubs.rsc.org/en/content/articlehtml/2022/na/d2na00175f

Michal Urbánek

The scientist is one of the most prominent figures of the contemporary Czech semiconductor-adjacent nanotechnology infrastructure, connecting nanofabrication, advanced characterisation, and semiconductor-related teaching. CEITEC emphasises that, since 2016, he has served as Head of CEITEC Nano research infrastructure, and since 2020 as coordinator of CzechNanoLab. Materials from BUT also record him as Head of Core Facility at CEITEC Nano. His significance for the Czech sector lies not only in his own research, but also in the fact that a critical infrastructure layer passes through him, without which cleanroom-based fabrication, nanostructuring, and advanced materials analysis for semiconductor and electronics projects would be impossible. It is precisely such figures that ensure the transition from individual articles and laboratories to a fully functioning national nanotechnology backbone.

Leading works:

1. Klíma, J., Wojewoda, O., Roučka, V., Molnár, T., Holobrádek, J., & Urbánek, M. (2024). Zero-field spin wave turns. *Applied Physics Letters, 124*(11), 112404. https://doi.org/10.1063/5.0189394
2. Lamb-Camarena, S., Porrati, F., Kuprava, A., Wang, Q., Urbánek, M., Barth, S., Makarov, D., Huth, M., & Dobrovolskiy, O. V. (2023). 3D magnonic conduits by direct write nanofabrication. *Nanomaterials, 13*(13), 1926. https://doi.org/10.3390/nano13131926
3. Güler, A. C., Antoš, J., Masař, M., Urbánek, M., Machovský, M., & Kuřitka, I. (2023). Boosting the photoelectrochemical performance of Au/ZnO nanorods by co-occurring gradient doping and surface plasmon modification. *International Journal of Molecular Sciences, 24*(1), 443. https://doi.org/10.3390/ijms24010443

Part 9

Rail Technologies

General Characterisation

Rail technologies in the contemporary Czech Republic represent one of the most systematically developed branches of the national technosphere, in which a traditional engineering base is combined with digitalisation, a high degree of export embeddedness, and active infrastructure modernisation. Their significance is determined not only by the historical role of the railways in Central Europe, but also by the fact that, in the Czech case, the rail sector covers practically the entire technological chain: rolling stock, signalling, control-command systems, track infrastructure, rail metallurgy, wheelsets, brakes, diagnostics, testing, certification, and transport telematics. ACRI directly characterises the branch as a major industrial cluster with turnover exceeding CZK 130 billion, employment of more than 22,000 people, and an average export share of around 50% of revenue. For 2024, ACRI was already reporting growth in aggregate revenue to EUR 5.3 billion and the continued maintenance of the export share at the level of half of all sectoral income. At the same time, the railway technological environment rests on one of the largest networks in the region: Správa železnic manages a railway system exceeding 9.3 thousand km in length, while the EIB in 2024 assessed the Czech network at approximately 9,463 route kilometres, around one third of which is electrified. That is why rail technologies in the Czech Republic should be regarded not as a specialised adjunct of the transport sector, but as a strategic technological system on a national scale. Its strength lies in the fact that it simultaneously supports internal mobility, international TEN-T corridors, urban rail transport, and the export of high-technology products. Already at this level, it is evident that the Czech rail industry develops not around one plant or one operator, but in the form of a ramified industrial-infrastructural ecosystem.

After the dissolution of Czechoslovakia, the rail sector of the Czech Republic did not experience a technological rupture, but passed through a complex institutional and market restructuring. On the one hand, basic infrastructural and manufacturing continuity was preserved; on the other, the branch was embedded in new European norms of competition, interoperability, and public financing. The Transport Policy of the Czech Republic for the period 2021–2027 proceeds directly from the premise that rail transport remains one of the principal instruments of sustainable mobility, while at the same time already facing the exhaustion of capacity on a number of main lines. The document emphasises that further development requires an increase in infrastructural capacity, the construction of pilot sections of high-speed connections, and a more rational distribution of capacity between passenger and freight segments. In this context, the contemporary Czech railway system is being built simultaneously as an open market environment and as a heavily coordinated public-technology system. This is clearly visible in the annual reports of České dráhy as well, where the company stresses that, while remaining the state carrier, it operates in an open market and must preserve its competitiveness. Consequently, the technological development of the Czech railway sphere after 1993 proceeded not through the conservation of the old model, but through adaptation to European interoperability logic, market opening, and publicly supported network modernisation. It is precisely this combination of institutional restructuring and technological continuity that has become the basis of the current maturity of the branch.

The infrastructural component of contemporary Czech railway technology is especially important, because it is precisely this that sets the framework for all the other segments—from rolling stock to signalling and high-speed development. According to Správa železnic, at the beginning of 2025 the network comprised around 9,355 km of lines and 3,271 km of electrified sections, while by the end of 2025 the basic characteristics of the network remained comparable in scale. This is a large, dense, and historically evolved system, but at the same time it bears the marks of different technological eras, which makes modernisation not a localised but a structural task. In 2024, the EIB emphasised that the current modernisation programme covers TEN-T lines across the country, increases in capacity for freight and passenger transport, improvements in safety and comfort, as well as around 40 sub-projects scheduled to continue until the end of 2028. Significantly, the modernisation affects not only the main lines, but also stations, level crossings, maintenance equipment, and accessibility for passengers with reduced mobility. In this sense, Czech rail infrastructure policy today is no longer reducible to the repair of individual sections, but is understood as the technological renewal of the entire network. Such a formulation is especially important for a transit country through which major Central European connections pass. Therefore, Czech rail technologies should be regarded as an infrastructure-led system in which network modernisation itself forms demand for new signalling solutions, rolling stock, diagnostics, telematics, and certification services.

The newest phase of this evolution is connected with the transition to the agenda of high-speed and fast connections, which radically changes the very understanding of Czech railway technology. In 2024, the Ministry of Transport stated directly that the Fast Connections project should modernise, develop, and strengthen the capacity of the Czech railway, while substantially reducing journey times. Official materials indicated that the first investments within the high-speed lines plan were to begin with the sections Nezamyslice–Kojetín and Kojetín–Přerov, and that, within ten years, trains should already be running on the first high-speed lines. In parallel, in 2025 the ministry reported that Správa železnic would receive CZK 62.7 billion for the development of lines and stations, part of which was to be directed precisely towards the start of the first 200 km/h sections and the further preparation of VRT. What matters here is that high-speed rail in the Czech Republic is not an isolated transport project, but a driver of change for the whole railway technosystem. It requires new solutions in signalling, traction power, alignment engineering, interoperability, procurement, and long-term financing. In other words, the technological characterisation of the contemporary Czech railway can no longer be limited to the existing network: it must also take into account the fact that the country is preparing for a qualitative transition to a higher-speed regime. This makes the railway sector of the Czech Republic one of the most promising technological arenas in Central Europe.

One of the most important signs of the maturity of the Czech rail technology ecosystem is the intensive digitalisation of traffic management and the accelerated deployment of European control-command systems. In the presentation of the Ministry of Transport and Správa železnic on the ERTMS rollout in 2024, it was stated directly that ETCS is the only target ATP system for the entire Czech railway network. The Rail Authority further records that, from January 2025, exclusive operation under ETCS began on part of the network, and already around 50,000 trains per month are moving under ETCS supervision; this corresponds to around 42% of the operational performance of the Správa železnic network in terms of train-kilometres and freight tonnage, with a declared reliability of 99.1%. České dráhy, for its part, highlights the programme of equipping 99 railway units with the onboard component of ETCS Level 2 with CEF support. In its annual report for 2024, the carrier also directly noted that preparation for the transition to unified ETCS had become the largest innovation project of the year. Yet digitalisation is not exhausted by ETCS alone. A specialised study on FRMCS, prepared in 2025, shows that the Czech Republic is already considering the conditions for the deployment of the future communications system as the successor to GSM-R, although a fully developed national implementation line is still absent from public strategies. Consequently, Czech railway technology today is developing within the logic of digital transition, in which safety, capacity management, and communications architecture increasingly determine the overall profile of the sector.

No less important is the industrial component of the sector, because it is precisely this that turns the Czech railway system into an export-significant industry, and not merely a domestic infrastructural network. ACRI structures the branch into several technological blocks—rolling stock, infrastructure, component suppliers, control-command and signalling and IT, research and design institutes, and testing laboratories. For 2024, the association emphasised that the Czech rail industry grew faster than national GDP and contrasted this result with the general decline in industrial production in the country and in the EU. Within this cluster, especially visible are Škoda Group, AŽD Praha, CZ LOKO, BONATRANS, DAKO-CZ, DT—Výhybkárna a strojírna, Třinecké železárny, and other actors that form the chain from trains, bogies, brakes, and wheelsets to turnouts, rails, and signalling systems. ACRI even states that almost every second railway wheel product in Europe is associated with Czech production, and that the Czech Republic itself is the largest supplier of metre-gauge trams to Germany. These assessments, even though expressed through an industry association, demonstrate the scale of the specialisation well. The contemporary Czech railway industry is therefore not only a domestic supplier base, but a high-value export manufacturing platform. It is precisely this export and technological density that distinguishes it from many other sectors in which the Czech Republic is strong chiefly as an assembly jurisdiction. In the railway case, the issue is one of much deeper industrial agencies.

Particular attention should be paid to the leading corporate and technological centres of this industry. For 2024, Škoda Group reported a sharp increase in new orders to EUR 1.7 billion, growth in EBITDA to EUR 62 million, and the production of 432 new vehicles—from trams and trolleybuses to trains and coaches. CzechInvest directly characterises AŽD Praha as the largest Czech manufacturer and supplier of control, security, telecommunications, and information technology for transport, and the company covers station and line signalling, level crossing systems, ETCS/ERTMS and GSM-R, while also conducting its own R&D, production, and assembly activities. CZ LOKO, for its part, remains an important centre of locomotive modernisation and production; in 2024, České dráhy reported the early completion of the modernisation of 14 locomotives of Class 742. Třinecké železárny continues to supply rails and railway superstructure accessories, and in 2025 ACRI indicated that, in 2024 alone, the company had produced 241 thousand tonnes of rails and railway accessories, 84% of which went to export. This combination of rolling stock, signalling, locomotive modernisation, and rail metallurgy shows that Czech railway technology retains a rare completeness of industrial profile. For a country of medium size, this is a serious achievement, because it makes it possible to link infrastructural modernisation with its own production contour.

