

Protection Systems of Multirole Jet Aircraft System

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Years of experience and searching for new solutions have resulted in designing modern and efficient engines. The multirole F-16 Block 52+ aircraft, used by the Armed Forces of the Republic of Poland, is equipped with a single Pratt Whitney F100-PW-229 jet engine with a maximum thrust of 129,6 kN. Fast and unfailing start of the jet engine is the primary condition to obtain the operational efficiency of an aircraft. This article is dedicated to the description of security systems of the Pratt & Whitney F100-PW-229 engine used in F-16 Block 52+ serving in the Polish Air Force. It presents general engine characteristics and general safety conditions in force when starting the engine, concerning pilots and technical personnel. The most significant part of the article is eight break-downs presentations with their short characterization as well as preventive procedures which were developed by experienced staff and pilots. In authors opinion, this information would prevent future jet aircrafts failures.

1. Introduction

First design works on turbojet engine started in 1930s. These works were carried out simultaneously by Frank Whittle in UK and Dr. Hans von Ohain in Germany (Bellis, 2018). The first jet fighter was Heinkel He 178, and Messerschmitt Me 262 was the first operational jet-powered fighter aircraft. Years of experience and searching for new solutions have resulted in designing modern and efficient engines.

Starting the engine consists of a few stages (Szczeciński, 1965) from the rotor's standstill to the idle speed. Independent work of the turbine engine, without the support from the starter, is possible when the turbine reaches the power equal to the sum of powers consumed by the compressor and generators and lost in the friction (Wiatrek, 1983). The engine under consideration belongs to the class of bypass engines (Szczeciński, 1971). Figure 1 presents F100-PW-229 engine, one of the afterburning bypass turbojets with a modular structure. The basic technical parameters of the F100-PW-229 engine are as follow:

- the engine's maximum thrust is 79.1 kN (the thrust with the afterburner is 129.6 kN);
- the engine thrust-to-weight ratio equals to 8:1. The F100-PW-229 engine is the engine with low bypass ratio equal to 0.36:1 and high overall pressure ratio equal to 32:1;
- the low-pressure compressor has three stages, and the high-pressure one – 10;
- the engine is equipped with the annular combustor;
- the turbine consists of two low-pressure and two high-pressure stages;
- the exhaust nozzle is a convergent-divergent one with the adjustable cross-section;
- the engine work parameters are operated and controlled by the Digital Electronic Engine Control (DEEC);
- the fuel is delivered to the engine through the main fuel pump (Main Fuel Control, MFC) and the afterburner fuel pump (Augmentor Fuel Control, AFC).

The F100-PW-229 engine is based on the modular structure concept which allows disassembling physically and functionally connected modules. Modules are treated as separate subassemblies of the engine. This concept facilitates and speeds up the process of reconditioning the engine in case of its serious failure. It is possible to install quickly another module in good working order instead of waiting for repair of the non-operational one, dismantled from the engine. Such a modular configuration also enables the replacement of subassemblies and elements of the engine, which is considered to be the most effective method of improving the engine functioning. Despite the possibilities of repairing the non-operational elements of the engine coming from the engine operation, it is very important to minimize the chance of the engine failure by application of appropriate safety

procedures during the engine start-up. Of great significance for the aircraft's safe operating is the safety procedure concerning the engine start-up on the ground; it includes all safety conditions from starting to shut down the F100-PW-229 turbofan engine of the F-16 aircraft. Operations carried out by the personnel while starting up the engine are described in detail in the instruction in force (Instruction T.O. PL1F-16CJ-2-70JG-00-21 Engine Operation).



Figure 1: Hush house of 31st Tactical Air Base in Krzesiny

2. General safety conditions

When operating the aircraft any person should remember about the used dangerous materials. The personnel working in the aircraft have to know the used dangerous substances, be familiar with and observe safety instructions delivered by the producer of those substances. Failure to comply with the safety instructions when handling with dangerous products can bring the threat not only of aircraft damage, but also of an explosion, eyes, lungs, skin, nose and throat damage, and even of a death. If there is a necessity to evacuate pilot or the technician from the aircraft during the procedure of the engine start-up, the most important thing is to abandon the aircraft and its closest vicinity. Abandoning the cockpit should be done into the direction of the aircraft's front "over its nose" or of either of its sides. Manual opening the cockpit canopy using the crank is very difficult and time-consuming. If there is a need to abandon the cockpit immediately, one should use the system for the canopy emergency removal. To complete any task safely every person should strictly observe the procedures and bans, including the ban on (Instruction T.O. 2J-F100-51-2 WP 008 00 Ground Safety Precautions, Instruction T.O. PL1F-16CJ-2-70JG-00-21 Engine Operation):

- staying in the vicinity of the hot gases exhaust, such as the jet fuel starter (JFS) nozzle, the convergent exhaust nozzle control (CENC) or the ECS nozzle,
- staying in the vicinity of the engine inlet when the engine is started up or is running due to the risk of being sucked into the intake tunnel,
- taking any actions in the vicinity of the PTO shaft when the engine is running,
- staying in the plane of rotation of the JFS turbine and engine's turbines set when the engine is started,
- staying in the vicinity of movable planes of the aircraft when the engine or the turbo starter JFS is started, is working or is shut down.

