ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1213540

PERFORMANCE AND EMISSION CHARACTERISTIC OF MINIATURE TURBOJET ENGINE FED JET A-1/ALCOHOL BLEND

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Abstract

This paper presents differences between fossil fuel (Jet A-1) and alcohol/Jet A-1 blend, during combustion process using laboratory test rig with miniature turbojet engine (MiniJETRig). The test rig has been created in Air Force Institute of Technology for research and development works aimed at alternative fuels for aviation. Fuel from different feedstock (non-fossil sources) is introduced into market due to ecological aspects, fuel price stability and energy security. Application of alcohol to propel aircraft has started form using a blend of aviation gasoline with ethanol in spark-ignited internal-combustion engines. Taking into account that large part of aviation fuels used by commercial aircraft is jet fuels, so in this area it has begun to look for possibilities to apply alcohol component. In 2016, international standard (ASTM) approved a synthetic blending component for aviation turbine fuels for use in civil aircraft and engines – alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK). According to standard, ATJ-SPK synthetic blending components shall be comprised hydro processed synthetic paraffinic kerosene wholly derived from isobutanol processed through dehydration, oligomerization, hydrogenation and fractionation. Two different fuel samples, a traditional fossil jet fuel (Jet A-1) and a blend of 10% butanol with Jet A-1 were tested. Laboratory tests of selected physicochemical properties and bench tests with the same profile of engine test were carry out for both fuel samples. The obtained results: engine parameters and exhaust gas emissions are compared and discussed.

Keywords: *miniature jet engine, alternative fuels, exhausts emission*

1. Introduction

The biofuels/biocomponents are developed as substitute for petroleum fuels since many years. The importance of biofuels/biocomponents is highlighted mostly on account of such aspects as ecology and energy security. Currently the biofuels of 1st generation – FAME and bioethanol are produce on industrial scale. FAME is commonly used as biocomponent of diesel fuel and biobutanol as biocomponent of gasoline. Higher-order alcohols, including butanol, arouse special interest because of the role they would play in the future [2, 3]. The butanol calorific value of 29.2 MJ/dm^3 is higher than bioethanol. Moreover, butanol has relatively low heat of vaporization, and is less corrosive than ethanol. Butanol is used only in limited range, but the extensive research work focused on expanding the use of biobutanol as biocomponent of another type of fuels, including aviation once. In case of heavier fuels such as for aviation turbine, the restrictions regarding direct use of butanol are bigger than in case of gasoline. However, butanol can be treated as semi-finished material for synthesizing of biohydrocarbons used in aviation applications and as oxygenate/biooxygenate blended with fuels for non-aviation turbine engines (for example in power generation).

The first pathway is currently developed by various research centres and becomes one of five developed technologies of biohydrocarbons production for aviation applications, adjacent to F-T SPK, HEFA, SIP and F-T SPK+A technologies [8].

Regarding to butanol use as fuel for turbine engines the paper [4,6] indicates, that blends of 10 % (V/V) of butanol isomers and fossil Jet A1 fuel meet requirements – laboratory tests, for Jet

A-1, excluding flash point. This parameter is important for safety of logistic operations in case the fuel is used in aviation application. The low value of flash point can be much less important when the logistic system is prepared to operate with such fuel, what is possibly in non-aviation applications. The extended laboratory testing regarding biobutanol use as component of fossil fuels is currently in progress. It is expected to perform comparative bench testing using miniature turbojet jet engine fuelled with traditional Jet A-1, and blend of Jet A-1 with chosen isomers of butanol. It is expected that it would be possible to translate laboratory test results into effects obtained during real engine operation, and simultaneously to evaluate comprehensively the effect of butanol blends on turbine engines operation.

2. Research object and methodology

For laboratory and bench tests were used, the most commonly fuel for commercial aviation – Jet A-1 and n-butanol (isomer of butanol). Tested jet fuel meets the Aviation Fuel Quality Requirements for Jointly Operated Systems (AFQRJOS) [1], often referred to as the “Check List”, which incorporates the strictest elements of both ASTM D1655 and Def Stan 91-91. The blend of 10% butanol with Jet A-1 was prepared and marked as Jet A-1+B10.

