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Fuel consumption in an air blower for agricultural use under different operating conditions

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Key words:

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internal combustion engines
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ABSTRACT

Evaluation of fuel consumption in internal combustion engines (ICE) of agricultural machinery and equipment is important in determining the performance under various operating conditions, especially when using biofuels. This study consisted of experimental evaluation of the gasoline (petrol)/ethanol consumption in a two-stroke 1-cylinder ICE, Otto cycle, functioning as an air blower for agriculture and related applications. A methodology for tests of non-automotive ICE, based on ABNT/NBR technical standards, was considered. The presented results refer to operation with commercial and non-commercial fuel blends. Characteristic curves for the tested equipment are presented, identifying consumption conditions and trend in the whole operating range of angular speeds (RPM), for five fuel blends (gasoline/ethanol). For the operating conditions of minimum and maximum angular speeds, 20 and 30% ethanol blends had the highest and lowest fuel consumptions, respectively.

Palavras-chave:

máquinas agrícolas
energia na agricultura
motores de combustão interna
biocombustíveis

Consumo de combustível em soprador de ar para uso agropecuário em diferentes condições operacionais

RESUMO

A avaliação do consumo de combustível em motores de combustão interna (MCI) em máquinas e equipamentos agrícolas é importante na determinação do desempenho em condições diversas de operação sobretudo quando biocombustíveis são utilizados. Este trabalho consiste da avaliação experimental do consumo de gasolina/etanol de um MCI, ciclo Otto, 2T e um cilindro, acionando um soprador de ar, utilizado em aplicações na agropecuária e afins. Foi considerada metodologia para realização de ensaios em MCI não automotivos, baseada em normas técnicas NBR/ABNT. Os resultados apresentados se referem ao funcionamento com misturas combustíveis comerciais e não-comerciais. Curvas características para o equipamento ensaiado são apresentadas identificando as condições de consumo e o comportamento em toda a faixa operacional de rotações (RPM), para cinco misturas combustíveis (gasolina/etanol). Nas condições operacionais de rotações mínimas e máximas as misturas de 20 e 30% de etanol na gasolina apresentaram o maior e o menor consumo, respectivamente.



INTRODUCTION

Currently, there are various stimuli (economic, social and environmental) to increase the use of biofuels to attenuate environmental issues and guarantee a certain level of self-sufficiency for Brazil, in its energy matrix, in relation to the global market of fossil fuels. From the total energy used in the world, more than 80% is used in combustion processes (RNC, 2016). Applications for power of medium or large size still use Diesel cycle (e.g. Diesel/Biodiesel-powered tractors), while small or medium size use Otto cycle (e.g. gasoline (petrol)/ethanol). The literature has few results for two-stroke (2-S) engines. In four-stroke (4-S) engines, the consumption and specific consumption of fuel blends are the parameters usually evaluated in Diesel cycle or Otto cycle.

The conduction of tests in engines of agricultural machines with Diesel cycle is the most common, such as the consumption in sugarcane harvesters evaluated by Ramos et al. (2016), who observed increasing consumption as the angular speed increased, at the three evaluated rotations. In Diesel cycle engines, recent studies have equally demonstrated the importance of the parameters of consumption, performance and emissions for diesel/alcohol blends (ethanol, methanol and butanol) and little is known (Kumar et al., 2013; Putrasaria et al., 2013; Gonca, 2014; Abedim et al., 2016; Fayyazbakhsh & Pirouzfard, 2016; Kumar & Saravanan, 2016); and also fuel preheating when considering vegetable oils (Delalibera et al., 2017).

This study consists in the experimental evaluation of an air blower actuated by a 2-S internal combustion engine with Otto cycle, regarding fuel consumption (kg h^{-1}), operating with different gasoline/ethanol blends and angular speeds of rotation of the engine/rotor shaft (RPM).

MATERIAL AND METHODS

The operational consumption was determined for 5 blends of gasoline/ethanol, namely: Gasool A20, A30, A38, A45 and A50. Nine angular speed ranges were considered, from minimum to maximum rotation (~ 2500 to ~ 7000 RPM), with the blades of the air blower rotor exerting mechanical effort (or "load") of operation to the engine.

