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SECURITY OF MILITARY AVIATION FLIGHT OPERATIONS CONCERNING THE QUALITY OF FUEL SUPPLIED TO AIRCRAFT

Summary. The specificity of military flights operations imposes a number of requirements on aircraft. One of the main factors concerning the realization of the air task is the reliability of the engine. The most common cause of aircraft engine malfunctioning is the quality of the fuel supplied. This paper presents the factors affecting the quality of fuel supplied to aircraft and the procedures preventing the delivery of aircraft fuel, which could interfere with the operation of the aircraft engine.
Keywords: aviation, aviation fuel, fuel quality

1. INTRODUCTION

As the saying goes, to build an aircraft, we only need a good engine and something to place this engine on, such as the door of the hangar. The main element in determining the performance of the aircraft is the aircraft engine. Thanks to its construction, efficiency and reliability, we accept a certain level of operation costs so that it is suitable for performing specific tasks. In addition to the construction of the engine, along with proper workmanship and materials needed to take full advantage of the modern combat aircraft engines, it is necessary to provide the appropriate fuel. Currently, liquid fuels are used in this context, particularly those with the prescribed chemical composition and calorific value of strictly

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defined, adequate physico-chemical characteristics, a high level of purity and with freedom from water. Due to the large quantity of fuel consumed per unit of time, the contents of even small amounts of impurities or water may interfere with the correct operation of engine units, and hence the entire engine. This is particularly important in the case of engines in military aircraft, due to the much stricter work procedures involved, compared with civilian aircraft.

Among the causes of failure relating to ab engine fuel system, a majority have been caused by the poor quality of the fuel supplied to the engine fuel system. The quality of the fuel results from its entire distribution system, from its production to its delivery to the aircraft tank. Of importance are the storage conditions at every stage of the distribution and all kinds of manipulations and procedures of the fuel [2, 7].

2. TYPES OF FUEL USED IN POLISH MILITARY AVIATION

The Polish Armed Forces mainly use two types of aviation fuel: NATO-coded F-34 and F-44. The F-34 fuel is known as kerosene and complemented by an inhibitor of water crystallization (FSII), which is coded S-1745. It is intended for the aircraft air units stationed on land. It is also known under the symbol JP-8 and AVTUR/FSII.

F-44 fuel is a type of fuel oil with a high flash point and a water crystallization inhibitor (FSII), which is coded S-1745. This fuel is used in naval aviation on the decks of warships in order to limit the fire risk.

Occasionally, the Polish Armed Forces use two other types of aviation fuel:

- F-35 fuel is equivalent to fuel employed by civilian airlines and known under the trade name Jet A-1 or AVTUR. It can be used instead of F-34 fuel and as emergency fuel instead of F-44.
- F-40 fuel is a fuel enriched with a water crystallization inhibitor (FSII code S-748) used in aircraft based on land. The fuel is also known as JP-4 or AVTAG/FSII. It can be a substitute fuel for F-34 and F-35 fuels [3].

Currently, the primary type of fuel for turbine aircraft engines in the Polish Armed Forces is F-34 fuel, which is produced in domestic petrochemical plants according to the requirements contained in Defence Standard NO-91-A258-2.

In order to achieve the adequate operation characteristics, we introduce into the fuel a number of individual additives in F-34 fuel, such as:

- an additive preventing the crystallization of water in the fuel - (S-1745) = 0.10 ÷ 0.15 (mg/dm^3)
- an additive for anti-corrosion and lubricity - (S-1714) ÷ 9.0 = 23.0 (mg/dm^3)
- an anti-static additive in fresh fuel, whose contents should be no more than 3.0 mg/dm^3; when prompted to add the total amount, the additive may not exceed 5.0 mg/dm^3
- deactivator metals, but not more than 2 mg/dm^3
- an oxidation inhibitor, which is added only in the case of the fuel produced on the basis of hydrorafinate in an amount of up to 2.0 mg/dm^3, and not more than 5.7 to the next refilling of the additive [3]

The NATO countries' standardization documents (*STANAGs*) for quality and physicochemical requirements define the minimum requirements to be met by petroleum products, including fuels for aviation technology. A basic document setting out minimum requirements for the aviation fuel is *STANAG 3747* [6]. In a significant number of documents drawn up by individual member states, these requirements are much stricter in order to achieve acceptable safety thresholds for these products. Table 1 contains selected quality requirements for the basic types of aviation fuel used in the Polish Armed Forces.

In addition to the physico-chemical requirements, a very important issue when supplying fuel to aircraft tanks is that it has a high level of purity. The document *STANAG 3149* includes provisions on the need to remove impurities from the fuel and for it to be water-insoluble (free water). Fuel supplied to the aircraft must have a light colour, be clean, must not contain visible dirt and be water-insoluble. The apparatus removing the water and the pollution should be placed close to the refuelling aircraft [5]. The efficiency of these devices should be checked at least once every three months. Increasingly, these devices have their own automatic control system efficiency.