The systemic maturity of the branch is especially clearly visible at the level of testing, certification, and applied research. The key node here is VUZ, and above all the Velim Test Centre. Official VUZ materials emphasise that its testing laboratory is one of the most modern and most sought-after laboratories in the field of rolling stock testing and research, while Velim itself possesses large and small test circuits, the possibility of activating ETCS, a dynamic laboratory, measuring cars, and services for comprehensive testing. VUZ also performs ETCS testing, cybersecurity-related railway services, interoperability assessment as NoBo/DeBo, safety assessment, and certification functions, which is especially important in an era of growing requirements for interoperability and digital safety. At the level of corporate statistics, the České dráhy group itself indicated in 2024 that the certification and testing segment had reached historically its highest profit, while VUZ in a broader sense continues to operate as an international testing and evaluation platform as well. In parallel, VUZ's research activity covers state-of-the-art control and signalling systems, friction brake properties, noise and vibrations topics, and international projects. All this means that Czech railway technology rests not only on production, but also on a powerful validation layer. Without such a base, the country could not retain serious positions either in rolling stock export, or in signalling, or in future high-speed and autonomous applications.

The personnel and scientific-educational reproduction of the railway sphere in the Czech Republic is likewise distinguished by high institutional density. The Faculty of Transportation Sciences at CTU in Prague defines its mission as education and scientific research in the field of transport, telematics, and telecommunications, with an emphasis on state-of-the-art technologies, intelligent transportation systems, and project-oriented teaching, while also participating in EURNE, IRRB, and ERRAC; the faculty itself stresses the existence of unique scientific laboratories and cooperation with AŽD in the creation of a competence centre. The Jan Perner Transport Faculty at the University of Pardubice, for its part, directly builds training around modern laboratories of the Educational and Research Centre in Transport, the Transport Hall, and the teaching laboratory "Central Control Room". The structure of the faculty includes the Department of Electrical and Electronic Engineering and Signalling in Transport, the Department of Transport Means and Diagnostics, the Department of Transport Structures, the Department of Transport Technology and Control, and the Transportation Laboratory. This means that the Czech rail technology ecosystem reproduces specialists not only in classical railway operations, but also in signalling, diagnostics, materials, structures, control, and research instrumentation. As a result, the branch rests on a sustainable human-capital base connected simultaneously with operation, engineering design, and applied science. It is precisely such a personnel architecture that enables the railway industry of the Czech Republic constantly to renew itself without losing engineering continuity.

Finally, a most important feature of the contemporary stage is the movement of Czech railway technology into the zone of experimentation, digital control, and partial autonomisation. The most vivid example is the AŽD project on the Kopidlno–Dolní Bousov line. The company's official materials indicate that it is developing systems for autonomous train operation at GoA4 level, with the aim of creating a complex system of autonomous and digital railways. On the experimental line itself there are deployed electronic interlocking, ETCS Level 2, line signalling systems, modern level crossing protection, axle counters, ATO in ERTMS/ATO design, full GSM-R coverage with 5G extension, sensor-based monitoring, and centralised traffic control. The experimental passenger train EDITA is used as a platform for the gradual integration of new autonomous solutions, while the line itself is described as a highly modern private experimental line. For the characterisation of the sector, this example is especially important because it shows that the Czech Republic is developing not only classical railway engineering and infrastructure, but also future technological scenarios of autonomous operation. Taken together with the ETCS rollout, high-speed preparations, a strong industrial base, and an internationally recognised testing layer, this makes it possible to assess Czech rail technologies as one of the most mature and innovation-rich branches of the contemporary period. It is in this sense that the railway sphere occupies within the Czech technological system a place comparable in strategic significance with aircraft manufacturing, electronics, and automotive engineering.

Achievements

What is important here is to identify precisely those results that make it possible to speak of the real achievements of the contemporary Czech Republic. In the Czech case, achievement in the rail sector is not only the modernisation of an individual line or the release of an individual series of trains. Much more important is the fact that the country has managed to preserve and develop the full contour of railway technological competence: from the manufacture of rails, wheelsets, brakes, rolling stock, and signalling systems to test tracks, certification, digital traffic management, and preparation for the high-speed era. Such complexity is especially valuable in the European context, where many countries are strong in only one or two links of the rail value chain. The Czech Republic, by contrast, has preserved precisely an integral model in which industry, infrastructure management, state policy, the research base, and exports operate in close conjunction. Therefore, the achievements of the Czech Republic in the railway sphere should be assessed simultaneously in several dimensions: industrial, technological, digital, infrastructural, export, and institutional. Only in such a multi-level perspective does it become clear why railway technologies remain one of the strongest and most strategically important branches of the contemporary Czech Republic.

The first fundamental achievement should be regarded as the fact that the Czech railway industry not only survived the post-socialist transformation, but turned into one of the most competitive industrial systems in the country. According to ACRI, the aggregate revenue of the Czech rail industry in 2024 reached EUR 5.3 billion, increasing by 2.3% year on year, while the sector grew faster than national GDP. Exports at the same time retained a share of 50% of total turnover, which demonstrates the high international embeddedness of the sector. Already in March 2026, when summing up the results of 2025, ACRI reported a further strengthening of export positions: 52% of the sector's output went to external markets, and exports exceeded CZK 68 billion. No less indicative is the quality of this specialisation: the association emphasises that almost every second wheelset in Europe is produced in the Czech Republic, while the country itself is the largest supplier of metre-gauge trams to Germany. These figures matter not only as economic indicators. They testify to the fact that the Czech Republic has managed to turn the railway sector into a sustainable export platform of European scale, rather than into a local industry dependent exclusively on domestic orders. It is precisely this that should be regarded as one of the principal achievements of the period 1993–2025.

The second major achievement of the Czech Republic was the retention and development of a strong national manufacturer of rail vehicles, capable not only of operating on the domestic market, but also of remaining a visible player on the European stage. In this case, the central role is played by Škoda Group. According to the results of 2024, the company produced 432 new transport vehicles—from trains and coaches to trams and trolleybuses—while the volume of new orders grew by 74% and reached EUR 1.7 billion. It is especially important that, among the key milestones of 2024, the company identifies the completion of the delivery of 110 RegioPanter units for České dráhy, including four battery-powered trains for the Moravian-Silesian Region, as well as the signing of a new contract for a further 15 battery trains. Škoda's battery platform has particular significance for Czech history: the company itself emphasises that this is the first train of this type not only in the Czech Republic, but in the entire history of Czech railway engineering. Moreover, the effect of these solutions is measurable: the four BEMUs in the region are expected to save at least 200,000 litres of diesel annually and to reduce CO_2 emissions by approximately 500 tonnes. Thus, the Czech achievement here consists not only in output volumes, but also in the fact that the national manufacturer has managed to move towards next-generation zero-emission regional rolling stock and to turn this technology into a new exportable product. This is no longer simply a continuation of the old rolling-stock engineering school, but its qualitative modernisation in the logic of contemporary sustainable mobility.

The third most important achievement was the rapid and, by European standards, highly effective introduction of ETCS as a unified digital traffic management and protection system. The Rail Authority of the Czech Republic records that ETCS is the single pan-European signalling standard ensuring a safe and interoperable railway. Yet precisely in the Czech case, the transition to this system became one of the most notable technological projects of the middle of the 2020s. In February 2025, the Ministry of Transport reported that the first month of exclusive ETCS operation on the main lines had shown reliability at the level of 99.1%; only 0.9% of trains were stopped by preventive safety reaction, while the average time for continuing movement after a stop had fallen to 2 minutes 51 seconds. In parallel, the ministry noted that, from January 2025, exclusive ETCS operation had started on 622 km of corridor lines. For Czech railway technology, this is extremely significant, because the issue is not a test section, but the real transition of a large part of the network to a new digital traffic architecture. At the same time, České dráhy is equipping major series of rolling stock with onboard ETCS components with CEF support, while ACRI at the end of 2025 was already reporting the receipt of new type approvals under the ETCS project for the Pendolino and control car series. Consequently, the Czech achievement here lies not only in the formal introduction of the European standard, but also in the ability to carry out a large-scale digital transition without systemic disruption to operations.

The fourth exceptional achievement of the contemporary Czech Republic should be regarded as the fact that the country has brought railway experimentation with autonomous operation to a level that has received Europe-wide recognition. In April 2025, AŽD officially declared 100% technological readiness to commence regular operation of the first autonomous train with passengers on a railway line in Europe. The company emphasised that this is precisely the first European case of a regular passenger line using a Czech autonomous train. The Kopidlno–Dolní Bousov line serves here not merely as a demonstration route, but as a platform for the development of a complex autonomous and digital railway system including ETCS Level 2, ATO, GSM-R, 5G coverage, sensor-based monitoring, and centralised traffic control. Already in 2021, AŽD had reported the first public demonstration in Europe of an autonomous train with passengers in real operation, and by 2025 the project had been brought to a new level of maturity. This achievement has more than public-relations significance. It shows that the Czech Republic is capable of working not only within the logic of catch-up modernisation, but also in the zone of technological experimentation where future standards of rail automation are being formed. For a sector of such scale, this is especially important, since autonomy in rail transport requires deep integration of signalling, telecommunications, software, and safety engineering. The Czech Republic has demonstrated that it can act as a testing ground and a developer of such solutions, and not merely as a market for their import.

