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Determination of the mass of harmful compounds emitted in the exhaust gas of the LM 2500 marine gas turbine engine during real operating conditions

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Abstract

The article presents a method for determining the mass of harmful compounds emitted in the exhaust gas of a LM 2500 marine turbine engine, which is part of a warship propulsion system, under real engine operation conditions. The assessment of harmful compound emissions in the exhaust gas of turbine engines of watercraft propulsion systems is associated with the activity of determining the impact of various technical objects on the environment. Examinations of harmful exhaust gas emissions from turbine engines used for the main propulsion of ships and ships require measurements of the concentration of harmful compounds in exhaust gas and determination of exhaust mass stream produced by the engine. The concentration of harmful compounds can be determined directly by measuring them in the exhaust stream. However, due to the high exhaust gas flow, the mass of exhaust gas should be determined indirectly. To this end, a series of measurements and analyzes should be carried out which will allow parameterization of the engine operating conditions. The obtained parameters and functional relationships between them can be used to determine the mass of generated flue gas, and then to determine the mass of harmful compounds emitted in the exhaust gas.

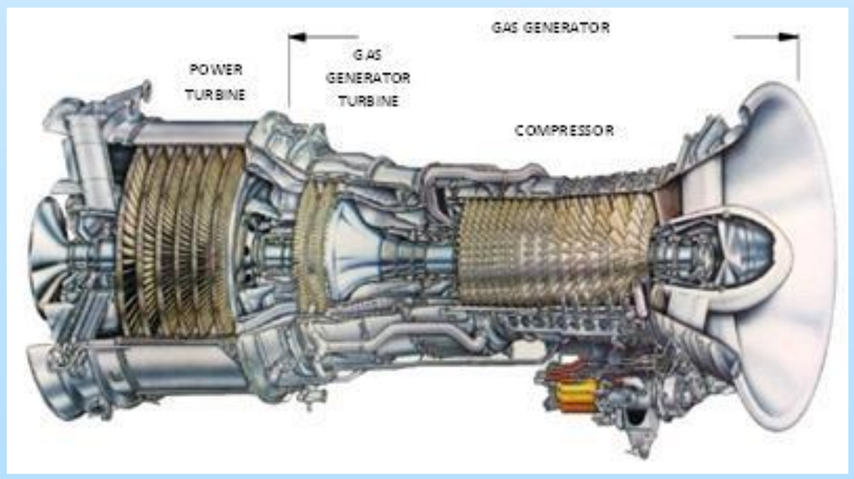

Fig. 1. LM 2500 gas turbine engine of FFG-7 class ship

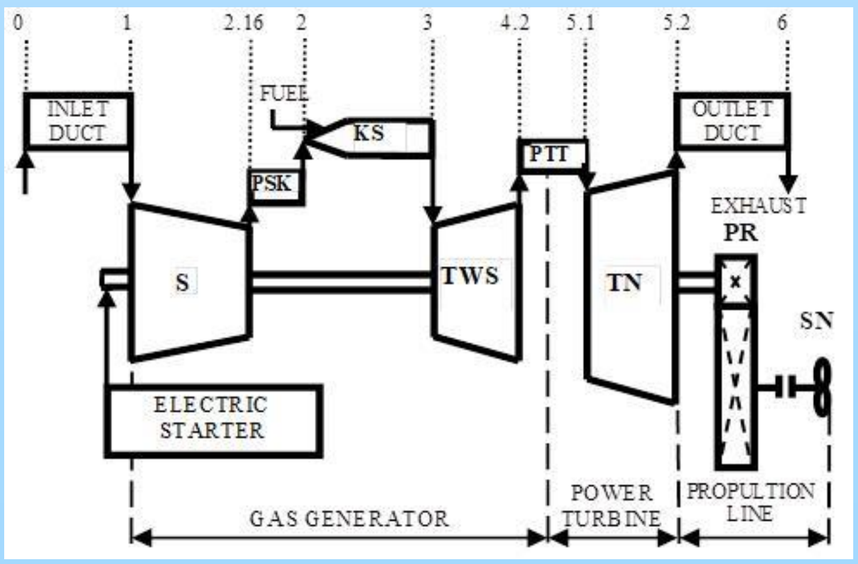

Fig. 2. Schematic diagram of LM 2500 gas turbine engine; S – compressor, KS – combustor, TWS - gas generator turbine, TN - power turbine, PR - reduction gear, SN – propeller, PSK - space between S and KS, PTT - space between TWS and TN

