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# A SUCCESSFUL DEFENCE INNOVATION ECOSYSTEM

## *To Mark the Work of Colonel József Jáky, Ministerial Commissioner for Air Defence Radar Development*

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ABSTRACT: *The lessons drawn so far from the Russo-Ukrainian War have shown that the failures of set objectives can be traced back not only to the errors of operational planning but also to shortcomings in the deployability of military equipment in given situations. Change is constant. The quality of (operational or military engineering) responses to the continuously changing situation is a function of the status of the defence innovation ecosystem. Economists, engineers, and doctors are looking to define the concept of innovation differently, based on the ecosystem surrounding them. The defence innovation ecosystem rests on three pillars: the current state of military science, the capabilities of the defence industry, and the defence requirements. Besides these three pillars, the defence innovation ecosystem's quality is determined by a network of connections among several other elements. What are the elements that need to be operated in the interest of a successful development? What are the connections among these elements? Can one give an exact description of all elements and connections of a defence innovation ecosystem, or does it have some general laws? This study aims to seek the elements of a defence innovation ecosystem required for fighting a successful war through the examination of a successful military technology research and development program: the Hungarian radar developments in the 1940s.*

KEYWORDS: *defence innovation ecosystem, research and development, radar development*

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## INTRODUCTION

The development of air defence radars during the Second World War was doubtlessly one of the most successful stories of research and development in Hungarian military technology. While researching the history of military technology, I examined the elements of the defence innovation ecosystem of the age, their connections, functioning, and the role of the talents who played a key part in development. My goal is to present the laws of cooperation among the scientific, industrial, military engineering, and operational elements necessary for the successful development of military hardware. In my account, I will lay emphasis on those engineering and operational requirements that triggered scientific and industrial responses during the "story".

## HISTORICAL BACKGROUND TO THE DEFENCE INNOVATION ECOSYSTEM

Defence innovation is not a creation of the 21$^{st}$ century, being itself the product of an evolving process. The continuous development of ever-newer offensive and defensive assets and procedures has occurred throughout human history. The evolution of the armed forces has produced organizations and a network of connections needed for their development everywhere. Military technology research and development is not identical with defence innovation, although it forms an important part of it. Defence innovation is an unfolding process in a rapidly changing security environment, being conveniently organized by innovation management. In the overwhelming majority of cases, this process of innovation involves more than one player. Rather, it is the interaction of a complex network of partnerships and elements, which we call the innovation ecosystem. This interaction takes place among the three pillars of the defence innovation ecosystem (Triple Helix model[1]) and the elements connected with them.

### Military Engineering Background to Radar Development

The lessons learned in the Battle of Britain showed that modern-day air defence cannot conceivably work without the use of radars. The Kingdom of Hungary expressed to Germany its interest in purchasing such equipment, but the Germans said no, as long as Hungary was unable to offset such a deal through the delivery of other goods and the war situation did not demand it. Organized by the Royal Hungarian Honvéd Institute of Military Technology, developments started in 1942, on the basis of broad cooperation. Within two years, a team of scientists organized by Professor Zoltán Bay, an industrial team by Edvin Istvánffy, and a military tasking and user team by Military Engineer Staff Corps Colonel Dr. József Jáky cooperatively built the prototypes of those radar variants that have been in use to the present day. Air surveillance radars already played a key role in the air defence of Budapest.

In the pre-war era, Hungarian and foreign physicists directed their interest toward the field of nuclear research and the study of microwaves. As there was neither industrial nor military need for nuclear research activities in Hungary, they remained in the realm of theory. This was not the case with microwaves, since there was an existing industrial background and civilian need for their use in the field of communications. The military need for the capability of determining the positions of aircraft in the dark, in fog, and through clouds prompted the start of research activities under the name of radiolocation in Europe, and radar (Radio Detection and Ranging) in the United States. Scientists in Hungary

1 The Triple Helix model was introduced into the conceptual toolkit of innovation by Etzkowitz and Leydesdorff (1995).

stayed in the international “bloodstream” of scientific work right until the autumn of 1941, receiving American periodicals via the Netherlands (Philips) and Switzerland. However, all they were able to gather from them on the research conducted in this field was that in 1942, more than 50 percent of military electrotechnology development funds in the United States would be allocated to radars, while on-board aircraft radio systems would account for a mere 40 percent. Quite understandably, no more information was disclosed, being both military and industrial secrets, and thus, Hungary had to start the developments on its own, in complete isolation.