Laboratory results are presented in Tab. 1. The properties were selected to characterize the fuel at the range of fuel-air mixture creation and combustion process as well as to guarantee correct operating conditions of the fuel supply system.

Tab. 1. Selected laboratory results of properties Jet A-1 fuel and a blend of 10% butanol with Jet A-1

Lp.	Property	Test method	Limits	Results		
				Jet A-1	Jet A-1 + B10	Relative change
1.	Density at 15ºC, kg/m³	ASTM D 4052	od 775.0 do 840.0	787.7	789.5	+0.2%
2.	Viscosity at -20ºC, mm²/s	ASTM D 445	max 8.000	2.997	3.177	+6%
3.	Specific energy, MJ/kg	PN-C-04062	–	43.99	42.68	-3%
4.	Smoke point, mm	ASTM D 1322	min 19	26	26	no changes
5.	Aromatics, %	ASTM D 1319	max 25.0	16.2	15.8	-2.5%
6.	Naphthalenes, %	ASTM D 1840	max 3.00	0.40	0.36	-10%
7.	Hydrogen content, %	ASTM D 3701	–	14.11	14.12	+0.1%
8.	BOCLE wear scar diameter, mm	ASTM D 5001	max 0.85	0.78	0.78	no changes
9.	Flash point, ºC	PN-EN 57	–	40.0	30.0	-25%
10.	Surface tension, mN/m	PN-C-04809	–	25.00	24.24	-3%

The analysis of laboratory results shows that input of 10% butanol did not cause significant changes in selected physicochemical properties. In this case, you cannot see any risks in the use of Jet A-1/butanol blend. Minor changes in the kinematic viscosity and surface tension should not have any influence on atomization process and creation of fuel-air mixture. The chemical composition, which practically does not change and a slight decrease in specific energy have minor importance. It can admittedly translate into a slight increase of fuel consumption, but in connection with use of butanol from renewable sources, it will be compensated by less negative impact on the environment. Blending fuel with butanol has not changed lubricity, so you can expect that moving parts of pump in fuel supply system will operate smoothly. It should be noted that these laboratory tests were carried out according with methodologies dedicated to fossil jet fuel, so operation may bring unexpected phenomena. Hence, the need to verify by the bench tests or even supervised operation.

The experimental activity presented in this paper was performed on Miniature Jet Engine Test

Rig – MiniJETRig. MiniJETRig is equipped with the following elements: miniature turbojet engine (see the technical specifications in Tab. 2) and dedicated measuring equipment, which includes: exhaust analyser, particulate matter analyser and control system with data acquisition based on the measurement cards. Detailed construction of the test rig and research potential were presented in the paper [5]. For the purpose of this paper, the exhaust system with straight duct was used and the engine was started up with compressed air. Such modification allows measuring the intake airflow rate and obtaining maximum thrust of 70 N.

Tab. 2. Miniature turbine engine specifications

Engine Type	Turbojet – Single spool
Compressor	Single stage radial compressor
Combustion chamber	Annular combustion chamber
Turbine	Single stage axial flow turbine
Pressure ratio	2.8:1
Minimum RPM	33 000
Maximum RPM	120 000
Thrust at max. RPM	140 N
Fuel consumption at max. RPM	500 ml/min
Mass flow at max. RPM	0.35 kg/s
Max. Exhaust Gas Temperature	750 ºC

The harmful components of exhaust gas were measured using a portable exhaust analyser. The exhaust gas sample probe was positioned in the centre of the exhaust stream at the end of straight duct. The details of the instruments used to measure the exhaust concentration of CO, CO_2, NO_x are provided in Tab. 3.

