Exhaust emissions from the PZL W-3 Sokol helicopter based on the measurements of the concentrations of exhaust components in the exhaust gases during a pre-flight test

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Abstract—**This paper presents the results of the tests on the exhaust emissions from a turboprop engine used for the propulsion of PZL W-3 Sokol helicopter. The tests were conducted in pre-flight conditions. The paper presents the test results and their analysis that enabled the determining of the values of the brake-specific emissions at selected load points. The load values were determined based on the courses of the parameters recorded by an on-board flight recorder during the pre-flight test. The obtained values of the brake-specific emissions as assigned to the engine load conditions were used for the evaluation of the emissions of the helicopter under actual operating conditions. The load conditions of the powertrain were determined based on the analysis of the operating data as obtained from several archival flight records. The analysis enabled an obtainment of the values of the exhaust emissions generated during the actual operating conditions of the helicopter.**

I. INTRODUCTION

The increasing demand for transport tasks dedicated to helicopters is directly translated into growth of the number of such types of aircraft in use. This, in turn, is significant for the condition of the natural environment. The emission of carbon dioxide and particulate matter is still a severe threat and, at the same, time an obstacle in the development of contemporary combustion engines - turboprop engines in particular [1, 2, 4]. The current provisions relating to the effects of the aviation transport upon the environment as introduced by the Environmental Protection Agency and International Civil Aviation Organization mainly relate to noise and exhaust emissions with particular consideration of nitric oxides [3, 5]. They relate to turboprop, turbofan and jet engines and include requirements for apparatuses and stationary testing procedures depending on the operating conditions of an engine [5]. Turboprop engines used in helicopters are classified with respect to all standards, but no limits of exhaust emission are determined. Therefore, an attempt was made to evaluate the exhaust emissions generated by engines of PZL W-3 Sokol helicopter in its actual operating conditions.

II. METHODOLOGY

I. *Object of tests*

The tests on the exhaust emissions generated by a helicopter turboprop engine were performed on PZL W-3 Sokol (Fig. 1) with its powertrain composed of two turboshaft PZL-10W engines. The exhaust emission tests were performed in real operating conditions of the helicopter during a pre-flight test. PZL W-3 Sokol was fitted with an on-board flight parameter recorder that not only records such parameters as flight velocity and altitude, but also the position angles of the helicopter and the operating parameters of the engines.

Fig. 1. PZL W-3 Sokol helicopter.

The engine schematics has been presented in Figure 2. The PZL-10W engine is a classic turbine engine with a free drive turbine. The basic components of this engine are: the intake system with a built-in transmission for the peripheral components. Before the intake, centrally in the compressor axis, an electric starter motor is located with a one-direction clutch. The engine compressor includes six axial stages and one final radial stage. The other functional sections of the engines are the combustor and the turbines driving the compressor. The drivetrain is composed of the turbine and the driveshaft. The final element is the engine exhaust system. The air is sucked in by the compressor through a heated intake duct. The compressed air is directed to the ring combustor.

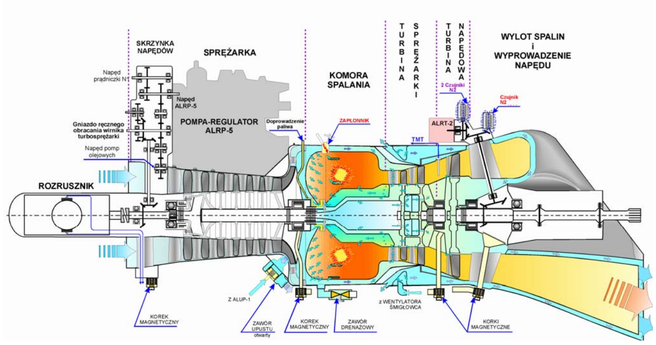

Fig. 2. Schematics of the PZL-10W engine.

In the combustor, the fuel atomized by the injector is mixed with the air. The formed air fuel mixture is then burned in the combustor. The hot gases from the combustor go through the turbine deflector to the vanes of the I and II stage of the compressor and then to the drive turbine. The exhaust gases after releasing the energy are directed to the exhaust. The drive of the peripheral components (the fuel pump-regulator and the oil pump) is taken off from the compressor shaft through the transmission box. The drive of the main transmission of the helicopter that drives the main rotor and the tail rotor is realized through a drive shaft connected directly to the drive turbine. On the turbine housing the drive of the limiter of the turbine speed is fitted. The basic technical parameters have been shown in Table I.