The process of basic research started with clarifying the principles of microwave communication technology and the workings of radars, then continued with building an experimental unit of a domestic radar. The initial engineering challenges were the excitation of microwaves on the shortest wavelength and with the highest power possible, as well as the reception and detection of microwaves with the lowest possible power, even in the presence of noise. The shortest possible wavelength was needed because whenever the wavelength gets reduced, microwaves increasingly take on the propagation characteristics of light. They propagate in a straight line, are not diffracted by the Earth, and are less reflected from the ionosphere or the clouds. Thus, they can be better directed and modulated as opposed to low-frequency radio waves, although they are less suitable for long-distance broadcasting.

Of the active elements used for generating forced oscillation, the only ones available on a domestic basis were electron tubes, although the operating principles of both magnetrons and klystrons were known to Hungarian developers. Given the short time frame and the limitations of available scientific engineering capacity, they did not even attempt to develop these devices. Instead, the members of Bay’s team of scientists – Ernő Winter, Zoltán Szepesi, and Andor Budincsevics – upgraded the new miniature tube type produced by the Egyesült Izzólámpa és Villamossági Rt. (United Incandescent Lamp and Electricity Ltd.), a company capable of developing and manufacturing already existing electron tubes. This was how the first microwave electron tube suitable for mass production in Hungary was created under the name EC 102. This electron tube’s output power was 2 W at wavelengths around half a metre (600 MHz), which already paved the way for experimentation with an experimental microwave transmitter and receiver and for the construction of a prototype, to be built by György Dallos.

The receiver unit needed for microwave communications also had a built-in EC 102 electron tube. The first experiments were carried out between the rooftop of the Tungsram building in Újpest and the Naszály Hill situated behind Vác, spanning a distance of around 100 km. As a result of the experiment, the scientists concluded that 50–100 mW transmitted power is enough for impeccable voice communication. The terrain features and buildings between the transmitter and the receiver obstructed the connection, while smaller trees and groves did not obstruct it, although they reduced the strength of the field. The scientists handed over their research results on microwave communications to Standard Electric Corp. for further use.

Telecommunications-related research results were also utilized during the development of radars. The experts not only proved that microwave propagation is not hindered by cloudy and foggy night-time weather conditions but also concluded that objects made of conductive materials – the physical dimensions of which are commensurable with the wavelength size – obstruct the propagation of microwaves. The discourse on theoretical issues of radiolocation measurement was based on the workings of a fire control radar. This is not by chance, since it was Colonel Jáky who already specified the military requirements.

## Military Engineering Elements of the Ecosystem that Determine the Directions of Development

The basic air defence assets of the age were fighter planes and anti-aircraft guns. Setting requirements for the use of military radars was only necessitated by mass night bombing raids carried out during the Second World War, since the nighttime darkness not only hindered the interceptor aircraft from precise aiming but also complicated early warning and the location of attacking bomber formations.

The development of anti-aircraft artillery pieces has always kept pace with the evolution of aircraft. This “sword and shield” relationship determined the developments already during the First World War, when military aircraft with new capabilities and roles were appearing in theatres of war on almost a daily basis. To be able to detect and warn about them, the militaries established observation and listening posts and created a system by integrating these into a network adapted to the communication possibilities of the age. The technical means of air surveillance, however, were unable to keep pace with the emergence of ever-faster all-day aircraft with continuously increasing service ceilings. The development of anti-aircraft artillery assets started on the basis of the artillery pieces of the time. The configuration designed to ensure aiming and shooting at high angles of elevation – allowing 360-degree rotation of the gun fitted on a column mount – was invented relatively early on, but in that age, the barrel length of field guns and their low muzzle velocity were insufficient for hitting fast-moving aircraft flying at high altitudes. Therefore, the need arose for the development of gun barrels with longer calibres, projectiles with higher muzzle velocity, fragmentation count, and precision time fuses, as well as predictors, optical devices, and rangefinders.