Table 1. Operating parameters LM 2500 engine

Name parameter, designation, unit	Measurment range
Barometric pressure, p_o, [hPa]	800 ÷ 1 040
Ambient temperaturę, t_o, [^oC]	-40 ÷ +40
The rotational speed of the gas generator shaft, n_{GG}, [rpm]	0 ÷ 12 000
The rotational speed of the power turbine shaft, n_{PT}, [rpm]	0 ÷ 5 000
The inlet air temperature to the engine, t_1, [^oF]	-40 ÷ +150
The inlet air total pressure to the engine, p^*_1, [psig]	0 ÷ 16
Air pressure on the outlet compressor, p_2, [psig]	0 ÷ 300
The temperature of the exhaust stream before the power turbine, $t_{4.2}$, [^oF]	0 ÷ 2 000
Total pressure of the exhaust stream before the power turbine, $p^*_{4.2}$, [psig]	0 ÷ 75
Temperature exhaust gas, T_6, [^oF]	0 ÷ 1 000
The fuel temperature before engine, T_f, [^oF]	0 ÷ 100
Pressure fuel injectors before, p_f, [psig]	0 ÷ 1 500
Torque (calculated) on the power turbine shaft, M_{PT}, [LB FT]	0 ÷ 50 000
Power on the power turbine shaft, P_{TN}, [KM]	0 ÷ 25 000

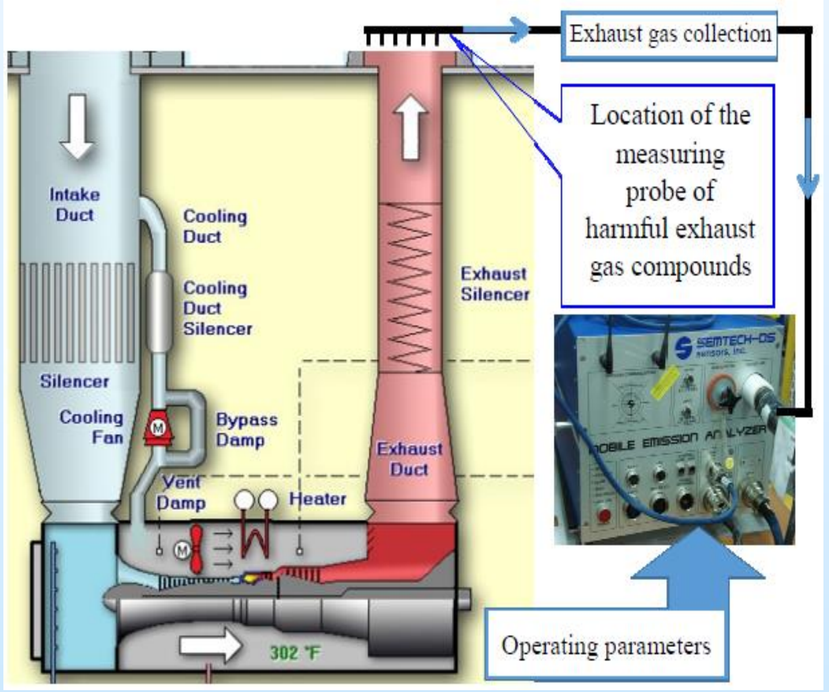

Fig. 3. The air intake system and the exhaust system of the LM 2500 engine installed on the missile frigate with marked sampling point and the Semtech-DS exhaust analyzer view

Table 2. Characteristics of the Semtech-DS analyzer

Name parameter, designation, unit	Measurment range
The concentration of oxygen, c_{O2}, [%]	0 ÷ 20
The concentration of carbon monoxide, c_{CO}, [%]	0 ÷ 10
The concentration of hydrocarbons, c_{HC}, [ppm]	0 ÷ 10 000
The concentration of nitrogen oxides, c_{NOx}, [ppm]	0 ÷ 3 000
The concentration of carbon dioxide, c_{CO2}, [%]	0 ÷ 20

