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DETERMINATION OF CO_2 EMISSIONS FOR SELECTED FLIGHT PARAMETERS OF A BUSINESS JET AIRCRAFT

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Abstract

In the last two decades, there has been observed a noticeable increase in the popularity and availability of air transport services, including regional ones. This intensive development of transport is accompanied by an increase in the adverse impact to the environment, increases noise level, and exhausts emissions, despite the modification and modernization of engines. Determining the emission for regional flights takes into account the specificity of the aircrafts design, such as the size of the aircraft and the performance of the engines. In this article, an attempt was made to determine the CO_2 emissions of a business jet flying from Gdansk to Rzeszow. The methodology of the research (the method of calculating emissions based on fuel consumption) and the performance characteristics of the aircraft engines have been described. In the first part of the article, the speed-altitude characteristics of the DGEN-380 engine for different cruise parameters were determined using the virtual engine test bench WESTT CS/B. These characteristics have enabled the engine to match the flight characteristics (altitude, speed). For specific flight parameters, the thrust and fuel consumption were determined. On this basis, for the adopted trajectory and flight time of an aircraft equipped with two DGEN-380 engines, total fuel consumption and CO_2 emission factors and values in CRUISE phase was determined with regard to the wind speed and direction. The obtained results were illustrated graphically and discussed.

Keywords: *CO_2 emissions, jet engines, business jet aircraft*

1. Introduction

Air transport is the most developing type of communication. Taking into account the speed of movement and the safety of operations, planes are a commonly used means of transport in passenger and cargo transport. The increasing intensity of air traffic adversely affects the natural environment. The emission of noise, as well as toxic compounds and greenhouse gases in jest engines exhausts are the main factors affecting the environment on a local (in airports vicinity) and a global (in the troposphere) scale.

Although aviation contributes slightly (up to 3%) to global environmental pollution [6, 12] the concentration of toxic compounds and greenhouse gases emitted by aircrafts engines is particularly high in the airport areas, where take-off and landing operations take place, as well as in the upper troposphere, where cruise is made. The more intensive air traffic takes place in a given area, the stronger impact to the environment it causes.

The impact of air transport on the environment in local, regional or global scale has been analysed in many studies, research projects and scientific papers, e.g. [2, 5, 13, 14, 16, 18, 20, 21].

Numerous attempts are being made to reduce emissions of harmful substances generated by jet engines. To this end, development of novel technologies is underway, e.g. [1, 7, 9, 15, 17, 25, 30].

At the same time, attempts are made to limit these emissions by optimizing the route of the aircraft or selected flight parameters or aircraft configuration due to fuel consumption, noise and exhaust emissions from aircraft engines, e.g. in [1, 3, 8, 22-24].

It is worth noting that most of these studies are of a general nature – they treat in general terms the problem of gaseous emission in jet engines exhausts and their impact on the environment, climate change and human health. Many studies focus on determining this impact in the area or vicinity of airports – during the LTO (Landing and Take-off Operations), where apart from emissions of harmful compounds in the exhausts, the problem of noise generation occurs. Most of them describe applied research methodology in very laconic way, without a detailed analysis of engine run (its load), resulting from specific flight parameters. Such an analysis should be carried out because the fuel consumption is related to the range of the engine run, which guarantees appropriate selection of emission indexes (EI).

Therefore, in order to perform a reliable analysis, it is necessary to associate the emission with the parameters of the aircraft engines during the flight. The article focuses on the determination of emission of the main greenhouse gas – CO_2. Knowing the dependence of the emission on the parameters of the environment during the flight (temperature, pressure, direction and wind speed) will enable in future research to optimize the trajectory of the flight in terms of CO_2 emissions. This emission is in turn correlated with the fuel consumption during the flight, thus reducing fuel consumption during the flight; also, the CO_2 emission is reduced.

2. Determination of performance characteristics of a DGEN-380 engine

2.1. The engine characteristics

To analyse emissions of harmful exhaust gases, the DGEN-380 engine from Price Induction Company was used because it was possible to use a virtual test bench with implemented engine operation parameters.