The fifth achievement should be recognised as the preservation and development of one of the most important centres of railway testing and certification in Europe—the Velim Test Centre and the broader VUZ structure. Official VUZ materials emphasise that the Velim complex possesses large and small test circuits, a Dynamic Test Laboratory, and infrastructure for static and dynamic testing of components, trains, and systems. Particularly important is the centre's ability to conduct comprehensive ETCS tests at levels L0, LNTC, L1, and L2, including dynamic transitions between modes. In 2025, Hitachi Rail, describing its own case of work at the test centre, separately emphasised that the availability of a reference vehicle at Velim accelerates certification and reduces costs for manufacturers and operators. Thus, the Czech Republic retains not only industrial production, but also a validation layer of international significance, making it possible to bring rail innovations to market more quickly. At the level of the national economy, this is of fundamental importance: a country possessing a major testing node acquires the role not simply of a supplier of products, but of an arbiter and accelerator of technological verification. In the case of the railway sector, this is one of the highest levels of branch maturity. Therefore, the development and international demand for the Velim Test Centre should be regarded as an independent Czech achievement, and not as a secondary service attached to industry.

The sixth major achievement was the preparation of the Czech railway system for a higher-speed operating regime and the transition to a new infrastructural era. In October 2024, the Ministry of Transport announced that the first sections of high-speed lines should begin construction already in 2025. In December of the same year, the ministry clarified that, in 2025, the first sections designed for 200 km/h would begin within the fast connection between Brno and Přerov, while intensive preparation of high-speed lines would continue. An additional technological marker of this transformation was the testing of the Břeclav–Vranovice line for a speed of 200 km/h, carried out by Správa železnic. What is especially important here is that the Czech achievements at present consist not yet in a fully completed high-speed network, but in moving the issue from the sphere of long-term projects to the sphere of practical engineering implementation: budget allocation, line testing, preparatory works, corridor upgrades, and interface planning with the future VRT network. For the technological history of the country, this is a fundamental shift. It shows that the Czech railway sector has ceased to be exclusively a system of modernised conventional rail and has entered a phase of real preparation for the high-speed transition. Even if this phase has not yet been completed, its very institutional and engineering irreversibility is already an important achievement.

The seventh achievement should be regarded as the preservation of deep component and materials specialisation, which makes the Czech rail industry especially valuable for Europe. In March 2024, ACRI reported that Třinecké železárny, as the only producer of rails and track superstructure elements in the Czech Republic, had produced 250 thousand tonnes of rails and related products in 2023, exporting them to 60 countries worldwide, with an export share of about 89%. Already in its summary for 2024, ACRI again emphasised that almost every second wheelset in Europe bears the marking Made in the Czech Republic. These data reflect not simply the commercial success of individual companies. They show that the Czech

Republic retains positions in the most “material” and critical parts of the rail value chain—steel products, wheelsets, and core components—without which neither rolling stock nor infrastructure renewal is possible. Under conditions of the European discussion on supply-chain resilience, this is especially significant. In effect, the Czech Republic acts not only as an assembly or engineering centre, but also as a supplier of the basic railway materials and components without which many foreign projects could not be realised at the same pace. This turns the Czech railway sector into a structurally important element of the European transport industry.

If one sums up, the principal Czech achievement in railway technologies over the period 1993–2025 lies in the formation of a model rare for a medium-sized country, in which major export industry, contemporary rolling-stock engineering, digital signalling revolution, an internationally significant testing base, advanced component metallurgy, and technological experimentation with autonomous operation coexist simultaneously. The Czech Republic has not become Europe’s largest railway power in terms of market volume, but it has achieved what is perhaps a more complex result: it has preserved and modernised its own rail subjectivity. It is precisely for this reason that the country today is capable not only of servicing its own network, but also of supplying trains, trams, wheelsets, rails, turnout systems, ETCS solutions, and testing services to external markets. What is also important is that many of these achievements fell precisely in the most recent years, when battery trains, ETCS exclusive operation, autonomous railway, and the first 200 km/h sections came to the fore. This means that the Czech railway industry lives not by virtue of the inertia of the industrial past, but through active participation in shaping the future European rail technology landscape. Therefore, in the overall picture of the technological development of the contemporary Czech Republic, railway technologies quite rightly occupy the place of one of the most mature, strategically significant, and innovation-rich branches.

Leading Figures and Their Publications

When moving from the general characterisation of the sector to the level of individual figures, it is important to bear in mind that the contemporary Czech school of rail technologies is not concentrated in a single centre and is not limited to one type of competence. It develops as a distributed research and engineering environment in which, on the one hand, Dopravní fakulta Jana Pernera Univerzity Pardubice is especially prominent, with its strong tradition in rail vehicles, wheel–rail contact, vehicle dynamics, and diagnostics, while, on the other hand, Fakulta dopravní ČVUT v Praze concentrates the lines of signalling, interlocking, transport telematics, and autonomous railway concepts. An additional, yet very important, level of this system is formed by researchers of ČVUT working at the intersection of dependable digital systems and railway safety-critical electronics. It is precisely in the combination of these clusters that the maturity of the contemporary Czech school of railway technology is manifested.

Such a selection is, of course, representative rather than exhaustive in character. Considerably more strong engineers, designers, researchers, and applied specialists are active in the Czech railway sector than can be covered in a single section. However, the figures singled out below are especially important because their activity reflects the key technological lines of the sector: movement dynamics and safety, wheel–rail contact, structural durability, interlocking and signalling architectures, the reliability of safety-critical systems, and the transition to autonomous railway control. Taken together, it is precisely such figures that make it possible to see that the railway school of the contemporary Czech Republic rests not only on strong companies and infrastructural programmes, but also on a sustainable intellectual body.

Within this environment, several stable research clusters may be distinguished. Bohumil Culek, Petr Voltr, and Tomáš Michálek represent above all the line of rail vehicle engineering, running safety, wheel–rail interaction, fatigue, and diagnostics. Martin Leso and Tomáš Brandejský embody the Czech school of railway control, interlocking, safe digital architectures, and autonomous railway operation. Hana Kubátová occupies a special place as a representative of dependability-oriented engineering for railway interlocking systems, linking transport logic with computational and hardware logic. It is precisely through such figures that one can see especially clearly how, in 1993–2025, the Czech Republic developed railway technologies not only as an industrial sphere, but also as a fully-fledged scientific and engineering discipline.

Bohumil Culek

The scientist is one of the most fundamental figures of contemporary Czech railway engineering, especially in the sphere of railway vehicles, structural durability, fatigue, axle safety, and rolling-stock diagnostics. His biography itself reflects a rare completeness of sectoral experience: a designer and strength analyst at Vagónka Česká Lípa, then a researcher and head of the Dynamic Test Facility at Výzkumný ústav železniční Praha, and, after 1993, a professor and one of the central figures of Dopravní fakulta Jana Pernera Univerzity Pardubice. The official page of the university already shows that his scientific and professional profile is built around the life cycle of railway rolling stock, the durability of frames and axles, the assessment of service loading, and methods of modern fatigue assessment. For the contemporary Czech Republic, this is especially important, because it is precisely such researchers who preserve continuity between classical rolling-stock mechanics and contemporary safety engineering. Through his works, one sees clearly that the Czech railway school remains strong not only in new digital solutions, but also in the fundamental questions of reliability and structural life.

Leading works:

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3. Culek, B., Schmidová, E., Malinský, J., Culek, B., & Pulda, J. (2023). *Experimentální výzkum materiálů kol a kolejnic na stendu VDP Univerzity Pardubice* [Experimental research on wheel and rail materials at the VDP stand of the University of Pardubice]. In *Současné problémy v koľajových vozidlách — PRORAIL 2023, Diel I* (pp. 53–60). VTS pri Žilinskej univerzite. https://dfjp.upce.cz/en/user/8365
4. Pulda, J., Culek, B., & Voltr, P. (2023). *Experimentální ověření vlivu spinu na síly v kontaktu kolo-kolejnice: současný stav poznání* [Experimental verification of the effect of spin on forces in wheel–rail contact: current state of knowledge]. In *Současné problémy v*

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5. Vágner, J., Culek, B., & Culek, B. (2009). Possibility of multiaxial test simplification of rail vehicle bogie frames. *Scientific Papers of the University of Pardubice, Series B, The Jan Perner Transport Faculty, 14*, 17–27. https://dfjp.upce.cz/en/user/5911

Petr Voltr

The scientist is one of the key figures of the contemporary Czech school of wheel–rail contact, adhesion phenomena, traction dynamics, and the diagnostic analysis of rolling stock. His research group at Univerzita Pardubice directly defines its principal directions as vehicle–track interaction, adhesion, wheel and rail wear, running safety, analysis of the dynamic behaviour of rail vehicles, and vehicle/infrastructure diagnostics. Through Voltr, the mechanical-dynamic component of railway technology in the Czech Republic becomes especially clear. His publications are consistently built around transient wheel–rail adhesion, rolling contact, lateral dynamics, and traction behaviour. This direction has strategic significance, because without it it is impossible either to design trains and locomotives correctly, or to assess running safety, or to move towards higher operating speeds. In the Czech case, Voltr represents that line of rail technology which connects the fundamental mechanics of contact with the applied questions of operation and diagnostics.

Leading works:

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3. Voltr, P., & Lata, M. (2014). *Transient problems in rolling contact of wheel and rail*. In *Proceedings of the 9th International Conference on Railway Bogies and Running Gears* (pp. 145–152). Budapest University of Technology and Economics. https://dfjp.upce.cz/en/user/6173
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Tomáš Michálek

The scientist is one of the leading figures of contemporary Czech research into rail vehicle dynamics, running resistance, the effects of lateral forces, and infrastructure-oriented diagnostics. In the research group at Univerzita Pardubice, he appears as one of the leaders of the most active line devoted to the analysis of the dynamic behaviour of railway vehicles, track loading, and diagnostic monitoring based on dynamic response during running. His significance has increased particularly in the context of the 2020s, when the Czech railway system is simultaneously preparing for higher-speed regimes, increasing its requirements for energy efficiency, and strengthening digital monitoring of technical condition. Through Michálek's work, one can clearly see how classical movement dynamics is gradually being joined to the applied tasks of model-based diagnostics, the analysis of running resistance, and S-curve behaviour. Thus, he represents that part of Czech railway science which connects simulation, measurement, and the operational assessment of movement safety.

