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# GENERAL ELECTRIC F110-GE-129 TURBOFAN ENGINE

**Marián HOCKO[1], Martin VENCEĽ*[1], Maroš DIVOK[1], Milan HUSŤÁK[1]**
[1]Department of Aviation Engineering, Faculty of Aeronautics, Technical University of Košice, Rampová 7, 041 21, Slovak Republic
**Corresponding author.* E-mail: martin.vencel@tuke.sk

**Abstract**. The article's subject is a design and systems analysis of the General Electric F110 GE-129 turbofan engine, which will become a part of the Slovak Air Force's arsenal in 2024 as a propulsion system for the F-16 Block 70 fighter aircraft. The article's objective is to inform both professionals and the general public with fundamental knowledge on the design and systems of the engine as well as its development.

**Keywords:** turbofan engine, aircraft, engine design, basic data

## 1. INTRODUCTION

A contract for the purchase of 14 F16 Block 70/72 fighter aircraft, as well as armament, logistical support, and training for 22 flying personnel and 160 ground personnel, was signed on December 12th, 2018, by Lockheed Martin Vice President Ana Wugofski and Slovak Minister of Defense Peter Gajdoš. The total price of the deal was EUR 1.589 billion. The F16s were supposed to be delivered to Slovakia in 2023, but that date has been moved to the second quarter of 2024.

Slovakia will receive the General Electric F110-GE-129 fourth-generation turbofan engine, the first American turbofan engine to be inducted into the Slovak Air Force, along with the most expensive fighter aircraft in history, according to the decision made by the Slovak government to make the purchase.

## 2. DEVELOPMENT OF THE GENEREAL ELECTRIC F110-GE-129

The development of the General Electric F110-GE-129 engine began in the 1970s. Pratt & Whitney F100 engines, which propelled the F-15 with twin engines and the F-16 with a single engine, went into service in 1974 after beating out a bid from General Electric. However, maintaining consistent compressor operation and sourcing spare parts in the required amounts were major operational issues with the Pratt & Whitney F100-PW-229 engines. As a result, the Alternate Fighter Engine (AFE) program was started in 1979 to discover an engine that was more dependable, had greater durability, and cost less to operate. The General Electric F110-GE-100 engine and a better version of the older F100-PW-220 engines were in competition. Unofficially, the contest was known as "The Great Engine War".

The F101-GE-100 turbofan engine that powers the B-1B bombers is used as the core for the General Electric F110 engine. A new blower was added to the engine core, and a newly created afterburner chamber with a controlled nozzle was built to obtain the best performance for the proposed category of aircraft. These components were enlarged versions of those found on the F404 turbofan engines that power the F-18 Hornet fighter plane. The F101DFE (Derived Fighter Engine) was applied to this modified turbofan engine. From its commencement in 1975 until the start of the competition, General Electric sponsored the development of the General Electric F110 engine with its own resources. Later, the USAF provided funding as part of a 30-month development program [1].

At Edwards AFB, the General Electric F110 engine's flight testing aboard an F-16 fighter started in December 1980. Pilot Philip F. Oestricher completed the first of the F-16 test flights. The F-14's engine testing resumed the following year. The USAF performed a thorough cost analysis for both rival engines (Pratt & Whitney F100-PW-229 and General Electric F110-GE-129) in 1984 to purchase and operate 2,000 engines over the ensuing 20 years. The USAF would have easily had better warranty conditions with the General Electric engine than with the Pratt & Whitney engine, even though the two engines were equally as capable and completely able to meet the requirements. The "Great Engine War" was won by the F110 turbofan engine, but if Pratt & Whitney and General Electric split the production of new engines, the difference in service costs would prove to be far more important. The final choice was decided in February 1984 with the assumption that 160 engines, including 75% F110s and 25% F100s, would be purchased in fiscal 1985. The first F-16 aircraft models had General Electric F110 Block 30 engines.

**Figure 1** F-16 Block 70 fighter [2].

Block 50/60/70 of the General Electric F110 is the designation for F-16 fighter aircraft powered by those engines. The Pratt & Whitney F100 engine-powered F-16 fighter aircraft are identified by the terminal number 2, Block 52/62/72.