After serious preliminary studies, the Hungarian Treasury purchased licences for the manufacture of 8cm L/50 calibre anti-aircraft guns (M 29) of the Swedish Bofors Works to destroy medium- and high-altitude air targets, and the Bofors licence for the manufacture of 40mm L/60 anti-aircraft autocannon (M 36) and its HE-FRAG shells against air targets attacking at medium and low altitudes with high angular velocity. These products met not only the then operational requirements but also the production technology capabilities of the domestic war industry.

Eliminating air targets over long distances requires very precise calculations. Complicating factors include, among others, not only the trajectory dispersion of active weapons but also the changes in target motion during the flight time of the projectile and the inaccuracies of their measurements, as well as the lengthiness of computing the set-forward point and transmitting the data. At first, the distances of air targets measured from the gun were determined with optical rangefinders, and these devices evolved significantly. However, the momentary slant range values did not and could not provide precise firing solutions. Thus, air defence artillerymen made estimates and used various command charts, which require the values of the elevation angle and the angular distance (azimuth). One can obtain a plot of the target by providing the slant range and the values of these two angles in a quick and precise way, periodically one after another; and the track of the target can be obtained by iterating this updating procedure. In the case of non-manoeuvring aircraft, one can calculate a speed and a bearing, and if the external ballistics of the gun is known, also a point of impact for the aircraft and the shell, so one can know the time of flight of the high-explosive shell, as well as the corresponding value to be set on its fuse. Insofar as one manages to successfully aim the gun at the target with the calculated lead distance, one must set this value on the fuse of the shell before loading it. The precise functioning of the fuse is key to achieving a high probability of hit. The bigger the speed difference between the target and the shell, the more precise ignition is needed. At first, this problem was solved with the use of small revolving-disc time fuses, but due to their poor reliability and low precision, they were considered only stopgap solutions. Under a German licence, the MOM[2] started to manufacture a small, wind-up delay-action fuse, which made it possible to achieve much higher precision. Hundreds of thousands of these fuses were produced before the war, with large quantities being exported to Great Britain.

Scoring a direct hit is not the most effective or economic method of destroying air targets, all the more so because it is much easier to bring the munition close to the target than to achieve a direct hit. Thus, besides accurate timing, it is also important that the fragment density created by the detonation in the vicinity of the target ensures a target kill.

## HUMAN ASPECTS OF DEFENCE INNOVATION

### Prominent Figures in Science and Industry

In Germany, intensive research to develop military radars started in 1939–40. Hungarian military leaders were well aware of two facts: Hungary would not receive any help from its ally, and modern air defence without radars is unthinkable. The very realization of these facts already presupposed the involvement of military engineers of the first pillar and the expert staff of the Institute of Military Technology (IMT), as it was laid down in its founding charter.[3] In 1941, the Institute of Military Technology was already working out the Common Military and Technical Requirements (HMK) of radars. They gathered information about the results of engineering sciences, the lessons learned abroad, and the capabilities of domestic universities and industry. On 25 January 1942, they submitted a report to the minister of defence, in which they already considered it a fact that the Bay team was to be formed, and specified its initial composition in the annex, together with its mission and remuneration.

Altogether 150,000 pengős were earmarked for financing the Bay team, whereas 400,000 pengős for the production of the four Sas (Eagle) radars. Thus, the Bay team was still being formed when the IMT had already worked out the costs of the basic experiments. The industrial team (led by Edvin Istvánffy) did not even get a mention, but based on the HMK, the IMT had already calculated the costs of the four Sas radars in cooperation with the industrial team. Although Jáky's appointment as ministerial commissioner took place no sooner than in March 1943, this authorization made him the commander of both the Bay team and the industrial participants. Besides enabling him to assign tasks to all players in the defence innovation ecosystem, the authorization also gave him the opportunity to save people and war industry equipment during the German occupation and the rule of the Arrow Cross Party.

[2] This factory was renamed Hungarian Optical Works (MOM) in 1939. Its founder, the Germany-born Ferdinand Süss managed the MOM until the end of the Second World War.