TABLE I
BASIC TECHNICAL PARAMETERS OF TEH PZL-10W ENGINE

Power output	660 kW
Unit fuel consumption	0.408 g/kWh
Mass flow rate	4.5 kg/s
Compression rate	7
Engine weight	150 kg

The exhaust emission tests were preformed in the actual conditions of the helicopter operation during a preflight test. The PZL W-3 Sokol helicopter is fitted with a flight recorder whose purpose is recording airspeed, altitude and helicopter angles as well as the operating parameters of the engines.

II. *Measurements equipment*

The exhaust emissions were measured in the actual operating conditions of the helicopter. This approach required installing a system of exhaust gases uptake in the helicopter near its exhaust in such a manner as to make it possible to operate the helicopter (Fig. 3).

Fig. 3. Placement of the exhaust gases probe.

A duct feeding the exhaust gas sample to the analyzer was conducted through an open window in the loading space of the helicopter. Semtech-DS portable analyzer manufactured by Sensors was used for the measurement of the concentration of the exhaust components (Fig. 4).

Fig. 4. View of the exhaust emission analyzer.

The analyzer enabled a measurement of the concentration of carbon monoxide, hydrocarbons, nitric oxides and carbon dioxide. The exhaust gases were introduced into the analyzer through a measuring probe that maintained the temperature of 191°C and then were filtered out of the particulate matter (only in the case of diesel engines) and the concentration of hydrocarbons was measured through a flame ionization detector. Next, the exhaust was cooled down to the temperature of 4°C and the concentrations of the following were measured respectively NO_x, CO, CO_2 and oxygen [2]. The analyzer measures the concentration of carbon monoxide, hydrocarbons, nitric oxides and carbon dioxide as per the characteristics given in Table II.

TABLE II
CHARACTERISTICS OF SEMTECH DS [6]
(A PORTABLE EXHAUST EMISSION ANALYZER)

Parameter	Measurement method	Accuracy
CO	NDIR, measurement range 0–10%	±3% of the measurement range
HC	FID, measurement range 0–10 000 ppm	±2.5% of the measurement range
NO_x	NDUV, measurement range 0–3000 ppm	±3% of the measurement range
CO_2	NDIR, measurement range 0–20%	±3% of the measurement range
O_2	Electrochemical, measurement range 0–20%	±1% of the measurement range
Exhaust flow rate	Mass flow rate	±2.5% of the measurement range
Exhaust temperature	Up to 700°C	±1% of the measurement range
Warm up time	900 s	
Response time	$T_{90} < 1$ s	

III. EMISSION TESTS RESULTS AND ANALYSIS

During the pre-flight test of the helicopter, concentrations of the exhaust components were measured. The results of the measurements of the concentration of CO, HC, NO_x, CO_2 were presented as measurement values for several minutes' measurement initiating from the moment before engine startup until several seconds following the stopping of the engines. The test course was additionally recorded by the flight parameter recorder. The obtained courses were compared and, then, used for further analysis of instantaneous values of engine loads (Fig. 5).