It is a bypass turbine jet engine with separate nozzles (without mixing streams) to be used on aircrafts weighing up to 1650 MTOW or on two-engine Business Jet aircrafts. This engine is a representative of a new family of propulsion using the latest developments in the field of construction materials and software supporting the design and manufacturing (CAD/CAM). Fig. 1 shows a cross-section of this engine, and its basic technical parameters are included in Tab. 1.

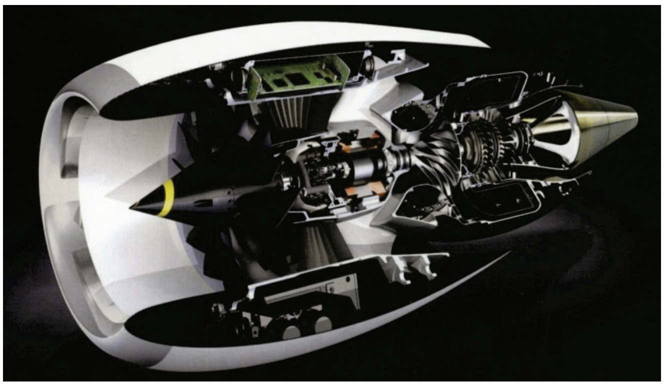

Fig. 1. The DGEN-380 engine – overview [19]

Tab. 1. Technical parameters of the DGEN-380 engine [19]

Take-off thrust	255 daN
Specific fuel consumption	0.44 kg/daNh
Mass flow	13 kg/s
Bypass ratio	7.6
Pressure ratio	5.3
Total temperature before turbine	1178 K
Engine weight	85 kg
Engine installation life	3600 h

For the above engine, speed and altitude characteristics were determined using the virtual WESST CS/BV engine test bench, which is located in the Aviation Engine Research Laboratory of the Department of Aircraft and Aircraft Engines at Rzeszow University of Technology.

2.2. Speed and altitude characteristics

The speed and altitude characteristics of an engine are the flight engine characteristics [4]. They describe the dependencies of the thrust, specific thrust and specific fuel consumption on the flight speed and its altitude. They allow determining the optimal area where the aircraft should move for the least fuel consumption. These characteristics can be read by means of flight tests. Based on rotational characteristics, it is also possible to approximate the run of thrust and specific fuel consumption, depending on the change in Mach number and flight altitude [26]. Fig. 2 presents the speed and altitude characteristics for a bypass engine.

