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INFLUENCE OF MODULAR F100-PW-229 ENGINE CONSTRUCTION UPON THE FLEET OF F-16 AIRCRAFT EXPLOITATION

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Introduction

Due to high operational costs of aircraft turbine engines, back in the 1970s, users of this type of engines – i.e. airlines and the military – began to search for ways of lowering the costs considerably. In consequence jet engines were replaced with jet turbine engines that were far more economical, particularly in case of their fuel economy. Another significant aspect was maintenance costs, in particular the necessity to conduct frequent repairs and overhauls, which largely increased and complicated the performance of the engines, especially for airlines, due to the fact that at that time turbine engines had to be serviced having flown several dozen hours and upgraded every few hundred working hours in specialist maintenance shops. The activities resulted in "grounding" of the aircraft for the period of maintenance and repair, instead of flying. The attempts of the largest engine users, that is large airlines and the US Air Force, caused that the manufacturers of aircraft engines (Pratt&Whitney, General Electric and Rolls Royce) initiated research and development work, which in the next years, led to the construction of engines that were capable of working for several thousand hours, without the necessity for dismantling the airframe. The new engines were not exploited in accordance with the old and reliable service life strategy, but with their technical condition. The immediate consequence was the time shortening as well as lowering repair and maintenance costs, although the engines had to undergo more detailed checkup and overhaul.

In order to conduct the work more efficiently and smoothly, a new class of engines started to be designed, in accordance with the so-called modular conception, which made aircraft engines flexible in terms of their exploitation, maintenance and diagnostics.

Modular construction engines enable:

- easy access to the components, systems and engine modules;
- easy adjustment
- maintainability
- safety of conducting maintenance tasks
- easy replacement of engine components, systems and modules
- unification and normalizing of engine components and subsystems. [4]

The engines, powering the F-16C/D aircraft and exploited in Poland since 2006, are F100-PW-229 manufactured by Pratt&Whitney company.

F100-PW-229 engine construction

Towards the end of the 1980s, through another modernization, the Pratt&Whitney company constructed the F100-PW-229 engine. Its design used the latest advances of engine technology, implemented from the F119 and F135 engines. The engine F100-PW-229 is an afterburning turbo-fan (twin turbine), equipped with a 13 stage axial compressor, annular combustor, four stage turbine, afterburning chamber with a mixer and an adjustable convergent-divergent nozzle.