## 3. BASIC PARAMETEERS OF THE GENERAL ELECTRIC F110 TURBOFAN ENGINE

Every The General Electric F110 engine is a turbofan, twin-turbocharged, small bypass-ratio, twin-shaft, turbocharged aircraft engine with a three-stage blower and a de-staged axial high-pressure compressor, a direct-flow annular main combustion chamber, a single-stage high-pressure axial-cooled gas turbine and a two-stage low-pressure axial-cooled partially cooled reaction-type gas turbine, and an exit system with an afterburner combustion chamber and an all-mode supersonic exit nozzle with independently controlled critical cross-section and exit cross-section according to separate control programmes.

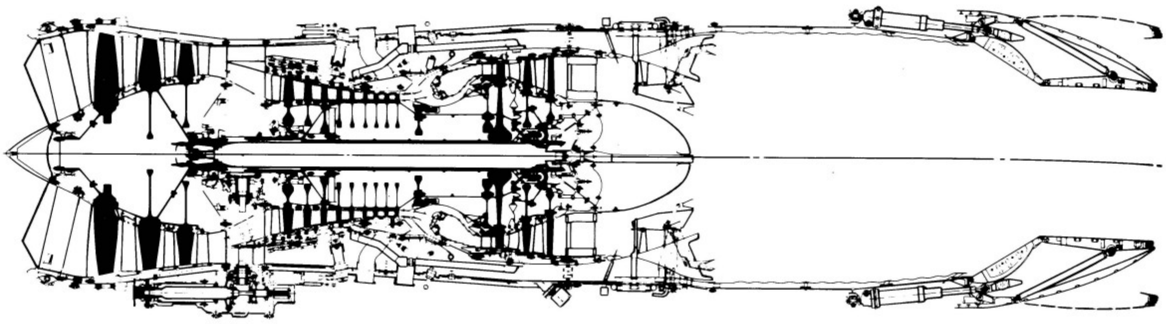

**Figure 2** Section of a General Electric F110-GE-129 turbofan aircraft engine

The sealed oil system, primary electro-nickel and secondary hydromechanical fuel control systems, and multipurpose diagnostic system are all features of the General Electric F110-GE-129 engine.

### 3.1. Basic data of General Electric F110-GE-129 turbofan engine

Engine thrust at maximum mode........................................ $F_{T,max}$ = 76.3kN
Engine thrust on afterburner mode........................................ $F_{T,A}$ = 131.2kN
Bypass ratio (in calculation mode)........................................ m = 0.76
Maximum air flow rate........................................ $Q_{air}$ = 124.7 $kg.s^{-1}$
Maximum total compressor compression ratio........................................ $\pi_{Ct}$ = 30.7
Maximum total compression ratio of low pressure compressor........................................ $\pi_{Ct,LPC}$ = 3.2
Maximum total compression ratio of high pressure compressor........................................ $\pi_{Ct,HPC}$ = 9.6
Specific fuel consumption at maximum mode........................................ $c_{m,max}$ = 0.067 $kg.N^{-1}.h^{-1}$
Specific fuel consumption on afterburner mode........................................ $c_{m,A}$ = 0.186 $kg.N^{-1}h^{-1}$
Maximum total gas temperature upstream of the gas turbine........................................ $t_{3t,max}$ = 1 396°C
Maximum total gas temperature downstream of the gas turbine........................................ $t_{4t,max}$ = 950°C
Maximum speed of low pressure compressor........................................ $n_{LPC,max}$ = 8 250 $min^{-1}$
Maximum speed of high pressure compressor........................................ $n_{HPC,max}$ = 14 600 $min^{-1}$
Maximum air pressure after high pressure compressor........................................ $p_{2,max}$ = 3.55 MPa
Total engine length........................................ $L_{max}$ = 4 630 mm
Maximum engine diameter........................................ $D_{max}$ = 1 181 mm
Maximum engine dry weight........................................ $G_{max}$ = 1 805 kg
Thrust-to-weight ratio........................................ $F_T.m^{-1}$ = 7.09

## 4. GENERAL ELECTRIC F110-GE-129 TURBOFAN ENGINE DESIGN

### 4.1. Basic data of General Electric

Depending on blower speed and at-atmospheric temperature, the F110-GE-129 engine inlet assembly has adjustable inlet guiding vanes and adjustable outlet sections. An anti-icing device that employs heated air obtained from the fifth stage of the engine's high-pressure compressor to heat the intake aerodynamic cone protects the leading edges of the inlet guiding vanes and the inlet aerodynamic cone of the inlet against frost. There are three operating modes for the anti-impact system: automatic, on, and off.

