Analyzes regarding aviation fuels parameters use on jet engines

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Abstract: *The properties of the fuels determine the quality of the combustion process and implicitly the performance of the turbojet engine. The optimal heterogeneous combustion process of an aviation fuel is ensured by a stoichiometric ratio (fuel/fuel), a combustion temperature and a maximum loading degree of the combustion chamber.*
The article includes a numerical analysis instrumented with Gasturb software that highlights the influence of fuel quality and combustion process characteristics of a Rolls Royce Viper turbojet engine on its performance.

Key Words: *fuel, jet petrol, Gasturb, numerical analysis*

ACRONYMS

JP	*Jet Petrol*	ρ	*Density*
T_1	*Inlet engine temperature (K)*	T_4	*Inlet turbine temperature (K)*
P_4	*Inlet turbine pressure*	*FN*	*Net traction (kN)*
TSFC	*Thrust specific fuel consumption (g/kN*s)*	*WF*	*Fuel flow (kg/s)*
FHV	*Fuel lower heating value(Mj/kg)*	P_{amb}	*Atmospheric pressure*
P8	*Nozzle pressure*	*NSpd*	*Nominal speed (rpm)*
T_F	*Flash point temperature*	*VABP*	*Volume average boiling point*
C_p	*Coeficient caloric*		

1. INTRODUCTION

The properties of fuels determine the quality of the combustion process (spraying, auto-ignition, vaporization, fuel combustion and engine wear) through a series of characteristics, the most important being: chemical composition, density, viscosity, surface tension, specific heat, thermal conductivity, temperature ignition/autoignition, cetane number, Diesel number, octane number, coke number, calorific value, freezing point, flammability, fractional composition and additives.

The multicriterial numerical analysis shows the degree of influence of the fuel parameters on the performance of the combustion process and implicitly on the performance of the jet engine, software analyzes performed with Gasturb [1, 2]. Numerical approaches are used for both duty cycle design and parametric analysis.

2. AVIATION FUELS

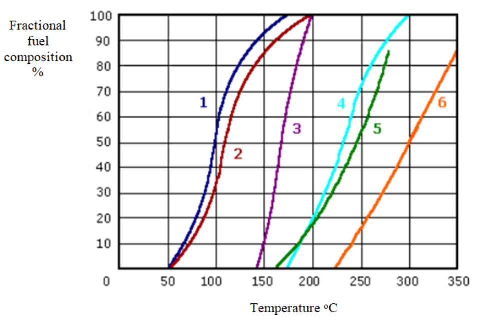
The quantitative assessment of the combustion process of a fuel is carried out through the so-called combustion calculation, which determines: the amount of air required for combustion, the combustion temperature, the quantity and composition of the combustion compounds.

In particular, the fuels used in turbo engines have combustion characteristics as: smoke test and brightness figure, density and volatility. The wear of the propulsion system is adversely influenced by a number of fuel properties, such as: the content of mechanical impurities, mineral alkalinity or organic acidity, and fuel transport is influenced by the freezing point, color or flash point, [3, 4, 5, 6, and 7]. The quantitative assessment of the combustion process of a fuel is carried out through the so-called combustion calculation, which determines: the amount of air required for combustion, the combustion temperature, the quantity and composition of the combustion products.

Avgas is used on aircraft equipped with piston propulsion systems; it is a gasoline with a high octane number compared to the common green gasoline for cars (between 110 and 130 octane); in this type of gasoline the old anti-knock additive (lead tetraethyl) has been reduced as a percentage due to polluting characteristics.

For jet propulsion systems, the technical fuel called kerosene or Jet-A1, or for the military JP-4 (Jet Petrol) is used. Jet-A1 has a higher density and lower volatility and a lower cost per liter than aviation gasoline.

In order to improve the characteristics of fuels and reduce the impact on the environment, both additives are used depending on the composition of the fuel and the field of use, as well as biocomponents, [8, 9, 10]. The most relevant functions of additives and inhibitors are: icing, corrosion, protecting the fuel against degradation due to physico-chemical contact agents, protecting the propulsion system against combustion compounds and improving the characteristics of fuels.