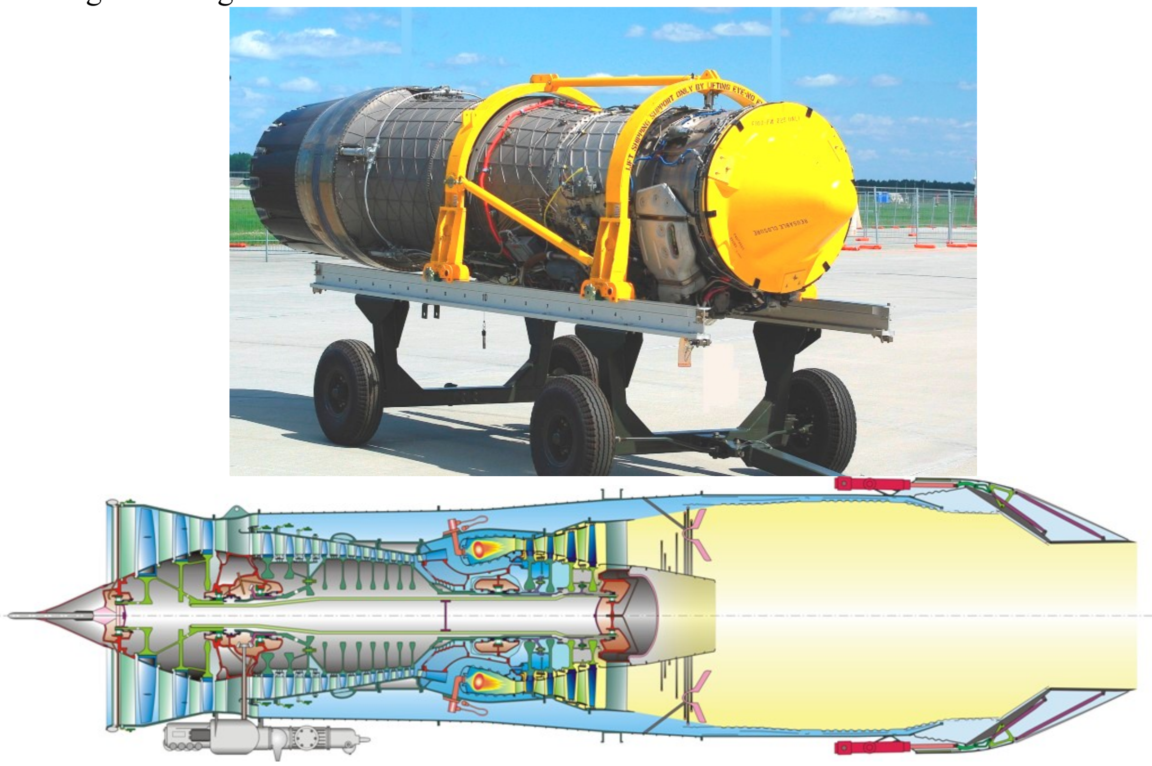

Fig. 1 F100-PW-229 engine [3]

The basic technical data of the engine are as follows:

- engine mass	1732 kg
- maximum thrust:	7918 daN
- maximum thrust with full afterburning	12945 daN;
- length of engine	5.283 m;
- inlet diameter	0.88 m;
- maximum diameter	1.18 m;
- bypass ratio	0.36;
- air mass flow	120 kg/s
- overall pressure ratio	32
- specific fuel consumption (maximum)	approx. 0.7 kg (daN x h);
- specific fuel consumption (full afterburning)	approx. 2 kg/(daN x h).

The F100-PW-229 consists of five modules:

- inlet fan;
- core engine;
- fan drive turbine;
- augmentor and nozzle;
- engine gearbox.

Apart from the above-mentioned modules, the engine comprises a number of components which are not integral module parts and therefore can be easily replaced. They are the so-called non-modular parts. [3]

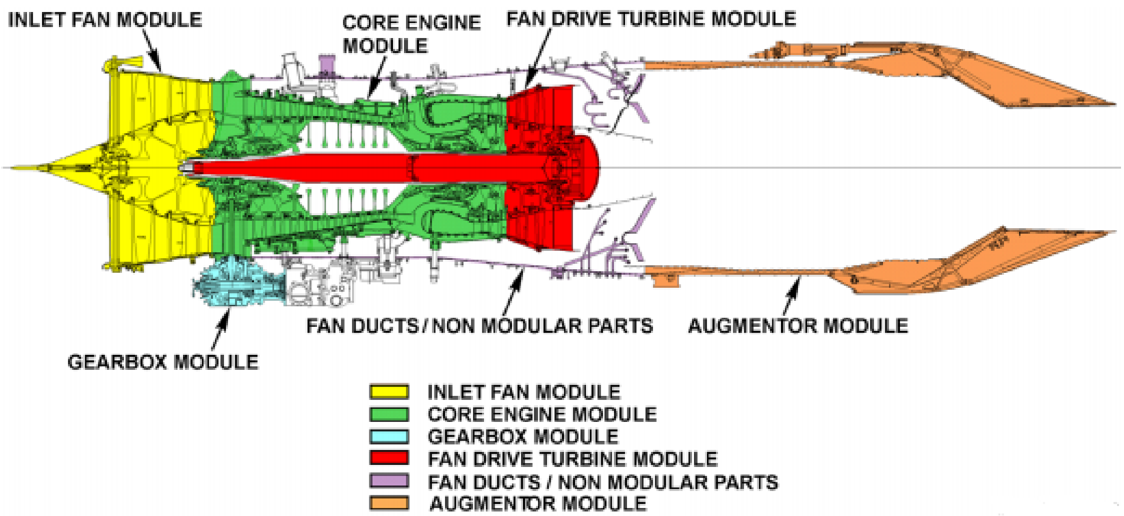

Fig. 2 Modular construction of F100-PW-229 engine [2]

