HISTORICAL PLACE OF TEI IN THE DEVELOPMENT OF OUR NATIONAL AEROSPACE ENGINES THAT EMPOWERS OUR DEFENCE

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Abstract

Apart from individual attempts such as flight trials of Hezârfen Ahmed Çelebi, aviation adventure of our country has started with the first airplanes imported during the last period of the Ottoman Empire. Although it was aimed to institutionally transform it into a national industry during the first years of the Republic, it completely failed in the following years, and Türkiye has become almost completely foreign-dependent in the field of aerospace engines until the 2010s. The awareness that has started during the Cyprus Embargo has become a state policy and turned into a "National Technology Initiative" in the last 20 years. Integrating its renewed mission and vision with significant state support provided to the defence industry, TUSAŞ Engine Industries (TEI) has achieved great success by developing 11 different, indigenous, and national aerospace engines in the last 8 years and left an unforgettable mark in Turkish aerospace history. This study shares the story of many national engines developed by TEI in recent years, some of which have achieved tens of thousands of successful operation hours in the sky.

Keywords
Aerospace Engine, Nationalization, Localization, Gas Turbine Engine, Piston Engine, National Technology Initiative

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1. Introduction

TEI started its operations on 25 January 1985 with the partnership of Turkish Aerospace Industries (TAI), General Electric (GE), Turkish Armed Forces Foundation (TSKGV) and Turkish Aeronautical Association (THK). Recently, TEI has left its mark in the propulsion systems of Turkish aerospace adventure. The purpose of TEI's existence and establishment was to supply the Turkish defence industry with domestic products and services. After starting its operations, TEI has been successful in all the projects it has undertaken. Based on the vision set in 1993, TEI has become a competitive company in a short time in engine assembly, maintenance, part and module manufacturing and after-sales services, by offering reasonable prices, delivering on time and enforcing zero defect principle in production. TEI has also become one of the most important suppliers of global aerospace engine producers anda worldwide rising value. TEI has updated its vision to include indigenous engine design and product development to its fields of activity in its 30th anniversary. Today, it is moving towards the objective of developing globally competitive indigenous power systems. As a result, TEI took a critical role in order to end Türkiye's foreign dependency in terms of aerospace engines.

2. The Importance of National Defence Industry

Efforts to minimize foreign dependency in the defence industry have paved the most important steps for the Turkish economy's growth and development. As Türkiye plans its own future and follows its own interests in foreign policy, it has been added to the sanctions list by other countries due to its geopolitical position.

Recent developments in the region around Türkiye have demonstrated the importance of the defence industry for all countries including our own. The occasional challenges posed by our foreign dependency have accelerated our development in the defence industry.

Since the establishment of the Republic of Türkiye, defence-related expenditures have always occupied a large part due to its strategic location. The Turkish defence industry, whose foundations date back to the rise of the Ottoman Empire, produced the most important tools of war at that time, established the "Tophane-i Hümayun" (Imperial Armory) and far outstripped European states in terms of the production capacity and the number of warships. However, the Turkish defence industry has lagged behind the developments in Europe since the 18th century (Presidency of Defence Industries, 2022). In the era of Turkish Republic, the government started defence industry initiatives by its own. General Directorate of Military Factories was established in 1921, and repair workshops for light weapons and cannons were established in Ankara in 1924. The first private initiative occurred in 1926 with the establishment of Tayyare ve Motor Türk A.Ş. (TOMTAŞ). Although domestic defence industry initiatives were started both by the state and private sector, with our entry into NATO during the Cold War, military aids have increased as a result of the financial support provided to our country in 1945 in accordance with the Truman Doctrine and Marshall Plan after the Second World War. This has slowed down the domestic and national defence industry initiatives (Presidency of Defence Industries, 2022). In 1974, during the Cyprus Peace Operation, Türkiye used the military equipment it has purchased previously to protect its national interests. Defence incentives provided to Türkiye were then cut off as some allied countries executed a ban on weapons. This condition has highlighted the importance of Türkiye's national defence industry in the country's capability to make independent decisions once again. In this context, Türkiye demonstrated a national response to the military and economic sanctions imposed on it. As a result, Foundations for Strengthening Land, Air and Naval Forces were established. Companies such as ASELSAN, HAVELSAN, ASPİLSAN were established by these state-supported foundations (Presidency of Defence Industries, 2022).

3. The Foundation and Development of The Domestic and National Engine Industry

It is necessary to provide the details of the production of domestic F-16 fighter jets in order to better explain the path taken for the development of indigenous engines. Established in 1973 with the aim to produce the airplanes needed by Türkiye, Turkish Aerospace Industries Corporation (TAI) turned into a 25-year partnership in 1984 as a Turkish-USA joint venture company. As a result of long research and work, it has been decided to build a military aircraft with a foreign country on the basis of co-production. F-16 of the American General Dynamics company were selected. To power this aircraft, F110-GE-100 model engine made by General Electric (GE) has been chosen. TUSAŞ Engine Industries Inc. (TEI) has been officially founded on 25 January 1985 for assembly and production of these engines in Türkiye. The shareholder structure of the company was 51% Turkish and 49% foreign (American General Electric Company) (TEI, 2005).

Shortly after its establishment, TEI started its first activities in February 1987 with engine assembly and produced 12 different parts for F110 engines in the same year (TEI, 2005). Going beyond engine assembly and part manufacturing only for national needs, TEI became a prominent company in the industry as the reliable supplier of leading engine producers in the world.

TEI added the design capabilities to its vision and established a Design and Product Development Group in 1996. J85 Nozzle System Ejector Development Project became the first project of the group. These efforts continued with engineering, design, and production responsibilities of some critical TP400 engine parts to be used in A400M aircrafts. Today, with these R&D efforts, TEI has become the company that achieved many firsts in our national aerospace engines by pursuing the goal of "becoming a center that can design and produce aerospace engines" (TEI, 2005).

As a company operating to meet the defence needs of the state, TEI is located in a sector and ecosystem where the policies regarding the products needed are directly determined by the state. Therefore, TEI aligns its activities and projects in parallel with state policies. Since the early 2000s, our country has taken decisive steps to produce national solutions, particularly in areas that require advanced technology. In particular, it was aimed to "acquire a competitive, self- sufficient, flexible, technological and managerial infrastructure that can be included in global collaborations in the fields of production-design-R&D in order to meet the needs with national facilities" as described as a goal in Türkiye's Ninth Development Plan, which was published in 2006 (Türkiye - Legal Gazette, 2006). Indigenous design works have become prevalent throughout the sector since 2010, as a result of the works progressing in line with this goal, and Türkiye's foreign dependency has been significantly reduced through a variety of projects realized.

The projects carried out at TEI are critical for Türkiye's defence and aerospace industry in the medium and long-term considering that progress in the defence industry can be achieved with the determination and policies of the state. In particular, 11 national and 1 licensed engine which were designed, developed, started and produced in the last 8 years are the concrete evidence of the company's effort to operate in the most effective way for the Turkish defence industry, as described in the founding ideal of the company.

4. Contribution of TEI To The National Technology Initiative

In line with its mission, TEI is taking decisive steps toward becoming a leading global engine company. In addition to its advanced manufacturing technologies, it receives the results of its determined efforts to achieve the goal of developing indigenous domestic engines with engine projects that have reached mass production stage. TEI has started its engine design and development efforts in 2004 with turbojet and turboprop gas turbine engines that can be used in Unmanned Aerial Vehicles (UAV), and further advanced its design work on UAV engines to include piston engines in recent years.

TEI has left an unmatched mark of success in Turkish aerospace history with 11 different indigenous and national engines designed, developed, produced and successfully started by TEI between 2014-2021 (Figure 1). Out of the 11 national engines developed by TEI in the last 8 years;

- 4 of them are jet fueled
  - TEI-TJ90,
  - TEI-TS1200-Core,
  - TEI-TJ300,
  - TEI-TS1400,
- 2 of them are gasoline-powered
  - TEI-PG115,
  - TEI-PG50
- 5 of them are diesel
  - TEI-PD155,
  - TEI-PD170-DT,
  - TEI-PD222-DT,
  - TEI-PD180-ST,
  - TEI-PD222-ST

The following 5 of these engines have started mass production:

- TEI-TJ90,
- TEI-PG115,
- TEI-PD155,
- TEI- PD170-DT,
- TEI-PG50

TEI-PG115 engine has exceeded 30,000 hours of successful mission time in the skies by April 2022.