Leading works:

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Martin Leso

The scientist is one of the most prominent figures of the contemporary Czech school of railway interlocking, transport telematics, and autonomous railway operation. His publication profile at Fakulta dopravní ČVUT v Praze shows a sustained concentration precisely on those themes that in the 2020s became central to the Czech railway: interlocking architectures, safety requirements under CENELEC standards, the Transport Laboratory as an R&D railway laboratory, and the safety of autonomous train operation at GoA3/GoA4 levels. Through Leso, it becomes especially clear how railway technology in the Czech Republic is increasingly moving beyond the limits of classical signalling hardware and entering the sphere of integrated digital control-command concepts. For the contemporary Czech Republic, this is especially important, because it is precisely such researchers who link Railway 4.0, ETCS-related architectures, safety assessment, and future autonomous railways. In this sense, Leso represents the most contemporary signalling-and-automation branch of the Czech rail technology ecosystem.

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4. Leso, M. (2017). *ITS on railway*. In *Modernization of Railway — IRICoN 2017* (pp. 27–28). Czech Technical University in Prague. https://www.fd.cvut.cz/en/faculty/people/person/1b7e77e6-217d-4e3d-869f-3a85a27b736a/publications

Tomáš Brandejský

The scientist is one of the representative figures of the Czech line of safe digital architectures for railway interlocking and traffic optimisation. His profile at ČVUT shows a combination of applied railway informatics, safety-oriented software development, and the modelling of railway control processes. It is precisely through Brandejský that one can see particularly clearly how the Czech signalling school developed from individual solutions for station interlocking towards a broader understanding of the integrated interlocking system within the Railway 4.0 concept. His works also show an interest in programming-language safety, safe system development, and the role of information systems in operative railway traffic control and conflict-free timetable planning. For the contemporary Czech Republic, this is especially significant, because the transition to centralised dispatching, ETCS, RBC functions, and future automation requires not only hardware, but also a safe software and architectural logic. Brandejský therefore embodies the software-and-systems side of Czech railway technology.

Leading works:

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Hana Kubátová

The scientist occupies a special place in the Czech railway technological environment, because she represents not classical transport engineering in the narrow sense, but the direction of dependability engineering for safety-critical railway systems. Her publication profile at FIT ČVUT shows many years of work on railway station safety devices, railway interlocking equipment implemented in FPGA, predictive reliability analysis, and hierarchical dependability models. For the contemporary Czech Republic, this is of great importance, because railway technology in the 21st century can no longer develop without a reliable hardware and software architecture designed for fail-safe operation. It is precisely such researchers as Kubátová who provide the intellectual bridge between digital design, fault-tolerant architectures, and practical railway control devices. Through her works, it becomes especially clear that the Czech rail technology school includes not only mechanical engineers and transport specialists, but also experts in the critical computational infrastructure of the railway.

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Part 10

Nuclear Engineering and Radiopharmaceutical Technologies

General Characterisation

Nuclear engineering and radiopharmaceutical technologies in the contemporary Czech Republic form not two accidentally neighbouring fields, but a single high-technology complex based on shared competences in reactor physics, radiochemistry, materials science, dosimetry, nuclear safety, the handling of radioactive substances, and engineering verification. In the Czech case, it is especially important that the nuclear sphere is not reducible solely to nuclear power generation. It encompasses large power units, research reactors, experimental loops and hot cells, critical assemblies, control and diagnostic systems, nuclear education, waste management, radionuclide production, and the manufacture of radiopharmaceutical products for clinical practice. Thanks to this, the Czech Republic retains a technological profile of a completeness that is rare for a country of medium scale. At the level of state and sectoral logic, the nuclear field is regarded as a long-term pillar of energy resilience, while radiopharmacy is viewed as a high-value medical and scientific specialisation. Such a dual structure is especially characteristic of countries in which nuclear science has managed to preserve continuity between energy, research, and applied medicine. That is why the development of this field in the Czech Republic should be understood as the formation of a unified nuclear and radiopharmaceutical ecosystem, and not as the parallel existence of several weakly connected sectors. In the overall picture of the country's technological development, this is one of the most institutionally mature and strategically burdened directions.

After the dissolution of Czechoslovakia, the Czech Republic did not begin its nuclear sector from scratch, but inherited a substantial part of the scientific, engineering, and educational base, which then had to be adapted to the market economy, European law, and new safety standards. As a result, the contemporary sector is constructed as a system in which historical institutions did not disappear, but were transformed and embedded in a new organisational environment. ÚJV Řež and the structures associated with it retained the role of a technological centre operating at the intersection of energy, industry, and health. Research Centre Řež was transformed into a major research platform oriented towards reactor physics, materials, diagnostics, and energy technologies. In parallel, Nuclear Physics Institute of the Czech Academy of Sciences developed an accelerator and radiochemical contour directly linked to the production and development of medical radionuclides. It is also significant that the radiopharmaceutical branch in the Czech Republic does not have a purely hospital origin, but grew out of a broader nuclear-scientific infrastructure. Such a trajectory explains why the contemporary Czech Republic in the nuclear sphere appears not as a country importing ready-made solutions, but as a country possessing its own layer of engineering authorship and scientific memory.

The energy core of this system consists of two operating nuclear power stations—Dukovany and Temelín. The Czech National Report under the Convention on Nuclear Safety for 2025 explicitly states that two operating nuclear installations are active in the country, both operated by ČEZ, with Dukovany comprising four VVER-440/213 units and Temelín two VVER-1000/320 units. Thus, the contemporary Czech Republic relies on six power reactors forming a stable low-carbon basis of the electricity system. ČEZ itself, in its 2024 annual report, emphasises that nuclear power stations will remain part of its carbon-neutral and stable portfolio, while the construction of new modular and large units is regarded as a continuation of this line. It is especially indicative that, on 4 June 2025, EDU II and Korea Hydro & Nuclear Power signed an EPC contract for the construction of two new power units at Dukovany. This means that Czech nuclear engineering in the middle of the 2020s is no longer confined to extending the lifetime of existing installations, but has entered a phase of major new construction. Consequently, the contemporary characterisation of the sector must take into account two levels at once: the reliable operation of the existing fleet and the preparation of the next generation of large nuclear generation. It is precisely this that makes Czech nuclear power not merely a preserved, but a developing technological system.

However, Czech nuclear engineering is not exhausted by power units, because its scientific and experimental base is unusually deep. Research Centre Řež directly describes LVR-15 and LR-0 as pillars of its technology. LVR-15 is used primarily for the irradiation of materials, the production of radiopharmaceuticals, neutron radiography, and other neutron-beam applications, whereas LR-0 serves as a flexible platform for modelling virtually any configuration of power reactors and verifying their neutronic characteristics. An additional layer is provided by VR-1 Nuclear Experimental Hub at CTU in Prague, which operates as a large research infrastructure with open access and supports research, education, and practical training in nuclear engineering. Faculty of Nuclear Sciences and Physical Engineering directly emphasises that education there is supplemented by experimental work in laboratories and on reactor VR-1, with an emphasis on neutron physics, thermohydraulics, and the design and operation of nuclear reactors. Taken together, this means that the Czech Republic possesses not only operating power units, but also a powerful system of experimental reactors and training installations. Such a system is especially valuable because it links fundamental science, engineering design, training, and validation in one institutional chain. It is precisely the presence of this layer that makes the Czech nuclear sphere resilient in the long term.

A substantial role in the contemporary Czech model is also played by the applied engineering contour that ensures the link between research and operation. Research Centre Řež describes its activity as focused on nuclear energy, reactor physics and technology, chemistry, and materials in support of Czech and foreign organisations. ÚJV Řež, for its part, directly defines nuclear power engineering as its priority, that is, support for operating units and preparation for new ones, together with a full-service contour for radioactive waste management. This means that the Czech nuclear sector is built not only around the operator of nuclear power stations, but also around technological organisations capable of carrying out calculations, diagnostics, engineering, safety support, and materials research for energy and related fields. Through such a structure, the Czech Republic retains strategic know-how within the country rather than transferring key competences wholly outside it. It is especially important that this applied engineering layer serves several directions simultaneously: the long-term operation of existing plants, preparation for new build, fuel-cycle-related services, waste and decommissioning tasks, and nuclear medicine applications. That is why Czech nuclear engineering appears as a multi-nodal system, rather than as a single energy project. For a country of medium size, this is one of the most important signs of technological maturity.

Another pillar of the sector is a developed system of regulation, safety, and radioactive-waste management. The IAEA IRRS mission, whose final report was published in 2024, examined the governmental, legal, and regulatory framework of the Czech Republic in the field of nuclear and radiation safety and explicitly noted the high level of cooperation of the country and SÚJB. This matters not as a diplomatic gesture, but as confirmation that the Czech nuclear system operates within a stable regulatory architecture oriented towards continuous improvement. No less indicative is the contour of radioactive waste management. In its 2024 annual report, SÚRAO states that the Czech deep geological repository is intended for waste not accepted by the existing Richard, Bratrství, and Dukovany facilities, while the expected commissioning date of the DGR is given as 2050. At the same time, in May 2025, Bukov Underground Research Facility II entered trial operation; the facility, at a depth of around 500 metres, is intended for a wide range of experiments, including demonstration models of future disposal spaces. Consequently, contemporary Czech nuclear engineering includes not only generation and research, but also the active development of the back end of the nuclear cycle. It is precisely this that substantially distinguishes a mature nuclear country from a state in which the operation of reactors is not accompanied by its own technological development in the field of final waste isolation.

The contemporary dynamic of the sector is also directed towards the future, above all towards small modular reactors. The Czech SMR Roadmap explicitly considers SMRs as an instrument for forming a zero-emission energy system, ensuring electricity and heat supply, and potentially producing hydrogen in an energy system based on renewables. In September 2024, the Ministry of Industry and Trade reported ČEZ's intention to create a strategic partnership with Rolls-Royce SMR; the government stressed that this should modernise the energy sector and open new opportunities for Czech industry. At the same time, the official statement explicitly says that ČEZ plans to build its first modular reactor near Temelín, and that both ÚJV Řež and regional structures are involved in the preparation. Importantly, in this case the Czech Republic seeks not merely to purchase a future technology, but to enter the global supply chain at an early stage. Thus, the SMR direction in the Czech model is not an alternative to large reactors, but an additional line of sectoral development. Taken together with the Dukovany II project, this shows that Czech nuclear engineering is moving along two trajectories simultaneously: large-scale new build and future modular technologies. It is precisely the combination of these trajectories that makes it especially interesting in the context of the 2020s.