The experiments were conducted at the Laboratory of Agricultural Mechanization (LMA) of the course of Agricultural Engineering of the Federal University of Grande Dourados (UFGD). Mean values of the environmental

parameters recorded during the tests (temperature, relative humidity and atmospheric pressure) are presented in Table 1, obtained as described in NBR 7.024 (ABNT, 2010).

Table 1. Environmental conditions during the tests for the intake air

| Fuel blends (Gasool) | A20 | A30 | A38 | A45 | A50 |
|---------------------------------------|------|------|------|------|------|
| T, Temperature ($^{\circ}\text{C}$) | 32.9 | 30.0 | 33.0 | 33.0 | 26.5 |
| Φ , Relative humidity (%) | 37 | 62 | 43 | 40 | 76 |
| P, Barometric pressure (atm) | 0.93 | 0.95 | 0.94 | 0.93 | 0.94 |

Air blower and measuring instruments

The evaluated device was an air blower (brand: STIHL, model: BG 86 C), which has multiple use, encompassing applications in agriculture, gardening and residences. It is a system formed by an internal combustion engine (ICE) thermal machine and a centrifugal (or radial) fan fluid machine, with blades curved forward whose nominal diameter of the rotor (or volute) is 120 mm. Figure 1 illustrates the portable blower.

The rotor shaft is directly actuated by the torque of the shaft of the 2-S 1-cylinder engine, with nominal power of 0.8 kW (~ 1.07 hp). Other technical characteristics are: cylinder capacity of 27.3 cm^3 , mass of 4.5 kg, $810 \text{ m}^3 \text{ h}^{-1}$ and 69 m s^{-1} respectively for maximum volumetric flow rate and maximum air speed, with the outlet pipe. The standard fuel of this 2-S ICE is a mixture of STIHL 8017H lubricating oil and commercial gasoline at the proportion of 1:50 (recommended by the manufacturer).

The description and respective technical specifications of the measuring instruments used to measure the parameters during the tests are: A) Semi-analytical scale (Gehaka, model: BK 8000), range of 0-8100 g, resolution of 0.1 g and accuracy of ± 0.2 g, B) Tachometer (Instrutherm, model: TDR-100), range of 5-9999 RPM, resolution of 1 RPM and accuracy of $\pm 0.1\%$ + 1 digit, C) Vacuum meter (Instrutherm, model: VDR-920), range of 1125 mmHg, resolution of 1 mmHg and accuracy of $\pm 1\%$, D) Chronometer (Instrutherm, model: CD-2800), range of 23 h 59' 59", resolution of 1/100", E) Software to acquire data from the tachometer and cable (Instrutherm, model: SW-U801 and SW-10).

Biofuel blends - Use and preparation of the samples

The fuel samples used in the consumption measuring tests were prepared using as reference the requirements established in the technical norms: NBR 13.992, NBR 13.993 and NBR 8.689 (ABNT, 2001; 2002; 2011), and also on resolutions of



Figure 1. Air blower: (A) complete set, (B) with scale and (C) opened rotor

the ANP - National Agency of Petroleum, Natural Gas and Biofuels (Nº 06/2005; 21/2009 and 23/2010). The commercial gasoline had, since October 1, 2011, 20% of ethanol (BRASIL, 2011) and 25% from May 1, 2013; currently, since 2015, it has 27.5% of ethanol. The results may serve as reference for future ABNT/INMETRO norms for energy efficiency labeling in small combustion engines, as in the engines of passenger automobiles (PBE, 2016).

According to the definitions and terminologies, the EAR is the Anhydrous Ethanol Fuel of Reference (or AEAC, anhydrous ethyl alcohol fuel of reference), while EHR is the Hydrated Ethanol Fuel of Reference (or AEHC, hydrous ethanol fuel of reference). Gasool is the denomination for car fuel composed mainly by gasoline, containing also EAR. Commercial gasoline was obtained in a gas station (Dourados, MS), and the ethanol content was verified according to the procedure described by the NBR 13.992 (ABNT, 2001). The HCV - Higher Calorific Value (according to the IS, kJ kg^{-1}) of the pure gasoline (Gasool A0) and pure ethanol (Gasool A100) are, respectively, 42.3 and 27.2 MJ kg^{-1} (Brunetti, 2012a).