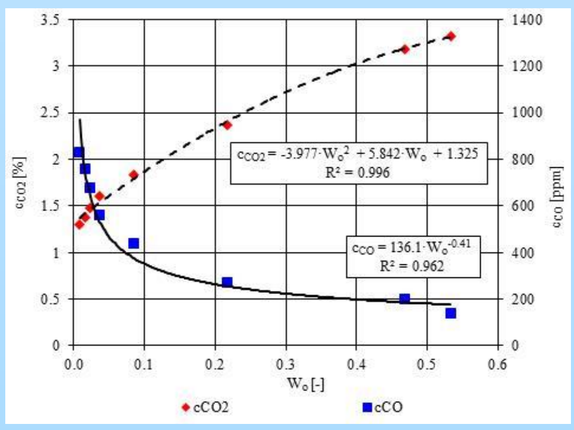

Fig. 4. The concentration of carbon monoxide (c_{CO}) and the concentration of carbon dioxide (c_{CO2}) in the LM 2500 1A engine exhaust as a function of the engine load factor (W_o)

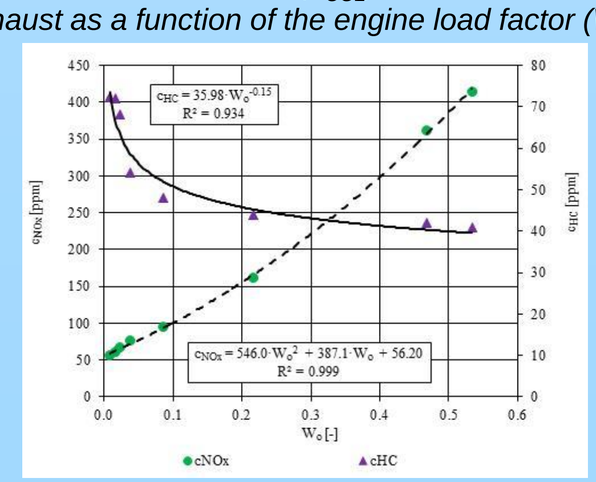

Fig. 5. Concentration of nitrogen oxides (c_{NOx}) and hydrocarbons concentration (c_{HC}) in the LM 2500 1A engine exhaust as a function of the engine load factor (W_o)

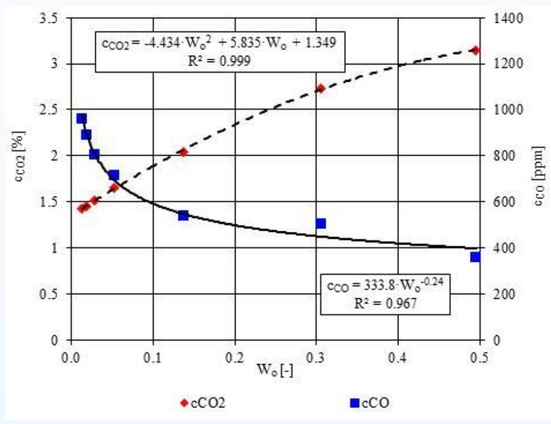

Fig. 6. The concentration of carbon monoxide (c_{CO}) and the concentration of carbon dioxide (c_{CO2}) in the LM 2500 1B engine exhaust as a function of the engine load factor (W_o)

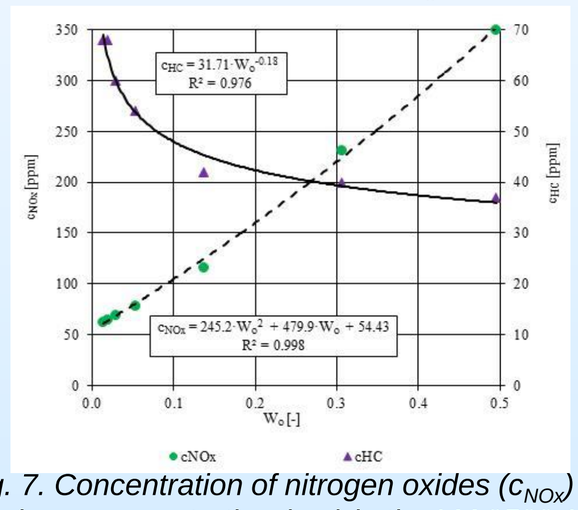

Fig. 7. Concentration of nitrogen oxides (c_{NOx}) and hydrocarbons concentration (c_{HC}) in the LM 2500 1B engine exhaust as a function of the engine load factor (W_o)