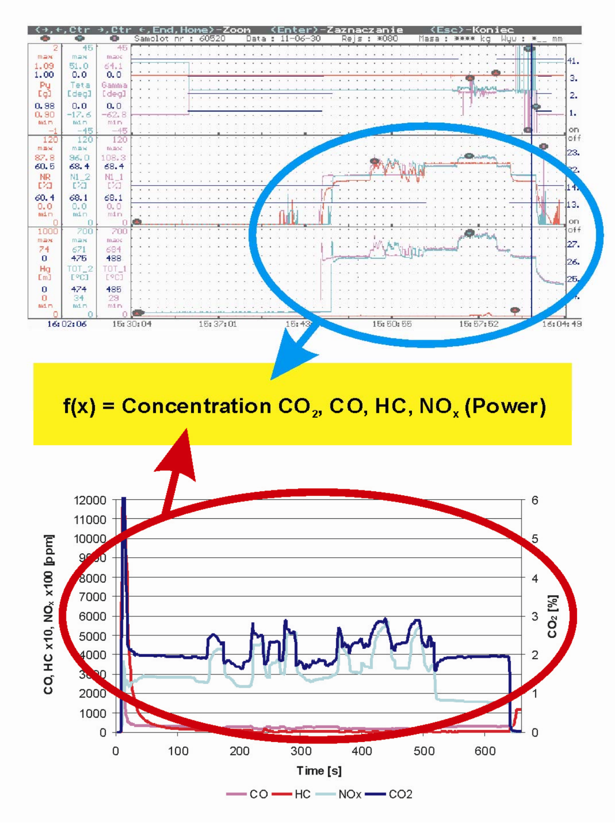

Fig. 5. The compared courses of concentration of individual exhaust components and the course of the operating parameters of engines as recorded by the flight parameter recorder during the pre-flight test of the helicopter.

On the basis of the recorded course, engine loads in time were determined. During the pre-flight test engines work under approximately 20% of maximum load for 24% time of the test, under the loads ranging from 65÷75% of the maximum load for approximately 43% of time and under 84 % of maximum load for approximately 33% of the test (Fig. 6).

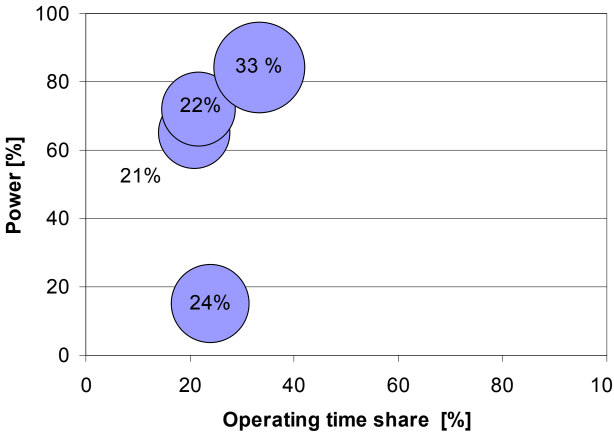

Fig. 6. Test operating time share of the powertrain of the W-3 Sokol helicopter during the preflight test.

On the basis of the available flow characteristics of PZL-10W engine and the measured instantaneous value of air excess coefficient, exhaust gas rate in individual points of load was measured.

The obtained values of instantaneous exhaust flow rate, multiplied by the measured instantaneous value of the concentration of a given exhaust component yielded the instantaneous emission of the individual exhaust components during the test (Fig. 7–10).

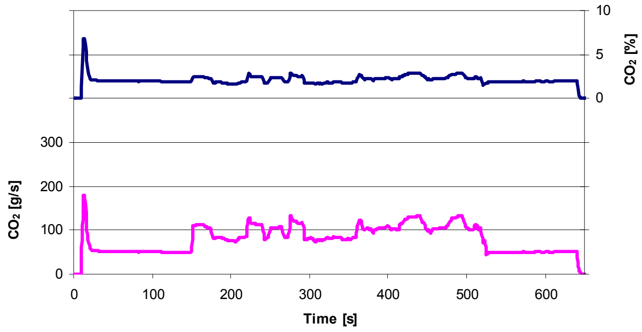

Fig. 7. The course of the instantaneous concentration and emission rate of CO_2 in the exhaust gases during the test.

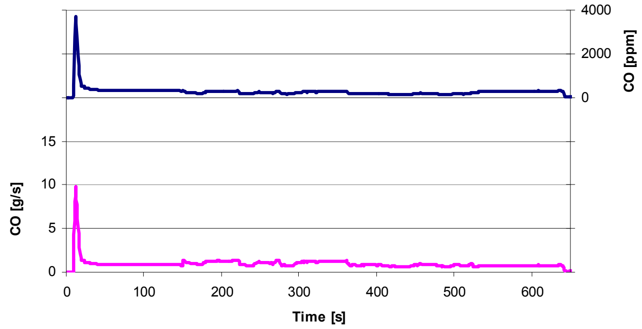

Fig. 8. The course of the instantaneous concentration and emission rate of CO in the exhaust gases during the test.