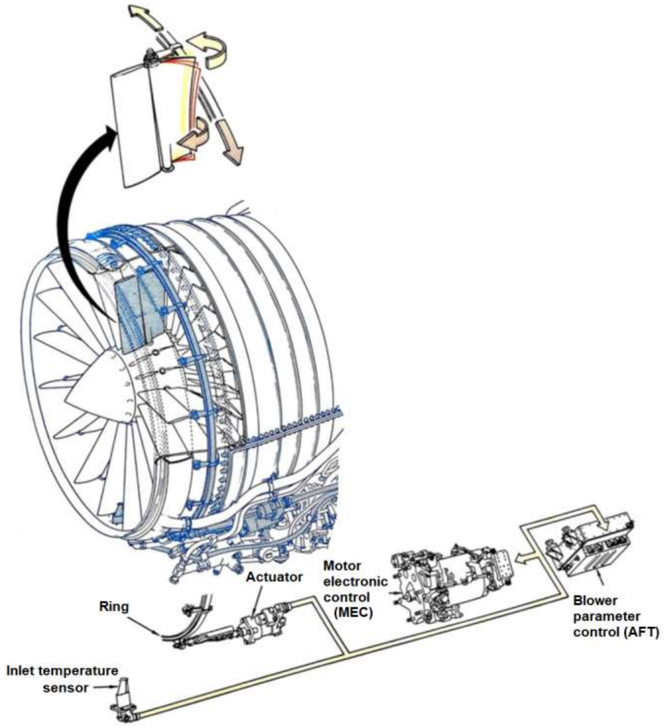


**Figure 3** F110-GE-129 inlet guide vane control and F110-GE-129 inlet control system

## 4.2. Engine blower

The blower of the F110-GE-129 engine is an axial, three-stage blower made of titanium alloys. Blower outer diameter is 970 mm. The total low pressure compressor compression ratio is $\pi_{LPC,t} = 3.2$. The low-pressure compressor rotor is connected to the shaft of a two-stage low-pressure gas turbine via a coupling.

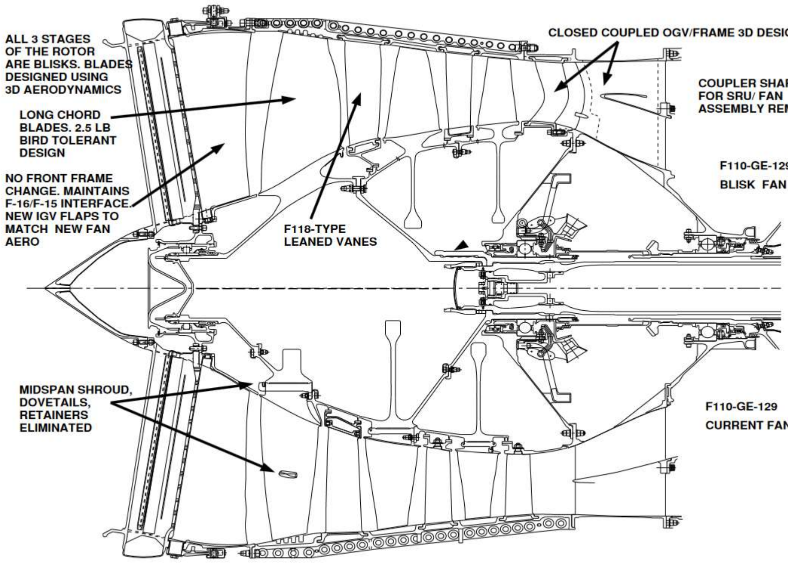


**Figure 4** Blower section of F110-GE-129 turbofan engine[3].

### 4.3. High-pressure compressor

An axial, nine-stage, disc-drum architecture makes up the high-pressure compressor for the F110-GE-129 engine. The high-pressure compressor's total compression ratio is $\pi_{Ct,HPC}$ = 9.6. Alloys of titanium are used in the first three steps. A286 steel alloy makes up the fourth through ninth stages. Depending on the speed of the high-pressure rotor and the temperature in front of the engine, the inlet guide vanes and the guide vanes of the first three stages are programmably adjusted by an electromechanical mechanism [4].