Five different blends of fossil fuel (gasoline) and biofuel (ethanol) were prepared (Silva et al., 2012a): 1) Gasool A20 (mixture of 80% in volume of pure gasoline, 20% in volume of EAR and 0% of EHR), commercial sample obtained during the tests (2012), 2) Gasool A30, 3) Gasool A38, 4) Gasool A45 and 5) Gasool A50.

Data acquisition - Description of the experimental procedure

The determination of fuel consumption, according to the NBR 7.024 (ABNT, 2010), was performed using the gravimetric method (Figure 1B). The consumed mass of fuel was indirectly measured by the difference of total mass of the device, recorded at the beginning and at the end of each test. The consumption through the volumetric method was measured using a graduated burette attached to the injector nozzle by a hose, as used by Barbosa et al. (2008) and Reis et al. (2013). Eqs. 1 and 2 are used, respectively, to determine fuel consumption and the discrepancy between the obtained values.

$$C_n \left(\text{kg h}^{-1} \right) = \frac{(m_{\text{final}} - m_{\text{initial}})}{\Delta t} \quad (1)$$

$$D \leq \left[\frac{(C_1 - C_2)}{C_1} \right] \times 100 \quad (2)$$

where:

m_{initial} - total mass of the set (blower and fuel tank) at the beginning of the test [g];

m_{final} - total mass of the set (idem) at the end of the test [g];

Δt - time of the test [min];

C_1 - fuel consumption in the first test [g min^{-1}];

C_2 - fuel consumption in the test in duplicate [g min^{-1}]; and,

D - discrepancy [%].

The tests considered the requirements and other information of interest described in NBR 6.396 (ABNT, 1976), applicable to 2-S, non-vehicular, reciprocating internal combustion engines, as in the case of the air blower. The angular speed (rotation)

of the engine shaft was recorded using a tachometer with output to the automatic data acquisition system via software (Instrutherm, model SW-U801). Each test had duration of 10 min and the rotation value was recorded every second, totaling 600 points per test. The Eq. 3 was used to determine the mean value of the angular speed (rotation) for each test.

$$v_m = \frac{\sum v_i}{n} \quad (3)$$

where:

v_m - mean angular speed (rotation) of the rotor [rpm];

v_i - angular speed recorded using a tachometer at the time "i" [m s^{-1}]; and,

n - number of values recorded during the test.

The complete experimental procedure is described by Silva et al. (2015). Step 1: Mount and turn on the data acquisition system for rotation; Step 2: Turn on the scale (15-20 min before use) for equilibrium with ambient conditions; Step 3: Turn on the air blower and maintain it in operation for 30 min in slow gear, for pre-heating of the 2-S ICE and adaptation to the utilized fuel blend; Step 4: After 30 min, turn off the engine and put it on the scale, wait for stabilization and record the mass value; Step 5: Turn on the engine and initiate the data acquisition relative to the rotation for the period of 10 min; Step 6: Turn off the device and repeat step 4; Step 7: Through Eq. 1, calculate fuel consumption; Step 8: Repeat steps 5, 6 and 7. These procedures must be repeated because of the need for valid tests in duplicate (two times) for each rotation; Step 9: After making the duplicate, calculate the discrepancy of the obtained results using Eq. 2. If the discrepancy is $\leq 5\%$, the values are acceptable; otherwise, repeat steps 5, 6, 7 and 9; Step 10: Alter the position of the rotation control ("trigger") to the next rotation of test and return to steps 5, 6, 7, 8 and 9; Step 11: End of test, repeat the procedure for a new fuel blend.

RESULTS AND DISCUSSION

Figure 2 presents the raw data of rotation along the time of test for the sample Gasool A38 and fuel consumption for the sample Gasool A20. It is noticed that there is a level of oscillation in the recorded values of rotation, especially in the first minute, but considered as normal for a 2-S ICE. Even with the pre-heating for permanent regime performed for 30 min, according to NBR 6.396 (ABNT, 1976), the oscillations in the rotation occur because of the operation principle and vibration level, higher than that of electric engines. Therefore, a mean value for the rotation is essential in the determination of fuel consumption for the different operational conditions analyzed, used for the results presented below. Still in Figure 2A, the operation range of the device is represented by 9 different rotations (mean values), for the sample Gasool A20, which corresponds to the commercial gasoline. In Figure 2B, minimum and maximum consumptions occur, respectively, for rotations below 5000 RPM with $C_{A20,\text{min}} \sim 0.10 \text{ kg h}^{-1}$ and $C_{A20,\text{max}} \sim 0.40 \text{ kg h}^{-1}$ (6500 RPM). For values immediately above 5000 RPM, there is a significant increase in fuel consumption from ~ 0.15 to $\sim 0.35 \text{ kg h}^{-1}$.