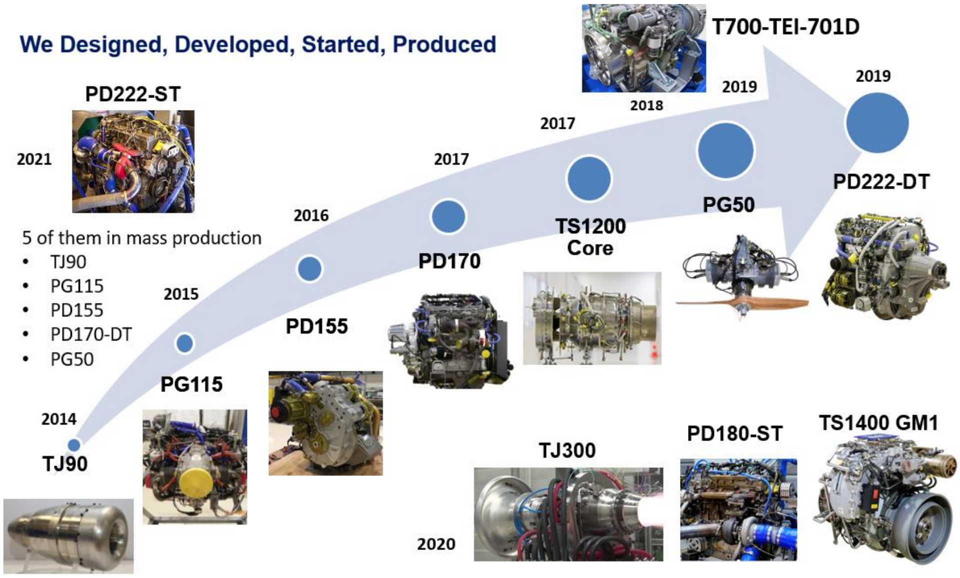

Figure 1. *Indigenous and national engines developed by TEI between the years 2014-2021*

Engine development efforts at TEI can be discussed under two main categories: piston engines and gas turbine engines.

5. Piston Aviation Engines Development

With wide variety of subsystems, Unmanned Aerial Vehicles (UAVs) can be used in many different areas in civil and military aviation such as exploration, observation, search and rescue, close air support, defence and attack. UAV systems attract attention as a technology that can make a difference, especially in the military field, by reducing operational costs day by day thanks to developing technology and manufacturing capabilities (Undersecretariat for Defence Industries, 2011). Based on these facts, the demand for UAVs has been increasing rapidly in the field of defence today. Türkiye has taken action to develop various subsystems of platforms, especially engines, with domestic and national resources. With various projects initiated under the leadership of the Defence Industry Agency, Türkiye has become one of the few countries that have flown the UAVs developed by its own, with the domestic and national indigenous aerospace engines that are also developed by its own.

5.1. Diesel Aviation Engines Development Works

In the field of piston engines, Operative UAV Engine Development Project was planned for integration with MALE (Medium Altitude Long Endurance) class UAVs, which servewith long flight times at medium altitudes. The project has started in 2013 with the support of the Defence Industry Agency with the aim to develop Türkiye’s first domestic and national aerospace engine that will produce 170 HP. While the design works of the project for TEI-PD170-DT engine continued, the shipment of the 155 HP import engine used for ANKA-S platform that is produced by Turkish Aerospace was stopped by the supplying country in 2014. An urgent need for a national engine solution arose for the continued production of these platforms. In order to meet this urgent need, until TEI-PD170-DT Turbodiesel Aviation Engine, the main intended propulsion system of the platform, went into mass production, all relevant TEI design team was directed to the TEI-

PD155 Engine Development Project. In order to develop an engine with 155 HP that can operate at an altitude of 30,000 ft in limited time, a strategy was followed to transform an existing civilian engine into an indigenous engine that will enable it to operate under military conditions to produce high power at high altitudes. The project started in rush on 31 October 2014, and TEI-PD155 engine was successfully developed with the extraordinary efforts of the TEI team in a short period of 2 years. Following the start of the first engine in December 2016 the shipment ban was lifted by the country supplying the import engine. TEI-PD155 engine was immediately put into mass production and 9 urgently needed engines were delivered to Turkish Aerospace in 2017 (Figure 2). Following the completion of platform integration works, ANKA platform successfully made its first flight with the national TEI-PD155 Engine on 20 February 2018 (Yıldırım, ANKA yerli motorla uçtu, 2018).

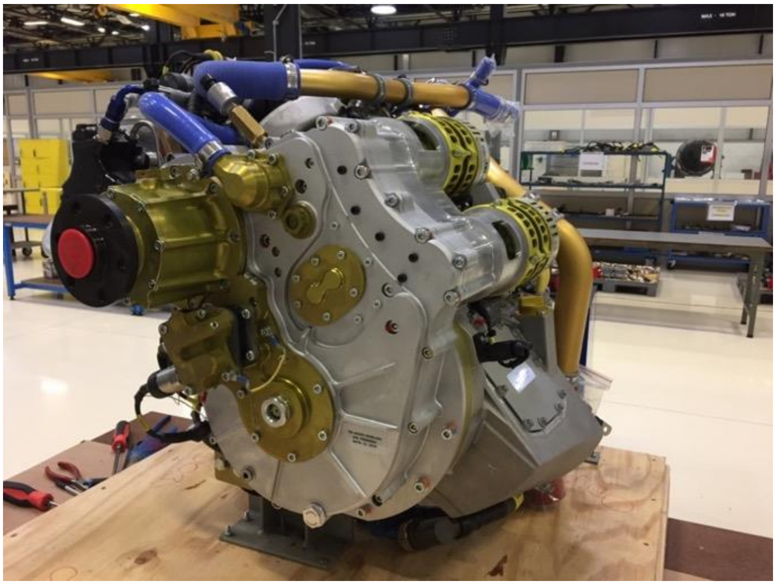

Figure 2. *First TEI-PD155 Engine shipped by TEI to Turkish Aerospace*

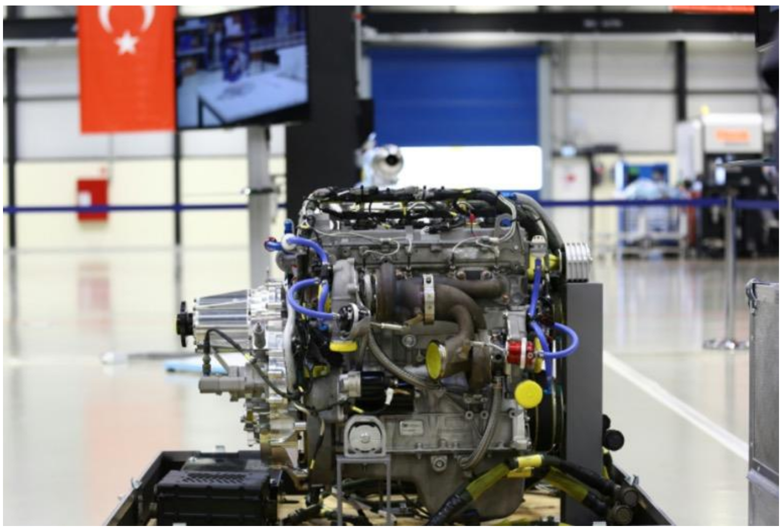

Figure 3. *First TEI-PD170-DT engine shipped by TEI to Turkish Aerospace*

While the development works of the TEI-PD155 engine were finalized, TEI design team continued to work on the Operative UAV Engine Development Project, which was designed with the aim to develop a superior and completely indigenous 170 HP turbo-diesel aerospace engine. Once again with the outstanding efforts of TEI team, the first TEI-PD170-DT engine was successfully started on 30 January 2017, right after the first TEI-PD155 engine was started. Beyond its completely national and indigenous design, TEI-PD170-DT engine has achieved domestic content of over 95% in terms of production and hardware. Following the maturation tests, the first TEI-PD170-DT engine was delivered to Turkish Aerospace on 3 November 2017 (Figure 3). Following the completion of the TEI-PD170-DT engine integration works to the platform by Turkish Aerospace, the first flight of the engine was successfully carried out on 27 December 2018 with ANKA platform under harsh conditions at -10 degrees (Bloomberg HT, 2018). The TEI-PD170 engine made several successful test flights in the following months. After the first batch of 13 engines that were produced as of December 2019, the mass production and deliveries of the TEI-PD170 engine continues (Figure 4). TEI-PD170-DT engine is also selected by Turkish Aerospace to supply power the AKSUNGUR platform, which is also developed by Turkish Aerospace following the ANKA platform. The first flight with AKSUNGUR platform was successfully performed on 4 October 2021 following the platform integration works. In addition, 3 engines have been delivered to Baykar for integration to Baykar platforms and ground tests.

Figure 4. *TEI-PD170-DT engines ready for shipment*

TEI-PD170-DT engine holds a record as the only turbo-diesel aerospace engine in its class that can reach a critical altitude of 20,000 ft. without losing any power. As seen in Figure 5, TEI-PD170-DT engine produces 43 HP (34%) more power than the imported engine, the closest competitor in its class, at a duty altitude of 20,000 ft. TEI-PD170-DT engine demonstrates an undisputed superiority when the Critical Altitude/Power ratio is compared to its competitors in the world (Figure 6).