(1. aviation gasoline, 2. auto gasoline, 3. withe spirit, 4. lamping oil, 5. tractor oil, 6. diesel)

Fig. 1 Fractional composition of fuels used in thermal (combustion) engines, [3, 13]

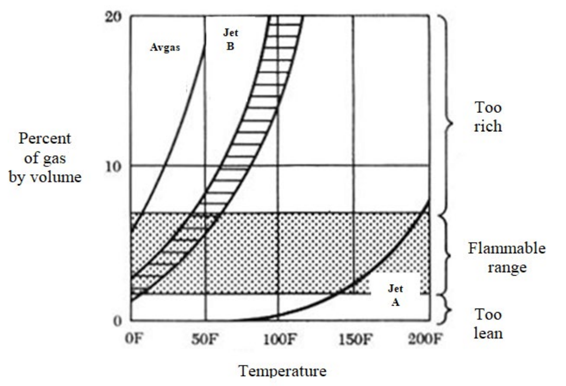


Fig. 2 Aviation fuels vaporization [14]

The combustion of liquid fuels in internal combustion propulsion systems takes place under optimal conditions (only in the gas phase); starting is easier the more the degree of fuel vaporization is accentuated, which leads to reduced wear and optimal operation. The percentage variation of the fractional composition for a series of liquid fuels is observed in figure 1.

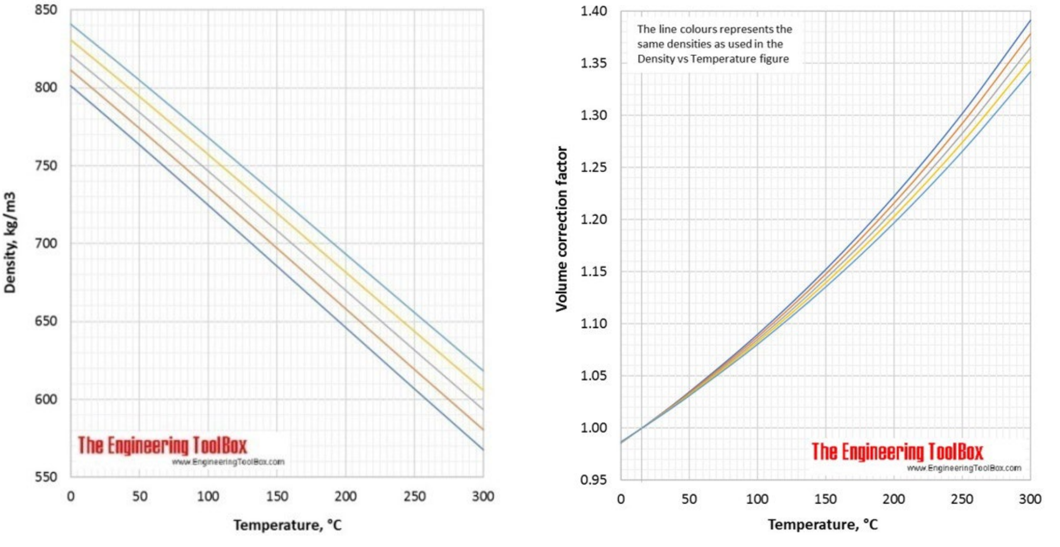
In aerojet engines, for the combustion of fuel in the combustor we have a precompression and a preheating of the air, the combustion occurring continuously in isobaric conditions at high values of the speed.

The limits of the thermal conditions of the combustion are the admissible temperature values at the turbine inlet (T_4).

The vaporization qualities, interpreted by the distillation curve and the vapor pressure, can influence the operational performance of the jet engines (concentration of pollution products, operational stability).

The characteristics of these fuels types are: the smoke test that provides information on the tendencies of the formation of coal deposits on the walls of the combustion chamber; brightness figure (with luminometers) for measuring bright/non-bright flames and determining the degree of heating of metal parts; the density that determines the calculation of the weight of the fuel and implicitly the estimation of some of the aircraft's performances; volatility or flash point (see figure 2 and equation 1) which can indicate the degree of dissolution of air and the favoring of fuel vaporization and foaming (especially at high altitudes); the fractional composition indicating the values of the fractional distillation curve; the viscosity that determines the flow and filtration values of the fuel at different temperatures, the thermal power that indicates the amount of combustion heat (see equation 5); boiling point as volume/weight average value, see also equation 2; enthalpy, heat capacity / heat of vaporization, see equation 6, [21, 22].