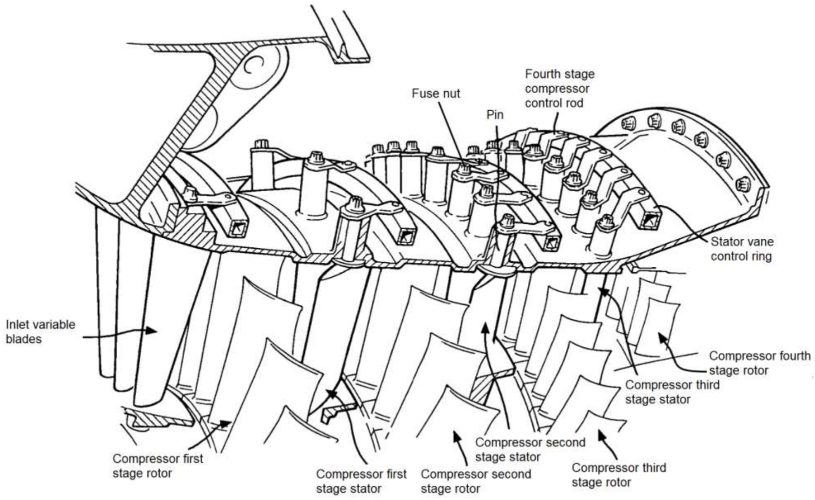


**Figure 5** Control of the inlet guide vanes and guide vanes of the first three stages of the high-pressure compressor of the F110-GE-129 engine [5].

### 4.4. Main combustion chamber

The main combustion chamber of the F110-GE-129 engine is annular, direct-flow. Fuel is supplied to the combustion chamber area via 20 duplex fuel nozzles. Vortices at the front of the combustion chamber provide agitation of the incoming primary air stream and its mixing with the injected fuel. Ignition of the fuel-air mixture is provided by three igniters. The ignition process is set in motion when 10% of the speed is reached and ends when 59% of the speed of the high-pressure rotor is reached. The main combustion chamber is made of chromium nickel molybdenum steel alloy, designated 'Hastelloy X'.

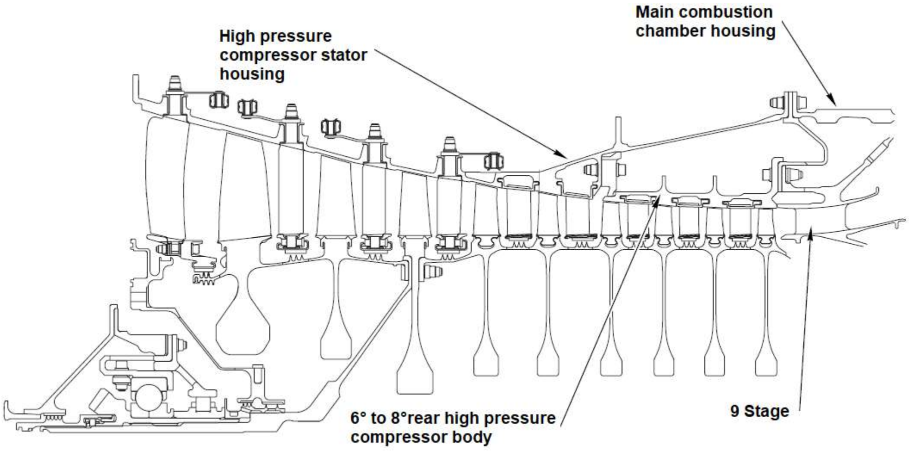


**Figure 6** F110-GE-129 engine high pressure compressor section

## 4.5. High-pressure gas turbine

Reaction type, axial, single-stage gas turbine with high pressure. A secondary stream of air from the combustion chamber cools the high-pressure gas turbine by passing via cooling channels in the stator and rotor blades' bodies. Rene 125, an alloy of nickel, cobalt, chromium, tungsten, aluminum, titanium, molybdenum, and carbon, is used to make the gas turbine parts.

**Figure 7** Cooled rotor blades of F110-GE-129 high pressure gas turbine engine

## 4.6. Low-pressure gas turbine

The reaction-type, axial, two-stage low-pressure turbine has two stages. The first stage's stator is cooled using air from the high-pressure compressor's fifth stage, but the low-pressure gas turbine's other components aren't. The low-pressure gas turbine's rotor propels the engine's rotor blower. The first stage's stator components are constructed from an alloy called "Rene95" that includes nickel, chromium, cobalt, aluminium, molybdenum, niobium, tungsten, titanium, and carbon. The rotor is constructed from the same material as the rotor of the high-pressure gas turbine known as the "Rene 125." The "Rene 80" alloy, which is composed of nickel, chromium, cobalt, molybdenum, titanium, and carbon, is used to make the components of the low-pressure gas turbine's second stage [13].