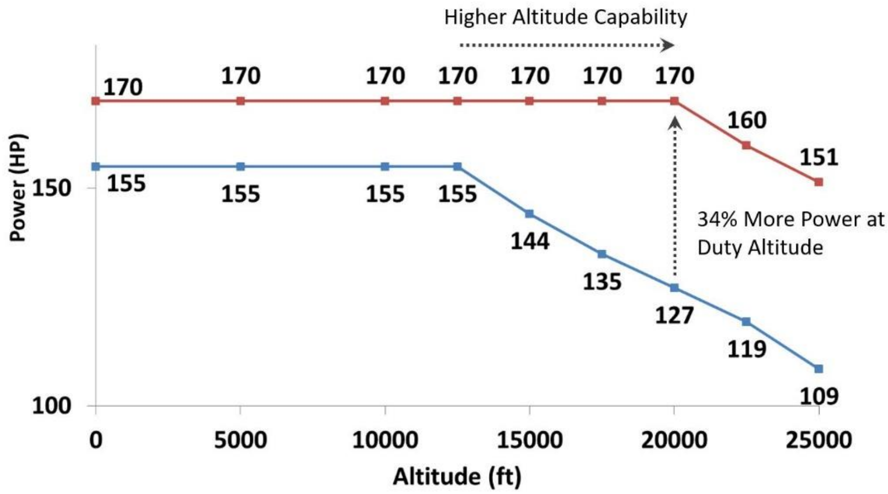

Figure 5. *Altitude performance comparison of TEI-PD170-DT and competing imported engine (Actual load values obtained from flight tests)*

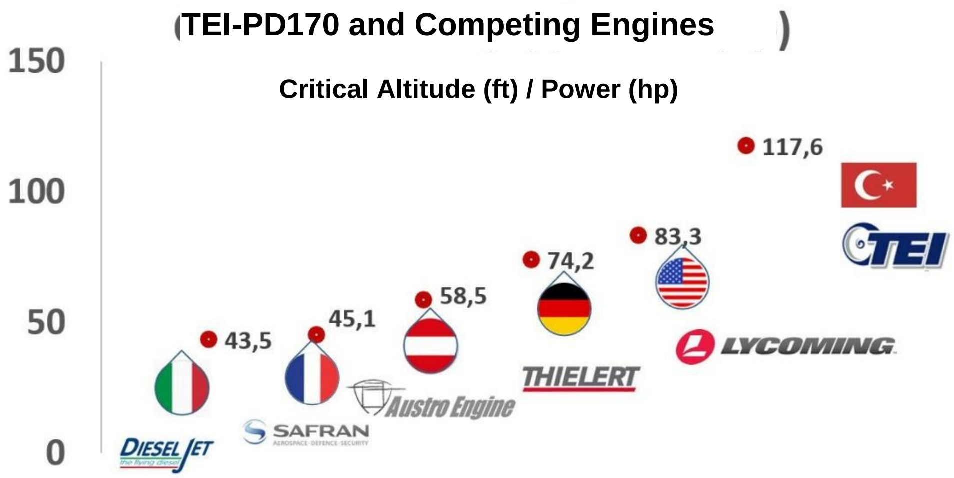

Figure 6. *Altitude performance comparison of TEI-PD170-DT and competing engines in this class in the world*

TEI-PD170-DT engine attracts attention with its superior altitude capability with indigenously developed special two-stage serial turbocharging system. TEI-PD170-DT engine can be operated with JP-8 or Jet-A1 fuels. It has a dry weight of 162 kg. In addition to superior altitude capability, with its special dual-turbo design, it distinguishes itself from all its competitors as the most superior engine in its class with its minimum specific fuel consumption (Figure 7). TEI-PD170-DT engine is developed in accordance with EASA CSE 440 civil aerospace standards. Thanks to its superior feature, it has the title of the world's highest altitude (45.000 ft) mass production turbo-diesel engine in its class. Software of the Engine's Redundant Engine Control System (ECS) is also developed by TEI. Mass production phase was initiated at the end of over 6000 hours of calibration and testing activities.

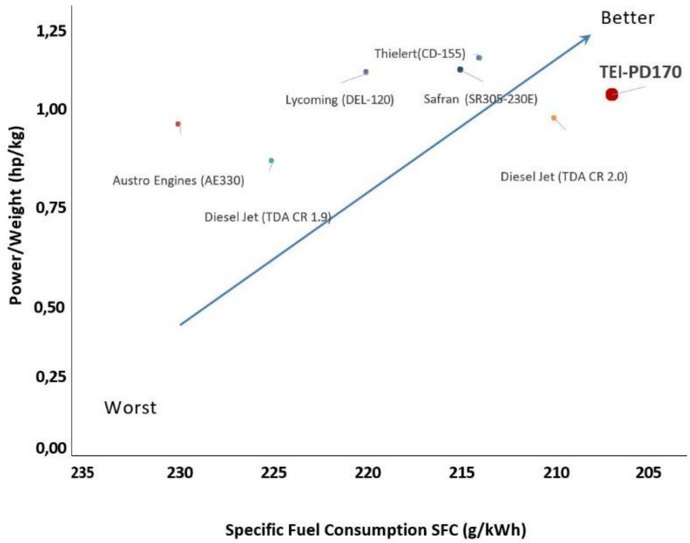

Figure 7. *TEI-PD170-DT is the best in the world among its competitors in this class with minimum fuel consumption*

Following the completion of the development of TEI-PD170-DT, based on the main configuration of this engine, and utilizing the experience and infrastructure gained through TEI-PD170 engine, a class of derivative engines have been developed to meet the variable power needs of MALE class unmanned aerial vehicles for various mission profiles. First of all, TEI-PD222-DT engine has been developed with higher take-off power with 225 HP. It has a dry weight of 168±2 kg. Later, weight of this engine has been reduced by 8 kg, and developed TEI-PD222-ST engine, which could still deliver 225 HP take-off power with a specially designed single turbo system (Figure 8). Likewise, TEI-PD180-ST derivative engine has been developed. It is 7 kg lighter than the TEI-PD170-DT engine and yet it can generate a little more take-off power, thanks to its specially designed single-turbo system. Tests and maturation phases of TEI-PD222-DT, TEI-PD222-ST and TEI-PD180-ST engines are still ongoing (TEI, 2022).

Figure 8. *TEI-PD222-ST subjected to challenging tests*

5.2. Gasoline Aviation Engines Development Works

With its superior technical infrastructure and design and production engineering capabilities and aiming maximum domestic production rate, TEI has developed TEI-PG50 engine, yet another piston UAV engine. TEI-PG50 is a gasoline powered UAV engine described as a 2-stroke boxer type engine. Türkiye's first 2-stroke aerospace engine TEI-PG50 is in the mass production phase. Negotiations are underway for the first batch order.

Figure 9. *TEI-PG50 gasoline UAV engines whose production has been completed before customer shipment*

TEI-PG50 engine, with 16.000 ft altitude capability and having a base engine weight of only 19 kg, produces 50±2 HP maximum take-off power. It stands out with the power it produces compared to other UAV engines used for similar purposes, its high power/weight ratio, electronic engine control system, injection and ignition systems, as well as fast technical and logistic support (TEI, 2022). TEI-PG50 engine has a specially developed clutch system that allows power transmission to engage when desired, based on the launch and usage needs of the platform it powers. It is the only engine in the world in its class which provides these features.

6. Gas Turbine Engines Development Works

In the field of gas turbine engines, TEI primarily aims to meet Türkiye's national needs, and to take its place in international markets in the medium and long term. As gas turbine technology applications, turbojet and turboprop engine development activities have been underway in TEI since 2004.

Figure 10. *TEI-TJ90 engines ready for shipment*

6.1. TEI-TJ90 Turbojet Engine

Within the scope of this attempt, the work for the development of the TEI-TJ90 Turbojet Engine Development Project was started in 2011 as part of the gas turbine engines development efforts. The first prototype engine produced within the scope of engine development activities supported by TÜBİTAK Technology and Innovation Support Programs Directorate, successfully made its first flight with the TEI experimental platform on 5 June 2013. TEI- TJ90 engine has a power generation capacity of 400 N (90 lbf). As the first application, it is developed for short-term missions on the target aircraft Şimşek platform developed by Turkish Aerospace. Following the completion of its integration on Turkish Aerospace's Şimşek Platform, TEI-TJ90 made its first flight with Şimşek on 7 June 2017 at 10,000 ft. altitude. Works for further development of the engine continue for TEI-TJ90 engine to be used in different and long-lasting UAV applications. As a result of these efforts, its combustion chamber technology has been developed to enable ignition at an altitude of 16,000 ft. Compared to similar engines, TEI-TJ90 Turbojet Engine attracts attention with its feature as ECU with data-connection to ground station, compliance with military standards, EMI/EMC compatibility, resistance to catapult launch loads, and starting with kerosene or electricity features (TEI, 2022).