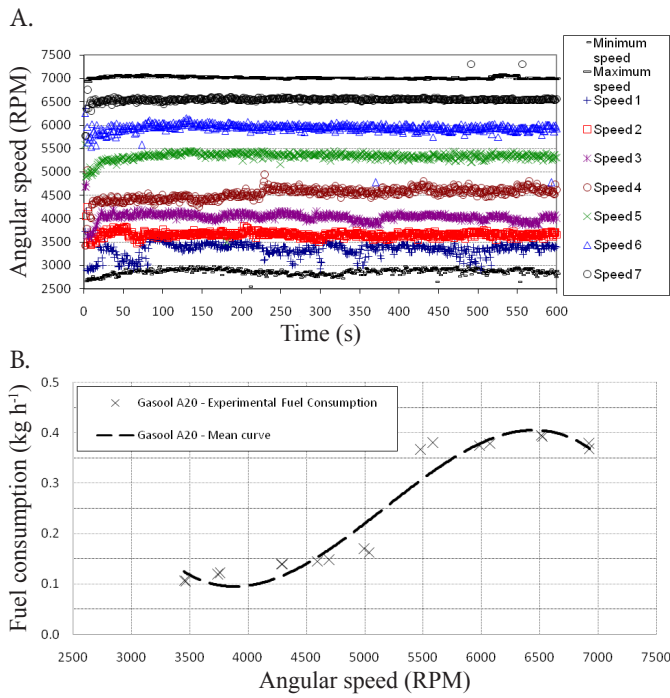


Figure 2. Gasool A38 - Data acquisition for angular speed (RPM) (A) and Gasool A20 - Fuel consumption versus angular speed (B)

Figure 3 shows the fuel consumption in the air blower (2-S ICE) for the tests performed with non-commercial fuel samples: Gasool A30, A38, A45 and A50. Since all tests were conducted using the same volume of combustion air in the internal fuel delivery system (there was no change in the carburetor regulation), the results presented here must consider the stoichiometric ratios correspondent to each fuel blend. The results for the Gasool A30 blend exhibit an approximately constant and regular consumption for any rotations below 4500 RPM, but immediately above these values it changes from ~0.15 to ~0.40 kg h⁻¹, increasing until the maximum consumption, close to 7000 RPM, with $C_{A30,max} \sim 0.45 \text{ kg h}^{-1}$. The fuel consumption for the sample Gasool A30, C_{A30} (g min⁻¹) was presented in detail and briefly discussed by Silva et al. (2012b). In addition, the minimum rotation exhibited by the air blower (2-S ICE) is ~2500 RPM, lower than that of the Gasool A20 blend (~3500 RPM). Increase in fuel consumption due to the rotation was also reported by Ramos et al. (2016).

Regarding the blends Gasool A38, A45 and A50 in Figure 3 (A, B, C, D), the fuel consumption shows a more regular increasing trend, as the rotation increases, without abrupt increments like those observed for Gasool A30 and A20. Additionally, it is also observed that the rotation of the device with trigger position for minimum rotation gradually increases as the ethanol content increases, but it is still inferior to 3500 RPM, which is the value recorded for Gasool A20. This fact can be explained by the difference in the HCV of pure gasoline (42.3 MJ kg⁻¹) and pure ethanol (27.2 MJ kg⁻¹), and by the stoichiometric ratio of the air:fuel ($\lambda = 1$), which corresponds to values between 15:1 and 9:1 (Brunetti, 2012b), respectively for ICE of pure gasoline (Gasool A0) and pure anhydrous ethanol (Gasool A100). Thus, from the condition of Gasool A20 to A30, the 2-S ICE requires a smaller volume of air to maintain $\lambda = 1$ and, since the regulation of fuel injection in the carburetor