The fan is a three-stage axial compressor with pressure ratio measuring four. The compressed air, behind the fan, is divided into two separate ducts. Part of the air reaches the external duct (so-called bypass air), whereas the rest flows into the high pressure compressor. The fan module in its rear part is connected to the intermediate case, constituting an integral part of the core engine. The fan is the part of the engine which is particularly prone to damage caused by foreign objects that may enter the engine via air inlets. The fan module comprises a number-one bearing.

The aim of the core engine is to produce hot gases and direct them at the fan drive turbine. The gases which leave the combustor transfer some of its energy to the high-pressure turbine, which powers the high pressure compressor and the engine gearbox. In terms of its construction, the core engine is made up with four systems – intermediate case, high-pressure compressor, combustion chamber and high pressure turbine.

The low-pressure turbine (fan drive turbine) transforms part of the internal gases energy into mechanical work, essential for the fan rotor. This module includes a long turbine shaft and number-five bearing.

The augmentor with an adjustable nozzle enables to diffuse the gases stream with the external air flow. It also directs this mixture towards the exhaust nozzle, where it decompresses to atmospheric pressure levels, accompanied by significant stream acceleration (in its maximum value and after-burning, the stream reaches supersonic speeds). If the engine operates on after-burning, in its after-burning section, additional amounts of fuel are combusted, which in turn leads to a temperature increase and raising gases pressure – this is when gases are exhausted from the exhaust nozzle at increased velocity, consequently translating to higher engine thrust.

The engine gearbox is used to power engine components (fuel pump, oil pump and engine generator). It also enables to forward the drive between the engine and the airframe. The engine gearbox takes the power from the high-pressure rotor by means of the vertical shaft, which is later transferred to the engine drive gearbox of the airframe (ADG) through the horizontal PTO shaft – during regular engine running, or in the reverse direction, while starting the engine. The gearbox is attached in three points to the bottom side of the intermediate case.

Influence of modular construction upon the scheduling of F-16 aircraft operation

The achievements in the field of commercialization and modularization of drives exploited in civilian aviation have made a noticeable impact on the construction and manners of F100-PW-229 engines exploitation. This type of engines requires extremely well-qualified maintenance personnel, who are capable of immediate controlling and monitoring the engines' technical condition, as well as repairing minor and major malfunctions and testing repaired engines. Therefore, the personnel of maintenance and engineering service in air force bases had to be increased by admitting engine specialists in air and technical squadrons. In the first place, during daily operation of aircraft, engine specialists are responsible for the current checkup of the engine technical condition, removal of minor malfunctions and failures, assembly and dismantling of engines from the airframe. In technical squadrons, engine specialists perform periodical engine maintenance and repair of major engine failures. The repair and maintenance team in Krzesiny deliver repairs that are connected with engine dismantling into modules (exchanging or repairing compressor blades and turbines, exchanging faulty bearings, injectors, seals, etc.); they also test engines on engine test facility on completion of repair.

The presence of engine specialists during each and every flight causes that engines are quickly and efficiently diagnosed after each flight and the discovered malfunctions are rapidly removed. In case of more serious failure or malfunction, which cannot be repaired in a short period of time, the engines are changed for an new one within one day. Meanwhile, the faulty engine is being repaired in the most optimal way. During the last seven years of F-16s operations in Poland, only five additional engines and one set of extra engine modules have been able to fully secure the exploitation of 48 aircrafts in two air force bases. Several dozen engine specialists delivered several dozen dismantles and assemblies of engines, several engine repairs, exchange of faulty components, where the engines had to be dismantled into modules. The repairs were performed either through exchanging faulty items (such as the removal of over one hundred compressor and turbine blades) or repairing them (for instance, approximately one hundred blades were repaired by blending). If an aircraft is to be fully operational after its repair, the manufacturer requires that it undergoes testing on a stationary engine test facility. Therefore, for a number of years, a specialist engine test facility called "hush house" has been in use in Krzesiny air force base.