The variations of density (ρ) of jet fuel as a function of temperature (p=1atm and t=15°C) show the corrections in the graphs of figure 3, and equations 3 and 4, [11, 12, 22].



(a) (b)

Fig. 3 Jet fuels density vs temperature (a) and Jet fuels correction [22]

According to [22] a number of fuel properties are controlled by the distillation curve with implications on the flash point, highlighted by equation 1:

$$T_F = 15.48 + 0.70704 \cdot T_{10} \quad (1)$$

where T_F –flash point temperature
T_{10} –temperature for 10% distillation

The average boiling point (VABP) represented by equation 2:

$$VABP = \frac{T_{10} + T_{50} + T_{90}}{3} \quad (2)$$

Density, in kg/m^3, with equations 3 and 4:

$$\text{for JP-5} \quad \rho = -0{,}8195 \cdot T[C] + 825.4 \quad (3)$$

$$\text{for JP-8} \quad \rho = -0{,}8122 \cdot T[C] + 819.3 \quad (4)$$

Kinematic viscosity υ (equation 5):

$$\upsilon = \eta / \rho \quad (5)$$

where η – dynamic viscosity
ρ - density

The enthalpy is calculated with equation 6 or for the enthalpy change (equation 7) for the calorific coefficient in equation 8:

$$\Delta H = C_p \cdot \Delta T \quad (6)$$

$$\Delta H = \int_{T_1}^{T_2} C_p \cdot dT \quad (7)$$

where C_p – calorific coefficient
ΔT – temperature variation

$$C_p = \frac{0.76 + 0.00335 \cdot T\,[K]}{\rho_r} \cdot 0.5\ [kJ/kgK] \quad (8)$$

3. INFLUENCE ANALYSIS OF THE FUELS ON THE JET ENGINES PERFORMANCE

3.1 Gasturb

According to references [1, 2] it is a numerical analysis software tool for quantifying the performance of jet engines (figure 4), it offers a series of calculation modules for simulation and evaluation, the most relevant being:

- *the module for the thermodynamic cycle,* which has numerical tools for analyzing the various components of the engine, allows a series of evaluations regarding temperature, pressure, mass flow and thermal efficiency at different points of the thermodynamic cycle, by changing the input parameters (combustion temperature, intake pressure, compression ratio);

- *the module for the parametric analysis of the components,* including calculation tools for the detailed analysis of the compressor, turbine, combustion chamber or exhaust nozzle, which allows modification of the design parameters for these components for an individual performance calculation with the identification of limiting factors their operating performance;

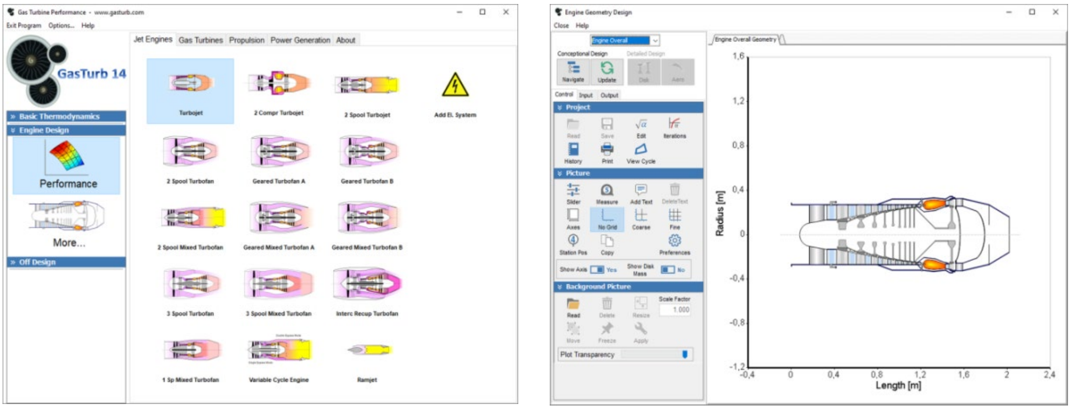


Fig. 4 Gasturb software

- *the off-design design mode,* which provides calculation tools in off-design conditions, such as the influence of ambient temperature or operation at different altitudes, to evaluate the impact of off-design factors on the efficiency and power of the propulsion system, or to optimize the operation in different operating conditions;
- *the fault diagnosis module,* which contains calculation tools regarding the diagnosis of component element faults by comparing the simulated results to identify the possible causes that determine the reduced performance.