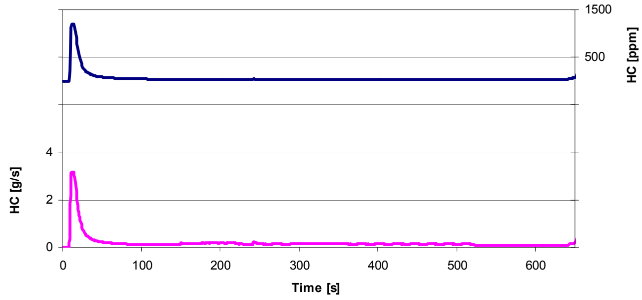

Fig. 9. The course of the instantaneous concentration and emission rate of HC in the exhaust gases during the test.

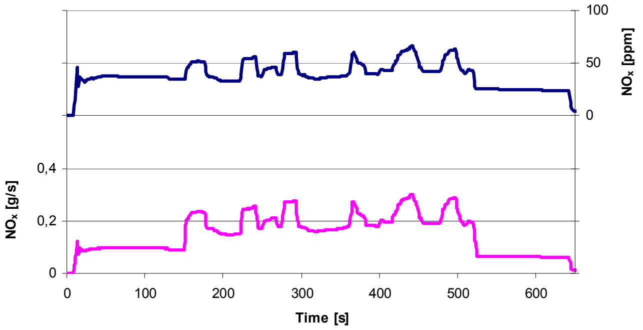

Fig. 10. The course of the instantaneous concentration and emission rate of NO_x in the exhaust gases during the test.

Analyzing the courses of the instantaneous emission rate of the individual exhaust components along with the time-share of the instantaneous loads the authors obtained the values of the mass of the exhaust components generated during the test (Fig. 11). During the test, approximately 68,500 g CO_2, 550 g CO, 2400 g HC and 150 g NO_x were generated.

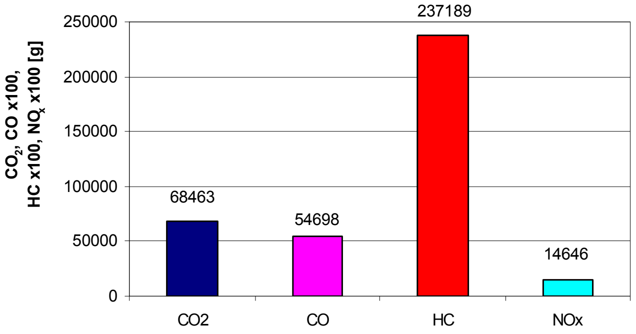

Fig. 11. The values of the mass of the exhaust components generated by the helicopter engine during the test.

The obtained values of the exhaust gas concentration as multiplied by the instantaneous value of concentration of an exhaust component resulted in instantaneous values of emission rate of particular exhaust gas components during the performed test. The obtained courses of instantaneous value of the concentration of the individual exhaust gas components were compared to the instantaneous values of the engine loads recorded by the on-board flight parameter recorder. The comparison resulted in obtaining of values of unit-based emissions of exhaust gas components for individual points of engine loads (Fig. 12). It results from the obtained data that the largest ecological nuisance is the stage of starting up and warming of the engine under small loads. With an increase of load, one may observe a decrease in the values of brake-specific emissions. It is particularly the case in the emission of carbon monoxide and hydrocarbons. The values of unit-based emission of carbon dioxide and nitric oxides change insignificantly for 65÷84% of the maximum engine load.

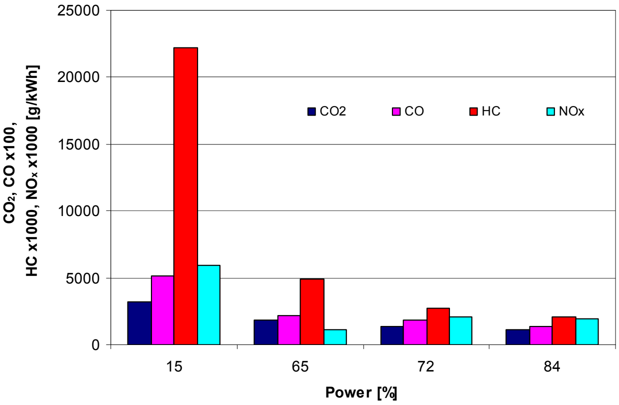

Fig. 12. The values of brake-specific emissions generated by the powertrain of W-3 Sokol helicopter during the pre-flight test and for individual load values.