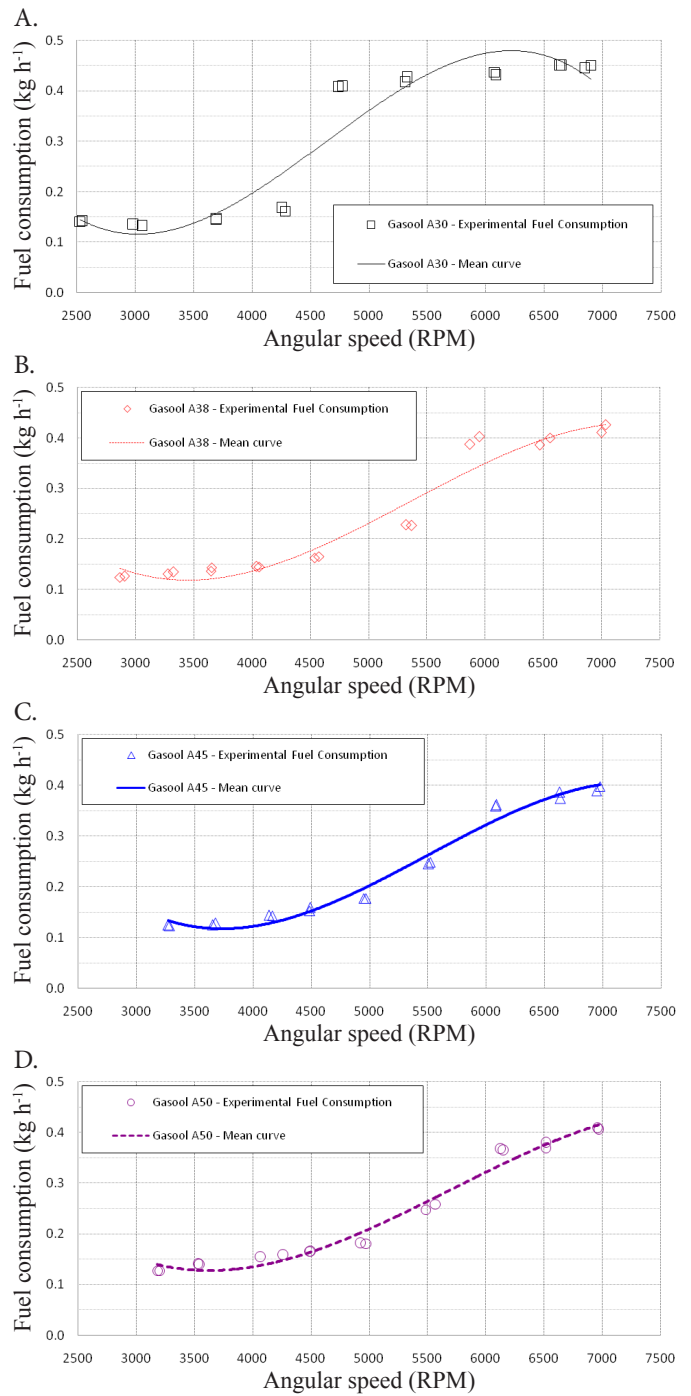


Figure 3. Fuel consumption versus angular speed – Gasool: A30 (A), A38 (B), A45 (C) and A50 (D)

is kept constant, there will be excess of air (trend to $\lambda > 1$) in the Gasool A30 blend and, consequently, lower rotation; for the other blends, this condition is intensified.

Figure 4 shows mean fuel consumption curves for the 5 tested samples of fuel. The behavior and intensity of consumption for the blends Gasool A38, A45 and A50 are very similar and there is a small difference in fuel consumption at rotations below 4500 RPM. At maximum rotation, the Gasool A38 blend shows the highest consumption, with $C_{A38,max} \sim 0.42 \text{ kg h}^{-1}$. In addition, for a wide range of consumption, the blends Gasool A45 and A50 are virtually coincident.

