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A Review on Gas Turbines Derived from Aero Engines

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Abstract

Gas turbines are one of the widely used and expensive industrial equipments, which are very important nowadays. These turbines are used in various industries and machines and their fuel is usually gas. These turbines are very big and huge and many metals are used in their construction. Their design, construction and maintenance are very difficult and are usually done by a team of expert engineers. These turbines have an internal combustion engine inside them, which, with their rotational movement, convert the energy caused by the stimulation of gases into electricity energy. The process of designing and manufacturing turbine engines has many complications and going through this process requires significant time and costs. Therefore, reputable gas turbine manufacturing companies have made a lot of efforts to shorten the design and manufacturing processes, one of these ways is to use aero gas turbine cores to build industrial gas turbines. In the gas turbine industry, these types of gas turbines are known as derivative gas turbines. Considering the special characteristics of aero gas turbines such as light weight, relatively small dimensions, high efficiency and performance, if the gas generator core of these turbines is used for the industrial gas turbine core, in addition to shortening the design and manufacturing process, it can be desired need to obtain an industrial gas turbine was achieved. In this study, the main types of gas turbines derived from aero engines including General Electric products,Siemens products , and Products based on Pratt and Whitney products, have been reviewed and the characteristics of each of them have been discussed.

Keyword: Industrial gas turbine, derived gas turbine, aero engines, modified engine, gas generator

INTRODUCTION

A gas turbine is a type of internal combustion engine of rotating equipment machines that operates on the basis of the energy of favorable gases produced from the combustion of different fuels. It is mainly used in fossil fuel power plants, but versions of gas turbines are also used in helicopter engines, engines of some passenger planes, engines of fighter planes and turbine engines of some types of ships.

In recent years, extensive studies have been conducted in the field of gas turbines [1–8]. The main goal of these studies was to better understand gas turbines and optimize their performance [9–12]. Researchers have tried to optimize the individual components of gas turbines such as inlets [13–18], compressor [19–21], combustion chamber [22–24] and related components such as atomizers [25–34], turbine [35–37] and outlet nozzle [38–40], aerodynamics of airfoils [41–50] to increase the overall efficiency of gas turbines [51–53]. The purpose of this study is to investigate the effects of mass flow rate and co00mpressor pressure ratio on compressor work, turbine work, net work and gas turbine cycle efficiency. Figure 1 shows an sample of a gas turbine.

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Gas turbines derived from aero engines are popular options for power generation [54]. Reliability, productivity and flexibility are the three prominent features of these machines. Compared to similar industrial gas turbines, these machines based on advanced materials and technologies of aero engines are significantly lighter and more agile in operational efficiency. Compared to heavier gas turbines with an average efficiency of 35%, these machines with an average efficiency of 45% are considered a suitable option for energy production purposes up to 100 megawatts.

The possibility of using different fuels, including a combination of natural gas and liquid fuel, is another advantage of these turbines. Over the past five years, the market for gas turbines derived from air engines has been growing at an average annual rate of five percent. Obviously, in Asia, a large number of these machines have been used in LNG production facilities. In North America, these machines are traditionally used in peak conditions or to compensate for disruptions in the electricity distribution network. In this study, some of the most successful samples in this category have been reviewed.


Figure 1. A sample of gas turbine [54].

General Electric Products

GE has the largest market share of gas turbines derived from air engines. The LMS100 machine cools the air flow between the low-pressure and high-pressure stages of the compressor using an intermediate cooler. Based on this, the LMS100 turbine can provide an output power of 115 megawatts with an efficiency of 44%. This industrial turbine is designed based on the main core of the CF6 turbofan engine, which supplies the propulsion power of the Boeing 747 family. The free turbine of this car can work with a frequency of 50 or 60 Hz without the need for a gearbox.

This machine can reach maximum power in less than ten minutes. Until 2018, GE has sold more than 62 units of this car to customers in ten different countries. By the beginning of 2018, these machines have recorded a total of 650,000 operating hours. Mainly, this turbine is used to stabilize the network or support in peak consumption mode. Argentina's Pampa Energia is the largest customer of the LMS100 turbine and purchased the machine in summer 2017 as a replacement for Frame 9E turbines in a combined cycle configuration.