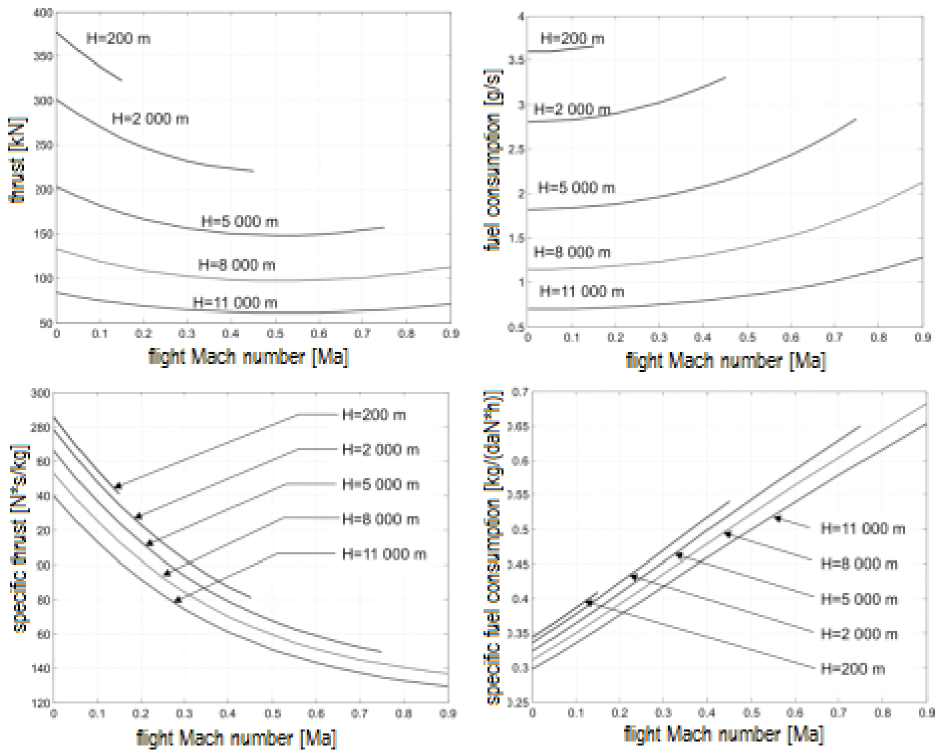

Fig. 2. Dependencies of selected performance parameters of a bypass engine as a function of flight speed v and flight altitude H [11]

Analysing the graphs, there can be noticed how the thrust value decreases with the increase of engine operation altitude and flight speed. The specific fuel consumption decreases with increasing flight altitude, but increases with increasing speed. This is related to the formula describing the specific fuel consumption *SFC*:

$$SFC = \frac{C_H}{K}, \tag{1}$$

where:
$\mathrm{C_H}C_H$ – fuel consumption [kg/h],
K – engine thrust [N].

2.3. Description of the engine test bench and the research results

The measurement of the specific fuel consumption *SFC* and the engine thrust *K* was made on the virtual simulator – engine test bench WESTT CS/BV. The device is located in the Aviation Engines Research Laboratory being the part of the Department of Aircraft and Aircraft Engines at the Rzeszow University of Technology. The engine test bench is depicted in Fig. 3.

Fig. 3. The engine test bench WESTT CS/BV in the front view, measurement data is displayed on the screens

The engine test bench consists of a set of computers with the numeric model of the DGEN-380 engine. The CS/BV engine test bench allows determining, record and graphically presenting the thermo-gas-dynamic parameters of the engine, determining its characteristics and velocity triangles on the rotor of the simulated propulsion unit. Fig. 4 shows the control system of the test bench.

Fig. 4. The control potentiometers and flying controls; the switches at the flying controls are used to start the virtual engine

The test was carried out for the cruising altitude analysed later in the article, i.e. 5000 m in the speed range from 0.1 to 0.44 Ma. The maximum speed results from the test bench limitations. The test was carried out three times: for the 50% range of the throttle lever (CRUISE), 75%

(acceleration, climb) and 100% power (take-off, fast flight, rapid climb). The obtained results are shown in Fig. 5 and 6.

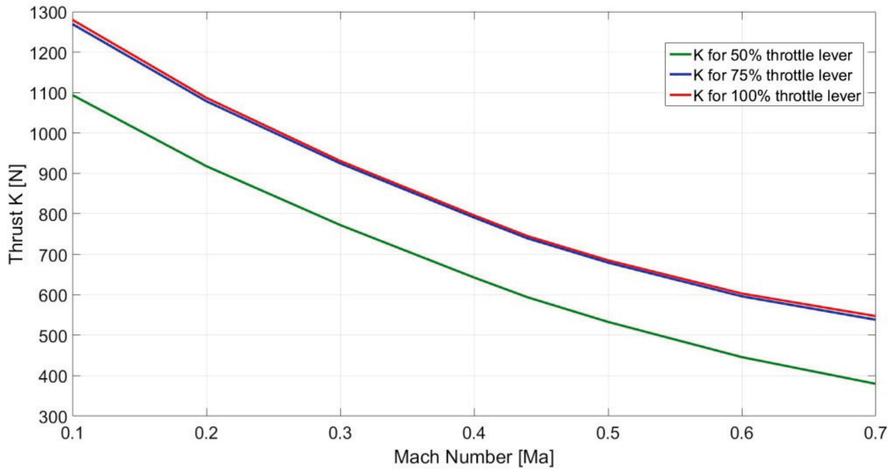

Fig. 5. Speed-altitude characteristics of the engine at the altitude of 5000 m and three throttle lever settings