Failure to comply with the above instructions may cause death or serious injury. Moreover, staying in the vicinity of the gas exhaust from the Standby Generator is forbidden. Wheel chocks designed for F-16 should be used while servicing the aircraft. If the Digital Flight Control Computer (DFLCC) is disassembled, the wheels' breaks are not working; in this case, the engine must not be started. Technical personnel servicing the F-16 aircraft should remember of many essential details; the most important, among other things, are (Instruction T.O. 2J-F100-51-2 WP 008 00 Ground Safety Precautions, Instruction T.O. PL1F-16CJ-2-70JG-00-21 Engine Operation):

- aircraft parking brake is released automatically after the throttle is shifted of a range greater than 1 inch,
- when the engine works with rpm above the IDLE revolutions, toe brakes should be used,
- if there is a need to carry out a long test of the engine with rpm above the IDLE revolutions but below 85 % of rpm, the aircraft should be fixed at the test cell. The level of 85 % of engine rpm should not be exceeded; in another case the aircraft could jump over the wheel chocks,
- having shut down the engine one should wait until all heated parts of the airframe and engine are cooled,
- within 10 minutes after the engine shut down, fuel auto-ignition may occur in the exhaust nozzle of the engine; it is manifested by a small explosion coming from the engine's nozzle,
- burning fuel may be accompanied by smoke, exhaust gases or small fire within the engine's nozzle,
- no one should come to or into the engine's nozzle within ten minutes after the engine is shut down,
- auto-ignition and concomitant effects do not pose a threat to the engine and the aircraft's construction. If such a phenomenon occurs, the fire could be extinguished by one-minute dry motoring,
- to prevent suction the area in the vicinity of the engine air inlet should be kept clean, without debris, tools, equipment or personal belongings,
- before the engine starts the rear seat should be placed at the position between the mid-height to the half-inch height above the lowest position. If the seat is positioned too high, there is a danger that the throttle would touch the Aft Ejection Seat Control Handle Safety Pin, which can cause damage to the aircraft equipment,
- if during the engine start-up, after the throttle lever has been advanced from the cut-off position to the position of IDLE thrust or above it, the Fuel Master Switch is in the Off position, the engine start-up must be stopped immediately.

Failure to comply with the above instructions may result in the engine damage. Particular caution should be exercised when the engine is starting up and running with the illuminated Fuel Low Caution Light; in another case, the fuel pump might be destroyed and the engine would be shut down automatically. Air Source Switch should be kept in the Off position for no longer than 30 minutes. Exceeding this time might result in damage to the onboard equipment. Time of engine work parameters stabilization should be observed; in another case, it might lead to a serious change of engine work characteristics and its damage. This time may be elongated but never shortened. Small vibrations of the aircraft might occur in flight or during the engine on-ground work, and when the throttle is positioned closed to IDLE or in other ranges. Those vibrations are not directly hazardous to the engine and the aircraft's construction, and they should disappear when rpm increase or decrease by approximately 5 %.

If there is a risk of the aircraft icing, the engine should not be started. Possible icing conditions are as follow:

- ambient temperature (TAMB) between -7°C and 7°C and precipitations or fog,
- dew-point within the limits of 5°C from the ambient temperature between -4°C and 7°C ,
- ambient temperature below 7°C and standing water or the mix of water and ice or snow in the close vicinity of the air inlet to the engine.

Ice accumulation on the inlet or the engine may lead to its damage. In the event of starting the engine and its run in possible icing conditions, the engine inlet has to be monitored constantly. If the ice cap exceeds the height of 0.25 inch on the inlet edge, the inlet inside walls or the inlet strut, to prevent damaging the engine, it should be stopped immediately and icing should be removed. Air condensation in the engine inlet may make it significantly hard to detect icing (Freyre-Fonseca et al. 2011). If atmospheric conditions indicate that icing is possible, reduce rpm to IDLE which enables observing the inlet area. If the engine was shut down with the iced inlet, icing should be removed completely before another starting (Instruction T.O. PL1F-16CJ-2-70JG-00-21 Engine Operation).