The values of unit-based exhaust emissions as determined for individual engine loads may be multiplied by the percentage share of time of engine load during the pre-flight test performed. This allows obtaining values of unit-based exhaust emissions constituting individual characteristics for a given engine in a given pre-flight test (Fig. 13).

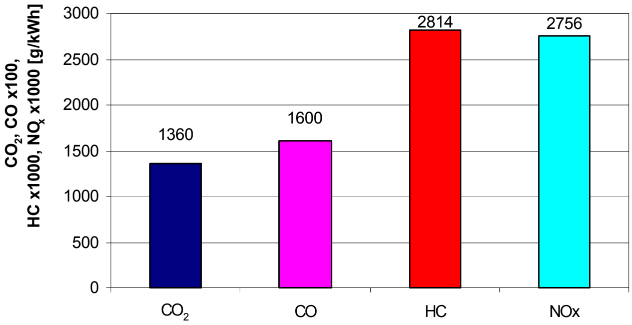

Fig. 13. The values of unit-based exhaust emissions as generated by the powertrain of the helicopter during the pre-flight test.

The unit emission of CO_2 was approximately 1360 g/kWh, CO approximately 16.0 g/kWh, HC approximately 2.80 g/kWh and NO_x approximately 2.76 g/kWh.

The unit emission of the exhaust components determined for the individual engine loads can be multiplied by the percentage share of the engine loads under actual operating conditions i.e. during the helicopter flight. We could, in this way, obtain the values of the unit emissions during the flight. That is why the authors carried out an analysis of the engine operating parameters recorded during ten randomly selected flights the example course has been shown in Figure 14.