The LM9000 turbine with an output power of 66 to 75 MW can operate in a simple cycle configuration with an efficiency of 43%. This machine is derived from the GE90 turbofan engine installed on the Boeing 777 passenger jet. The time required to reach the maximum power is less than 10 minutes, and the inspection time for hot section parts is 36,000 hours, and 72,000 hours for total reconstruction. This machine can be used to support the network, supply electricity to industrial units, support the distribution network in peak consumption conditions, and also provide local electricity in remote areas. The use of this turbine in LNG compression and barge applications has been welcomed. The configuration of LM9000 is based on the main core derived from the air engine in such a way that it can be used to provide power in a small space on ships. GE Company delivered the first LM9000 turbine to customers in 2019.

The LM6000 gas turbine is one of the most successful GE products in this class, with an operating fleet of more than 1,270 units and a record of 37 million operating hours. This gas turbine has been developed based on the core of the CF6 turbofan engine, which supplies the propulsion power of Boeing 747 and 767 and Airbus A330 airplanes. The output power of different models of this machine is reported from 44 to 57 MW in simple cycle mode and from 117 to 149 MW in dual use mode as combined cycle. The low-powered models of this car use the SAC combustion chamber based on the use of water to control pollution and have recorded more than 26 million operating hours.

More powerful examples of the LM6000 machine are equipped with a DLE combustion chamber and have passed more than 11 million operating hours. In addition to supporting the grid in peak mode, this gas turbine is also used for the simultaneous production of electricity and heat in industrial complexes and mechanical drive applications. This machine was developed on the basis of optimal two-axis design with the aim of reducing maintenance costs, and it only takes five minutes to reach maximum power.

LM6000 and DLE57 are the newest members of this family, which have been delivered to customers since spring 2017. Compared to the previous sample, the output temperature of the DLE57 sample has increased by 39 degrees Celsius. Also, its output power has increased by seven megawatts in simple cycle mode. In March 2018, two units of this car were installed in Thailand. The LM6000 is the first GE turbine that uses a battery-based energy system.

The LM2500 car is another GE derivative of the CF6 turbofan engine. This machine, which was introduced in 1971, has three different models that provide output power from 22 to 37 megawatts, respectively. The combustion chamber of these cars are available in two models, SAC and DLE. With more than 2,300 units installed and more than 90 million operating hours, the LM2500 family of turbines is the world's most popular aero engine-derived gas turbine.

The main application of this turbine is mechanical drive and offshore power supply as well as simultaneous production of electricity and heat. General Electric has also released a mobile model called TM2500 based on this turbine. The complete equipment of this turbine is transported by three trailers and will be ready for operation in less than 11 days at the location of the trailers. Within ten years of its initial launch, more than 200 units of these machines have been sold to customers from 25 different countries. Table 1 shows the history of the gas turbine of General Electric Company:

Table 1. GE Gas Turbine History[55].

General Electric 3.5 MW Gas Turbine (1949)	The 3.5-MW gas turbine, also known as the Frame 3 unit, was GE’s first commercial power generating gas unit. It was installed to support the existing steam turbine at Belle Isle Station, owned by the Oklahoma Power and Electric Company. This unit exceeded design expectations as it routinely provided an electrical output far above its 3,500 kW rating. On many days its output reached 5,000 kW with an average of 4,200 kW daily over the three years from July 1949 to July 1953. Of special note is also how the exhaust from the unit was used to help power the adjacent steam turbine. This “combined cycle” setup was a first for the United States.