Tab. 1

Selected physical and chemical requirements of aviation fuel for turbine aircraft engines used in the Polish Armed Forces

Characteristics	**Aviation fuel**			
	F-34	**F-35**	**F-40**	**F-44**
Exterior view at ambient temperature	Clear, transparent, light			
Aromatics content, % (v/v), not more than	25.0			
Mercaptan sulphur, % (m/m), not more than	0.003			
Sulphur total, % (m/m), not more than	0.30		0.30	
Fractional composition (distillation normal)				
Temperature of the beginning of distillation, °C	Score			
10% distilled to a temperature, °C, not more than	205		Score	205
20% distilled to a temperature, °C, not more than	Score		145	Score
50% distilled to a temperature, °C, not more than	Score		190	Score
90% distilled to a temperature, °C, not more than	Score		245	Score
Final boiling point: temperature, °C, not more than	300		270	300
Rest, % (v/v), not more than	1.5			
Loss, % (v/v), not more than	1.5			
Flash point, °C, not more than	38			60
Vapour pressure at 38°C, kPa			14-21	
Density at 15°C, kg/m^3	775-840		751-802	788-845
Freezing point, °C, not more than	-47		-58	-46
Kinematic viscosity at -20°C, mm^2/s, not more than	8.0			8.5
Calorific value, MJ/kg, not more than	42.8			42.6
Copper corrosion, 2 h/100°C, not more than	1			
Thermal stability - pressure drop, mm Hg (kPa), not more than - deposits on the tube, degree not more than	 25.0 (3.33) <3			

Cont. tab. 1

Existent gum, mg/100 cm^3, not more than	7			
Water reaction interface rating not more than	1 b			
Separation of water not more than	85			
Content of metal deactivator, mg/l, maximum	5.7			
Icing inhibitor content % (v/v)	0.10-0.15		0.10-0.15	0.10-0.20
Electrical conductivity at the point of delivery to the user, pS/m	50-600	50-450	150-600	150-600

Different countries demand different levels of purity in aviation fuels. The level of purity is defined as the amount of impurities and water per unit volume of the fuel. According to the NATO minimum, the refuelling of aircraft must be stopped when the impurity content exceeds 1 mg/l and the water content is higher than 30 ppm. The research on the impurity content is defined in NATO standardization document *STANAG 3149*. Due to the internal requirements of the associated countries, national normalization is much sharper, for example, in the case of the French Army: the mechanical impurities in the fuel at the moment of refuelling the aircraft cannot be greater than 0.5g/dm^3, and the water content of the dispersed may not be greater than 5 ppm.

In the Polish Armed Forces, the requirements for cleanliness and water limits are set out in Defence Standard NO-91-A800 [4]. Apart from the quantitative requirements, the standard contains the methodology of inspection regarding the cleanliness of the aviation fuel. The selected requirements are presented in Table 2.

Tab. 2

Acceptable amounts of the mechanical impurities and water in fuel intended for filling aircraft tanks

Specification	**Unit of measure**	**Value**
Content of micropollutants and the size distribution of solid foreign objects: 1) Symbol pattern micropollutants, not more than 2) Symbol pattern of the grain-size composition, not more than	- -	A-6, B-6, C-6 D
Content of the mechanical impurities, not more than: 1) in a single sample 2) on average in mg/dm^3	mg/dm^3	1.0 0.1
Grain-size distribution of foreign bodies, not more than: 1) in the interval dimension >5 μm 2) in the interval dimension >15 mm pieces/100 cm^3	Pieces/100 cm^3	78,000 14,000
Presence of free water in the fuel (by visual inspection)	-	None
Presence of foreign bodies and free water in the fuel samples (visually)	-	None
The water content of the dispersed fuel, not more than: 1) in a single sample 2) on average	% V/V	0.003 0.001

3. CHANGES IN THE QUALITY OF AVIATION FUEL AFFECTING FLIGHT SAFETY

Research tests conducted by military research centres and laboratories lead to the conclusion that changes in the quality of aviation fuel, which occur during storage on airbases, are mainly due to the contamination of fuel by water or solid contaminants. The deterioration in the physico-chemical characteristics as a result of the contamination by microorganisms present in the aviation fuel is extremely rare, in particular, during long-term storage. On airbases, aviation fuel is kept for a relatively short period, usually no longer than a year. During such a period, the ageing processes that occur in the aviation fuel may not cause change in the quality of flight safety. The process of supplying the military airbases in the aviation fuel is mainly due to the supply of fuel directly from production. Although there is a need to rotate ("refresh") fuel stocks held in depots, fuel is sometimes stored for longer than ideal because of possible acts of war or other events causing protracted disruption in the production or supply of liquid fuel to military units. This happens periodically, depending on the adopted refreshing plan. The fuel is stored for a minimum period of four years and transported from large fuel depots to the airbases. Currently, tank trucks are usually involved in transportation, although, in previous years, this would have been done by rail as well. A long period of storage could mean that the process of ageing has begun and physical and chemical changes have occurred. Before being directed to the airbases, the fuel is subjected to laboratory research testing related to the B-2 test or the A test, depending on the storage period of the batch of fuel.