[3] "The Institute of Military Technology has been established as an organ of the Royal Hungarian Ministry of Defence with the mission of representing, in an economical way, the advancement of technology in the supply of the army with weapons, armaments and other equipment."

It was György Papp, Károly Simonyi, and Antal Sólyi who started the work of the Bay team, the second pillar. Instead of a request, the Bay team was formed on the basis of an order provided by the laws in force. Nobody was asked whether they wanted to join or not. They had to give answers to some fundamental questions. How much transmitted energy is needed to make sure that a sufficient amount of energy returns? What should the bandwidth be, and what is the optimal pulse length for the signal?

According to the worked-out theory, a microwave, a short and high-power pulse packet emitted by a transmitter, is sent towards an aircraft with the help of a directional antenna. Then, the low-power echo signals reflected from the aircraft surface in the direction of the antenna are fed into a sensitive receiver unit. The slant range between the place of transmission and the aircraft can be calculated from the time delay from transmission to reception, by taking into consideration the propagation velocity of electromagnetic waves. The antenna's axis points to the aircraft, so its deviation from the northern and horizontal directions provides two angular values. Knowing the place of transmission, one can determine the spatial coordinates of the aircraft using these two angular values and the slant range.

By the spring of 1943, the team had built an experimental radar and used it to detect barges on River Danube and aircraft from atop the Egyesült Izzólámpa és Villamossági Rt's building. The microwave transmitter needed for this purpose was constructed by Ernő Winter and Andor Budincsevics. The third pillar already contributed to the creation of this experimental device. The scientists set up another experimental unit on the top of the Standard building to experiment with microwave signal transmission, which was more convenient than relocating to Naszály Hill in Vác on each occasion and making contact with Újpest from there.

Although Standard and Edvin Istvánffy formed the centre of the third pillar, several other companies were also involved in the manufacturing of radars, such as the Egyesült Izzólámpa és Villamossági Rt., MOM, Gamma, the Hungarian Wagon and Machine Works, Telefunken, Philips, BAMERT, and a number of small enterprises. All players were expected to maintain complete secrecy and loyalty, so it is no wonder that the work almost stopped after 19 March 1944, the day of the German occupation. The IMT radar team was relocated to Nógrádverőce, which was a safer place, but its members could not do any work there due to the unsuitable electrical grid.

## Military Engineer Officers

As the contemporary saying goes, military engineers do not grow on trees. This was the case after Trianon, too. Neither military engineer training, nor military technology research and development did the Austro-Hungarian Monarchy let slip out of its reach. As both were important parts of the independent Hungarian statehood, the Institute of Military Technology was established in 1920, and young officers were enrolled in various engineering programs of study, characteristically at the Royal Hungarian "Palatine Joseph" University of Technology. After graduation from the basic training, they were supposed to take military engineering and then Military Engineer Staff Corps courses. Students with worse than excellent exam results were rarely admitted among the engineers of the Institute of Military Technology. Teachers realized the officers' triadic training goal by mentoring talents in the fields of engineering science and complementing their studies with military knowledge so that they can be integrated into all three pillars. Officially, we are told that the Győr Program of Hungary's rearmament was launched in 1938. In my opinion, that year saw only the financial resources being allocated to it. The (innovation) process necessary for the Program started as early as the first young and talented soldiers were schooled to make sure that in 10–20 years, a sufficient number of military engineers would be available for the developments.

### Unfolding Talent

József Janicsek was born in Eperjes (today Prešov, Slovakia) on 26 March 1897. He magyarized his name to Jáky in 1934. On 13 November 1915, he volunteered to enlist in the Imperial and Royal 34th Infantry Regiment, with which he deployed to serve on the Russian front for six months. He was ordered to attend the second year of the mechanical engineer specialization at the University of Technology in 1921, and in addition, he had to fill a teaching position at the Ludovika Academy as well.

When the Royal Hungarian Institute of Military Technology was officially established in 1930, he was appointed head of the IMT electronics laboratory. He built and headed this laboratory for eight years, where the core components of innumerable IMT-developed, wired and wireless devices were made. As of 1 October 1938, he was appointed head of the IMT Special Department No. 4. In 1941, he doctorated in engineering sciences after submitting his thesis on “the electronic methods of measuring projectile velocity”.