6.2. TEI-TJ300 Turbojet Engine

With funding from TÜBİTAK, TEI-TJ300 MRAS (Medium Range Anti-Ship) Airbreathing Jet Engine Project was initiated with a protocol signed between TEI and Roketsan in September 2017. The first prototype has been successfully started on 25 February 2020 in a short period of 2 years of design and development with the outstanding efforts of the TEI team.

In order to be adapted to certain existing systems in the inventory of Turkish Armed Forces, TEI-TJ300 engine has been specifically developed to produce all the thrust needed by a missile over 300 kg within a limited diameter of 224 mm. It is a superior engine with an advanced compressor technology that is not available in any of the competing missile engines in this thrust class in the world. The compelling constraints on the engine dimensions extends the field of use of the relevant missile system so that it can be used in many platforms. The TEI-TJ300 engine is capable of operating at high speeds up to 90% of the speed of sound at an altitude of 5.000 ft. The capability to start with windmilling effect without the need for any starting system (starter motor) makes it possible to apply the platform to air, sea and land defence systems. In April 2021, TEI-TJ300 engine set a world record in its class by reaching a thrust level of 1.342 Newtons with a small engine diameter of 224 mm (Figures 11 and Table 1) (Çalkaya, 2021).

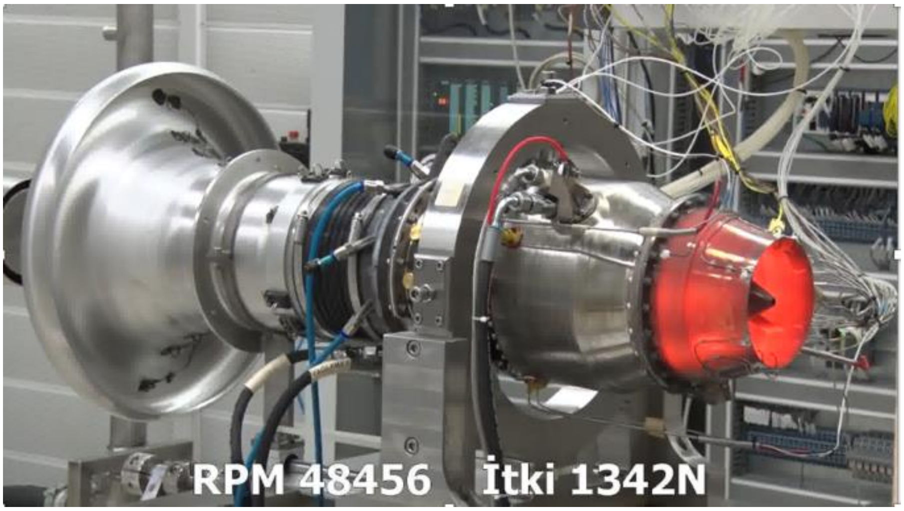

Figure 11. *A snapshot from the test where TEI-TJ300 engine reached record thrust*

Table 1. *Engine Diameter - Thrust Comparison of Competitors of TEI-TJ300 Engine*

Brand	Country	Model	Engine Diameter	Thrust
Safran	France	TRS 18-1	330.2 mm	1446 N
PBS	Czechia	TJ100	272 mm	1250 N
AMT	Netherlands	Lynx	261.4 mm	1450 N
Jetbeetle	Taiwan	H-250	250 mm	1250 N
PBS	Czechia	TJ80-11	235 mm	900 N
Jet Cat	Germany	P1000-PRO	234 mm	1100 N
TEI	Türkiye	TEI-TJ300	224 mm	1342 N

220-250 mm Diameter Class

6.3. TEI-TS1200-Core and TEI-TS1400 Turboshaft Engines

Contract for the Indigenous Helicopter Program was signed by Turkish Aerospace on 26 June 2013 for a 6-ton class national general-purpose helicopter which was later named as GÖKBEY. Following the signing of this contract development, efforts for a national engine for the national helicopter have started in 2014 with preliminary approval of TEI Board of Directors. Initially, it was projected that 1200 HP class turboshaft engine configuration would be sufficient for the power need of the helicopter. In the later stages of the project, due to changing and developing demands, the power need per engine has been updated as 1400 HP. With the contract signed between Defence Industry Agency and TEI on 7 February 2017, "TS1400 Turboshaft Engine Development Project" has officially started. The aim of the project is to develop a 1400 SHP turboshaft engine that will provide power for the National General Purpose Helicopter GÖKBEY, and to establish design knowledge and the infrastructure required for the development of a national gas turbine engine (İhlas Haber Ajansı, 2017). Through extraordinary efforts of TEI team, the national helicopter engine has been developed in Türkiye from scratch in a very short time and, the first prototype has been delivered to Turkish Aerospace, the owner of the platform, on 5 December 2020 with the participation of President Recep Tayyip Erdoğan, (Figure 12) (Özer, 2020). The project plan is that the matured engine for mass production will have a civil type certificate. In preparation for manned flights, maturation tests continue on other engines produced after the delivery of the first engine. The target delivery date for the first mass production engine to Turkish Aerospace is set as December 2024. Work is underway to achieve this target.

Figure 12. *TEI-TS1400 first prototype delivery ceremony, 5 December 2020*

Gas turbine engines take different names such as turbofan, turboprop, turboshaft with various additional modules and developments made on the main body which is called Core Engine. Before reaching the final configuration of TEI-TS1400 engine, a first core engine was developed. This core engine was named TEI-TS1200-Core and completed many tests. Therefore, within the scope of TEI-TS1400 Turboshaft Engine Development Project, a 1200 HP power "jet engine" core, has been developed in addition to the final 1,400 SHP power turboshaft engine. This core engine named as TEI-TS1200-Core is actually gas turbine (jet) engine in Turkish aerospace history. With the extraordinary efforts of TEI team, design, manufacturing, and assembly phases were completed very quickly within 3.5 years (Figure 13), and the engine achieved its first ignition successfully on 3 November 2017 (Figure 14). This date has a golden mark as a turning point in the history of Turkish aerospace, when our country has reached to the class of developed countries having gas turbine (jet) engine technology.

Figure 13. *TEI-TS1200-Core engine before the first test*

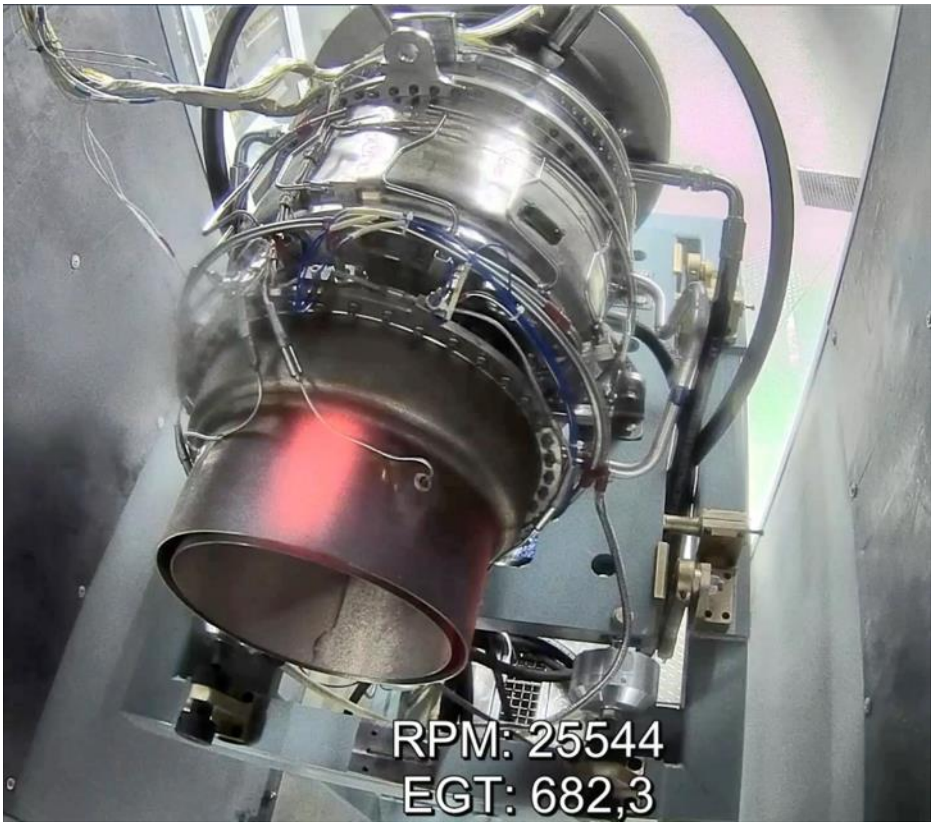

Figure 14. *An image from early ignition tests of TEI-TS1200-Core Engine.*

Since the work on National General-Purpose Helicopter GÖKBEY project started 4 years earlier than the National Turboshaft Engine Development Project, the import engine with maximum continuous power of 1,292 HP and maximum take-off power of 1,373 HP, which is also used in the ATAK helicopter, will be used in the GÖKBEY helicopters produced in the first batch until the first national engine development work is completed. TEI-TS1400 engine, which is being developed nationally by TEI within the scope of the "Turboshaft Engine Development Project", has maximum continuous power of 1,411 HP and maximum take-off power of 1470 HP (Table 2).