**Figure 8** Disassembled low pressure gas turbine of engine F110-GE-129 node [6].

### 4.7. Afterburner combustion chamber

The mixing chamber, where the first stream's exhaust gas streams and the second stream's air are mixed, contains the afterburner chamber. The afterburner combustion chamber houses three circular flame stabilisers. Through 201 fuel nozzles, fuel is delivered into the additional combustion chamber. One igniter serves as the source of ignition for the fuel-gas mixture. The afterburner chamber's component sections are built of nickel alloy with chromium, molybdenum, titanium, niobium, and other alloying elements, known commercially as "IN625" [7].

**Figure 9** Afterburner combustion chamber of the F110-GE-129 turbofan engine [8].

### 4.8. Outlet nozzle

A programmable, all-mode, supersonic Laval-type nozzle, the F110-GE-129 engine's output nozzle has independently variable critical diameter and outer diameter in accordance with distinct control programs. Parts of the exit nozzle are constructed of titanium.

**Figure 10** F110 all-mode adjustable supersonic engine output nozzle [9].

## 4.9. Cabinet of engine aggregates

The drive system for the F110-GE-129 engine's auxiliary aggregates ensures that torque is transferred from the high-pressure compressor shaft of the engine through the central drive housed in the compressor transition box to the engine's aggregates box, where it drives the engine's auxiliary aggregates, and to the aircraft's aggregates box, where it drives the aggregates required for the operation of the airframe's systems. On the bottom of the F110-GE-129 engine's outer case are the auxiliary power units [12].

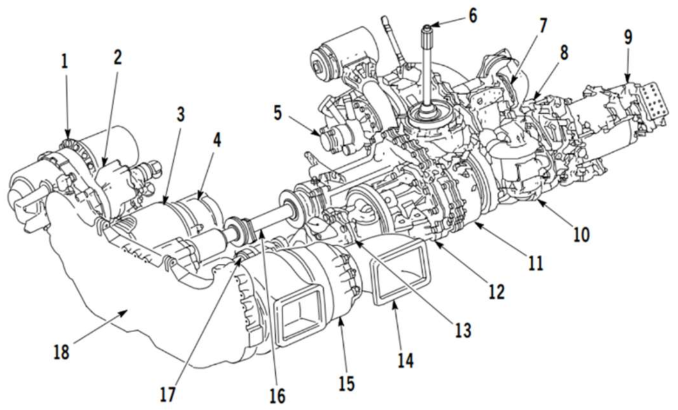


**Figure 11** Cabinet of engine aggregates
1 - backup generator, 2 - hydraulic pump, 3 - constant speed drive, 4 - main generator, 5 - afterburner fuel pump, 6 - angular gear, 7 - fuel pump, 8 - engine alternator, 9 - engine control unit, 10 - main fuel pump, 11 - transmission mechanism, 12 - engine oil pump, 13 - engine hydraulic pump, 14 - exhaust from air starter, 15 - air starter, 16 - output shaft, 17 - secondary circuit hydraulic pump, 18 - auxiliary gearbox

## 4.10. Engine fuel-regulating system

The fuel-regulating system provides regulated fuel supply to the main combustion chamber, control of the compressor control gears and regulated fuel supply to the afterburner chamber. The engine control system consists of three main components: digital electronic control (DEC), afterburner control (AFC) and main engine control (MEC). The engine has two main selectable modes of operation: primary (PRI) and secondary (SEC). In addition, there are two other modes of operation between primary PRI and SEC that the pilot cannot select: hybrid (HYB) and hybrid with variable stator blade angles (HYB VSV).

In the Primary Electronic Engine Control (PRI) mode of operation, the change in the position of the engine control lever is transmitted as an electrical signal to the DEC engine control block, where the individual logic operations in the engine control process are programmed. The processed and evaluated signals are subsequently, according to the control laws, transmitted by means of commands to the individual units that provide the engine control.

The information about the change of the engine control lever position is transmitted by pulling to the main hydromechanical engine control unit (MEC). The engine control parameter block (AFT) receives the engine control lever repositioning information via a transducer that converts the engine control lever repositioning value into an electrical signal. This electrical signal is used as a secondary control method (SEC) in the event of failure of the primary engine control. After the fault is corrected, the system returns to the primary electronic engine control (PRI) mode. Maintenance personnel are informed of the control system failure by the engine monitoring system (EMS) [11].