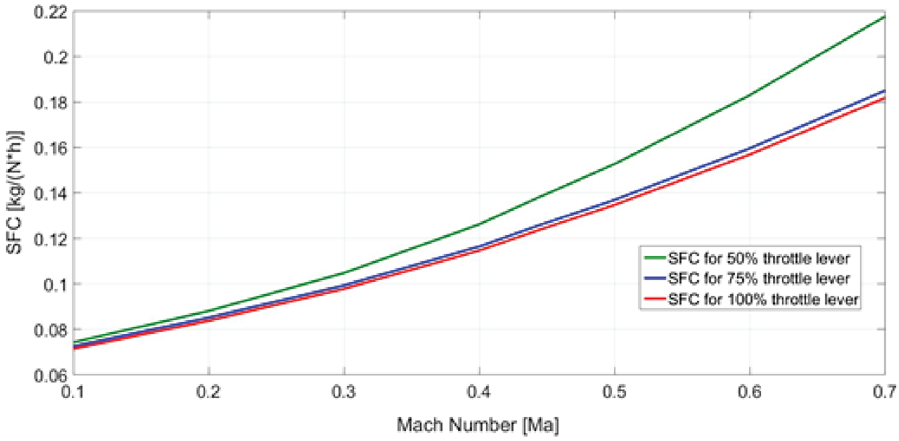

Fig. 6. Speed-altitude characteristics of the engine at the altitude of 5000 m and three throttle lever settings

3. Determination of CO_2 emission during an exemplary flight of the aircraft equipped with DGN-380 engines

Based on the speed and altitude characteristics determined in the first part of the article, the engine CO_2 emission corresponding to the ambient conditions during the engine operation during the steady flight was determined (CRUISE – 5000 m altitude and 0.425 Ma flight speed).

Based on an exemplary mission of an aircraft equipped with DGN-380 engines on the route from Gdansk to Rzeszow, an exemplary flight trajectory was adopted, as shown in Fig. 7.

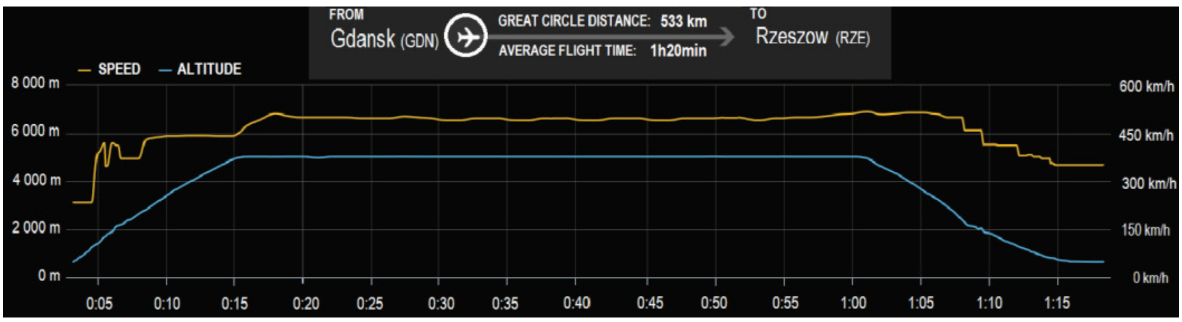

Fig. 7. Trajectory of an aircraft equipped with two bypass DGEN-380 engines (based on [28])

Assuming no wind conditions, the aircraft reaches a cruising altitude of 5000 m 15 minutes after the take-off and a relatively constant speed of 490 km/h, which corresponds to 0.425 Ma. It descends for the last 18 minutes of the flight. In the analysed case, the research on CO_2 emission concerns 47 minutes of a steady flight (from 15th to 62nd minute of flight), which corresponds to a flight trajectory of 384 km.