Table 2 shows the direct comparison between the fuel consumptions at minimum and maximum rotations, respectively, minimum and maximum efforts in the rotor shaft

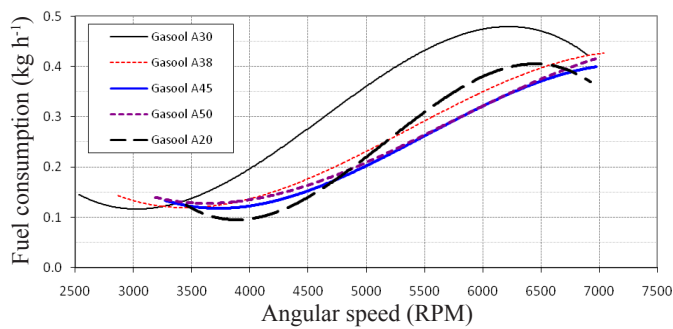


Figure 4. Fuel consumption (mean curves) – Gasool A30, A38, A45 and A50

of the air blower. The highest and lowest consumptions in all tests were highlighted, which occurred for the blends Gasool A30 and Gasool A20, respectively. Among the other blends, the consumptions gradually increase for A38, A50 and A45 at the minimum angular speed and, in the inverse order occurs for maximum angular speed.

Typically, the 2-S ICE operates in a condition of poor stoichiometric mixture ($\lambda < 1$), which leads to incomplete combustion and emissions in significant amounts in the exhaust gases, usually ten times higher compared with a 4-S ICE. Based on the obtained results, if the air injection system in the carburetor is not altered, there is a trend to obtain a rich mixture, with excess of air, which is a beneficial aspect that helps to reduce the amount of emissions (ppm) in the exhaust gases.

Reductions in the emissions of up to 35% in CO (and reduction also in CO₂ and NO_x) in a small 2-S ICE (model JAP-J34, 0.5kW&4000 RPM) were reported by Ghazikhani et al. (2013; 2014), operating with the blends Gasool A5, A10 and A15, besides obtaining other characteristics of improvement in the performance, attributed to the faster evaporation of ethanol in the combustion chamber, compared with the evaporation of gasoline. Nietiedt et al. (2011) and Monteiro et al. (2013) evaluated the consumption of diesel/biodiesel blends from various origins in Diesel cycle engines.

The evaluation of combustion engines under actual operation conditions without alterations in the air and/or fuel delivery system, with mixtures of gasoline/ethanol and/or diesel/biodiesel, exhibits some interesting characteristics recorded in the literature. Zhang et al. (2013) report increase in the operation range (rotations) of 2-S ICE, in comparison to 4-S ICE, using auxiliary control of autoignition. On the other hand, these authors highlight the significant reduction of emissions as the ethanol content increases in the fuel blend and also better thermodynamic and combustion efficiency, due to the reduction of thermal losses, with 5% more of efficiency in fuel conversion using Gasool A85.

Table 2. Fuel consumption at minimum and maximum speeds or rotations ($\Delta T_{\text{test}} = 120$ s)

| | Blend | |
|------------|------------------------------|------------------------------|
| | Minimum speed | Maximum speed |
| Gasool A20 | 17.7 x 10 ⁻³ kg* | 62.1 x 10 ⁻³ kg* |
| Gasool A30 | 23.6 x 10 ⁻³ kg** | 74.5 x 10 ⁻³ kg** |
| Gasool A38 | 20.9 x 10 ⁻³ kg | 69.7 x 10 ⁻³ kg |
| Gasool A45 | 21.7 x 10 ⁻³ kg | 65.6 x 10 ⁻³ kg |
| Gasool A50 | 21.2 x 10 ⁻³ kg | 67.8 x 10 ⁻³ kg |

*Lowest consumption; **Highest consumption

CONCLUSIONS

1. There is a significant increase of fuel consumption for the operation above 4500 RPM (Gasool A20 and A30), indicating a possible restrict performance for certain percentages of ethanol as biofuel in these devices.

2. For non-commercial blends (Gasool A30, A38, A45 and A50), there is an increase in the minimum value of the angular speed of rotation, when the ethanol content increases.

3. For the operational conditions of minimum and maximum rotations, the blends Gasool A30 and A20 exhibit highest and lowest consumptions, respectively. Among the others, the consumptions gradually increase for A38, A50 and A45 at minimum rotation, and the inverse order occurs for maximum rotation.

4. Operating conditions of the device at rotations lower than 4500 RPM, for any of the test fuel blends, lead to reduced fuel consumption and rotation not much different from the maximum value (7000 RPM).

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