GE 5 MW Gas Turbine "Kilowatt Machines" (1951)	In 1951, Rutland, Vermont, become the recipient of three (3) 5 MW gas turbines based on the Frame 3 design but with some enhancements. These were a two-shaft variation giving the units twin recuperators and intercoolers. These became known as the "kilowatt machines".
GE Blackout Busters (1967)	In 1967, in response to increased electric grid regulation, GE installed the first dedicated, combined-cycle plants in Ontario, Canada. For the City of Ottawa, it was the GE 11-MW FS3 model gas turbine and for Wolverine Electric of Ottawa, the 21-MW FS5 model was chosen. The Great Northeast Blackout in the fall of 1965 prompted regulators to require utility companies to install quick starting and compact power generating plants which would increase system reserve margins and help halt a blackout.
GE Frame 5 Upgrade (1970)	Frame 5 gas turbine model variations continued to be highly sought after not only by utility companies but also by industrial plants and factories. In response to a specific power consumption need, GE upgraded its Frame 5 gas turbine plant design to have the highest output rating yet of 24-MW. This install was for a smelting facility in Bahrain and was followed by many more.
GE Frame 7 Turbine (1970, 1971, 1972)	A new design emerges, the MS7000, which is a Frame 7 turbine. It's rated at 47.2-MW. This prompts working with Alstom on the Frame 9 turbine, a 50 Hz design. This leads to several successful turbine lines developed in the 1970s including the 7E which was first put in service in Shoreham, UK, and the 7B rated at 51.8-MW.
GE Frame 9 (1975)	The GE Frame 9 debuts for the French utility company, EDF, with an 80.7-MW rating.
GE Frame 6B (1978)	The Glendive station of the Montana-Dakota Utilities system sees the first 6B turbine installed. This becomes the first of many hundreds installed around the world and is still in use to this day. With ongoing line upgrades and technology improvements, the 6B model continues to be a competitive option in the gas turbine marketplace.
GE F-Class Machines (1990)	In 1990, the first F-class machine was installed at the Chesterfield Power Station for the Virginia Electric and Power Company. For simple cycle service, it was rated for 147-MW, whereas in combined cycle mode, the output regularly reached 214-MW. With more than 1,500 turbines installed, the F-class has proven to be one of the most versatile gas turbine lines for GE and is currently available in simple and combined cycle models with outputs from 51-MW to over 1,000-MW.
GE H-Class Turbines (2003)	In 2003, Baglan Bay Power Station in Wales gets a 9H 480-MW single-shaft combined cycle turbine plant, the first H-class system. The H-class systems were a huge leap in technology but due to high initial startup and maintenance costs, they were discontinued. The silver lining of this cloud was that GE's H-class system sparked and fueled more competition in the large turbine marketplace which led to technological innovations throughout the industry.
GE Frame 6C (2003)	First introduced in 2003 with a 42-MW model, the GE Frame 6C leads the way for combined cycle and cogeneration efficiency for turbines less than 100-MW. Remarkably, in cogeneration mode, it can reach rates of more than 80% efficiency, and in 2×1 combined-cycle operation, over 58% efficiency.
GE 9HA & 7HA Air-Cooled Turbines (2014)	With the release of two new H-class turbines, the 9HA and 7HA, GE showcased its advancements in manufacturing, aerodynamics, and materials. With a range of 290-MW to 571-MW, these air-cooled turbines offered great versatility in application. Combined with integrated software and onboard analytics, these turbines continue to set new efficiency records. PSEG became the proud owners of the first dual-fuel H-class turbine. This 540-MW plant can operate on either natural gas or ultra-low-sulfur distillate fuel oil. The latest in the 7HA turbine series, the 03 model is rated for single-cycle mode at 430-MW marking a sizable leap from the 02 models. For combined-cycle operation, it offers 640-MW with an efficiency of 63.9%. In 2021, the first two GE 9HA.02 turbines begin operating at the Track 4A plant in Malaysia. With advancements in combustion and the premixing fuel nozzles, the combined cycle efficiency is greater than 64% and the 9HA.02 is rated for 575-MW.

Siemens Products

Siemens has acquired ownership of several aero-engine derived gas turbines from Rolls-Royce. These machines include SGT-E05 with a power of 4 to 7 MW derived from the T56 (501-K) engine, SGT-E20 machine with a power of 10 to 15 MW derived from the Avon 200 engine, SGT-E30 and SGT-E35 machines with a power of 27 to 38 MW derived from RB211 turbofan engine, SGT-E45 machine with power of 41 to 44 MW and SGT-E65 machine with power of 53 to 66 MW are derived from Trent 800 turbofan engine. The total installed fleet of these gas turbines reaches 2,500 units worldwide.

In 2014, Siemens acquired Rolls-Royce's aero engine-derived gas turbine division and renamed them after its system. Based on this, the industrial model T56 (501-K) will be known as Siemens SGT-E05 from now on. More than 1600 units of this machine have been used for industrial purposes in 40 different countries of the world. These machines have logged a total of 110 million working hours since their introduction in 1963. The SGT-E05 machine is designed based on the core of the T-56 turboprop air engine.

This air engine provides propulsion power for the C-130 Hercules tactical transport aircraft, the E2C Hawkeye surveillance and reconnaissance aircraft, and the P-3 Orion maritime patrol aircraft. The features of this gas turbine derived from the air engine include its completely modular structure, ease of field repair, and the use of different fuels. E05 machines with an output power between 3.9 and 6.4 megawatts are used in various applications, including simultaneous production of electricity and heat, offshore facilities and power supply in emergency situations.