Thanks to his scientific work and radio developments, he personally knew the members of the Hungarian engineering elite of the time, as he was collaborating and researching with them or learning from them. The theoretical foundations of radiolocation were already known at that time, and researchers had access to foreign special literature until the end of the 1930s. The construction of the first operable radars, however, was shrouded in complete secrecy. Although Jáky participated in study tours to Germany on two occasions, the German side did not share any technical information, and the issue of radars was shrouded in such secrecy even in Hungary that Jáky’s immediate colleagues only knew that he was researching this issue, but were not let into the details.

## SCIENTIFIC AND INDUSTRIAL ACHIEVEMENTS AT THE IMT

The Council of Scientific Engineering at the IMT was already functioning in 1938–39, with Dr. Zoltán Bay among its members. Back then, scientists were investigating the effect of the ionosphere on the propagation of radio waves, and they also came up with the idea of radar already at that time. Jáky applied for the newly organized Communications Technology Department of the University of Technology in 1944. Dr. Zoltán Bay was a member of the nomination committee. Of several applicants, the committee nominated Dr. József Jáky as the Teacher of Communications Technology at the University of Technology.

### Sas (Eagle) Air Surveillance Radar

In January 1943, acting on the IMT’s proposal, the Ministry of Defence placed an order with Standard for four Sas (Eagle) radars. In those times, Hungary had already been producing and delivering electronic components, for German radars among others, and received promises of German radars to be delivered in exchange, but the German side refused to hand over the manufacturing documentation belonging to them. They had good reason to do so since they knew that we could have used the information contained in those documents for our own developments. Nevertheless, the construction of Sas radars was proceeding at a great pace, and the first installations started already in November 1943.

The first Sas was set up next to the lookout tower on János Hill. The detection range of meter-wave radars is, to a large extent, affected by the reflection of the surrounding, preferably flat area of land. As this was not given at the hilltop, the experts soon rejected this installation site and, acting on Jáky's proposal, relocated the radar unit to the experimental premises of the IMT in Sári, so that they could take part in the control of three Würzburg D radars already operating in the fire system of Budapest. The next two Sas radars were scheduled to achieve operational readiness by the spring of 1944, and the MoD planned to install them at a site in Jászkisér. For defence against the attacking Anglo-American formations, this did not seem a good choice from an operational point of view. It is no accident that subsequently, Lovasberény also emerged as another installation site, and the radar sets were relocated there on an unknown date. The Sas radars were set up in pairs. While one of them performed omnidirectional surveillance, rotating at three revolutions per minute, the other performed a sector scan in the main direction. According to oral recollections, the Sas radars were able to detect air targets already above the Adriatic Sea (400–500 km). Knowing the transmitted power of the instrument, this seemed no more than a legend until the appearance of István Balajti's article in the periodical Haditechnika,[4] in which he called attention to the fact that the Sas radars were installed in a so-called quasi-monostatic configuration. Set up in pairs, the transmitted power of the two Sas radars, the gains of their transmitter and receiver antennas, as well as the echo signals reflected from the target surface, were integrated, which doubled the detection range of the radars.

Thanks to the fulfilment of operational conditions, the three pairs of Sas air surveillance radars – set up respectively on the premises of the IMT in Sári village, in Jászkisér, and then in Lovasberény – significantly contributed to the early warning of the population of Budapest on the occasion of air raids, and thereby saved many lives.

## Installation Sites of the Sas Radars

After the experiment on János Hill, the first two Sas radars were set up on the premises in Sári village and started operating in November, controlling the three Würzburg D radars integrated into the Budapest fire system. In his book, based on the residents' recollections, Pál Szabó estimated that the installation site was approximately 8 kilometres from Sári in the direction of Mántelek.[5] This contradicts the drawings of the installation sites, Captain László Sifter's recollections, and the photo published by him, but first and foremost, it contradicts the fact that there was no suitable electrical grid available on the location referred to in Szabó's book and its establishment incurred substantial costs and required planning and implementation work on every other installation site. Without disputing the reminiscences of local residents, the site and the circumstances of the construction they described did not meet the requirements for setting up an air defence radiolocation battery. There must have been something there indeed, but it certainly was not the installation site of Sas radars. The facility on Sári premises was camouflaged as a small garden at the end of the village. Jászkisér is referred to as an installation site in several documents, and the construction of