Tab. 3. Details of measurement equipment for gas emissions

Parameter	Sensor type	Range	Least count	Accuracy
CO	electrochemical	0 – 2 000	0.1 ppm	± 5% measured value
CO_2	infrared	0 – 25	0.01 %	± 5% measured value
NO	electrochemical	0 – 500	0.1 ppm	± 5% measured value
NO_2	electrochemical	0 – 100	0.1 ppm	± 5 ppm

Bench tests were carried out of according to the operating procedure (Fig. 1). Upon ignition, the engine was given maximum of 60 seconds to reach a steady state, whereby the engine speed remained constant at approximately 33 000 rpm (idle speed). The measurements of parameters were recorder at four rotational speed: 39 000, 70 000, 88 000 and 112 000 rpm. All engine rotational speeds were maintained in stationary conditions (changes in range of ± 2 000 rpm) for different times of operation. Times were specified on the basis of previous tests. At the end of a profile of engine test, rotational speed was decreased to 70 000 rpm and the engine was shut down. The sampling rate was five times per second for all measurement parameters.

The operating procedure was repeated twice for both tested fuel samples: Jet A-1 and Jet A-1/butanol blend. Tests were performed during the same day with the ambient conditions shown in Tab. 4. The average value of the parameters was then calculated for each rotational speed.

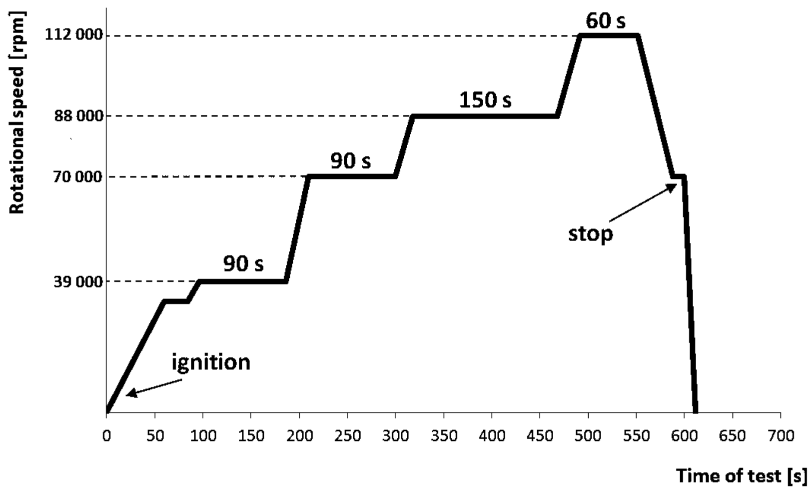

Fig. 1. Operating procedure of engine test

Tab. 4. Mean ambient conditions during the tests

		P_o (bar)	T_o (°C)
Jet A-1	Test 1	1.010	15.6
	Test 2	1.012	13.7
Jet A-1 + B10	Test 1	1.012	14.4
	Test 2	1.012	14.2

3. Results

The results of engine parameters and emissions for exhaust gas components are illustrated in Fig. 2-8.