The industrial model of Avon200 is now known as SGT-E20. The prototype of this machine was introduced in 1964 and was especially welcomed in North America in the oil and gas industry. Its other uses include transmission and pumping lines, as well as use as a storage unit in combined cycle power plants. More than 1,200 units of this car have been sold so far.

The low weight and relatively high output power of SGT-E35 gas turbines derived from the RB211 air engine has made it a favorable option for users in the field of offshore oil and gas. This machine is available in two different models with output power of 34 and 38 MW. Based on the main core of the RB211 engine, Siemens has combined a new example of the SGT-E35 turbine with Dresser-Rand equipment and introduced an optimized set for use in vessels. This sample is 30% lighter than industrial machines derived from RB211.

Industrial examples derived from RB211 have recorded more than 37 million operating hours. The 38 MW model of this machine was introduced based on the improvement of the gas generator by adding a floor to the beginning of the compressor and without any change in the turbine part, its output power was increased by 10% without changing the combustion temperature. This increase in power is provided by increasing the current passing through the motor core and increasing the efficiency of the compressor.

The SGT-E65 machine is the most up-to-date three-axis gas turbine derived from the Siemens air engine. This car is designed based on the Trent 800 air engine and can provide power between 3000 and 3600 horsepower without the need for a gearbox. To increase the power, it is enough to change the number of blades in the low pressure part of the compressor. This machine has two floors of low pressure compressor, seven floors of medium pressure compressor and four floors of high pressure compressor.

Siemens has also developed a mobile example of this machine called SGT-E45, which is able to provide power equivalent to 44 megawatts, and it takes two weeks to install and run it. All equipment related to this machine is transported by three trailers. This car needs only eight minutes to reach maximum power. Figures 2 and 4 provide information about the classification of Siemens gas turbines and the burning of hydrogen in them From Figure.2 it can be seen that the 2 main types of gas turbines , ؘ engines are aero derived from SiemensSGT-A05 andSGT-A35 whose power is in the range of ,4-6 and31-39 megawatts, respectively.Figure 3 shows that the hydrogen capa bil ity for these two types of .gas turbines is in the range of 2-5% and 15-100%, respectively