[4] Balajti 2021, 8–15.
[5] Szabó 2014.

the site and the installations were in progress indeed, so much so that even a trial run took place there, but so far, we have not found any drawings or photos. Considering the directions of attacks by Anglo-American bomber formations, this installation site seems to be a bad choice from an operational point of view, as it could not provide information about these formations to the Budapest fire system. In his article, Captain László Sifter makes specific mention of the operation of repaired Sas radars on the Lovasberény installation site in the interest of the air defence of Budapest.[6]

## Borbála Fire Guidance/Control Radar

The Borbála and the Bagoly radars were almost completely identical in terms of their technical content, but their radar antennas were totally different due to the diverse requirements. The parabolic reflector of the Borbála radar was a concave copper plate dish measuring 3 metres in diameter, whereas the antenna of the Bagoly was an array with a diameter of 7.5 metres. The Borbála was manufactured at Standard Corp. under Edvin Istvánffy's supervision. Because the instrument package of the Bagoly was identical with that of the Borbála, the construction of Bagoly radars also required successful work on the part of Standard. While Jáky commissioned the Gamma and Ganz companies to develop the actuator of the Borbála radar, he assigned the task of building a prototype of the reflector to a craftsman. On 23 April 1943, the experts installed the first unit of the Borbála radar on the rooftop of an Egyesült Izzólámpa és Villamossági Rt. building, and started measurements with an air target flying to and fro over River Danube on the route Budapest–Vác. In July 1943, already three Borbála radar devices were being manufactured by Standard, and the Ministry of Defence allocated to the factory three autocannon carriages with reinforced wheel structures for the radars.

## Bagoly (Owl) Fighter Control Radar

As ministerial commissioner, Jáky commissioned the Győr Wagon and Machine Factory to manufacture the structure of the Hungarian fighter control radar. At a meeting held on 14 May 1943, the factory was represented by CEO Imre Pattantyús-Ábrahám. Captain Dezső Ritter, a member of the military engineering development team, was present on behalf of the IMT. The participants divided the work process into three main phases: the supervision and drawing of the radar design, the production of components, and the assembly of component parts. As the radar was a bulky device with instrument-level precision, the factory could not undertake this work, which required a company or person specialized in instrument design and manufacturing. The factory undertook to manufacture some, mostly major, parts and to provide the assembly site. Jáky understood and accepted the reasons, so he made arrangements to expand the negotiations by involving experts from Standard and Gamma. Thus, Standard now had a stake in designing/manufacturing the complete electronics of the radar, whereas Gamma in that of the precision mechanical components. At that point, it was already clear that the domestic fighter-control radar would certainly not be completed in 1943, and as a matter of fact, two Bagoly radars outlived the end of the war in an assembled but uninstalled condition.

[6] Sifter 1948, 48–49.

## Turul Airborne Radar

The British night bombing raids against Germany prompted Hungarian military leaders, too, to find a solution to countering them. Introducing measures for complete night black-out seemed an evident solution, yet it proved to be insufficient due to the increasingly pre-cise navigation and the dropping of illumination bombs slowly descending with parachutes. Neither did the illumination of the night sky with searchlights for the anti-aircraft artillery lead to the desired efficiency. After the Bay team worked out the theoretical foundations, in view of the foreseeable military requirements, the Institute of Military Technology and the Institute for Aviation Experimentation launched a joint development project to construct a radar-equipped night fighter plane on the basis of a domestically manufactured Me 210, since there was no chance of any German delivery, like in the case of fire control and air surveillance radars. The experimental radar prototype was completed at the Hungarian Philips Works by 19 March 1944 and was built into a Me 210D destroyer with side number ZO+03 in the place of the bomb bay. There are no extant data about the experimental flight of the onboard aircraft radar codenamed Turul and its result.