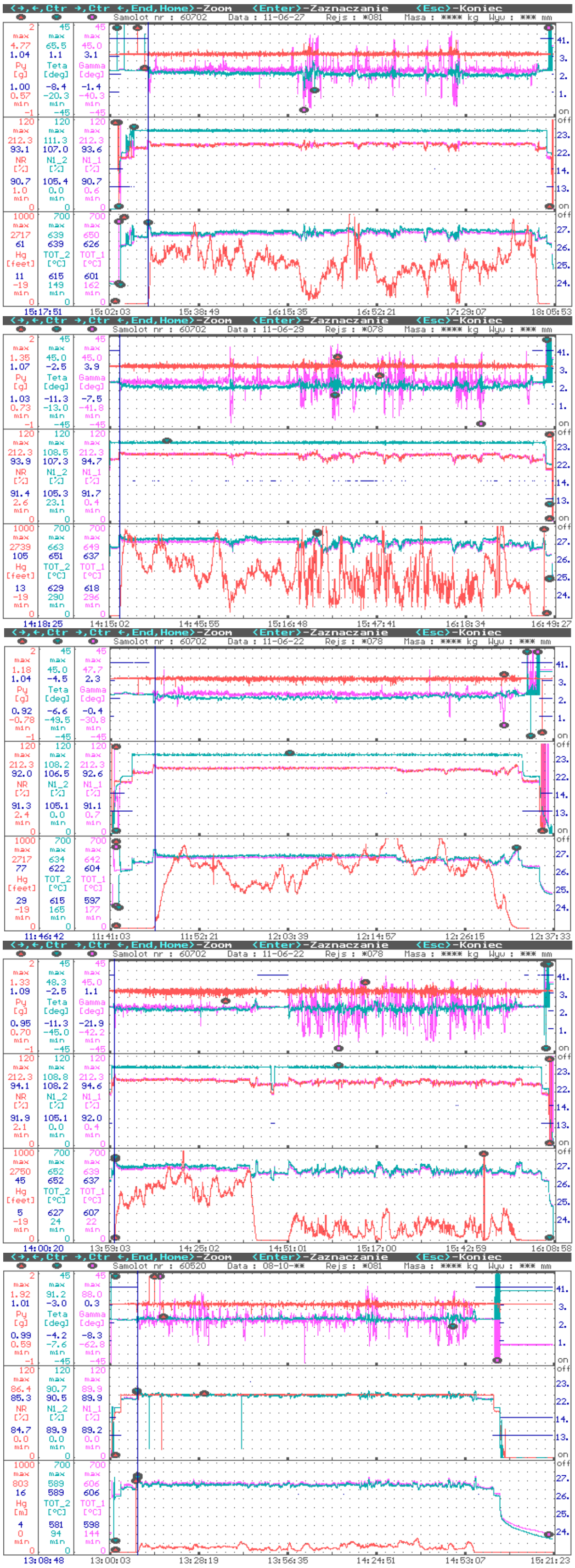

Fig. 14. Example records from the flight recorder of the operating parameters of the engines during the flight of the W-3 Sokol helicopter.

Further proceedings involved an analysis of engine operating parameters recorded by the on-board recorder during actual flight conditions. It results from the analysis that for 96% of the helicopter operating time, engines work under 80–90% of maximum load, 2.7% the time under 60–70% of maximum load and approximately 1.3% of the time under approximately 15% of maximum load (Fig. 15).

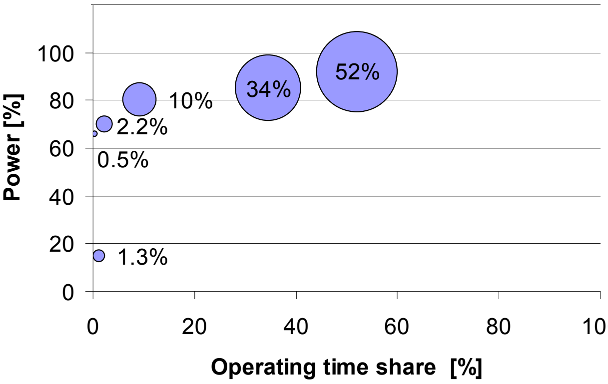

Fig. 15. Operating time share of the powertrain of the PZL W-3 Sokol helicopter under actual operating conditions.

The determined percentage shares of engine load time during the flight were multiplied by the values of the brake-specific emissions corresponding to the determined engine load conditions. Thus, values of the brake-specific emissions generated by the helicopter engine were obtained during the flight (Fig. 16).

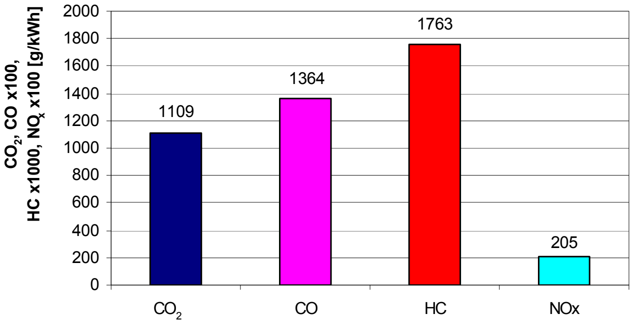

Fig. 16. The values of the brake-specific emissions generated by the powertrain of W-3 Sokol helicopter during actual pre-flight conditions.

The obtained values of the unit exhaust emissions from the PZL-10W helicopter engine fitted in the PZL W-3 Sokol helicopter are: for the carbon dioxide 1109 g/kWh, carbon monoxide 13.64 g/kWh, hydrocarbons 1.763 g/kWh and nitric oxides 2.05 g/kWh.

IV. CONCLUSIONS

The conducted exhaust emissions tests from PZL W-3 Sokol during the pre-flight test enabled an obtainment of data on the concentration of exhaust gas components in the exhaust gases of a helicopter turboprop engine. A further analysis of the results as compared to the engine operating parameters provided values of brake-specific emissions generated by the powertrain for individual engine loads. Based on the obtained values, actual exhaust emissions from the powertrain of the helicopter during the pre-flight were determined. The here-discussed evaluation constitutes a part of a larger work aimed at the evaluation of negative impact of operation of transport helicopters upon the natural environment. The work is also connected with the development of a universal test facilitating the determination of exhaust emissions generated by helicopters.

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