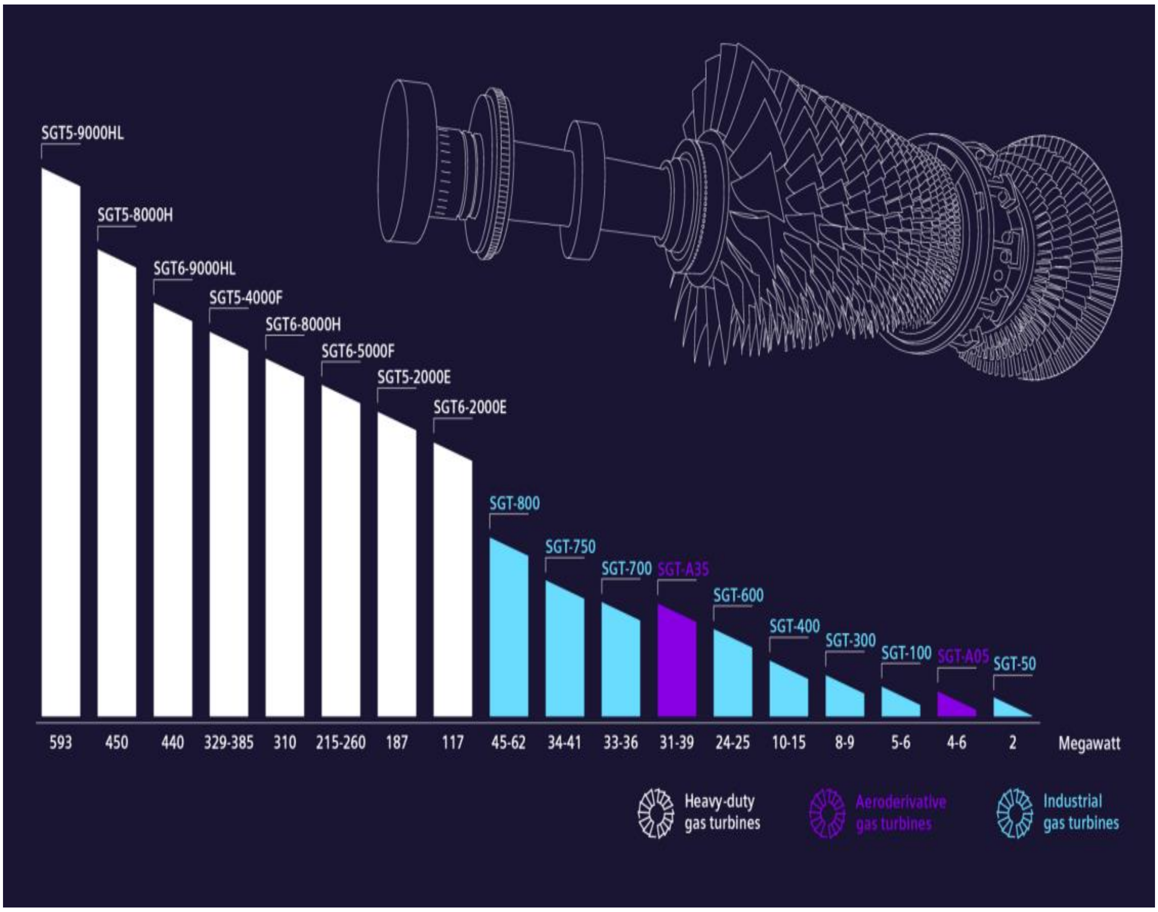

Figure 2. Classification of Siemens gas turbine [56].

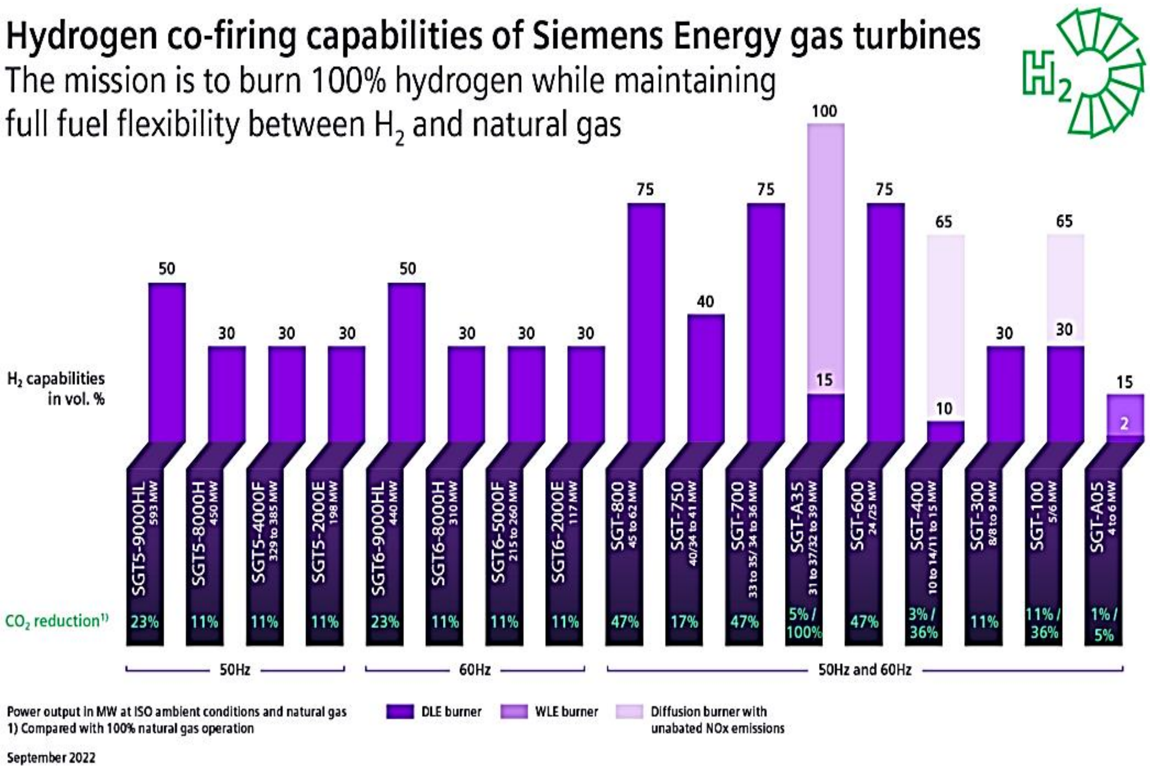

Figure 3. Siemens gas turbines burning of hydrogen [56].