Table 2. *Technical Features of TEI-TS1400 Engine.*

	TEI-TS1400	**Imported Engine**
Continuous Maximum Power	1411 Hp	1292 Hp
Take-off power (5 min)	1470 Hp	1373 Hp
Emergency Power (2 min)	1570 Hp	1501 Hp
Service Altitude	20.000 ft	20.000 ft
Output Shaft Speed	23.000 rpm	23.000 rpm

Imported accessory systems used in the first TEI-TS1400 turboshaft engine, which was delivered with a ceremony on 5 December 2020, have been rapidly developed with local suppliers. Critical accessory systems such as gearbox, oil tank and pump were also developed domestically. The test bench to be used in engine tests has been also designed, developed, built and commissioned entirely by TEI engineers and technicians (Figure 15). As design intended, the first TEI-TS1400 engine equipped with locally supplied accessory systems such as gearbox, oil tank and pump has successfully reached maximum power of 1,411 HP with a shaft output speed of 23 thousand rpm, during the tests conducted in January 2022 (Figure 16).

Figure 15. *First national engine test bench designed, developed, built and commissioned for testing and qualification of TEI-TS1400 Turboshaft Engine by TEI engineers and technicians*

Figure 16. *TEI-TS1400 Turboshaft Engine being tested in the national engine bench developed by TEI, together with accessory systems such as national gearbox, oil tank and pump*

6.4. TEI-TF6000 Turbofan Engine

Taking all the development efforts in gas turbine engines one step further, TEI has initiated a new development program for TEI-TF6000 turbofan engine in 2020. It is a technology demonstrator engine designed to provide 6,000 lbf thrust. The program aims to develop technology and know-how for large scale turbofan engines towards National Fighter Engine (TFX) Program. As of May 2022, first round of design work is completed, and production of first prototype has started (Figure 17).

Figure 17. *Türkiye's first turbofan engine, TEI-TF6000 technology demonstrator*

7. Establishing Mass Production Engine Manufacturing Capability

While the development and prototype production of completely indigenous national engines continued, it was necessary to gain the missing infrastructure and experience in terms of mass production of these engines. Ever Since it was established in 1985 for assembly and production of F110-GE-100 engines to provide power to F-16 aircrafts under General Electric (GE) license, TEI has some relevant experience. However, it took until 2018 for a turboshaft helicopter engine to be produced in Türkiye.

7.1. Turbofan/Turbojet Engine Production Capability

TEI gained the capability to produce F110-GE-100 Turbofan Engines under General Electric license from the early days of its establishment and shipped its first F110 engine in 1987 after successful production (Figure 18). TEI carried out assembly and testing processes of all F110 engines for F-16 fighter aircrafts in the inventory of the Turkish Air Force (271 units under Peace Onyx I and Peace Onyx II Programs, 42 units under Peace Onyx Program). Parts manufacturing started with 12 engine parts; however, domestic content did not reach 50% of the engine over the years.

Figure 18. *First GE-F110 engine produced at TEI Eskişehir facilities*

Turbofan/Turbojet Engine Test Bench established within TEI has the capacity to test engines up to 100,000 lbf thrust (Figure 19). This capacity is large enough to test all engines in production except for GE90/GE9X, which is the world's largest engine. In the National Combat Aircraft Program it has been decided to use F110-GE-129 engines until a national engine is developed. Negotiations are continuing for these engines to be locally produced at TEI Eskişehir facilities with minimum 50% domestic content.

Figure 19. *100.000 lbf thrust capacity Turbofan/Turbojet Engine Test Bench at TEI Eskişehir facilities*

7.2. Turboshaft Engine Production Capability

Apart from the national and indigenous GÖKBEY National General Purpose Helicopter Development Project, the Defence Industry Agency initiated the Turkish Utility Helicopter Program(TUHP) in 2014. It aims to produce Sikorsky S70i Helicopters domestically under license with the name of T70 Turkish Utility Helicopter. The project scoped for local production of the helicopter platform by Turkish Aerospace, avionics systems by ASELSAN, and the engine by TEI under license in Türkiye. In 2018, TEI successfully produced (under GE license) 2,000 HP T700-TEI-701D helicopter engines domestically for the first time in Türkiye within the scope of the Turkish Utility Helicopter Program. A T700 engine test bench was established within TEI in order to conduct tests and qualifications of these engines (Figure 20). The first mass produced T700-TEI-701D domestic helicopter engine (Figure 21) has been produced by TEI at Eskişehir facilities. It completed all tests and qualifications for flight and was delivered to Turkish Aerospace with a ceremony in 2019 (Açık, 2019).

Figure 20. *Engine test bench established for test and qualification of domestic production T700-TEI-701D Engines at TEI Eskişehir facilities*

Figure 21. *Our first domestic T700-TEI-701D Engine produced at TEI Eskişehir facilities and delivered to Turkish Aerospace*

T700-TEI-701D Turboshaft Engines, which are produced by TEI in Türkiye, produce maximum power of 2,000 SHP with 207 kg weight, and can operate safely under the most challenging environmental conditions including desert dust. Powered by T700-TEI- 701D engines, T70 Turkish Utility Helicopter will meet Türkiye's general purpose helicopter needs for cargo, search and rescue, firefighting, air ambulance and coastal security missions.

Mass manufacturing stage has been initiated quickly after the first T700-TEI-701D engine produced in 2018. TEI delivered the 50th serial production domestic helicopter engine to Turkish Aerospace in 2021 (Figure 22) (Defence Turkey, 2021). TEI has reached a mass production capacity to produce one T700-TEI-701 engine per week. The number of mass production T700-TEI-701 engines has exceeded 70 as of April 2022. TEI has reached local production rate exceeding 50% in these engines including combustion chambers which require high technology.

Figure 22. *Delivery of 50th T70-TEI-701D Engine in November 2021*

Within the scope of the project, TEI will produce a total of 236 T700-TEI-701D Turboshaft Engines at Eskişehir facilities under the General Electric license. The Turkish Utility Helicopters will be used by the Land Forces, Air Forces, Special Forces and General Command of Gendarmerie, General Directorate of Security and General Directorate of Forestry (TEI, 2022).

8. High-Technology Infrastructure Development Projects

In order to design, develop, produce and test completely indigenous and national gas turbine engines, it is necessary to acquire various high-technology infrastructure and know-how that were not available in Türkiye before the 2010s. Acquiring design capability alone is not sufficient to successfully complete engine development projects. In this context, various technology development projects are still being conducted with the support of the Defence Industry Agency. Particularly, significant progress has been made about additive manufacturing methodology, which is called the manufacturing technology of the future. In addition to being one of the companies with the highest additive manufacturing capabilities in Türkiye today, TEI has also become one of the first companies in the world to operate engines using additive manufacturing method in rotating parts. In addition, cooperation is enhanced with other domestic companies for the development of engine subsystems. These initiatives are supported to develop a permanent aerospace engine industry and ecosystem in our country.

8.1. Advanced Production Process Technologies Development for Raw Material and Semi-Finished Supplies

Advanced design, production, testing, and special process technologies, which are necessary for the design, development, production and operation of our national aviation engines, were not previously available in Türkiye. These capabilities have been developed under the leadership and execution of TEI with the support of the Defence Industry Agency and the Ministry of Industry and Technology. In 2017, single crystal casting technology of superalloy turbine blades has been successfully developed for the first time in Türkiye with the KRİSTAL Project, in which TEI, TÜBİTAK MAM and GÜRMETAL teams took part (Figure 23) (Presidency of Defence Industries, 2022). As a very important project output, GÖKBEY helicopter's turboshaft engine single crystal Stg 2 and Stg 1 turbine blades with cooling channel are still being produced by TÜBİTAK MAM at prototype scale. Similarly, a precision aircraft engine Titanium part casting has been produced for the first time in Türkiye in 2018 within the scope of the İNCİ Project (Figure 24) (TEI, 2022). Again in 2018, aerospace-quality forging of Titanium alloy compressor wheel and Nickel Superalloy turbine disk (Figure 25) have been accomplished within the scope of the ÖRS Project for the first time in Türkiye (TEI, 2022).