Impact of modular construction upon F-16 aircraft operational costs

The modular engine construction as well as operations in accordance with its technical condition led to extension of the service life of the F100-PW-229 engine in comparison with the Russian engines, mounted on the Su-22 or the Mig-29. The operations of AŁ-21F3 and RD-33 engines are based on their service life. The number of engine operating hours equals 1,600 hrs, whereas engine life between overhauls are held every 400 hrs. F100-PW-229 engines have their durability specified in the so-called TAC (Total Accumulated Cycles). In case of an engine used in a civilian (commercial) aircraft, usually one TAC is an equivalent to one flight. If a flight lasts three hours, the engine consumes approximately 1 TAC. F100-PW-229 power combat aircraft, whose flight characteristics considerably differ from the one of a civilian aircraft. A pilot of a combat aircraft during take-off and climb frequently uses the afterburner; while performing maneuvers, the engine often changes rotational speed, which consequently leads to the changes in gas temperatures in the engine, and ultimately in components of the combustion chamber, afterburner and the exhaust nozzle. Therefore, for military aircraft the average TAC consumption has been assumed as 1 flight hour = 2.5 TAC. In case of the Polish F-16s, after seven years of their operation, the above-mentioned value proves to be genuine.

The F100-PW-229 engine manufacturer specified their service life between overhauls at 4,300 TAC. This value is identical for all engine modules, except the engine gearbox. Having assumed that one hour of flight consumes 2.5 TAC, it appears that 4,300 TAC translates to 1,700 flying hours. After this time, the aircraft are eligible for an overhaul. Between 2007 and the end of 2013, the most frequently operated F-16 aircraft, in Poland, flew 1,000 hours. Provided that the intensity of operations is sustained in the following years, it is no earlier than the year 2018, which is after eighteen years of their operations, that the first engines will be scheduled for an overhaul. (Fig. 3)

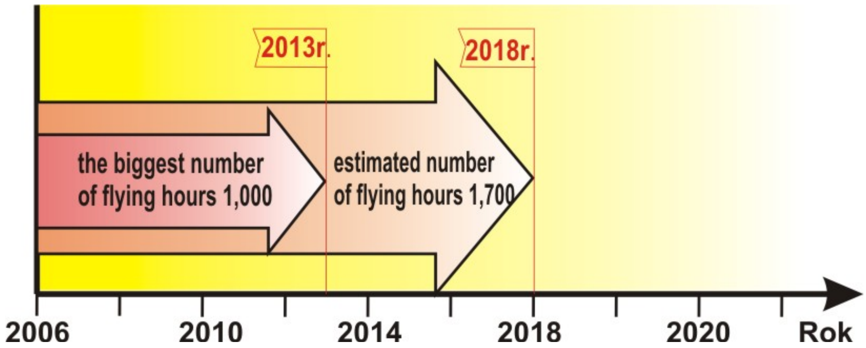

Fig. 3 Current and estimated flying hours of the most frequently exploited F-16 aircraft

While comparing the F100-PW-229 operations with the RD-33 operation, it becomes evident that in the first 12 years:

- the F100-PW-229 engine will not require major maintenance and overhaul costs;
- one RD-33 engine will undergo three overhauls and a new one must also be purchased.