Products Based on Pratt and Whitney Products

PW Power Systems Company (PWPS) is a group of companies affiliated with Mitsubishi Hitachi Industrial Group. This company has developed its gas turbines as a derivative of high-performance air engines. More than two thousand units of this company's products have been installed and launched in 50 different countries of the world. These products are able to provide power from 30 to 140 megawatts. FT4000 Swiftpack machine is the latest gas turbine offered by PWPS company. This machine has two axles and an axial flow gas generator and is designed based on the PW4000 air engine. The PW4000 family of aero engines are capable of providing thrust between 52,000 and 90,000 pounds.

The industrialized example of this air engine connected to a free turbine forms the FT4000 machine, which can produce 60 to 70 megawatts of power as a single engine, and between 120 and 140 megawatts of power is supplied by it in a two-engine configuration. The efficiency of this gas turbine in the simple cycle configuration is 41%, and based on the fully modular design, it can be easily installed and set up and requires less than 10 minutes to reach maximum power. In 2015, after the end of the testing and evaluation stages, the first samples of the FT4000 gas turbine were put into operation. Customers from America and Argentina took delivery of the first samples and by the beginning of 2018, these machines have passed more than 19 thousand operational hours.

The FT-8 Mobilepack gas turbine with a power of 30 MW with the ability to move is another PWS product in this field. The complete equipment of this complex is carried by two trailers, one of which includes gas turbine, electric generator, output collector, diffuser and engine oil system. The second car carries the 15 kW switch, control system, operation panel, protective relays, batteries and chargers, engine control center and hydraulic starting equipment. The complete FT-8 mobilepack turbine set can be set up in less than 9 days. Until 2018, more than 130 units of the FT-8 turbine have been sold to customers all over the world, of which more than 40 units have been moved from the initial location to another location. The space required to install this turbine is only 22 x 16 meters and there is no need to lay a foundation or prepare the installation site.

The FT-8 gas turbine can be commissioned in less than 30 days. This machine provides output power between 30 and 60 megawatts. Its complete set includes gas generator, power turbine, sealed inlet, lubrication system and outlet section. This machine can be used in a combined cycle configuration. The installation of this turbine is very simple and it can be used to provide power in remote areas and help the network during peak consumption or stabilize the distribution network. The FT-8 gas turbine is an example derived from the JT8D turbofan engine. The production of this car started in 1991 and until 2018, more than 500 units of it have been used.

The operational fleet of this machine has registered more than 6.5 million operational hours. In addition to the production and supply of gas turbines derived from air engines, PWPS also operates in the field of providing long-term maintenance and support services, supplying spare parts, conducting annual inspections and field support. In addition to the main manufacturers whose products are mentioned in this article in the field of turbines derived from air engines, some active companies in the field of energy such as Sulzer, MTU, RWG and Ethos Energy are actively involved in the repair, maintenance and support of these turbines. It operates globally.

The Pratt & Whitney Canada PT6 is a turboprop aircraft engine produced by Pratt & Whitney Canada. Its design was started in 1958, it first ran in February 1960, first flew on 30 May 1961, entered service in 1964 and has been continuously updated since. It consists of two basic sections: a gas generator with accessory gearbox and a free power turbine with reduction gearbox, and is often seemingly mounted backwards in an aircraft in so far as the intake is at the rear and the exhaust at the front. Many variants of the PT6 have been produced, not only as turboprops but also as turboshaft engines for helicopters, land vehicles, hovercraft, and boats; as auxiliary power units; and for industrial uses. By November 2015, 51,000 had been produced, had logged 400 million flight hours from 1963 to 2016. It is known for its reliability with an in-flight shutdown rate of 1 per 651,126 hours in 2016. The PT6A covers the power range between 580 and 1,940 shp (430 and 1,450 kW) while the PT6B/C are turboshaft variants for helicopters [57]. A brief history of the pt6a engine can be seen in Figure 4.