Figure 23. *First superalloy turbine blades cast in Türkiye.*

Figure 24. *First aerospace-quality large-scale Titanium engine part cast in Türkiye*

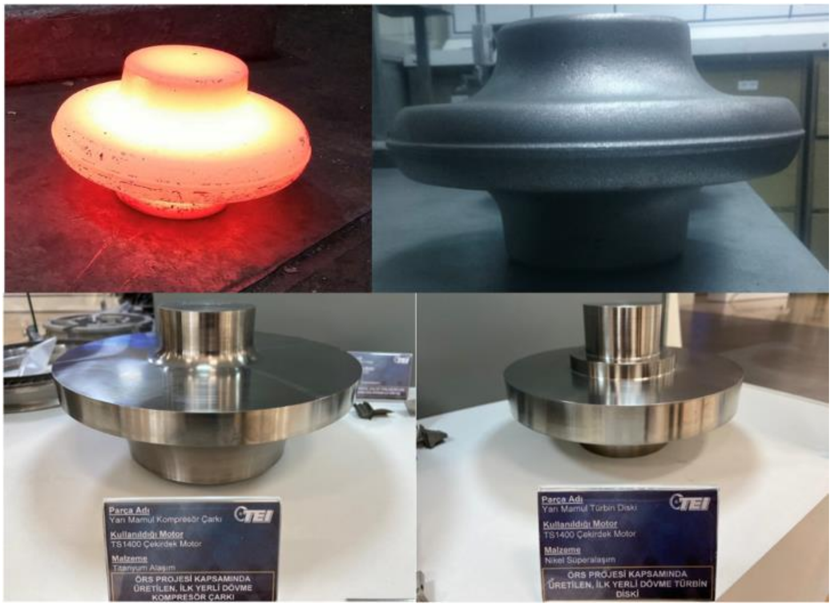

Figure 25. *First aerospace-quality Titanium alloy compressor wheel and Nickel Superalloy turbine disc forged in Türkiye*

8.2. Aerospace Materials Alloying and Production Technologies Development

In addition to special aerospace process technologies such as single crystal casting, precision casting and forging, with the support of the Defence Industry Agency, other technology projects have been initiated in order to develop and produce special quality materials and alloys to be used in these processes in Türkiye (Yıldırım & Çalkaya, Savunma Sanayisinde 6 Ar-Ge Projesi İçin İmzalar Atıldı, 2021). Within the scope of DİNÇ Project, Türkiye's first Nickel-based IN718 Superalloy and the first aerospace-quality AISI 321 stainless steel alloy have been successfully produced at TÜBİTAK MAM Materials Institute in 2020 (Figure 26 and 27). Efforts are underway to develop critical aerospace alloys within the scope of CEVHER (2021) and KÜLÇE (2022) projects.

Figure 26. *First aerospace-quality IN718 Nickel Superalloy and AISI 321 stainless steel produced in Türkiye*

Figure 27. *The first aerospace-quality IN718 Nickel Superalloy, AISI 316L and AISI 321 stainless steel produced at TÜBITAK MAM laboratories in Türkiye, in the form of billets as they come out of the furnace*

Laboratory-scale high-technology vacuum induction melting, and vacuum arc melting furnace capabilities have also been acquired by TEI to be used in the development of materials needed by domestic, indigenous and national power systems projects (Figure 28). In order to complete the certified material testing and characterization infrastructure, and vacuum induction and vacuum furnaces technological infrastructure, an engineering team has been established in 2014. This team has been transformed into Materials and Process Development Department to develop important alloys, materials and superalloys needed by our country's aerospace industry.

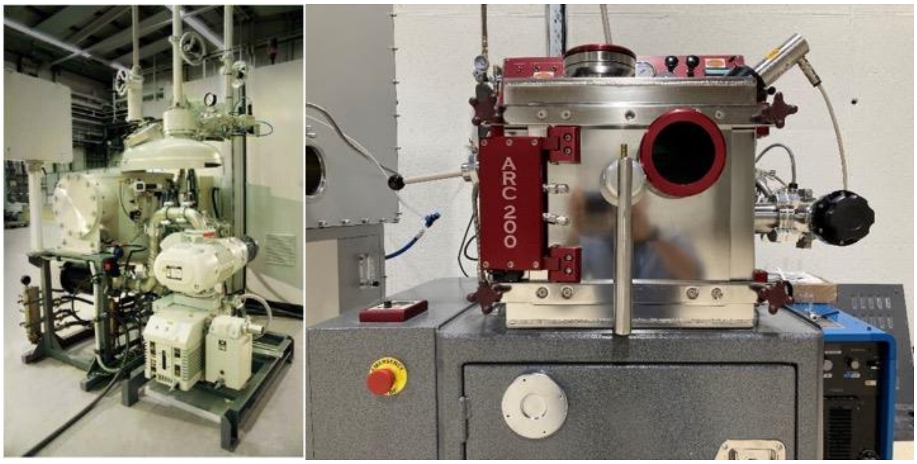

Figure 28. *Vacuum induction and vacuum arc melting furnaces at TEI*

8.3. Establishment of International Accredited Material Test and Characterization Infrastructure

To ensure nationally developed and domestically produced alloys comply with international material standards, and that their mechanical and physical properties can be determined and certified, Türkiye's first International Aerospace (NADCAP) Certified Materials Testing, and Research Laboratory (Figure 29) has been established and put into service by TEI on 29 July 2019 (Savunma Havacılık ve Uzay Derneği, 2019). With tens of thousands of certified material data produced in this laboratory under various operating temperatures and loading conditions, Türkiye's first certified material database was created for the use of TEI R&D and design engineers.

Figure 29. *Opening of Türkiye's first NADCAP accredited material test and research laboratory*

TEI Materials and Test Research Laboratory (Figure 30) has the capability to conduct detailed chemical composition analyses, mechanical and physical tests especially under high temperature exposure at international standards for aerospace materials. In this context, TEI Materials and Testing Research Laboratory has international accreditation and

NADCAP certification for tensile, compression, fatigue, creep and crack propagation tests. Temperature dependent density, elastic modulus, specific heat, conductivity, thermal expansion etc. properties can be determined within the scope of physical characterization tests. In order to support alloy development projects, characterization, test and verification studies of alloys developed by TEI are also conducted.

Figure 30. *TEI material test and research laboratory*

8.4. Advanced Manufacturing Technologies and Acquiring Certified Special Process Capabilities

Advanced manufacturing engineering and special manufacturing process skills are also required in order to process the raw materials into complex engine parts at high precision, even if raw materials, alloys, semi-finished supplies such as casting and forging that are needed for the production of a high-technology turbine engine, are acquired. It is necessary to combine these capabilities with high-technology manufacturing systems to obtain the final engine parts. With its manufacturing engineering team of more than 200 engineers, TEI has the capability to model and manufacture all kinds of complex modern aircraft engine parts. In 2017, TEI has achieved NADCAP accreditation for 43 different processes in 10 different process groups such as Chemical Processes (CP), Non-Destructive Testing Methods (NDT), Heat Treatment (HT), Surface Enhancement (SE), Non-Conventional Machining (NM), Coating (CT), Measurement and Inspection (MI), Welding (WLD), Conventional Machining as a Special Process (CMSP) and Material Test Laboratories (MTL). TEI became the company with the most NADCAP accredited special process capabilities among over 4,000 aerospace companies worldwide. As of April 2022, aircraft engine part manufacturing capabilities, which started with 12 parts in 1987, have reached the ability to manufacture more than 1,500 latest generation aerospace engine parts for more than 50 different engines. As of 2022, TEI ranks second in the world among aerospace engine production facilities in terms of the number and diversity of its certified special process manufacturing capabilities (TEI, 2022).

In order to produce the complex parts of modern and advanced aerospace engines of our age, a high-technology manufacturing systems infrastructure is required in addition certified special process capabilities. A comprehensive TEI manufacturing capabilities map was created at the beginning of 2014. The manufacturing infrastructure and technology level, that will produce a complete gas turbine engine, has been reached in a short period of 3.5 years by systematically gaining the missing manufacturing technologies and capabilities to produce a gas turbine engine. Following the acquisition of this competence, the production of the TS1200-Core, Türkiye's first real gas turbine (jet) engine, was completed in October 2017, and the engine was started on 3 November 2017. Some of the prominent special manufacturing and process technologies owned by TEI are presented in Figure 31 through Figure 40.