Any manipulation of the fuel between tanks, particularly when it involves the transport of fuel from the pipeline or flexible hoses, which are not constantly filled with fuel, creates a risk of fuel contamination during pumping. This is due to the exposure of the surface of the inner pipe to the atmosphere. Transmitted by air, mechanical dirt and moisture deposit on the inner surfaces of the pipe (hose), causing its pollution or the formation of the corrosion processes. When pumping the next batch, the fuel is likely to include particles of dirt, water and other corrosive elements. Depending on the length of the contaminated section of pipeline and the time that it remained unfilled, the extent of the pollution located on the inner surfaces can vary.

Depending on the amount of the pollution stored in an airbase's individual storage, there may be a variety of the threats to the functioning of the distribution system of aviation fuel, as well as for the safe operation of flights using military aircraft.

The majority of the impurities, including free water, are removed from the fuel with the use of distribution procedures. The first procedural step to improve the quality (purity) of the fuel is a detachment of the fuel and a pooling of the embedded contaminants from the lowest point of the transport rail tank or the transport car tank. Depending on the size of the tank transport (a column of liquid), the detachment time can vary from a period of 30 min/1 m column of fuel. It is also the first stage in the purity control of aviation fuel supplied to the airbase [4]. Detached fuel testifies to its purity. In the absence of mechanical impurities, and free or dispersed water, the detachment of the fuel will be clear, transparent, light in colour and with no sediment on the bottom of the vessel control. After a positive result of the detached fuel, there is a fuel quality control measure related to the C test, which consists of checking the conformity of the fuel with the received laboratory documents. Then, the fuel is pumped into a storage tank depot at the airbase.

The detachment of fuel procedure is repeated many times in the process of distributing aviation fuel. This allows, in a simple way and without significant investment, the isolation of any mechanical impurities and water. Depending on the construction of the storage tank, wherein the fuel is currently stored, detached fuel is removed by the gravity or by means of special pumps. In addition, the construction of the storage tanks and cisterns of airport distributors is designed, so that the fuel is taken from the bottom of the tank. This prevents the distribution system from sucking up any of the water or dirt accumulated on the bottom of the tank. The removal of impurities and free water from the bottom of the reservoir is necessary not only to avoid the possible penetration further into the distribution system, but also because the sludge and water can become a breeding ground for microbial growth. It may cause a corrosion of the metal parts of the tank and reduce the surface tension of the fuel. Consequently, it reduces the efficiency of water filtration from the fuel. In addition, the growth of colonies of microorganisms increases the amount of impurities resulting from the decaying microorganisms. A large number of microorganisms can cause valve crashes, blocking of filters and accelerated wear of the pumps.

A shorter time storage of aviation fuel at airbases is not conducive to the occurrence of microorganisms. Another factor in preventing the growth of microorganisms is adding a crystallization inhibitor to water, which is also a potent biocide, on the airbase.

During the storage and distribution of fuel, changes in fuel quality occur, caused by reactions between various less stable components of the fuel, such as sulphur compounds, olefins, and oxygen and nitrogen compounds, particularly when contact is made with the dissolved oxygen in the fuel. These processes are much faster in the case of fuel contact with metals such as copper and its alloys, zinc and cadmium. These processes cause a reduction in the fuel’s thermal stability, characterized by an accelerated ageing process through the formation of high molecular weight hydrocarbons. These compounds are not sprayed and settle on the engine components to form hard deposits, causing interference with the work of the injectors or vaporizers; in extreme cases, the deposits can cause the complete blockage of the openings of the injectors. The forming sediments reduce the heat dissipation from the engine components, which can cause them to overheat or burnout, which, in turn, may cause improper engine operation or the engine failure.

The alloys of copper, zinc and cadmium have been the main construction materials for the internal coat protection of fuel installations for many years [1]. Zinc has been the main component. The use of these metals in distribution installations has caused them to come into contact with the fuel, such that alloys of these metals chemically or electrochemically corrode to form a volatile layer of corrosive product on the alloys’ surface, which has also been damaged by the flowing fuel contaminating them. When the corrosive product is dissolved in the fuel, it the causes the speeding-up of the fuel’s ageing process.