The radiopharmaceutical branch constitutes the second strategic support of this chapter and shows how far Czech nuclear competence extends beyond electricity generation. ÚJV Řež explicitly states that, in the field of nuclear medicine, it is engaged in the development, production, and distribution of radiopharmaceuticals and operates three PET centres—in Prague, Brno, and Řež. A separate page on the PET centres specifies that the Prague centre was the first in the Czech Republic and was established in cooperation with the IAEA, and that it was there, in August 1999, that the first patient in the country was examined by means of PET. The Brno PET Centre was established to provide the Moravian regions with their own supplies of PET radiopharmaceuticals, while the centre in Řež combines research-and-development and manufacturing functions and is oriented, in particular, towards ultra-short-lived PET radionuclides. Industrial scale is also important: ÚJV stresses that it supplies radiopharmaceuticals to a wide range of nuclear-medicine institutions in the Czech Republic and abroad. In November 2025, the company announced that it had become a contract manufacturing organisation for Curium and had produced the first commercial batches of diagnostic radiopharmaceuticals for patients in Slovakia and the Czech Republic. All this means that, in radiopharmacy, the Czech Republic possesses not only academic competence, but also a fully-fledged production-and-clinical contour.

The scientific depth of this direction is especially clearly visible in the case of Nuclear Physics Institute of the Czech Academy of Sciences. Its Department of Radiopharmaceuticals was established in 1997 with the aim of introducing PET radiopharmaceuticals into Czech hospitals and developing research on radionuclides and labelled compounds for diagnosis and therapy. The official page of the department emphasises its close link with Department of Accelerators, which operates cyclotrons TR-24 and U-120M in Řež and the MT-25 microtron in Prague. Among the current scientific directions listed are cyclotron production of novel medical radionuclides, including non-conventional PET metals, cyclotron production of 99mTc, work with labelled antibody fragments, and microfluidic systems for automated labelling. Such a formulation is especially significant because it takes Czech radiopharmacy far beyond routine FDG production and connects it with advanced nuclear chemistry, targetry, radionuclide innovation, and translational biomedicine. Consequently, the radiopharmaceutical part of the Czech nuclear sphere is not a secondary medical service, but a fully-fledged scientific and technological direction based on accelerators, radiochemical laboratories, and research teams. Combined with research reactors, PET centres, and the industrial activity of ÚJV Řež, this forms one of the most substantial and high-technology medical branches of contemporary Czech science. That is why the general characterisation of Chapter 10 should be built as an analysis of the unified complex of nuclear engineering and radiopharmaceutical technologies, and not as a description of two disconnected industries.

Achievements

It is fundamentally important to identify precisely those results that make it possible to speak of the achievements of the contemporary Czech Republic, and not merely of the existence of an industry. In the Czech case, achievement in the nuclear sphere does not consist only in the operation of already constructed power units. Much more important is the fact that the country has managed to preserve and develop an almost complete contour of nuclear competence: operating nuclear power stations, research reactors, engineering and analytical support, waste-management systems, personnel training, an accelerator base, the production of medical radionuclides, and the manufacture of radiopharmaceutical products. It is precisely such completeness that makes the Czech case especially indicative for Europe. The Czech Republic is not the continent's largest nuclear power in terms of scale, but it has achieved a result that is rare for a medium-sized country: it has preserved nuclear subjectivity, that is, the ability not only to operate imported solutions, but also to develop its own scientific-engineering and applied directions. Therefore, the achievements of the Czech Republic in 1993–2025 should be assessed simultaneously in several dimensions—energy, research, engineering, regulatory, and medical. Only in such a multi-level perspective does it become clear why Chapter 10 occupies a special place in the overall picture of the technological development of the contemporary Czech Republic.

The first fundamental achievement should be recognised as the fact that the Czech Republic not only preserved operating nuclear power after the dissolution of Czechoslovakia, but retained it as a stable and modernisable foundation of the national energy system. The Czech

National Report under the Convention on Nuclear Safety for 2025 directly states that the country has two operating nuclear installations, operated by ČEZ: Dukovany with four VVER-440/213 reactors and Temelín with two VVER-1000/320 reactors. This fact alone is important, since the issue concerns six power units forming a stable technological framework of the sector. But the key achievement lies not in the number of units itself, but in the ability constantly to update and strengthen their safety and operational reliability. The same national report shows that, in 2022–2024, specific safety improvements were implemented at Dukovany and Temelín, including pressure reduction systems in gas receivers, which increase resilience to beyond-design-basis accident scenarios, while the reconstruction of certain systems at Dukovany continued in 2024 and further on some units in 2025. This means that Czech nuclear power in the 2020s is developing not according to a model of passive survival of ageing installations, but according to a model of active long-term operation supported by engineering upgrades. For a Central European country, this is in itself already a major technological achievement.

The second greatest achievement of the contemporary Czech Republic has been the fact that, after a long period of preparation, the country moved the theme of new nuclear build from the sphere of concepts into the sphere of real contractual and engineering implementation. In its annual report for 2024, ČEZ directly describes the construction of two new units at Dukovany as the largest contract in the Czech Republic, noting that, in July 2024, the government designated KHNP as the preferred supplier, while the company itself proceeds from the assumption of the start of construction in 2029 and trial operation of the first new unit in 2036. The Ministry of Industry and Trade then confirmed that, on 4 June 2025, EDU II and KHNP signed the EPC contract for the construction of two new power units. It is especially important here that the issue concerns not only a major investment, but also the return of the Czech Republic to the club of countries that in the twenty-first century are genuinely launching new large-scale nuclear construction. For the technological history of the country, this is a watershed moment. It shows that Czech nuclear engineering has not confined itself to operating the legacy of the late twentieth century, but has entered a new cycle of development requiring design, supply-chain integration, licensing support, personnel reproduction, and substantial participation of national industry. It is precisely for this reason that Dukovany II should be regarded as one of the most large-scale technological achievements of the Czech Republic in recent years.

The third important achievement should be considered the fact that the Czech Republic did not confine itself to relying on large units, but in parallel built a fully-fledged line of development in the field of small modular reactors. The Czech SMR Roadmap directly formulates for SMRs a long-term role in decarbonised energy, heat supply, and potential hydrogen production, while, in September 2024, the Ministry of Industry and Trade reported the formation of strategic cooperation between ČEZ and Rolls-Royce SMR. The official statement emphasised that ČEZ plans to construct its first modular reactor near Temelín. This is especially significant because it demonstrates the maturity of the Czech approach: the country is not waiting for the end of the global SMR cycle, but is attempting to enter it at an early stage and embed its own engineering and industrial base within it. Consequently, the Czech achievement here lies not in an already built modular reactor, which does not yet exist, but in the fact that the country has institutionally and strategically secured itself within one of the most promising directions of world nuclear technology. In combination with the large-unit project, this creates a rare two-track model of sectoral development: large new build plus a modular future. For a medium-sized country, such a dual strategy is a serious achievement of long-term planning.

The fourth achievement of the Czech Republic has been the preservation and development of research nuclear infrastructure, which in certain respects is no less important than nuclear power generation itself. The National Report under the Convention on Nuclear Safety for 2025 indicates that four research reactors are in operation in the country: LVR-15 and LR-0 in Řež and VR-1 with VR-2 at the CTU site in Prague, and that they function as large research infrastructures in open access mode. VR-1 Nuclear Experimental Hub at CTU directly defines itself as a large infrastructure for research, development and innovation with open access, supported for 2023–2029, and emphasises its role as a key experimental base for the teaching of nuclear engineering, nuclear safety, reactor and neutron physics, and fuel-cycle-related work. Of particular significance is the commissioning of the subcritical reactor VR-2 in June 2023, because this shows that the Czech educational-experimental base is not only being preserved, but is also developing. Research Centre Řež, for its part, continues to rely on LVR-15 and LR-0 as the principal experimental platform for irradiation, neutron applications, and reactor-physics validation. As a result, the Czech Republic has achieved a result that is rare for Europe: it has preserved a full chain of “power reactors—research reactors—educational reactors—open-access experimentation”. It is precisely this chain that makes its nuclear school reproducible, and not accidental.

The fifth important achievement should be recognised as the strengthening of the applied engineering layer that links reactor science, operation, long-term safety, and new technological directions. In its annual report for 2023, ÚJV Řež directly states that it remains a key provider of expert support for Temelín and Dukovany, works in fuel-cycle services, radioactive-waste management, nuclear safety, and materials engineering, and also carries out developments relating to operating reactors, Gen IV, and small modular reactors. Particularly indicative are references to its own reactor-physics software ANDREA, projects on the integrity of pressure vessels, advanced ultrasonic inspection robots, and participation in international projects APIS, McSafer, EURAD, and PREDIS. This means that the Czech nuclear sector possesses not merely an operator of nuclear power stations and research sites, but a fully-fledged engineering and technical support organisation capable of conducting long-term analytical, design, and diagnostic work. For a country of this scale, this is a serious achievement, because it is precisely such structures that retain critical know-how within the country, which would otherwise quickly pass to external contractors. In the long term, it is precisely this applied engineering layer that makes possible both new reactors and the safe long-term operation of the old ones, as well as the development of medical directions linked to nuclear infrastructure.

The sixth major achievement of the Czech Republic has been the fact that the country conducts not only front-end nuclear activity, but also systematically develops the back end of the nuclear cycle, above all deep geological disposal research. In its annual report for 2024, SÚRAO confirms that the Czech Republic continues to prepare a deep geological repository for waste not accepted by the existing facilities, with a target commissioning horizon of around 2050. A particularly important step was the entry of Bukov Underground Research Facility II into trial operation on 5 May 2025. According to SÚRAO, the new facility is located at a depth of approximately 500 metres in a former uranium mine and includes 13 testing chambers and a system of corridors up to 95 metres long, intended for a wide spectrum of experiments connected with deep geological disposal. For sectoral assessment, this is exceptionally important: the maturity of a nuclear country is measured not only by electricity generation and laboratory research, but also by the extent to which it is capable of developing its own solutions for the long-term isolation of waste. The Czech Republic demonstrates here a consistent and technologically rich line of work, and not symbolic activity. This makes it possible to regard waste management and underground research as one of the real achievements of Czech nuclear engineering.