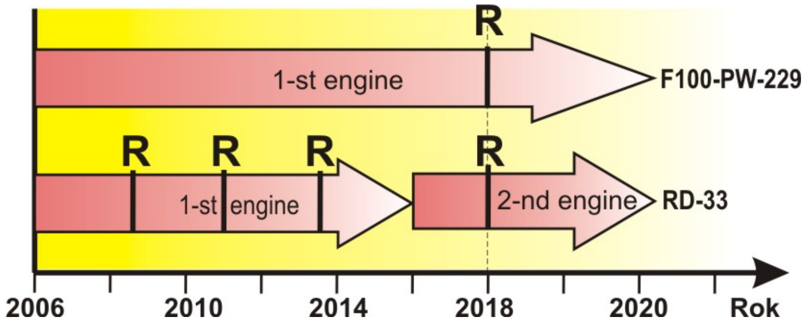

Fig. 4 Comparison of F100-PW-229 and RD-33 engine overhauls

Procurement and maintenance of a modern combat aircraft is a huge expense for the state, and therefore it must be exploited for a period of at least 30 years. The operational costs are largely connected with the power unit – its durability, current maintenance and overhaul costs. In commercial aviation, it is assumed that the power unit consumes 35-40% total aircraft maintenance and repair costs. [1] In military aviation, this share is quite similar. Figure 5 depicts a comparison of the frequency of overhauls and procurements in new aircraft, in the period of 30 years, for F-16 and MiG-29 aircraft, providing that the number of annual flying hours remains on the same level.

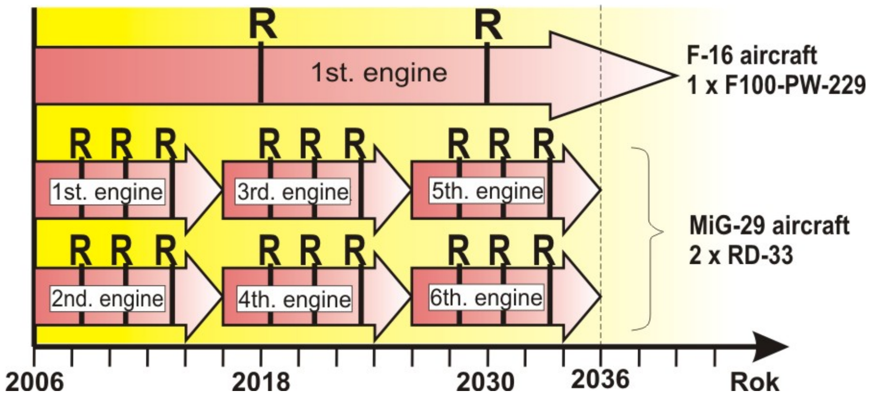

Fig. 5 Comparison of the frequency of overhauls and procurements in F-16s and MiG-29s

The diagram shows that

- in order to secure the maintenance of one F-16C/D aircraft, in the span of 30 years, it is enough to possess one engine, which will undergo two overhauls;
- in order to secure the maintenance of one Mig-29 aircraft, in the span of 30 years, it is enough to possess six engines, which will undergo eighteen overhauls.

Concluding, it seems that in case of the Polish F-16s which are to conduct air operations for the period of at least 30 years, two cycles are sufficient, around the year 2018 and 2030, when each engine will undergo an overhaul. Due to this relatively low number of overhauls (maximum 96 overhauls), it is not economically feasible to schedule engine overhauls in Poland. All the engines will, therefore, be overhauled outside of Poland.

Conclusion

Based on the above-mentioned facts and comparisons of modular construction F100-PW-229 engines, exploited in Poland in accordance with their technical state, it is possible to observe a number of positive aspects of their use, such as:

- reducing the time when the engine is not operational;
- in case of malfunctioning on one engine element, it is possible, within a short period of time, to replace only the engine module, which includes a particular component, without stopping the operation of the whole engine;
- high qualifications of the maintenance personnel enable to solve almost all failures on site, without involving the headquarters and technical institutions;
- running maintenance shops, even on an average level, means that it is not necessary to send engines for emergency repairs, which significantly affects lowering the costs of operating the system of engine exploitation;
- a modern engine with modular construction may boast of prolonged exploitation, and in consequence significantly reduce total costs of service life of the F-16 product.

Readings

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