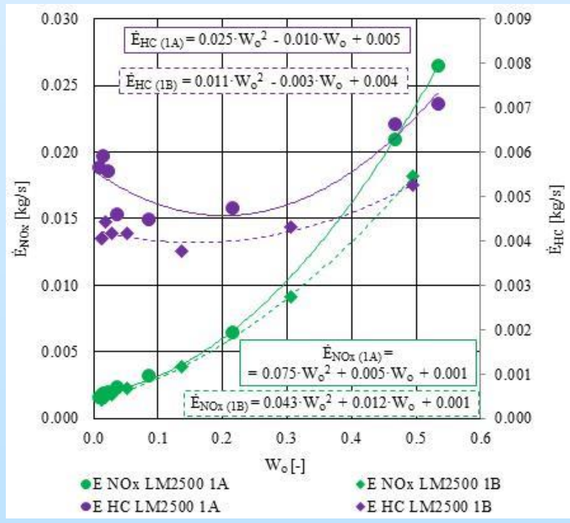

Fig. 8. The mass emission intensity of nitrogen oxides ($\dot{E}_{NOx}$) and hydrocarbons ($\dot{E}_{HC}$) in the LM 2500 1A and LM 2500 1B engines exhaust as a function of the engine load factor (W_o)

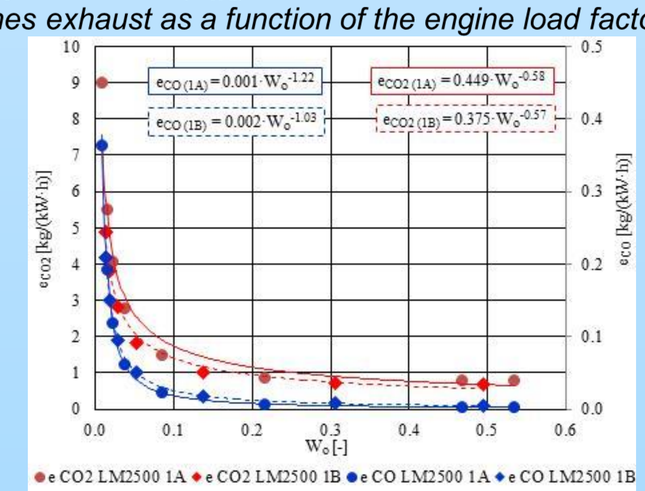

Fig. 9. The unit emission of carbon dioxide (e_{CO2}) and carbon monoxide (e_{CO}) in the LM 2500 1A and LM 2500 1B engines exhaust as a function of the engine load factor (W_o)

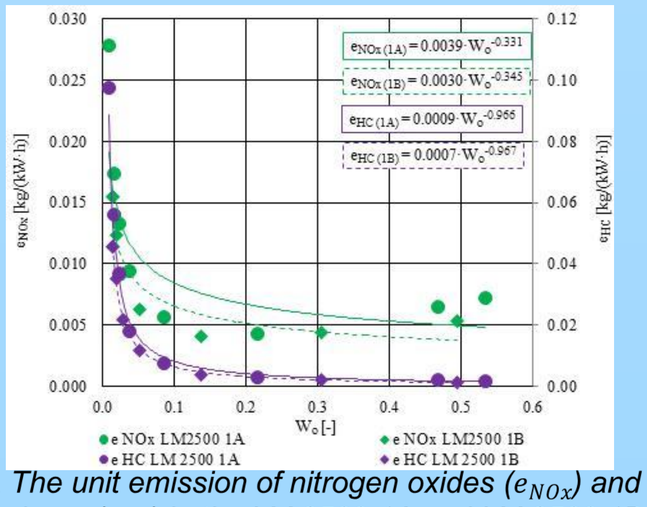

Fig. 10. The unit emission of nitrogen oxides (e_{NOx}) and hydrocarbons (e_{HC}) in the LM 2500 1A and LM 2500 1B engines exhaust as a function of the engine load factor (W_o)