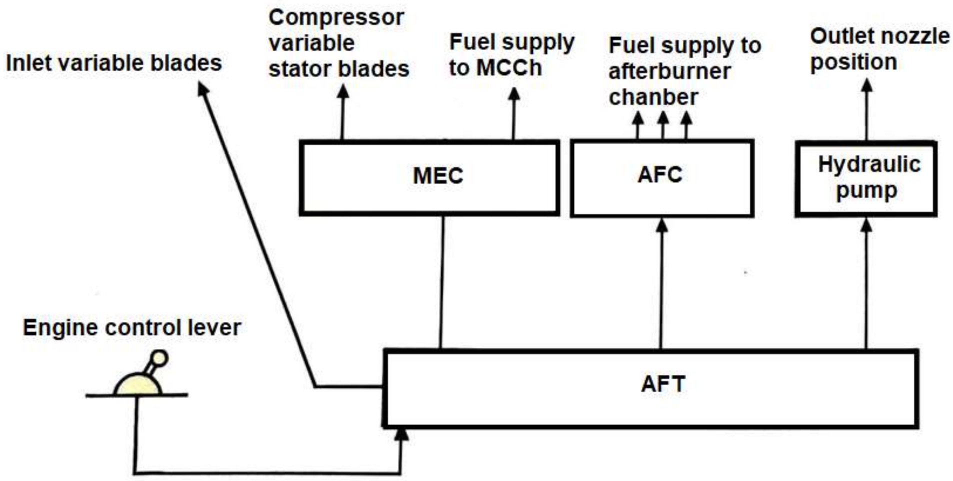


**Figure 12** Block diagram of F110-GE-129 primary engine control

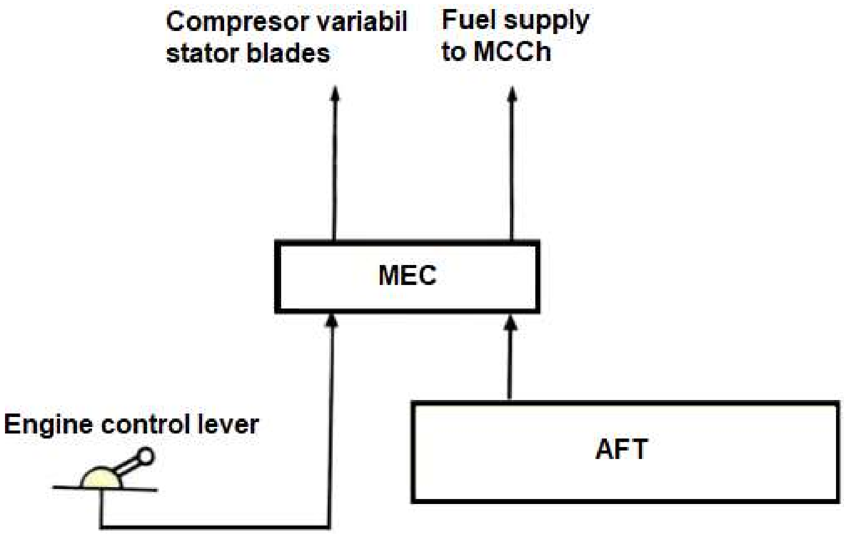


**Figure 13** Block diagram of secondary engine control

### 4.11. The engine oil system

The engine oil system lubricates and cools the engine bearings, supplies pressurized oil to the hydraulic pump that controls the engine output nozzle, and lubricates and cools the gears in the aggregate housing. MIL-L-7808 (USAF) or 0-148 (NATO) synthetic oil is used in the engine oil system [8][14].