The seventh achievement, already at the intersection of nuclear science and medicine, has been the formation in the Czech Republic of a genuinely strong radiopharmaceutical contour. In its annual report for 2023, ÚJV Řež directly describes itself as the largest supplier and producer of radiopharmaceuticals for the Czech market, providing more than 85% of PET examinations in Czech nuclear medicine. This is a very strong indicator: it means that Czech radiopharmaceutical competence has moved far beyond the laboratory stage and has become an infrastructurally critical part of clinical diagnostics. No less important is the fact that ÚJV has developed a network of PET centres. The official page of the PET centres states that Prague PET Centre, built with IAEA support, was the first centre of this type in the country, opened in August 1999, and that it was there that the first patient in the Czech Republic was examined by means of PET. Subsequently, Brno PET Centre was established in order to make the Moravian regions independent of supplies from Central Bohemia, while PET Centre Řež occupied the development-manufacturing-application niche for new radiopharmaceuticals with ultra-short-lived radionuclides. Thus, the Czech achievement here lies not only in the production of preparations, but also in the creation of a national network of production and clinical application of PET radiopharmaceuticals.

The eighth and perhaps most contemporary achievement should be regarded as the fact that, in 2025, Czech radiopharmacy advanced from a national supporting function to a more pronounced international and innovative profile. In November 2025, ÚJV Řež reported that it had become a Contract Manufacturing Organization for Curium and had produced the first commercial batches of diagnostic radiopharmaceuticals: first for patients in Slovakia, and then for patients in the Czech Republic. This is an important transition from internal provision to an internationally integrated contract model. In parallel, the Department of Radiopharmaceuticals at the Nuclear Physics Institute CAS shows that the Czech school is not limited to routine production, but is conducting research on the cyclotron production of novel medical radionuclides, including non-conventional PET metals, cyclotron production of 99mTc, labelled antibody fragments, and microfluidic systems for automated labelling. The Department of Accelerators of the same institute additionally provides the technological basis for this work by operating cyclotrons TR-24 and U-120M and the MT-25 microtron. If these facts are brought together, the picture becomes quite definite: the Czech Republic has achieved in radiopharmacy not merely clinical self-sufficiency, but scientific and production maturity, in which accelerators, radiochemistry, targetry, PET centres, and commercial production form a unified system. It is precisely this that makes the radiopharmaceutical direction one of the most impressive achievements of contemporary Czech nuclear science.

Leading Figures and Their Publications

When moving from the general characterisation of the sector to the personal level, it is important to take into account that the contemporary Czech school of nuclear engineering and radiopharmacy is not concentrated in a single institute. It develops as a distributed research and engineering environment in which Katedra jaderných reaktorů FJFI ČVUT v Praze, Oddělení radiofarmak and Oddělení urychlovačů Ústavu jaderné fyziky Akademie věd České republiky, as well as the broader applied contour associated with research reactors and the engineering support of nuclear power engineering, are especially prominent. It is precisely this institutional diversity that makes the Czech case especially illustrative: energy, research reactors, the accelerator base, and radiopharmacy here form one interconnected system, rather than a set of isolated directions.

This selection is representative rather than exhaustive in character. Considerably more strong engineers, physicists, radiochemists, and applied specialists are active in the Czech nuclear sphere, yet it is precisely the figures singled out below that most clearly reflect the principal lines of development in 1993–2025: reactor physics and kinetics, reactor instrumentation, fuel-cycle and safety teaching, accelerator-driven radionuclide production, radiopharmaceutical chemistry, and translational nuclear medicine. Some of them represent the reactor-engineering core of the Czech school, others the accelerator-radiochemical and radiopharmaceutical branch.

Within this environment, two major groups of figures are especially prominent. Jan Rataj, Ondřej Huml, and Ľubomír Sklenka represent above all the Czech line of reactor physics, experimental reactor engineering, nuclear education, and safety-oriented analysis. Ondřej Lebeda, Jan Ráliš, and Milan Štefánik embody the accelerator-radiochemical and radiopharmaceutical direction, in which cyclotron production of radionuclides, target systems, excitation functions, PET/SPECT radiopharmaceuticals, and emerging alpha-therapy isotopes become central. It is precisely through such figures that one sees especially clearly how the Czech Republic preserves continuity between nuclear power engineering, research reactors, and the medical applications of nuclear science.

Jan Rataj

The scientist is one of the central figures of the contemporary Czech school of reactor physics and nuclear reactor engineering. His official profile at FJFI ČVUT shows that he heads Katedra jaderných reaktorů, while his publication profile links him with VR-1, reactor kinetics, reactor dosimetry, measurement methods, and the broader questions of applying advanced reactor concepts in Czech conditions. His work shows especially clearly how the Czech nuclear school connects the educational reactor contour with serious research themes—from delayed neutron fraction and benchmark experiments to assessments of the prospects of high-temperature reactors. For the contemporary Czech Republic, this is especially important, because it is precisely such researchers who ensure continuity between reactor education, experimental validation, and future-oriented nuclear engineering.

Leading works:

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Ondřej Huml

The scientist is one of the most prominent figures of the Czech line of experimental reactor physics, neutron measurements, mixed-field dosimetry, and VR-1/VR-2 development. His profile at FJFI ČVUT and his teaching and grant activity show that he works at the intersection of advanced experimental reactor physics, neutron spectroscopy, reactor diagnostics, and subcritical systems. His publications show particularly clearly how applied methods for measuring neutron fields, mixed neutron/gamma environments, transient reactor behaviour, and training-oriented research infrastructure are being developed in the Czech Republic. For the contemporary Czech Republic, this is of fundamental importance, since it is precisely such researchers who turn educational and experimental reactors into fully fledged platforms for contemporary dosimetry, spectrometry, and reactor validation.

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Ľubomír Sklenka

The scientist is one of the most representative figures of the contemporary Czech reactor-engineering school in the fields of core physics, fuel management, the safe operation of nuclear facilities, and long-term nuclear education. His profile at FJFI ČVUT emphasises not only his affiliation with Katedra jaderných reaktorů, but also his teaching specialisation in core physics and fuel management, the nuclear fuel cycle, and the safe operation of nuclear facilities. This is important because Sklenka represents that part of the Czech nuclear school in which fundamental reactor physics is connected with operational safety and the practical training of specialists. His publications show clearly how the Czech school worked on reactivity coefficients, instrumentation for zero-power research reactors, fuel transitions, and broader debates on future reactors. As a result, Sklenka appears as one of the key figures in maintaining continuity between reactor operation, fuel-cycle awareness, and higher nuclear education in Czechia.

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1. Bílý, T., & Sklenka, Ľ. (2014). Measurement of isothermal temperature reactivity coefficient at research reactor with IRT-4M fuel. *Annals of Nuclear Energy, 71*, 91–96. https://doi.org/10.1016/j.anucene.2014.03.033
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Ondřej Lebeda

The scientist is one of the key figures of contemporary Czech radiopharmacy and accelerator-based radionuclide production. The official page of Ústav jaderné fyziky Akademie věd České republiky shows that he heads Oddělení radiofarmak, has led projects on copper isotopes and new theranostics, microfluidic labelling systems, and work on cyclotron production of ^{99m}Tc; it also notes his participation in KATRIN and in the work of European Pharmacopoeia structures. Moreover, in 2026 it was precisely he, together with Jan Ráliš, who led the AlphaStar project on the development of a technology for obtaining ^{225}Ac, in which ÚJF AV ČR achieved its first production run at the 1 GBq scale. Through Lebeda's figure, one sees especially clearly how the Czech radiopharmaceutical school combines classical nuclear chemistry, cyclotron physics, clinical diagnostics, and emerging targeted alpha therapy. For the contemporary Czech Republic, he is one of the most significant figures at the intersection of nuclear science and medicine.

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3. Lebeda, O., Ondrák Fialová, K., Ondrák, L., Červenák, J., Ráliš, J., & Štursa, J. (2025). Cross sections of the ^{226}Ra(p,xn) reactions relevant for ^{225}Ac production. *Nuclear Medicine and Biology, 142–143*, 108995. https://doi.org/10.1016/j.nucmedbio.2025.108995

4. Čepa, A., Ráliš, J., Marešová, L., Kleinová, M., Seifert, D., Sieglová, I., Král, V., Polášek, M., Paurová, M., Lázníček, M., & Lebeda, O. (2019). Radiolabeling of the antibody IgG M75 for epitope of human carbonic anhydrase IX by ^{61}Cu and ^{64}Cu and its biological testing. *Applied Radiation and Isotopes, 143*, 87–97. https://doi.org/10.1016/j.apradiso.2018.10.021

Jan Ráliš

The scientist is one of the most prominent figures of the contemporary Czech radiopharmaceutical branch, especially in the directions of copper-labelled antibodies, excitation-function studies, translational radionuclide work, and emerging ^{225}Ac production. Official materials of ÚJF AV ČR confirm that he is deputy head of Oddělení radiofarmak, and in 2026 he, together with Ondřej Lebeda, co-led the AlphaStar project aimed at obtaining clinically relevant quantities of ^{225}Ac. An additional important layer of his activity is connected with participation in KATRIN-related source work, which shows a rare combination in one individual of radiopharmacy and nuclear-physical calibration applications. His publications show clearly how the Czech radiochemical school is moving from copper PET isotopes and antibody fragments towards more complex therapeutic radionuclides and high-purity production problems. For that reason, Ráliš represents one of the most promising lines of contemporary Czech radiopharmacy.