3.2 Analysis conditions

The construction and operating parameters are considered similar to the Rolls-Royce Viper Mk.632-41R aerojet engine (figure 5), having the values recorded in table 1, table 2 and appendix 1. [15, 18]

Table 1 - Features and performance

Characteristic	Value	Characteristic	Value
Diameter/ length	0,747 / 1,806 m	Engine weight	376 kg
Specific fuel consuption	2,75 $*10^{-5}$ kg/s	Static traction	17659 N
Air mass flow rate	26,3 kg/s	Static traction afterburning	22241 N
Compression ratio	5.9:1	Nominal speed	13760

For the more precise instrumentation of the numerical simulation, a series of (static) analysis conditions considered by the Gasturb software tool are considered, according to table 2.

Table 2 - Gasturb analysis conditions

Characteristic	Value	Characteristic	Value
Atmospheric temperature	289 K	Burning temperature	1250 k
Atmospheric pressure	101 kPa	Fuel heating value	43.323
Compressor efficiency	0,91	Burner efficiency	0,91

Fig. 5 Rolls Royce Viper [17]

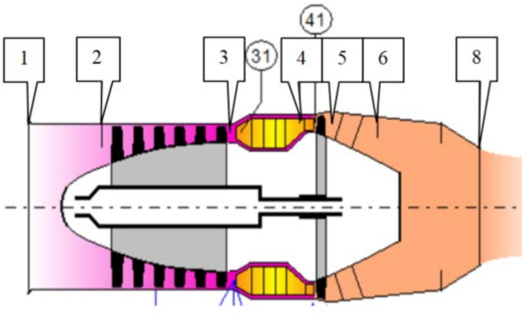


Fig. 6 Jet engne main section, [11]

According to figure 6 we have the following sections: *1. inlet air addmision; 2. compressor inlet;3. compressor exit; 3.1. combustor inlet; 4. combustor exit; 4.1. turbine inlet; 5. turbine exit; 6. turbine diffuser (gas generator) exit; 8. nozzle exit.*

3.3 Results and parametric graphical interpretations

For the calculation of the net traction at a fixed point depending on the fuel parameters, the software instrumentation included a series of parametric graphic scenarios, the most relevant being the following (the fuel caloric coefficient / fuel heating value):

- the fuel caloric coefficient vs the ambient pressure (figure 7 and figure 11);
- the fuel caloric coefficient vs temperature T_1 (figure 8 and figure 12);
- the fuel caloric coefficient vs the isentropic efficiency of the compressor (figure 9);
- the fuel caloric coefficient vs the angle of the flaps of the reaction nozzle (figure 10);
- the fuel caloric coefficient vs the combustion pressure ratio (figure 13 and figure 14).

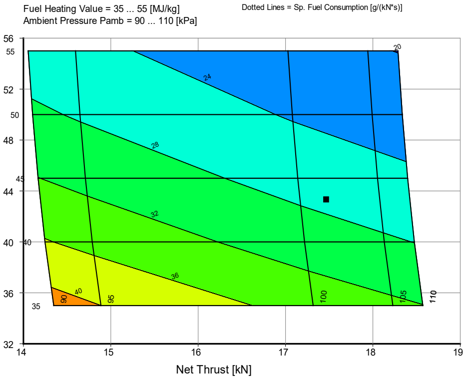


Fig. 7 Variation of caloric value vs ambient pressure

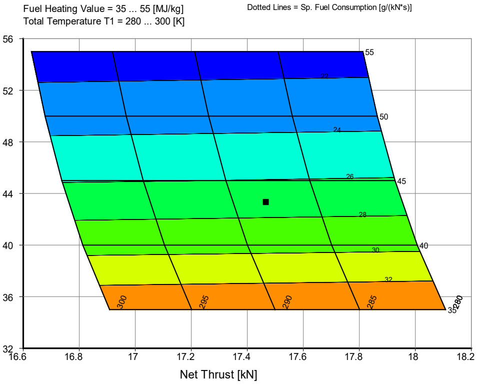


Fig. 8 Variation of caloric value vs inlet temperature T_1

The location of the analyzed parameters are according to the diagram regarding the main sections of the propulsion system in figure 6.