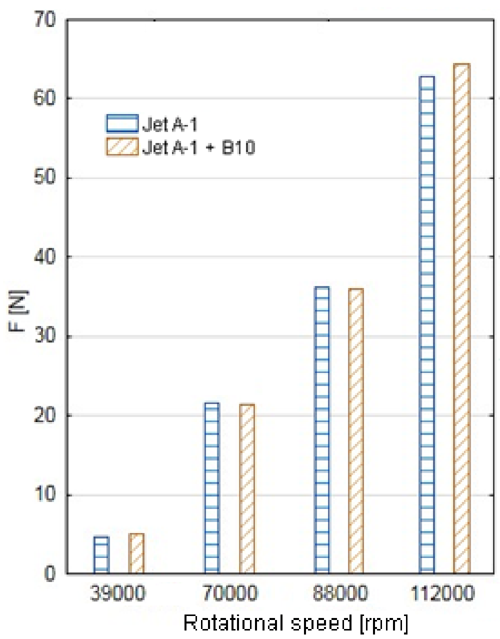

Fig. 2. Thrust as a function of rotational speed

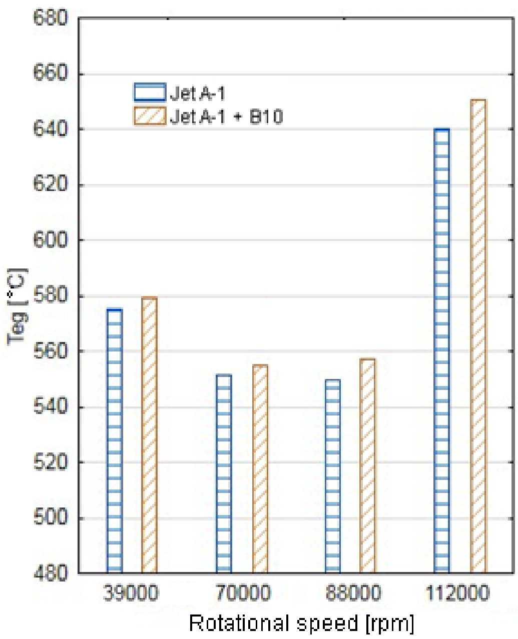

Fig. 3. Exhaust gas temperature as a function of rotational speed

The analysis of bench tests shows that use a blend of 10% butanol with Jet A-1 does not give significant changes in thrust. For all rotational speeds (except 39 000 rpm) differences between obtained thrust do not exceed 3%. The fuel consumption was found to increase with butanol content in the blend (difference up to 5%). The differences in fuel consumption translate into differences in the specific fuel consumption. The addition of butanol increases the specific fuel consumption with compare to neat Jet A-1. In the field of exhaust gas temperature, blending fuel with butanol does not cause noticeable changes. The differences between a neat Jet A-1 and blend of Jet A-1 with butanol does not exceed 2%.

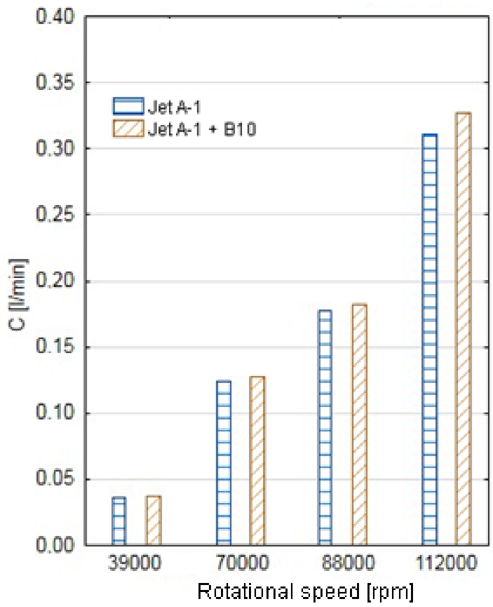

Fig. 4. Fuel consumption as function of rotational speed

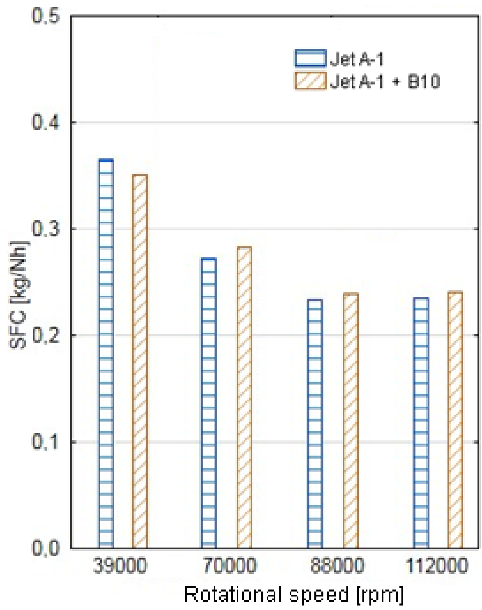

Fig. 5. Specific fuel consumption as a function of rotational speed

The trends of CO and NO_x emissions for both fuels are similar to the characteristics obtained on full-scale jet engines. With increasing engine, power output is followed CO emission decrease and NO_x emission increase [7].