In subsequent studies, the influence of wind (its speed and direction) on the variation in CO_2 emission was taken into account [10]:

$$E_{CO2} = EI_{CO2} \cdot K \cdot SFC \cdot z \cdot t, \tag{2}$$

where:
EI_{CO2} – CO_2 emission factor equal to 3.1517 kg CO_2/kg of fuel,
K – engine thrust [N],
SFC – specific fuel consumption [kg/(N·h)],
z – number of engines,
t – engine run time at a given thrust [h].

In order to simplify the calculation of CO_2 emissions at various wind speeds and directions, the MM coefficient [kg CO_2/h] was introduced, where:

$$MM = EI_{CO2} \cdot K \cdot SFC, \tag{3}$$

In the next step, the MM coefficient was multiplied by the flight time, which, due to the wind, is variable. Tab. 2 summarizes data describing flight time as a function of wind speed and direction, whereas in Fig. 8 one case of wind direction is presented on the map (headwind during the flight).

Tab. 2. The flight parameters taking into account the wind speed and direction

Flight parameters	Wind speed at the altitude of 5000 m [km/h]	Aircraft speed over ground [km/h]	Time of CRUISE [h]	Time of CRUISE [min]	Emission ECO_2 for the aircraft equipped with two DGEN-380 engines [kg]	Percentage change in CO_2 emission [%]
– flight altitude: 5000 m – distance: 383 km – wind direction: front (headwind)	0	490	0.7816	47	400.42	0
	20	390	0.8149	49	417.46	4.3
	40	365	0.8511	51	436.01	8.9
	60	340	0.8907	53	456.29	14.0
	80	315	0.9341	56	478.55	19.5
	100	290	0.9821	59	503.09	25.6
	120	265	1.0351	62	530.28	32.4
– flight altitude: 5000 m – distance: 383 km – wind direction: rear (tailwind)	0	490	0.7816	47	400.42	0
	20	590	0.7510	45	384.71	–3.9
	40	615	0.7226	43	370.20	–7.5
	60	640	0.6964	42	356.74	–10.9
	80	665	0.6719	40	344.22	–14.0
	100	690	0.6492	39	332.55	–16.9
	120	715	0.6279	38	321.65	–19.7

In the analysed case, the MM coefficient is 256.14 kg CO_2/h. In the next step, this coefficient was multiplied by the flight time and number of engines on the plane (2 units). The CO_2 emission results are shown in the last two columns of Tab. 2 and presented graphically in Figs. 9 and 10.

In fact, these figures illustrate the extent to which wind direction and speed determine the time of flight and thus the amount of fuel burnt. This directly affects the amount of carbon dioxide emitted into the atmosphere.

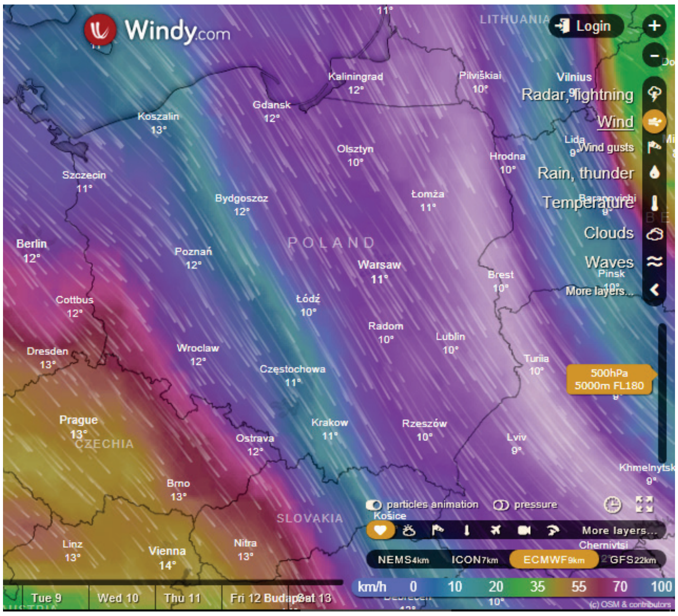

Fig. 8. Distribution of wind direction and speed at the altitude of 5000 m in the research area (a map from [29])