Since Polish accession to the NATO structures, the process of upgrading fuel systems for the storage and distribution of aviation fuel has taken place. This process involves, among other things, the removal from the aviation fuel distribution system of the metals that can cause changes in fuel quality. It also involves a process of technological change in the aviation fuel distribution system used by the Polish Armed Forces.

On most airbases, it has been necessary to remove the devices, assemblies and components that used metals or their alloys that were not appropriate for aviation fuel. In addition, the existing distribution system was based on the so-called “open distribution system of aviation fuel”, which was particularly sensitive to the impact of weather conditions. The filling of railway cisterns, distributors’ airport tanks and most aircraft took place using an open container, which was penetrated by mechanical impurities, moisture from the air and even precipitation.

Fig. 1. Portions of the corroded filter on the measuring tube of the storage fuel tank

The higher requirements of modern aircraft in relation to the purity of aviation fuel demanded the introduction of another system of fuel pumping between the different parts of the distribution system, enabling the maintenance of high-purity fuel all the way to its distribution point. The pressure fuel distribution system has substantially reduced the risk of impurities and water from the atmosphere entering into the fuel. Thus, it reduces the levels of corrosive product and the risk of microorganisms, as well as the intensity of the fuel's ageing process. The pressure system is based on hermetic connectors (socket-head), which transfer the fuel to the aircraft's tank in virtually all weather conditions without fear of contamination of the pumped fuel.

This system allows for a greater intensity of fuel pumping into the aircraft's tank, which, in turn, significantly reduces the risk of fire and the possibility of environmental pollution due to fuel spillage.

Fig. 2. Refuelling of the aircraft with a pressure head

4. CONCLUSION

The introduction of the pressure pumping aviation fuel system allows for maintaining the high quality of fuel supplied to aircraft tanks. Changes in the distribution system and material components, which create a risk of deterioration in the aviation fuel, are necessary. That said, this should not be regarded as the end of any action to address the quality control of aviation fuel supplied to the aircraft.

The intensive exploitation of the fuel infrastructure on airbases makes it necessary to constantly monitor the filter equipment, the transport equipment and the fuel storage equipment. A very important factor, which is often taken into account as it has a significant impact on the safety of the flights operated by the Polish Air Force, is the degree of training and the level of practical skills among service staff implementing the distribution of aviation fuels, lubricants and other materials. These skills are particularly important for conducting quality control of fuel, manipulating the product and conducting laboratory tests. A failure to follow procedures can result in erroneous measurements, which could lead to poor quality fuel being used to refuel aircraft, thereby threatening flight safety. This risk should be heeded by all professional staff on an airbase, namely, technicians, operators, laboratory technicians and engineers operating the exchange of the filters of stationary equipment. Improper handling of the filter cartridge can result in the inefficient operation of the entire filter and the supply of poor quality fuel.

References

1. Bonczek Jerzy. 2002. Eksploatacja lotniskowych systemów dystrybucyjnych paliw z wewnętrznymi powłokami cynkowymi do turbinowych silników lotniczych. [In Polish: Operation of airport fuel distribution system with internal zinc coatings for turbine aircraft engines]. PhD thesis. Warsaw: Air Force Institute of Technology.
2. Karp Grażyna, Wojciech Dzięgielewski. 2011. "Course of chosen properties of aviation fuels in the time of the storage and on trade channels". Journal of KONBiN, Vol. 1(17): 121-134. Warsaw: Air Force Institute of Technology**,** Poland. ISSN 1895-8281.
3. NO-91-A258-2: Materiały Pędne i Smary - Paliwo do Turbinowych Silników Lotniczych kod NATO F-34. [In Polish: NO-91-A258-2. Petroleum, Oil and Lubricants – Aviation Turbine Fuels – Part 2: Fuel of NATO Code F-34]. Warsaw: Ministry of National Defence.
4. NO-91-A800: 2003. Materiały Pędne i Smary - Magazynowa i Lotniskowa Kontrola Zystości Paliw do Turbinowych Silników Lotniczych. [In Polish: NO-91-A800. Petroleum, Oil and Lubricants – Store and Airbase Inspection of Aviation Turbine Fuel Purity]. Warsaw: Ministry of National Defence.
5. STANAG 3149: Edition 10 - Minimum Quality Surveillance for Fuels. Brussels: NATO Standardization Agency.
6. STANAG 3747: Guide Specifications (Minimum Quality Standards) for Aviation Turbine Fuels (F-24, F-27, F-34, F-35, F-40, and F-44). Brussels: NATO Standardization Agency.
7. Havenga Jan H., Anneke de Bod. 2016. "Freight corridor performance measurement system: A framework for South Africa". Journal of Transport and Supply Chain Management, Vol 10, No 1: 1-11. DOI: http://doi.org/10.4102/jtscm.v10i1.252. ISSN: 2310-8789.

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