Leading works:

1. Čepa, A., Ráliš, J., Král, V., Paurová, M., Kučka, J., Humajová, J., Lázníček, M., & Lebeda, O. (2018). In vitro evaluation of the monoclonal antibody ^{64}Cu-IgG M75 against human carbonic anhydrase IX and its in vivo imaging. *Applied Radiation and Isotopes, 133*, 9–13. https://doi.org/10.1016/j.apradiso.2017.12.013
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Milan Štefánik

The scientist is one of the key figures of contemporary Czech accelerator-based nuclear technology at the intersection of fast neutron sources, activation analysis, cyclotron applications, and isotope-production-related research. In February 2025, he became head of Oddělení urychlovačů Ústavu jaderné fyziky AV ČR, while materials of CANAM additionally show him as one of the responsible figures for fast neutron sources and nuclear data work. His research line is especially important because it links the reactor and accelerator parts of the Czech nuclear school: from VR-1 activation analysis and neutron spectrum measurements to cyclotron-driven neutron fields relevant for fusion and radionuclide production. An additional important aspect is provided by the project on measuring neutron leakage from the $^{18}O(p,n)$ reaction used for ^{18}F production, where his activity directly intersects with radiopharmaceutical infrastructure. For that reason, Štefánik represents that part of the contemporary Czech nuclear sphere in which accelerator physics, dosimetry, activation methods, and medical-isotope support form a unified technological line.

Leading works:

1. Štefánik, M., Sklenka, Ľ., Huml, O., & Rataj, J. (2019). Activation analysis of Tibetan coins and thermal neutron flux measurement at the VR-1 training reactor. *Radiation Physics and Chemistry, 155*, 304–309. https://doi.org/10.1016/j.radphyschem.2018.06.032
2. Štefánik, M., Rataj, J., Huml, O., & Sklenka, Ľ. (2017). Study of dietary supplements compositions by neutron activation analysis at the VR-1 training reactor. *Radiation Physics and Chemistry, 140*, 471–474. https://doi.org/10.1016/j.radphyschem.2017.03.017
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Conclusion

The history of the technical sciences and technologies in contemporary Czechia from 1993 to 2025 demonstrates not a simple story of post-socialist recovery, but the formation of a distinctive national model of technological development. This model did not emerge immediately after independence, nor did it arise as a direct copy of Western European innovation systems. Rather, it was built gradually through institutional preservation, legislative reform, European integration, infrastructural expansion, and the later strategic concentration of resources in those branches where the country possessed genuine engineering depth. In the Czech case, the decisive issue was never merely whether science would survive, but what type of science-and-technology system would be constructed after the collapse of the old branch-research order. By 2025, the answer had become clear. Czechia did not become a venture-dominated digital economy centred on platform corporations and radical startup disruption. Instead, it developed into a polycentric, business-centred, infrastructure-rich, and application-oriented technological system grounded in manufacturing competence, strong technical universities, public research organisations, and selective frontier specialisations. Its strongest features lie in applied engineering, industrial R&D, complex instrumentation, computational infrastructures, transport technologies, and technologically sophisticated exports. Its weaknesses remain equally visible, above all in venture financing, broad-based digital transformation, labour productivity, and the fuller conversion of scientific strength into a more dynamic innovation ecosystem. For this reason, the overall trajectory of Czech technological development should be understood as the emergence of a mature engineering civilisation on a national scale rather than the rise of a universally dominant innovation economy.

The first post-1993 phase was defined by institutional recomposition under conditions of uncertainty. The independent Czech Republic inherited a substantial scientific and technical base from the Czechoslovak period, yet that inheritance was embedded in an economic and organisational logic that was already disintegrating. The country therefore had to solve two problems at once: to create a new national framework for the governance of science and to adapt the research sphere to privatisation, marketisation, and European integration. In the technical sciences, this was especially difficult because engineering research depends heavily on expensive equipment, stable procurement, long cycles of development, and enduring institutional continuity. The 1990s were therefore not a period of linear innovative growth, but a time of survival, reassembly, and legal-political construction. Funding was unstable, many former branch institutes were transformed or weakened, and the applied sector did not immediately find a new equilibrium. Yet the decade was not lost. Its main achievement was the prevention of systemic collapse and the creation of a normative skeleton within which Czech technical science could continue to exist, reorganise itself, and gradually move into a European framework. The Academy of Sciences preserved the research core, universities began to strengthen their research role, and the state shifted from reactive budgetary administration to the language of policy, programmes, evaluation, and strategic coordination. Thus, the 1990s should be seen as the foundational period in which the Czech Republic ensured continuity under radically altered historical conditions.

The second phase, spanning roughly 2004 to 2013, marked the true institutional maturation of modern Czech technological science. After accession to the European Union, Czechia moved from a regime of preservation to one of purposeful expansion. Europeanisation changed not only the sources of funding, but also the organisational culture of research. Framework programmes, public-research-institution reform, and the convergence of research policy with innovation policy gradually embedded the Czech system in a broader supranational architecture. The creation of TA ČR gave applied research a more coherent institutional centre of gravity, while the reform discourse of the late 2000s increasingly insisted that successful science must be able to move from laboratory to prototype, from publication to technological value, and from isolated expertise to systemic innovation chains. Most importantly, this period saw the infrastructural leap enabled by European funds. OP VaVpI and related instruments allowed Czechia to move beyond the incremental modernisation of inherited institutes and to build entirely new centres of excellence and regional R&D centres. The emergence of CEITEC, ELI Beamlines, and IT4Innovations symbolised this transformation. They demonstrated that Czechia was no longer merely adjusting its research laws, but was physically constructing European-class infrastructures in laser science, advanced materials, and supercomputing. By the end of this period, Czech technical science had acquired strategic direction, material depth, and a much more visible position within the European research area.

The third phase, extending from 2014 to 2025, gave the Czech system its clearest profile. If the preceding period had been about building infrastructures, the later phase was about consolidating them, populating them with research teams, integrating them with strategy, and selecting areas of long-term advantage. During these years, Czechia increasingly ceased to describe itself as a country merely catching up with the West. Instead, it began to articulate a model based on engineering specialisation. OP VVV linked infrastructure to human capital and research quality. RIS3 introduced a framework of structured specialisation rather than undifferentiated modernisation. Updated roadmaps for large research infrastructures, peer-review procedures, and the treatment of infrastructures as elements of critical state capacity all signalled that Czechia had entered a more mature phase of science policy. At the same time, the period was marked by the approval of Industry 4.0, Digitální Česko, the Innovation Strategy 2019–2030, national AI strategies, cybersecurity frameworks, and later the semiconductor strategy. This meant that the technical sciences became not merely an expert field, but a central component of national development discourse. The state no longer treated technology policy as a narrow industrial matter. It treated it as a cross-sectoral instrument for competitiveness, resilience, and future-oriented economic transformation. In historical terms, this is the point at which Czech technological development acquired a stable self-understanding.

The contemporary structure of Czech technical science is defined above all by the dominant role of business R&D and the centrality of applied engineering. By 2024, total expenditure on R&D had reached CZK 146.9 billion, or 1.82% of GDP, and more than CZK 93 billion was financed from business sources. Around two-thirds of R&D expenditure was performed in the business sector, and the personnel structure likewise shows the business sphere as the largest arena of technical research activity. This is not an incidental statistical feature. It defines the whole character of the Czech model. Technical science in Czechia is not primarily organised around purely academic excellence detached from production, nor around a startup-finance nexus. It is organised around industrial research, component engineering, testing, product improvement, process optimisation, and the embedding of knowledge in manufacturing value chains. The public and university sectors remain indispensable, but they operate in a system of division of labour in which companies, research centres, and technical universities are tightly interconnected. This is why applied engineering functions as the true centre of gravity of the contemporary Czech model. It is also why the country appears especially strong in medium- and high-technology industrial activity, but more limited in radical commercialisation and entrepreneurial renewal. In this sense, the Czech Republic represents one of Europe's clearest examples of a mature manufacturing-based innovation system.

The strengths of this model are substantial and should not be underestimated. Czechia has succeeded in developing a technologically sophisticated productive economy strongly integrated into European and global value chains. Its strengths lie in engineering niches, in medium- and high-technology exports, in public-private knowledge exchange, and in the capacity to host R&D centres linked to international industry. It also possesses a notable density of institutional cooperation between companies, universities, infrastructures, and regional innovation actors. Unlike countries whose innovation systems depend excessively on a single capital-city cluster or on one technological platform, Czechia has built a more differentiated landscape of competence. This includes advanced manufacturing, scientific instrumentation, automation, digital industrial systems, transport engineering, energy technologies, and computational infrastructures. Such a configuration gives the country resilience. It also means that Czech technical science is not an abstract layer above the economy, but one of the mechanisms through which the economy reproduces its technological sophistication. At the same time, this strength is not merely domestic. The book shows repeatedly that Czechia's successes are tied to international cooperation, European frameworks, and the ability of Czech teams and institutions to function within transnational research and industrial networks. The contemporary system therefore combines national depth with international embeddedness in a way that is particularly characteristic of medium-sized European technological states.

Yet the same analysis also makes clear that Czechia has not yet built a fully balanced innovation ecosystem. The limitations are structural, not accidental. Venture capital remains weak, productivity growth has slowed, the digital transformation of business is uneven, and the country still faces serious skills mismatches and labour shortages. Some regions remain caught in a low-skilled equilibrium, while the broader translation of scientific and engineering capacity into economy-wide productivity gains is incomplete. The Digital Decade assessment also points to a gap between strategy and ambition, while the broader innovation profile remains that of a strong but not leading European innovator. This does not negate the achievements of the Czech model. On the contrary, it clarifies their exact character. Czechia is stronger in the improvement, upgrading, and complex engineering renewal of products and systems than in the rapid creation of entirely new technological markets. It is strong in industrial depth, but less strong in venture dynamism. It is strong in infrastructural and technical competence, but not yet equally strong in all forms of commercial diffusion and entrepreneurial scaling. Therefore, the principal problem of the present stage is not the absence of technological capacity, but the uneven realisation of that capacity across the whole economy and innovation chain.