## Würzburg D (Dora) Tracking Radar

Although the Borbála radars were completed, their constructors with anti-fascist senti-ments certainly did not hand over or develop anything during the German occupation. The Germans were definitely not interested in the successful completion of Hungarian developments. Under the earlier contract, 3+1 German Würzburg D radars were delivered. According to the plans, when installed on location in the corner of Megyeri cemetery, on Kis-Sváb Hill, and in the northern part of Csepel, they constituted a part of Budapest's fire system. As the Dora radars were mobile and it was necessary to train the Hungarian crew as well, they turned up in several places. Some remember the Megyeri installation site, which Professor Bay also attempted to visit. There are some built remains of the Kis-Sváb Hill installation site, which was integrated into a nature conservation area, and there is an extant photo of a radar installed at the junction of Mexikói Road and Szőnyi Road, where the site was used for training purposes, but their further fate remains unknown.

## The 272$^{nd}$ Air Defence Radiolocation Battery in Dunapentele

On 18 May 1943, a meeting was held to organize the construction of a fighter control post. Large-scale night air raids against Germany were already going on, and the Hungarian military leaders were attentively monitoring them. Considering that this already touched a nerve among German interests, and given that the production of Hungarian Bagoly ra-dars was not yet finished, we were promised to have one Freya early warning and two Würzburg-Riese fighter control radars delivered to us. Although the delivery was sched-uled to take place in early April, the radars did not arrive before late May or early June. One suspected direction of the attack was in the Danube Valley from the south, and that is why Dunapentele was chosen as an installation site. The meeting was summoned by Jáky with the purpose of discussing the selection of participants, the budget, the appropriation of the area, and the contract of the constructor of the post. The chosen area was the first element in a countrywide network, but no data have been found on the construction of other elements. The installation site was located southeast of Dunapentele, at spot elevation 153, and Telefunken Corp. was commissioned with the construction.

During the construction of Dunaújváros, the area in question was completely transformed, but the Trinity Church of Dunaújváros can still be seen on period draft maps, so one can find its location. This area corresponds to the site of today's Theme Park. The three radars were needed because target aircraft were identified based on data from the air surveillance radar, and then one of the fighter-control radars took over the tracking of the aircraft, while the other was tracking its own night fighter plane. The data were presented on a Seeburg Tisch (plotting board). The radio communications of the post were planned with German FuG16 and Hungarian R7/a and R/14 radio sets, and Jáky also had a crucial role in their development.

The two Würzburg-Riese radars were delivered in June, to be followed in September by the Freya early warning radar for their control, but these radars came with some of their parts missing, and the construction of the post was not completed by the deadline. On 20 December 1943, Jáky reported that the 272nd Air Defence Radiolocation Battery in Dunapentele was ready for operation.

### The Development of Surface-to-Air Missiles in 1944

Acting on the order of Major General Zoltán Hihalmi Harmos, Colonel Jáky held a discussion in his office on 12 August 1944 with the participation of experts from the Institute of Military Technology, Standard, and the MOM. The topic of the meeting was "remote control of glide bombs". Jáky revealed that the efficiency of conventional tube anti-aircraft artillery was no longer satisfactory and that there was an opportunity to find a revolutionary new solution based on a MOM patent. Deputy CEO of MOM, Mr. Grosh, noted that the mechanical components of the steering system had already been designed, the servomotor was ready, and could be tested in the wind tunnel of the University of Technology in three months. Speaking on behalf of Standard, Edvin Istvánffy asked for a moratorium due to the radar program, which he did not consider a hindrance, as both the radar and the range finding were solved issues. IMT expert First Lieutenant Takács told the participants that the authorized divisions of the IMT would start experiments for the construction of solid-fuel and bipropellant liquid (hydrogen/oxygen) variants of a missile with an effective range of 10–20 km.

Jáky convened another technical advisory meeting on 17 August, inviting Károly Bors, who was to be tasked with the design of the control unit of the observation station. It was recorded in the minutes that the participants did not wish to share the current state of the development with their allies – less than five months after the first day of the German occupation. This development topic is of present interest also because it shows that – provided they exist and are interconnected – the elements of the defence innovation ecosystem may bring about revolutionary achievements.