According to figure 7, the influence of the variation of the values of the caloric coefficient of the fuel type (vertical axis) versus the values of the ambient pressure (horizontal axis) on the net traction is observed with the overlap of the gradient of the specific fuel consumption (dotted line); obviously the increase of the ambient pressure causes the increase of the net traction.

Figure 8 highlights how the net thrust is influenced by the pair of values: fuel caloric value vs inlet temperature T_1 together with the specific fuel consumption value. Obviously, the decrease in T_1 (ambient) inlet temperature causes the increase in net traction.

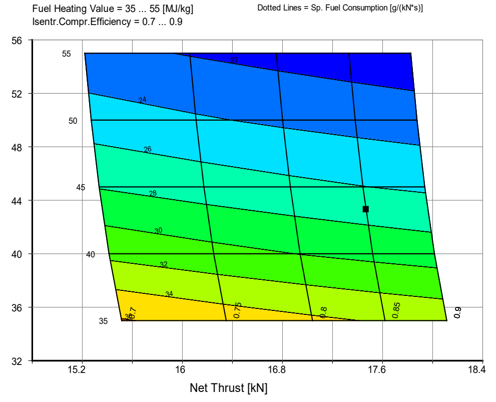


Fig. 9 Caloric coefficient variation vs compressor efficiency

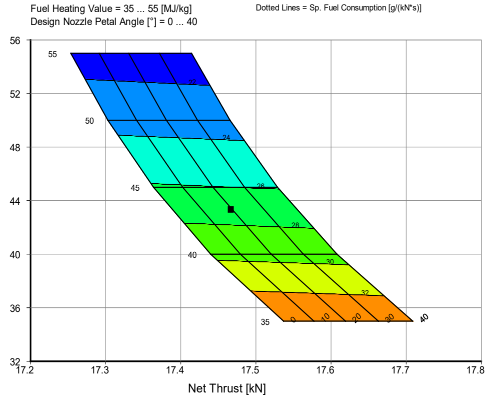


Fig. 10 Variation of the caloric coefficient vs the angle flaps of the reaction nozzle

Figure 9 shows the influence of the variation of caloric value versus compressor efficiency along with specific fuel consumption; as expected the increase in compressor efficiency causes the net thrust value to increase.

Figure 10 shows the dependence of the variation of the net thrust by the pair of values: the calorific coefficient of the fuel vs the turning angle of the flaps of the reaction nozzle together with the value of the specific fuel consumption.

Obviously, increasing the turning angle of the reaction nozzle flaps causes an increase in net thrust.

Figure 11 shows the influence of varying calorific value versus ambient pressure along with fuel flow; as expected increasing ambient pressure causes the net thrust value to increase.

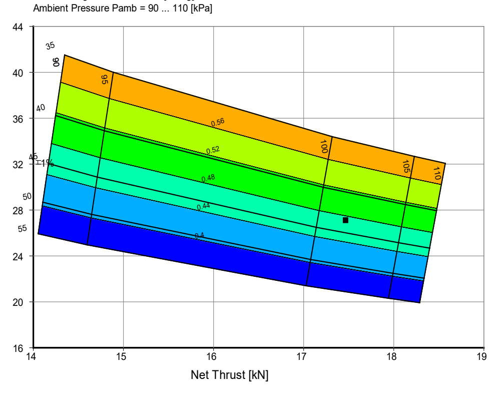


Fig. 11 Variation of caloric value vs ambient pressure

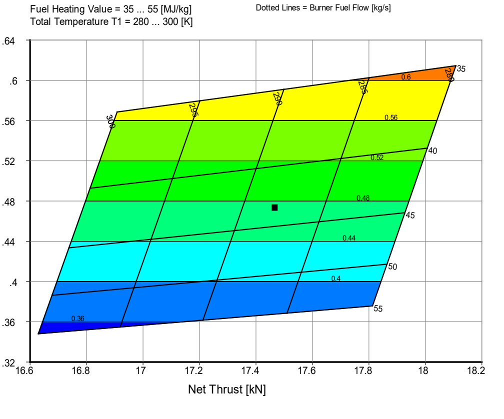


Fig. 12 Variation of caloric coefficient vs temperature T_1

Figure 12 shows the dependence of the variation of the net traction by the pair of values: the calorific coefficient of the fuel vs the temperature T1 together with the value of the fuel flow; the decrease in the temperature T1 causes the increase of the net traction.