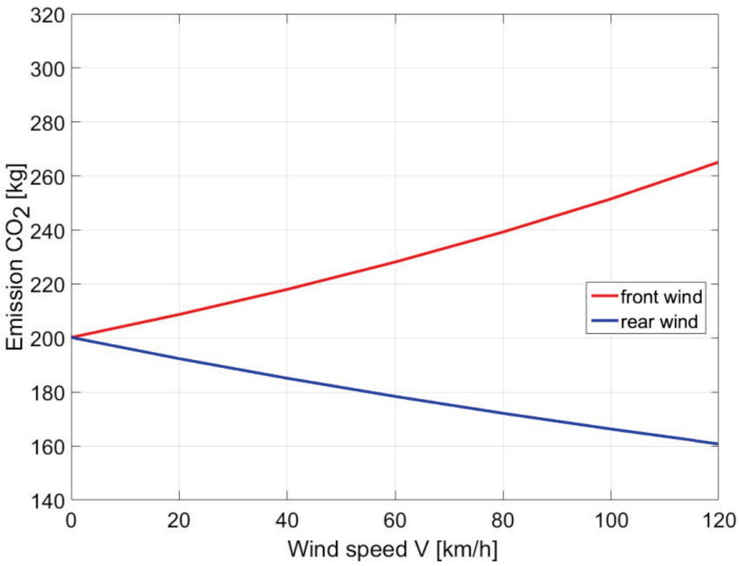

Fig. 9. Emission of CO_2 in the function of wind speed and direction

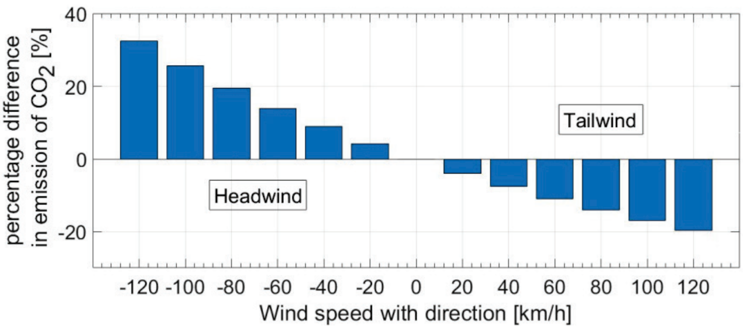

Fig. 10. Percentage change in CO_2 emission (in relation to the windless variant) in the function of wind speed and direction

4. Conclusion

The article attempts to determine the impact of wind on fuel consumption by the Business Jet aircraft during the flight (CRUISE phase). In the research there was adopted a route from Gdansk to Rzeszow and the cruising altitude at 5000 m.

There were taken into account the wind direction in relation to the trajectory of the aircraft (headwind or tailwind) and the wind speed (from 0 to 120 km/h). Then an analysis was carried out for various external conditions, which led to the following observations. The higher headwind speed, the longer duration of the trip, and the higher the CO_2 emission values. In the case of tailwind (pushing) wind, the situation is reversed. For example, at the headwind speed of 100 km/h, the flight was extended by 12 minutes and at the tailwind with the same speed, the flight time was shortened by 8 minutes in relation to windless conditions. It is worth noting that the wind impact was not symmetrical, e.g. for the headwind speed of 100 km/h, the emission was 503 kg CO_2, which gives an increase of 26% in relation to the lack of wind. However, at the same speed of tailwind, the emission was 333 kg CO_2, which corresponds to a 17% reduction in emissions compared to the lack of wind. It shows that the direction and force of wind has a significant impact on the amount of fuel consumed, which directly converts into CO_2 emission values. It may be worth considering the research on the optimization of the aircraft's flight trajectory, so that it is covered with the most preferable wind direction.

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