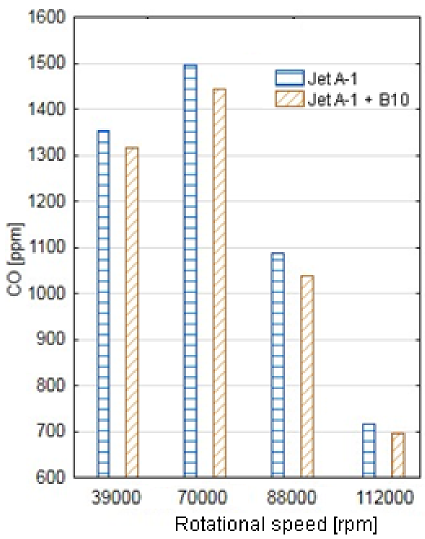

Fig. 6. CO emission as a function of rotational speed

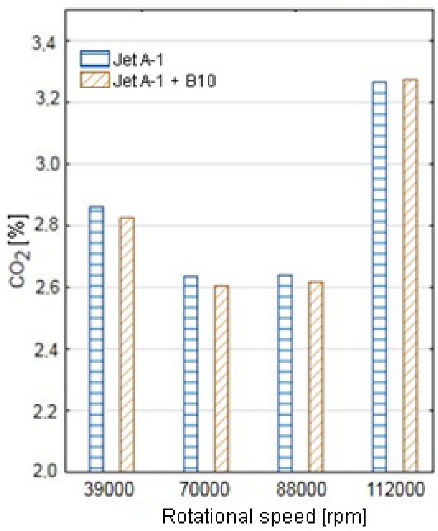

Fig. 7. CO_2 emission as a function of rotational speed

Addition of butanol to Jet A-1 causes reduction of the exhaust gas emission, i.e.: CO, CO_2 and NO_x for various modes of engine (rotational speeds). The differences of exhaust gas emission for blend of 10% butanol with Jet A-1 in relation to neat Jet A-1 are in the range:

- CO emission – up to circa 5%,
- CO_2 emission – up to circa 2%,
- NO_x emission – up to circa 2%.

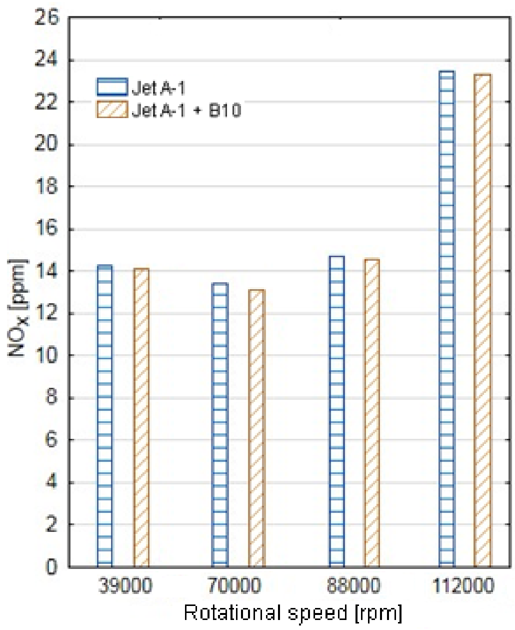

Fig. 8. NO_x emission as a function of rotational speed

4. Conclusions

The subject of development, research and implementation of alternative fuels for aviation is currently very important. Many international research programs are aimed at this area. Use of alternative fuels derived from renewable sources, has ecological significance of reducing exhaust gas emissions (including CO_2) generated during combustion process in jet engines into the environment. Research using full-scale jet engines is very complex and expensive. Hence, the proposal to carry out such development works on a test rig with a miniature jet engine seems to be very interesting.

In this paper, the performance and emission characteristic of a miniature turbine jet engine, using Jet A-1/butanol blend were studied. Neat Jet A-1 and blend had volume concentration of 10% butanol were compared. Selected chemical and physical properties of samples fuels were also determined in specialized laboratory. Bench tests were performed on laboratory test rig – MiniJETRig, according to specific operating procedure.

The results show that the performance parameters such as thrust and exhaust gas temperature for Jet A-1/butanol blend are comparable to those for pure Jet A-1. Only fuel consumption and specific fuel consumption is slightly higher for blend with butanol than Jet A-1. This is due to the lower fuel calorific value for blend. On the other hand, the values of carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen oxides (NO_x) concentrations for Jet A-1/butanol blend were slightly lower compared to that of Jet A-1.

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