3. States of emergency

Safety procedures apply also to actions taken by the personnel staying in the cockpit. Below we present some hazardous situations which can occur when the engine is in operation and the recommended measures in such situations.

First hazardous situation is FOD (foreign object damage). FOD mostly damages compressor blades. Figure 2 presents photos of jet engine RD-33s blades damage (Bartoszewicz, 2016), and Figure 3 presents compressor blade after repair. Compressor blade is often grinded, or changed for new one.

Engine fire - Engine or JFS fire can be indicated either by illuminating Engine Fire light when the Main Power is on, by finding the fire, smoke or explosion, or after receiving a signal from the ground personnel. When the fire occurs and, additionally, the internal leakage of oil in the engine is suspected, do not use the JFS to turn the turbine. Rotating the rotors may cause the spread of fire due to an additional quantity of oil being pumped into

the engine. If, after the engine shut down, the fire is limited to the interior of the engine or the air inlet, the air inlet to the engine should be sheltered (only if Anti-Personnel Screen is not installed) and the extinguishing agent should be pumped into the engine nozzle. If the fire occurs within the space of the fuselage, turning the turbine using the JFS is forbidden. Driving the engine may result in adding fuel to the fire. If the fire is limited to the engine nozzle, use dry motoring in order to blow the fire out. If, as a result of the engine start-up, both hydraulic accumulators are discharged and the engine has been ignited with a delay, it may mean that the after-burning of fuel has occurred in the JFS. In this case, the covers of gas inlet to an exhaust from the JFS may stay open. The flame should go out spontaneously after a lapse of a minute. This situation should be carefully observed because the fire may spread to other parts of the airframe. If the fire is limited to the interior of the JFS, no extinguishing agent should be pumped into it, except when the fire lasts for a longer period of time or spreads over the airframe.

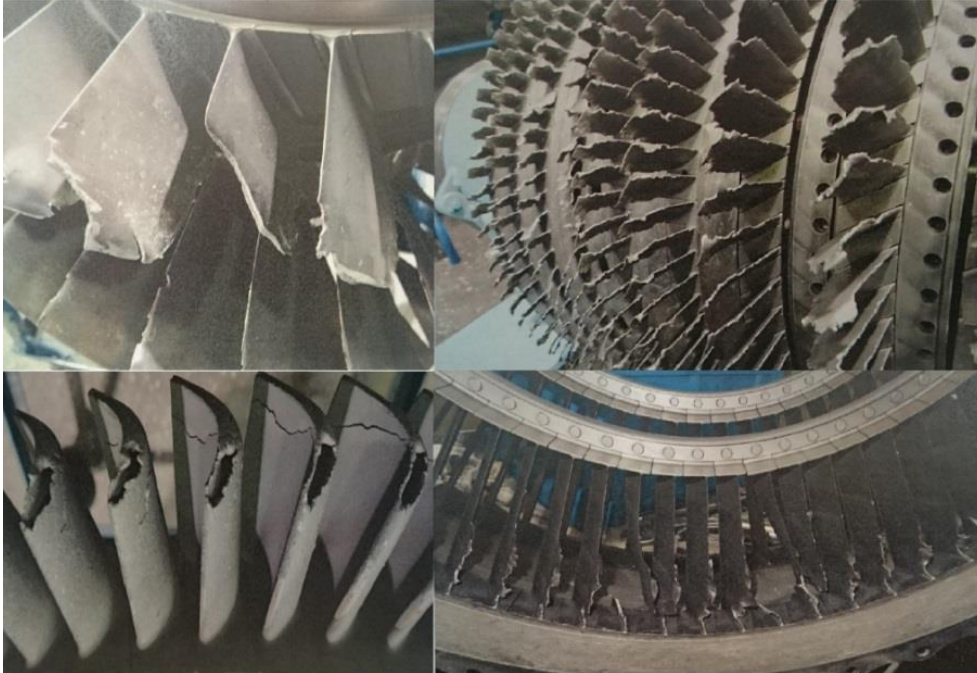


Figure 2: Damaged blades of the RD-33s compressor



Figure 3: Compressor blade before and after repair (grinding)

Uncommanded or auto acceleration may occur when the engine is starting before the throttle was advanced from the STOP position to the IDLE position. It is manifested by increasing the engine rpm beyond 30 %. This may also happen after the engine start-up cycle is finished. If the engine rpm increase beyond 30 % while starting it or the FTIT (Fan Turbine Inlet Temperature) begins to grow before the throttle is advanced to the IDLE

position, immediately turn the Fuel Master switch to the Off position, which will result in cutting the power off and gradual rpm decreasing (Staniszewski, 1998).