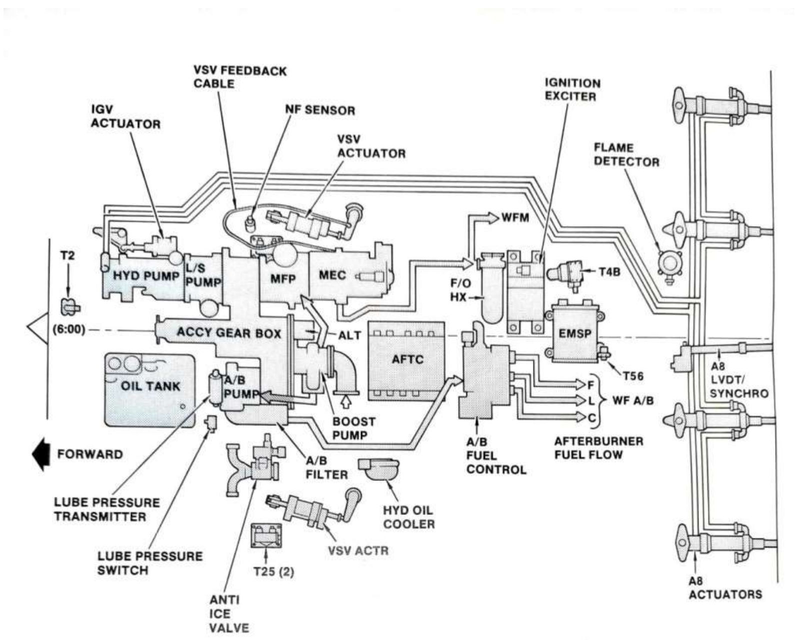


**Figure 14** Principle diagram of F110-GE-129 engine oil system

### 4.12. The engine starting system

The engine starting system provides automated engine starting on the ground and in flight. The high-pressure rotor of the engine is spun by the turbine starter during start-up. In the event of unstable operation of the engine compressor, the engine is switched off and the engine is then automatically started in flight [10].

## 5. CONCLUSION

Slovak Air Force will have the most potent fourth generation F110-GE-129 turbofan engine with the launch of the F-16 Block 70 fighter plane. This engine performs better than the ones that were previously in use in terms of maximum thrust in maximum mode and afterburner mode, as well as operational effectiveness and robustness. The cutting-edge EMS monitoring system enables real-time monitoring of the engine status and maintenance based on the engine's current state.

Due to its innovative design and ongoing improvements, the General Electric F110-GE-129 turbofan engine, whose development started in the 1960s, is still regarded as one of the best in its class and has a promising future.

## REFERENCES


[1] “The F110 Engine,” The F110 Engine | GE Aviation Available: https://www.geaviation.com/military/engines/f110-engine.
[2] archive of the author
[3] Wadia, A. R., James, F. D.: F110-GE-129 EFE – Enhanced Power through Low Risk Derivate Technology. ASME TURBOEXPO 2000.
[4] https://www.globalsecurity.org/military/systems/aircraft/systems/afe.htm
https://aviation.stackexchange.com/questions/25877/in-a-turbofan-what-holds-the-spinning-axis
[5] http://www.enginehistory.org/Museums/GEF110/f110ge100.shtml
[6] https://www.airliners.net/photo/USA-Air-Force/General-Dynamics-F-16C-Fighting-Falcon-401/1253136/L
[7] https://www.geaerospace.com/propulsion/military/f110
[8] https://www.portsanantonio.us/standardaero-F-16-engine
[9] Lockheed Martin Corporation - F-16 C/D Flight manual
[10] Richardson, D.: Bojová letadla, F-16. Naše vojsko 1994. ISBN 80-206-0224-0.
[11] Wadia, AR, & James, FD. "F110-GE-129 EFE — Enhanced Power Through Low Risk Derivative Technology." Proceedings of the ASME Turbo Expo 2000: Power for Land, Sea, and Air. Volume 1: Aircraft Engine; Marine; Turbomachinery; Microturbines and Small Turbomachinery. Munich, Germany. May 8–11, 2000. V001T01A019. ASME. https://doi.org/10.1115/2000-GT-0578.
[12] Raymer, D.P., Aircraft Design: A Conceptual Approach, 5th ed., AIAA Education Series; American Institute of Aeronautics & Astronautics: Reston, VA, USA, 2012.
[13] Liew, K. H., Urip, E., and Yang, S. L. Parametric Cycle Analysis of a Turbofan Engine with an Interstage Turbine Burner. Journal of Propulsion and Power. 3. Volume 21, 546–551. http://dx.doi.org/10.2514/1.2546.
[14] P. Gasparovic, L. Fozo, M. Hovanec, K. Semrad, "Project IMAF – research on measurement of airspeed of unconventional flying vehicles," in: Acta Avionica, vol. 23, no. 2, pp. 21–24, 2021. doi:10.35116/aa.2021.0012 https://acta-avionica.tuke.sk/ojs/index.php/aavionica/article/view/1097.


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