An especially important conclusion of this book is that the contemporary Czech system is territorially polycentric. Prague and the Central Bohemian Region concentrate governance functions, AI coordination, and major international infrastructures such as ELI. Brno has become one of the country's strongest poles of scientific instrumentation, microscopy, nano-and micro-engineering, and advanced inter-university cooperation. Ostrava has established itself as the principal national node of high-performance computing. Plzeň and Řež hold major positions in nuclear engineering and energy-related research. The industrial belt connected with Mladá Boleslav, Plzeň, and Moravia remains central for automotive and mechanical-engineering competence. This polycentricity matters because it shows that Czech technological development is not reducible to a single metropolitan concentration. It rests on a network of regional complexes in which universities, academic institutes, infrastructures, industrial R&D units, and regional innovation agencies interact. Such a pattern is one of the core institutional achievements of the post-1993 period. It gives Czechia a broader territorial base for engineering specialisation and helps explain why certain technological branches have achieved depth, continuity, and recognisable international status.

Among all branch achievements, electron microscopy and scientific instrumentation occupy a particularly emblematic place. This field demonstrates with unusual clarity how Czechia has been able to combine historical continuity, industrial production, methodological innovation, open-access infrastructure, and regional branding into one coherent technological cluster. The Brno school, rooted in the legacy of Armin Delong, survived the socialist and post-socialist transitions and developed into a globally visible centre of instrumentation. Later generations associated with Ilona Müllerová, Luděk Frank, Vilém Neděla, and Ivo Konvalina extended this tradition into very-low-energy microscopy, cathode-lens approaches, environmental electron microscopy, detector technologies, and hybrid analytical modes. The branch is important not only because of its publications and instruments, but because it shows the Czech capacity to create a whole ecosystem in which science, engineering, manufacturing, education, and international cooperation reinforce one another. The transformation of Brno microscopy into an internationally recognisable technological brand is therefore not a peripheral matter of image. It is evidence that Czechia can create globally identified centres of excellence in highly specialised high-technology domains. Within the broader history of Czech technical science after 1993, this branch stands as one of the most convincing demonstrations of sustainable technological specialisation. It exemplifies the Czech path at its best: historically grounded, methodologically deep, industrially connected, and internationally legible.

A second major pillar is high-performance computing, AI, and robotics. The emergence of IT4Innovations, its connection to PRACE, and the launch of supercomputing capacity signalled that Czechia was capable of building not only classical industrial competence, but also high-level computational infrastructure. What makes this sphere especially important is that it links multiple dimensions of the contemporary model: large research infrastructure, digital policy, AI strategy, industrial transformation, and broader national competitiveness. The book makes clear that Czech AI policy was not formed as an isolated consumer-tech agenda. It was embedded in a wider stack including HPC, cybersecurity, digitisation, advanced manufacturing, and public-sector modernisation. This is entirely consistent with the Czech pattern of engineering specialisation. AI in Czechia developed less as a narrative of platform capitalism and more as an engineering and applied-science domain integrated with industry, public systems, and computational infrastructures. In the same way, robotics is significant not merely as a symbolic frontier technology, but as a logical extension of the country's strengths in automation, manufacturing systems, and Industry 4.0. The importance of this cluster therefore lies in its integrative role. It connects the inherited industrial base of Czechia with the frontier digital-technological agenda of the 21st century.

Cybersecurity and network technologies form another strategic layer of the mature period. Their significance lies not only in the growing technical complexity of digital environments, but also in the fact that cybersecurity has come to be understood as part of a broader vision of Resilient Society 4.0. This reframing is crucial. It shows that Czechia no longer treats cybersecurity as merely a specialised technical matter for ICT professionals. Instead, it places it within a wider framework involving organisational, educational, diplomatic, legal, and infrastructural preparedness. In combination with participation in the Digital Europe Programme and with the rise of AI and semiconductor strategies, cybersecurity illustrates the shift from classic sectoral policy to technological-stack thinking. It is one of the domains through which Czechia has entered the frontier politics of digital sovereignty, system resilience, and strategic autonomy. The same is true, in different ways, of semiconductors and electronics. The approval of the National Semiconductor Strategy in 2024 reflects an ambition to position Czechia within the European Chips Act framework and to define those chip-related segments where the country has real potential. Such moves do not imply that Czechia is abandoning its engineering-industrial identity. They show that it is trying to extend that identity into the key strategic technologies of the present decade.

Automotive engineering and Industry 4.0 remain among the most structurally important branches of Czech technical development. Their significance exceeds the boundaries of one industrial sector because automotive production, supplier networks, process engineering, automation, and digital manufacturing have long functioned as a backbone of the Czech productive economy. The approval of Industry 4.0 in 2016 crystallised this relationship at the policy level. The Czech response to the Fourth Industrial Revolution was explicitly engineering-oriented. It focused not on replacing industry with a digital economy, but on digitalising and strengthening the industrial core itself through automation, cyber-physical systems, data, standards, and workforce adaptation. This approach corresponds closely to the whole post-1993 trajectory described in the book. Czechia did not reject its manufacturing inheritance; it upgraded it. The automotive and Industry 4.0 complex therefore represents the most concentrated expression of Czech applied engineering in the contemporary period. It combines export capacity, business R&D, technical universities, supplier ecosystems, and national strategic discourse. As long as Czechia remains one of Europe’s most manufacturing-intensive economies, this branch will continue to serve as both a source of strength and a test of whether the country can move from engineering maturity to higher innovation leadership.

Aircraft manufacturing, rail technologies, and transport engineering together reveal another long continuity within Czech technological history: the ability to sustain complex transport-related branches that require advanced design, testing, certification, signalling, diagnostics, and systems integration. These sectors matter because they show that Czech engineering specialisation is not confined to one industrial chain. In rail technology especially, the book identifies a particularly dense ecosystem. It combines industrial production, validation and testing institutions, specialised university training, signalling and telematics, and movement towards autonomous and digitally controlled operations. The example of AŽD’s experimental line, with its deployment of ETCS Level 2, ATO, GSM-R coverage, sensor systems, and centralised traffic control, illustrates this forward movement especially vividly. It shows that Czech rail technology is not limited to maintaining a classical engineering tradition, but is actively participating in future-oriented scenarios of automation and digital operation. This is strategically significant because rail technologies integrate infrastructure, software, safety systems, rolling stock, and public-value transport. Together with aircraft manufacturing, they also confirm that Czechia remains strong where engineering complexity, applied research, and validation culture intersect. These are not marginal successes, but indicators of a durable technological civilisation rooted in transport systems.

Nuclear engineering and radiopharmaceutical technologies complete the picture by showing how Czechia has preserved and modernised technologically demanding fields that depend on high regulatory standards, specialised infrastructures, and long scientific traditions. Their significance lies partly in their direct industrial and medical value, but partly also in what they reveal about the Czech system as a whole. A country cannot sustain such branches without a high degree of institutional continuity, technical education, research depth, and state-level strategic capacity. The same broader observation applies to materials science, energy-related infrastructures, and other high-complexity domains associated with the country's major research centres and regional poles. In this respect, the book demonstrates that Czech technical development has not proceeded through one fashionable sector alone. It has been cumulative. New digital priorities have been added to, rather than substituted for, older engineering and scientific strengths. This cumulative character is one of the reasons why Czechia's technological model appears mature and resilient, even when it does not appear radically disruptive. The country has built not a narrow monoculture of innovation, but a layered system of mutually reinforcing competencies. That layered structure is itself one of the central historical achievements of the period under review.

No less important in this trajectory are the leading figures who gave these branches an intellectual and human face. In electron microscopy, Armin Delong stands as the foundational figure whose work established the very model of combining science, instrumentation, and engineering. Ilona Müllerová and Luděk Frank deepened the Brno school through low- and very-low-energy methodologies, while Vilém Neděla advanced environmental electron microscopy and Ivo Konvalina represented newer detector and hybrid analytical developments. The very structure of this lineage is revealing. It shows a field reproducing itself across generations without losing methodological ambition. Similar patterns are visible elsewhere in the book, where contemporary Czech technological development is tied not only to institutions and programmes, but also to scholars and engineers capable of shaping entire directions. This matters because technological history is never merely the history of strategies, ministries, or funding instruments. It is also the history of people who create schools, stabilise methods, design instruments, lead infrastructures, and transmit competence across periods of transformation. In that sense, the branch chapters collectively show that Czechia has not only built infrastructures and strategies, but also sustained a cadre of figures through whom these structures acquired substantive meaning. The maturity of the system is therefore both institutional and personal.

If one were to define the contemporary state of Czech technical science by 2025 in the most concise terms possible, it could be described as polycentric, application-oriented, industrially embedded, strategically selective, and infrastructure-based. It is polycentric because it rests on several powerful technological poles rather than on one exclusive metropolitan centre. It is application-oriented because the business sector and engineering practice remain the central carriers of research intensity. It is industrially embedded because its strongest lines are inseparable from manufacturing, transport, instrumentation, and production systems. It is strategically selective because RIS3, AI, cybersecurity, semiconductors, and related policies increasingly concentrate support around domains of perceived national advantage. And it is infrastructure-based because world-class facilities, computational platforms, and equipment-rich centres now form an indispensable part of the country's scientific and technological capacity. These features together define the special place of Czechia within Europe. It is not among the continent's largest research powers, but neither is it a peripheral technological space. It occupies an intermediate yet increasingly solid position as a country of advanced engineering competence, complex industrial knowledge, and selected frontier capabilities. This position is historically grounded and institutionally real.

The final conclusion of this book, therefore, is that contemporary Czechia has succeeded in creating its own model of technological development after 1993. This model is not universal, and it does not solve every structural problem facing the country. It still requires stronger venture mechanisms, broader digital modernisation, better knowledge transfer, higher productivity, and a more ambitious movement from engineering strength to wider innovation leadership. Yet its achievements are substantial and historically durable. Czechia has preserved its scientific and engineering core, transformed it through European integration, built major infrastructures, strengthened business R&D, and articulated clear strategic priorities in a range of advanced technological fields. It has created several internationally recognisable clusters and sustained complex industrial branches that depend on deep technical knowledge. It has shown that a medium-sized European state can remain technologically relevant not by imitating every global trend, but by developing selective excellence around its own real strengths. For that reason, the history of Czech technical science from 1993 to 2025 should be interpreted as a successful passage from post-socialist dislocation to consolidated engineering specialisation. Its broader lesson is clear: Czechia's technological future will depend not on abandoning this model, but on deepening, accelerating, and more ambitiously extending it.

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