Figure 31. *Turbine disc broach opening process*

Figure 32. *TEI is one of the few companies in the world that has inertial welding technology without electrode and welding filler*

Figure 33. *TEI is one of the few companies which has Blisk (Monolithic Bladed Disc) manufacturing technology*

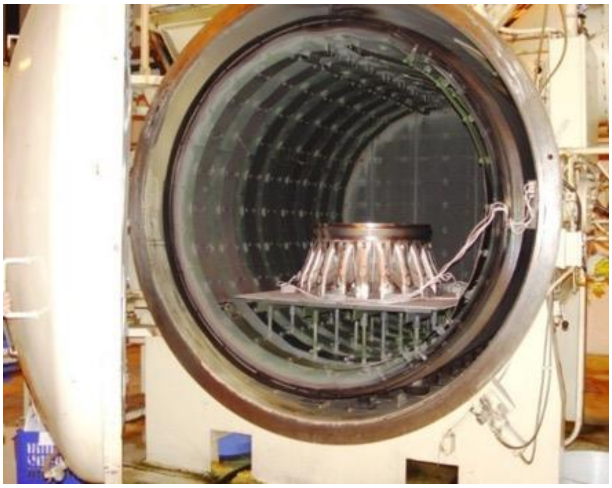

Figure 34. *High-technology heat treatment furnaces with precision vacuum technology*

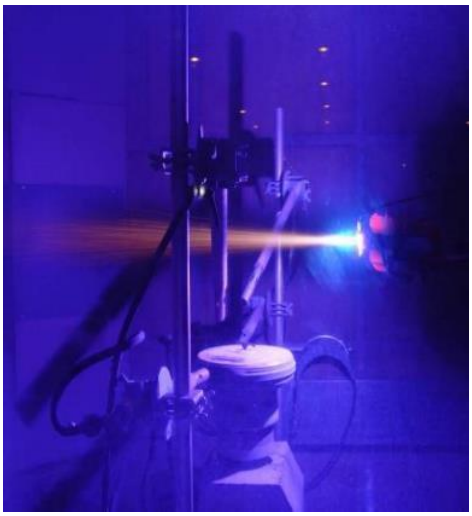

Figure 35. *One of special ceramics/thermal coating systems at TEI*

Figure 36. *TEI has additive manufacturing capabilities with both "Selective Laser Melting" and "Electron Beam Melting" technologies.*

Figure 37. *6-Axis Electro-Chemical Processing Technology Providing High Material Removal Capability for Super Alloy Materials*

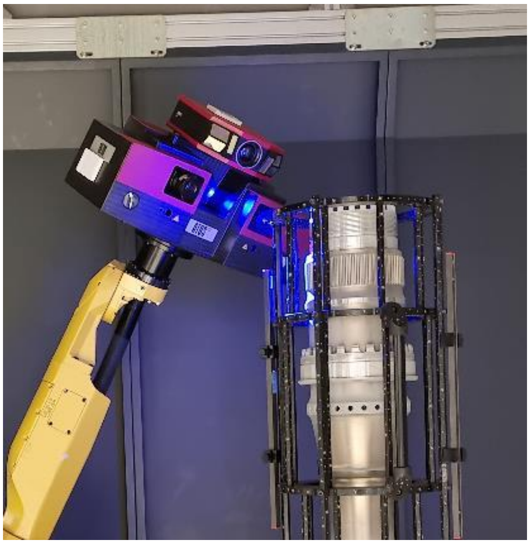

Figure 38. *All measurements on the part can be taken within minutes with CMM precision using indigenous "High Precision Optical Measurement Capability" developed by TEI*

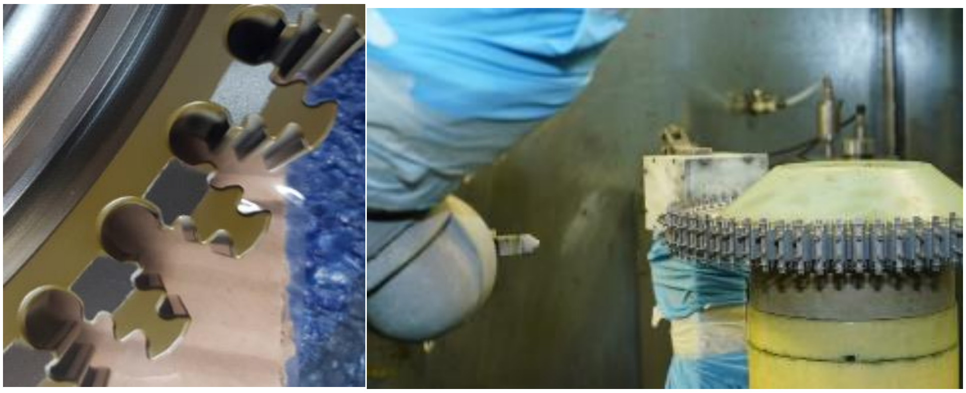

Figure 39. *TEI applies anti-corrosion coating technology on turbine disks to increase thermal shock resistance of the materials under high temperatures*

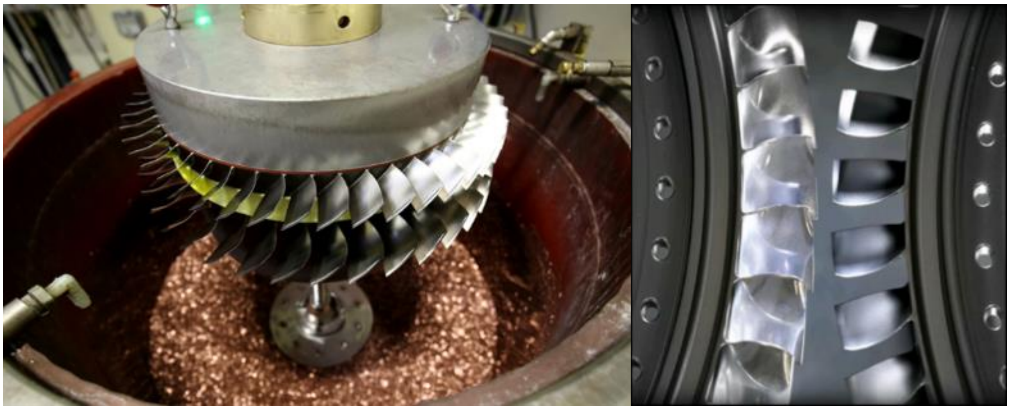

Figure 40. *Engine compressor performance is increased by reducing the roughness level of Blisk blades with ultrapolish process*

8.5. Digital Transformation in Manufacturing and Industry 4.0

In 2016, TEI has started Industry 4.0 studies and digital transformation in manufacturing by developing indigenous digital platforms and systems within the company. As part of these efforts, a database has been created for the data collected from the system by connecting the machinery and equipment in the advanced manufacturing technologies building to a network with internet of things (IoT) applications (Figure 41). Possible errors that may occur can be predicted and measures can be taken, while opportunities can be identified in advance and actions can be taken quickly by analyzing the collected real-time data and transforming it into meaningful information. In addition, an indigenous digital quality application has been designed, developed and put into operation in order to systematically monitor the errors that occur in production, as well as to plan, implement and report corrective actions. As a result, First Time Yield rate has increased, and a significant improvement has been achieved in terms of loss costs.

Figure 41. *Internet of Things (IoT) Applications in CNC Machinery at Advanced Manufacturing Technologies Building*

With the digital competencies gained by TEI, various software has been developed to address issues such as paperless manufacturing, data analytics, digital twin applications, data processing and reporting platforms. As a result, end-to-end digital traceability in manufacturing was ensured, decision-making processes were made based on data, and productivity, agility and quality were increased in manufacturing processes.

8.6. Developing Indigenous Engine Design Tools, Software and Engineering Codes

Indigenous engine design and analysis software as well as engineering tools are required in order to ensure that highly complex advanced engine designs requiring high technology can be quickly selected from all possible alternative configuration options. Commercial and professional engineering codes can only be effective in detailed analyses after the general engine configuration is determined. Like all other OEM companies that develop and produce aerospace engines, an Engine Design Tools Development (EDTD) team has been established within TEI as of 2014. Thanks to the engine design tools development studies conducted at TEI, it is ensured that analysis, calculation, drawing and assessment, etc. operations to be performed during engine design and development processes are carried out with engine design tools using indigenous software. Indigenous design tools, which are important elements of engine design process, are in the category of know-how that engine manufacturers protect at the most critical level of confidentiality. Working for this purpose, TEI EDTD team develops engine design tools with indigenous codes that will manage engine design processes with quality, in secure, quick and accurate manner. EDTD software team programs the engineering methods needed by R&D and design teams, and makes them available to the TEI engineering teams via an "Application Store" with indigenously developed user interfaces (Figure 42). In this context, more than 30 indigenous software and engineering tools have been made available, and tool development studies continue in line with priorities.