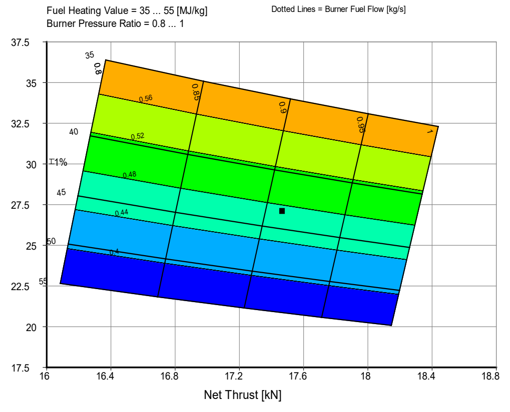


Fig. 13 Variation of caloric value vs pressure ratio in the combustion chamber

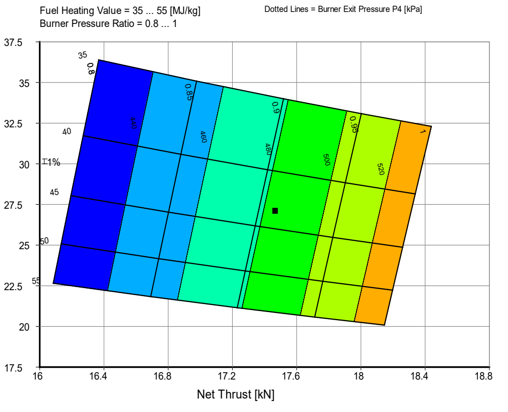


Fig. 14 Variation of caloric value vs pressure ratio in the combustion chamber

Figures 13 and 14 indicate the influence of the variation of the caloric coefficient versus the gas pressure ratio in the combustion chamber; the increase of this ratio causes the increase of the net traction value. The different aspect is revealed by the directly proportional dependence of the combustion gas pressure at the exit from the combustor (P4).

Figures 7-14 indicate the construction point of the propulsion system (black square) corresponding to the JP-4 fuel under the conditions considered in table 1 and table 2. The ratio of the calorific value of the fuel to different operating scenarios can have a relevant positive influence on the traction net depending on atmospheric or operating conditions.

3.4 Parametric numerical results

Compared to paper [16], the numerical simulations performed based on the constructive parameters and the analysis conditions for the selected fuel types generated the results according to table 3:

Table 3 - Results net traction (FN) vs fuel type [19, 20]

Fuel	Caloric coeff.	Net force	Fuel	Caloric coeff.	Net force
Acetona	31,8 MJ/kg	17,54 kN	JP-4	43.32 MJ/kg	17,32 kN
Ammonia	18,90 MJ/kg	18,15 kN	JP-5	42,94 MJ/kg	17,47kN
Butane	45,27 MJ/kg	17,43 kN	JP-10	42.07 MJ/kg	17,43 kN
Diesel	42.74 MJ/kg	17,46 kN	Methanol	21,10 MJ/kg	18,05 kN
Ethanol	21,10 MJ/kg	17,83 kN	Pentane	48,6 MJ/kg	17,25kN
Natural gas	49.73 MJ/kg	17,63 kN	Propane	46,28 MJ/kg	17,42 kN
H_2	118.42 MJ/kg	17,89 kN			

4. CONCLUSIONS

The need for studies applied to jet propulsion systems with the help of software tools requires obtaining comparative numerical values based on the manufacturers' technical data and understanding the dependence of calculated values on the initiated analysis conditions.

The work summarized in the first part a series of relevant parameters for aviation/jetfuels, and in the second part presented a multiparametric numerical analysis starting from a series of fuel types used in aerojet engines.

The study effort focused on highlighting the influence of the atmospheric and operating conditions applied to a Rolls Royce Viper 631-41R turbojet propulsion system for the quantification of the net propulsion force. Although the analysis conditions and parameters were approximated according to the specialized references, credible traction values were obtained, a fact that determines a continuation of the study based on the numerical instrumentation of the case.

Future study intentions include more refined instrumentation of the conditions of use of the propulsion system under multi-criteria and multi-parameter conditions compared to substantiate valid predictions of the performances of this propulsion system under the conditions of using biofuels with calorific coefficients selected from specialized references.

ACKNOWLEDGMENT

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Anexa 1. Export text simulare numerică (selecție de date)

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