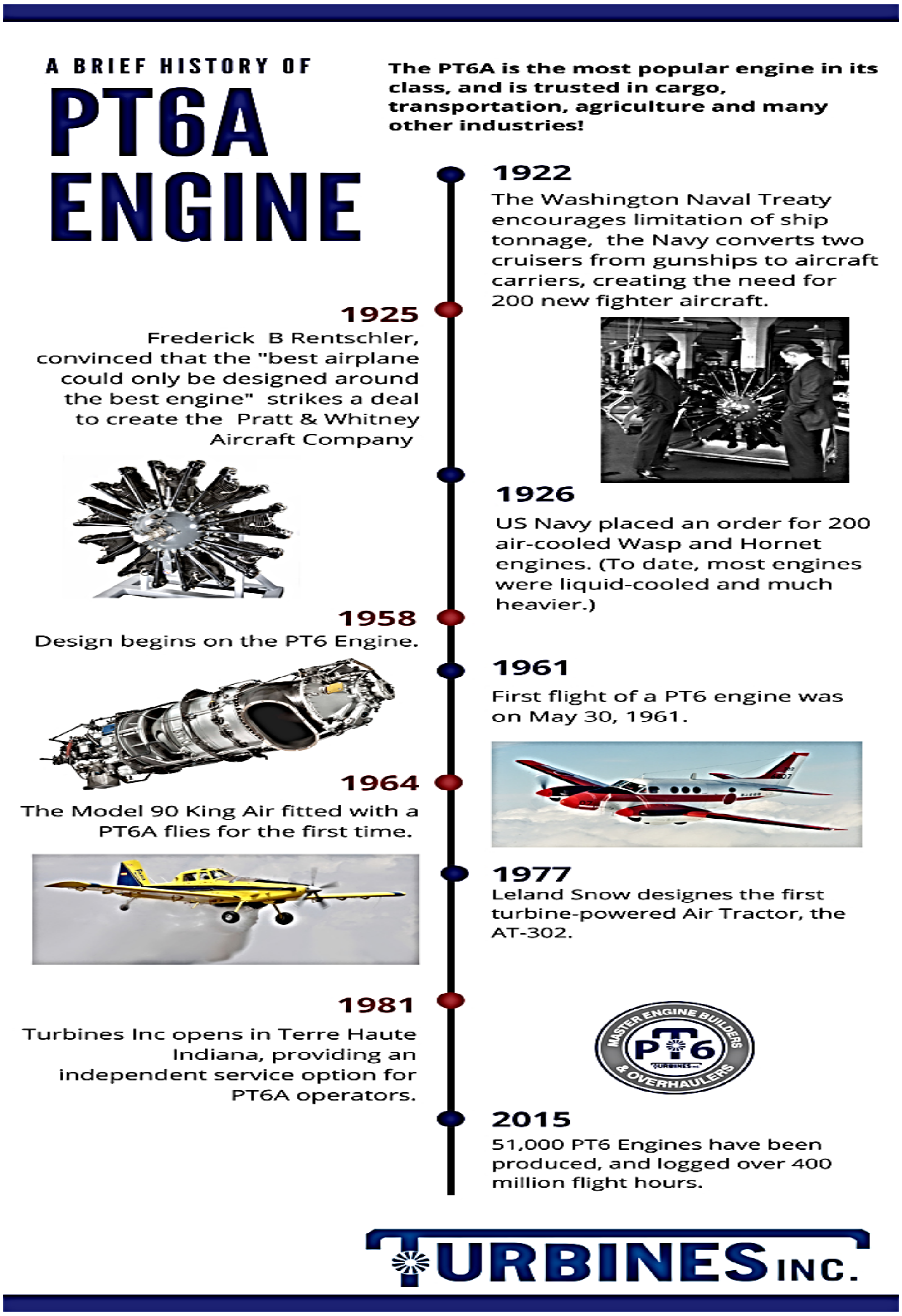

Figure 4. A brief history of the pt6a engine [58].

CONCLUSION

Due to the complexities in the design and construction of turbine engines, reputable gas turbine manufacturing companies always seek to shorten the design and construction processes. One of these ways is to use aero gas turbine core to make industrial gas turbine. In the industry, these types of gas turbines are known as derivative gas turbines. The special features of air gas turbines, such as light weight, relatively small dimensions, high efficiency and performance, have caused that if the gas generator core of these turbines is used instead of the industrial gas turbine core, in addition to shortening the design and manufacturing process, The desired need to obtain an industrial gas turbine was achieved. In this study, the main types of gas turbines derived from air engines have been reviewed and the characteristics of each of them have been discussed.

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