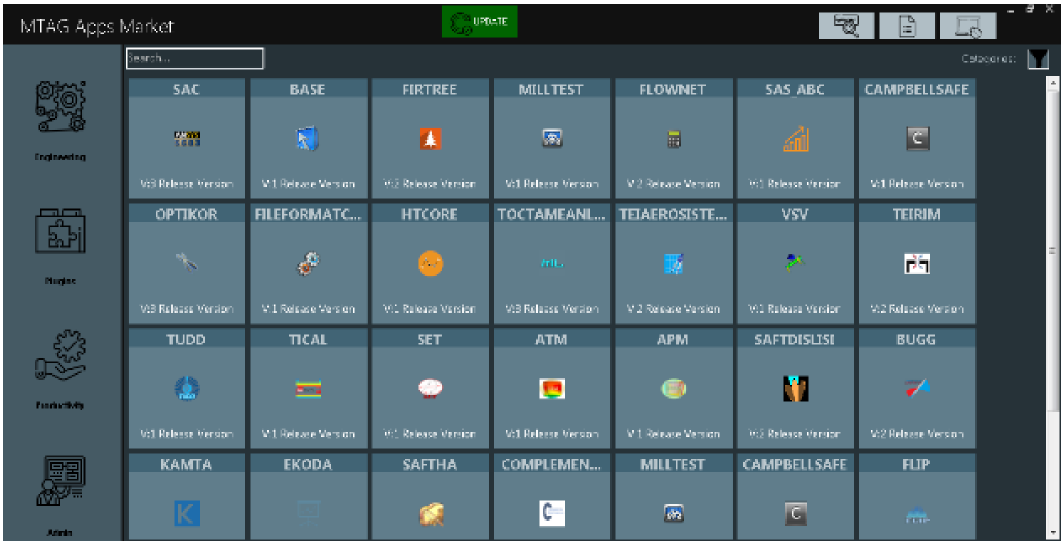

Figure 42. *A sample display from indigenous Engineering Software Application Store (App Store) created by TEI MTAG (Engine Design Tools Development) team*

8.7. Development of Engine Control (FADEC) Software and Hardware Technologies

In addition to design, analysis, manufacturing, testing, raw material and semi-finished manufacturing technologies, one of the most critical technologies for the development and production of a high-tech aerospace engine is engine control software and hardware technologies. In order for the engine to provide the best performance under challenging flight and operating conditions, it needs a high-technology engine control unit including Electrical, Electronic, Control and Embedded Systems (EECES), that is, a FADEC (Full Authority Digital Engine Control) unit, as it is named in aerospace. In order to develop all electrical-electronics sub-systems to be used in indigenous engine programs at TEI, a design and development team has been established in 2014. The purpose of this unit is to design Engine Control and Electric Systems among safety-critical sub-systems of the engine.

R&D studies that started with the development of the control system for TEI-TJ90 engine continued with the development of electrical systems (alternator/generator, engine wiring, electrical power generation and control units) for TEI-PG115 and TEI-PD155 engines. All of the control and electrical systems for TEI-PD170-DT Turbodiesel Aviation Engine, especially FADEC (Full Authority Digital Engine Control), have been indigenously designed with special focus on safety in terms of airworthiness, and have been verified by ground and flight tests. FADEC, i.e. Engine Control System (Figure 43), is the unit responsible for providing engine performance in the best way possible according to the data received from sensors in the engine such as engine temperature, pressure, fuel temperature, fuel flow, air density in response to the commands received from the pilot on the platform. While doing all these, it monitors the health level of both the engine and its own electronic hardware and software, and issues warnings to the pilot based on the defined engine limits. FADEC, which is one of the highest safety-critical systems of the engine, operates with a redundant architecture.

Figure 43. *TEI-PD170-DT engine control system (FADEC)*

The design capability gained for the control of TEI-PD170-DT engines has been developed and implemented also to gasoline engines (TEI-PG50) in addition to various derivative diesel engines in the following years. Electrical power generation systems design capability was also gained in all of these engines. Design of the alternators/generators which are responsible for meeting the electrical power needs of not only the engine but also the platform (Figure 44), as well as their power control units (Figure 45) have also been completed and verified with flight tests.

Figure 44. *TEI-PD170-DT alternator system*

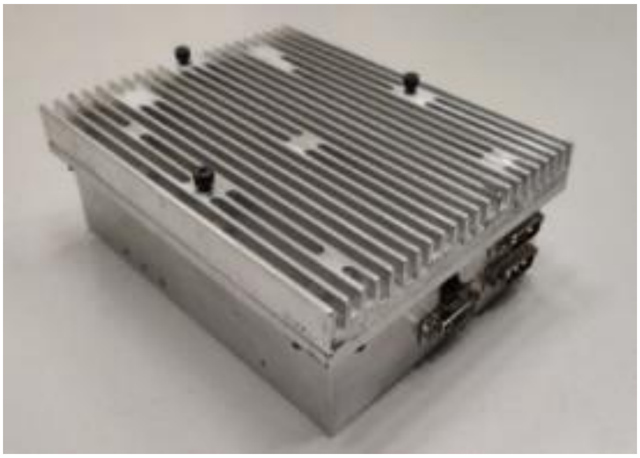

Figure 45. *TEI-PG50 power control unit*

In addition to the design capabilities acquired on the piston engines side, efforts have started on the development of engine control and electrical systems for the gas turbine engines, thanks to development and verification infrastructure. The experience gained with gas turbine engine control systems developed for TEI-TJ90 and TEI-TJ300 engines also served for TEI-TS1400 engine.

Figure 46. *An image from TEI EECES (Electrical, Electronics, Control and Embedded Systems) software-hardware development laboratories*

TEI electrical-electronics subsystems team, which initially started its activities as a small unit, has been transformed into a fully equipped EECES (Electrical, Electronics, Control and Embedded Systems) Department in 2016, consisting of 4 main disciplines: control, avionics system, hardware and software. Both the development and verification infrastructures, and laboratories have been established within this unit for all engine control and electrical systems designed within TEI (Figure 46). The developed prototype-level sub-units are verified first at the card level in the laboratory environment, and then at the box level in the Hardware-In-the-Loop (HIL) test systems by performing software-software and software-hardware integration (Figure 47).

Figure 47. *Hardware-In-the-Loop (HIL) Test System*

Starting from the core engine, the engine control algorithm, embedded system software and hardware have been matured in accordance with the ARP 4761, ARP 4754, DO 178 and DO 254 standards required by civil aviation authorities. While the infrastructure has been established and developed within TEI, a software and hardware subcontractor ecosystem was created throughout Türkiye. These subcontractor companies have been trained in various projects, and equipment and low-level software services have been received. Cooperation is made with TÜBİTAK-BİLGEM in terms of Real-Time Operating Systems.

Apart from meeting the needs of existing engine projects, TEI EECES team continues to work on the development of new generation engine control and power technologies in Türkiye. In this context, development of indigenous permanent magnet alternator (PMA) per aerospace standards is also underway. With the expectations that electric based thrust systems will increase proportionally in aerospace, hybrid thrust systems development studies are carried out, and indigenous design capability is gained for electric motor and motor drive systems technologies.

9. Conclusion

Recently, Türkiye has been making a major breakthrough in the defence and aerospace industry. The support of government institutions and government policies are of great importance in this breakthrough. Thanks to this support, Türkiye has become one of the few countries that produces its own aircrafts, ships and tanks. In doing its part to support this process, which has turned into a "National Technology Initiative", TEI continues its efforts for the development of indigenous aerospace engines needed by our country. With its nearly 40 years of experience and the most qualified staff in its field, TEI has successfully built a permanent aviation engine industry and established the technology infrastructure in our country as aimed at the establishment of the company. TEI has rapidly developed its capabilities to design and develop indigenous national engines in recent years, and successfully started Türkiye's first turbine (jet) core engine on 3 November 2017, by doing so it elevated Türkiye to the league of high-technology countries. On 5 December 2020, by delivering the first indigenous helicopter engine prototype to the customer for the initiation of platform integration studies, TEI has leaped to a higher class among companies producing parts and modules, and now become one of the main engine manufacturers. Over the last 8 years, through design, development and production of 11 different indigenous national aviation engines, TEI has successfully left a legacy in Turkish Aerospace History. In addition to all these indigenous engines developed in such a short time, TEI has now reached a level of technology to develop and produce a military turbofan engine that will produce 35,000 lbf class thrust at the technology level that will provide a 5th generation fighter aircraft the "supercruise" capability (supersonic flight without afterburner support). With all these achievements, TEI made a permanent mark in the aerospace history of our country. TEI continues to work resolutely to make significant contributions to the "National Technology Initiative" in line with the needs of our state.

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Born in Denizli, Türkiye in 1967, Prof. Mahmut F. Akşit has graduated from Mechanical Engineering Department of the Boğaziçi University in 1991. Continuing his academic studies at Rensselaer Polytechnic Institute in Troy, New York, USA, Akşit completed his Master Degree (MSc) in 1993 and Doctoral Degree (PhD) in 1998 in the Department of Mechanical and Aerospace Engineering. He received the titles of Associate Professor in 2004 and Professor in 2015. During his stay in the USA, he served as "Consultant Research Engineer", "Senior Researcher", "Static Seals Manager" and finally "Advanced Seals Research Team Leader" for 10 years at the General Electric Corporate R&D Centre. Akşit returned to Türkiye in 2001 and served as the Head of the Department of Energy Systems Engineering at Gebze Institute of Technology. Continuing his career in Mechatronics Engineering Department of Sabancı University after 2003, Akşit received the title of Professor in 2015. Professor Akşit has been serving as President&CEO since December 2013. In addition to these duties, he also serves as the Chairman of the Board of the ESAC Eskişehir Aviation Cluster Association and a member of the International Gas Turbine Institute Heat Transfer Technical Committee. Professor Akşit has more than 30 years of experience in aircraft engines, gas and steam turbines, over 60 patents issued in 16 different countries, and has produced nearly 150 articles, papers, NASA and NATO technical reports and similar scientific publications.