## MILITARY ENGINEERS AND ANTI-FASCIST RESISTANCE

Jáky's task in the group led by Endre Bajcsy-Zsilinszky would have been to construct a high-performance radio set that would have enabled the members of the group to get in touch with the Soviet Army Headquarters to avoid the siege of Budapest. Captain Andor Lányi also came to his assistance in building the 5-kW transceiver. Pál Almásy – who had first met Jáky on the Hajmáskér shooting range – was tasked with recruiting anti-German officers into the resistance group led by János Kis. The tasks were assigned to them by the later mayor of Budapest, József Kővágó.

Altogether, two devices were built in the IMT, and the components of the second were accounted for as spare parts. The radios had been completed by early December 1944. Although the resisters tried to transport a radio to the planned site, the truck driver drove on when he spotted some Germans, who had already uncovered the planned installation site of the transceiver. There is no extant data on the further fate of the radio station. Following the relocation of the IMT from Budapest, Jáky, together with several other resisters, stayed in the Hadik barracks. The IMT was ordered to relocate to Rábafüzes, and then to Szombathely. Jáky was supposed to go to Dresden, but he and the others stayed home, keeping up the semblance of an official unit using documents and stamps stolen by Engineer Staff Corps Colonel Béla Cserneczky. Colonel Cserneczky undertook to take command of the remaining cell. His task in Endre Bajcsy-Zsilinszky's group would have been to prevent the demolition of bridges over River Danube. To this end, he gave 100 kg of explosives to the resistance movement and manufactured 1000 detonators without charges to replace the ones the Germans had planted on the bridges. In late November, the resistance movement was discovered, and he was unable to conduct any activities anymore. Several military engineers, scientists, and soldiers specialized in development and production wrote in their memoirs that everything changed after 19 March 1944, the day of the German occupation. Developments were halted, not only because their management and financing were stopped but also because the moral ground of further works was called into question. From that point on, these works served the interests of a foreign power rather than homeland defence.

## CONCLUSION

By the spring of 1944, thanks to the availability of all necessary elements of the defence innovation ecosystem and their planned management, Hungary was capable of producing radar prototypes belonging to cutting-edge science and technology in the world, and commissioning and operating four Sas air surveillance radars.

The existence, workings, and management of the elements of the defence innovation ecosystem are not self-evident. The development of the military industry did not start with the Győr program, it rather started with the training and organization of military engineers as a key component. During the German occupation, everything changed in Hungary. Among the things that ceased to exist were the moral ground, the governmental intention, and with it, the will operating the pillars of defence innovation, and then the cooperation among its three crucial pillars.

Military engineering knowledge forms the basis of successful research and development in military technology. Jáky's knowledge of military technology set requirements for Professor Zoltán Bay's team of scientists and Edvin Istvánffy's industrial engineers during the process of creating the Sas radar. Professor Tódor Kármán, the founder of the Advisory Group for Aerospace Research and Development (AGARD) – who earlier worked on the development of PKZ helicopters at the research institute of the Austro-Hungarian Monarchy – recognized this law and formulated it in the Scientific Advisory Board of the USAF: "scientific results cannot be used efficiently by soldiers who have no understanding of them, and scientists cannot produce results without an understanding of the operations".[7]

[7] Van der Bliek 1999, 1.

The results of defence innovation and their utilization involve many industrial and military secrets, and therefore, the key issue is that they should offer advantages on the battlefield and market. This goal can be achieved only through cooperation. The goal of making good use of the "secret" wherever it is needed requires joint research teams, laboratories, and testing grounds of science, industry, and national defence. Loyalty – to the state, to the alliance – is the cohesive force holding them together, being the moral ground of defence innovation. If this cohesive force ceases to exist or changes, defence innovations will not be utilized at all, or not in the place intended by the original will.

The most significant defence developments are always connected with some outstanding talent. On examining the talents' career paths, we always find that the process of planned talent mentoring built on a central will is present. It is especially true of the education of military engineers, where the needed outstanding talents not only know the state of the art in science and industry but are also able to creatively use their knowledge in a rapidly changing security environment. Industry 3.0–5.0 and Education 4.0 programs might be related to but are too broad to fit into the scope of the current study, therefore, I suggest this topic as a basis for another paper.

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