Engine hot start is characterized by an increase in the temperature of exhaust gases FTIT over 8,000 °C (Du et al. 2011) Engine hot start may occur if – during the startup – the FTIT grows over 5,000 °C while engine rpm is below 40 % or the FTIT grows in an uncontrolled way (too fast) over 7,500 °C. The hung start is characterized by the stoppage of the engine rpm growth below the IDLE value and stabilization of the FTIT below 8,000 °C. When such a defect is found, immediately retard the throttle to the STOP position (Bartoszewicz and Bogusławski, 2010).

If an improper engine oil indication is found, the engine start-up should be stopped. The same refers to the cases when the indication of oil pressure does not appear within 1 minute from igniting the engine, the oil pressure exceeds maximum values (such exceeding lasting for 1 minute is acceptable while starting the cold engine), or when the oil pressure decreases below 1034 hPa (15 psi).

Engine stall (Bartoszewicz et al., 2014) may occur when the engine rpm is stabilizing within any range or when the throttle is being advanced to the Intermediate Power position or the Full Augmentation position. Stall may be accompanied by the noise coming from the engine. It usually disappears automatically. If stall lasts we deal with the stagnation, which is characterized by the growth of the FTIT and the decrease of rpm, or by the growth of the FTIT while rpm is below 60 %. In both cases the engine does not respond to the throttle's movements; however sound effects do not have to occur. When this defect is found, the throttle should be advanced to the Intermediate Power position, and when the stall disappears, the engine should be shut down.



Figure 4: Engine compressor stall (Mallinson, 2006)

Failure to react to the FTIT overtemperature leads to decrease of the engine rpm and further growth of the FTIT, which will result in the engine damage. If this occurs within the range of afterburning, advance the throttle to the Intermediate Power position; if the temperature does not decrease, immediately retard the throttle to the IDLE position, and if it does not help and the FTIT is still beyond the permissible values, retard the throttle to the STOP position. Observe the FTIT. If it remains above 5,000 °C, turn the turbine using the JFS until the FTIT decreases below 2,000 °C. If this occurs within the range below afterburning, retard the throttle to the IDLE position. If the FTIT is still beyond the permissible values, retard the throttle to the STOP position. Observe the FTIT. If it remains above 5,000 °C, turn the turbine using the JFS until the FTIT decreases below 2,000 °C.

Due to a considerable thrust of the engine and relatively little weight of the aircraft the personnel should take a special care that the aircraft does not jump over chocks. If so happen, retard the throttle to the IDLE position. Press maximally the toe brake. If it does not react, turn the brakes switch to the Channel 2 position, and once more press the toe brake (Instruction T.O. 2J-F100-51-2 WP 008 00 Ground Safety Precautions).

When hydrazine leakage is noticed the personnel should make sure that in the vicinity of the aircraft there are no casual persons. The engine should be shut down. Personnel should abandon the aircraft and its vicinity. Hydrazine (diamine) is a compound nitrogen group, in another word it is a compound made of nitrogen and hydrogen. Among the most frequently mentioned threats for living organisms authors noted as follow (Ciołek

and Demel, 2008): burns and allergic reactions of the skin, eye damage (e.g. conjunctivitis), toxicity if swallowed or inhaled (hyperaemia and degenerative changes in the liver, kidneys, lungs, spleen, heart muscle or bones, a high probability of pulmonary edema), aquatic toxicity, central nervous system stimulation, irritation of nose and throat when exposed to fumes. In addition, hydrazine is probably carcinogenic. Thus, among the categories of substances Carc. 1B, which are known or presumed to be carcinogenic.

4. Conclusions

This article describes the safety procedures which can be found in instructions of F-16 jet fighter. The operation of the aircraft, and in particular of the engine, requires from the ground and flying personnel a huge amount of information to collect, and to concerning on the structure of the aircraft and safety procedures. This knowledge is complemented by the skills acquired during numerous training. The effectiveness of the aircraft and the life and health of the personnel, both - the maintenance crew of the aircraft on the ground, and pilots using the aircraft during the flight depend on the appropriate behavior in specific situations. The pilot, who controls the plane and performs his tasks in the air, entrusts his health and life to the technical staff, but he cannot blindly believe in their work. He must have skills that will allow him to verify certain activities he has done. Safety procedures for starting every jet fighter engine are known to every army pilot. They belong to this area of knowledge that is always used when the pilot performs his daily tasks. The analysis of hazardous situations which occurs on modern jet aircraft leads to faster reaction and often to save human life.

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