Jet engine combustor parametric analyzes

Vasile PRISACARIU*,[1], Irina ANDREI[2], Ionica CIRCIU[1]

*Corresponding author
[1]"Henri Coanda" Air Force Academy,
Mihai Viteazul 160, 5000287 Brasov, Romania,
prisacariu.vasile@afahc.ro*, ionica.circiu@afahc.ro
[2]INCAS – National Institute for Aerospace Research "Elie Carafoli",
B-dul Iuliu Maniu 220, Bucharest 061126, Romania,
andrei.irina@incas.ro

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Abstract: *The combustion processes specific to jet engines involve aerodynamic, thermodynamic, combustion chemistry and heat transfer aspects with implications on performance and environmental pollution reduction. The operating performances of a combustion chamber are influenced by two groups of parameters: atmospheric and operating. Depending on the constructive or operating limitations, a series of optimizations are adopted based on parametric pre-design analyses that can provide numerical data on the operating intervals of the combustion chamber in particular and of the jet engine in general. The article includes a series of parametric analyses on the combustion process, using the GasTurb software tool, to determine the degree of influence of relevant combustion parameters on the performance of jet engines.*

Key Words: *combustor, numerical analyses, combustion parameters, GasTurb, fuel heating value*

ACRONYMS

ATJ	*Alcohol to Jet*	*BET*	*Burner exit temperature*
BFF	*Burner fuel flow*	*BDE*	*Burner design efficiency*
BPC	*Burner partload constant*	*BPR*	*Burner pressure ratio*
FHV	*Fuel heating value*	*GUI*	*Graphic unit interface*
HDO SK	*Hydro-Deoxygenated Synthesized Kerosene*	*HHV*	*Higher Heating Value*
JP	*Jet Propellant*	*LHV*	*Lower Heating Value*
NT	*Net thrust*	*NSS*	*Nominal spool speed*
SFC	*Specific fuel consumption*	*TMB*	*Tetra-Methyl-Benzene*
c_p	*Specific heat coefficient*	T_1	*Inlet compressor temperature*
T_3	*Inlet combustor temperature*	T_4	*Inlet turbine temperature*

1. INTRODUCTION

1.1 Overview

The combustion processes specific to jet engines involve aerodynamic, thermodynamic, combustion chemistry and heat transfer aspects with implications for performance and environmental pollution reduction. The operating performances of a combustion chamber depend on atmospheric parameters and operating parameters, the latter being dependent on the constructive (design) characteristics.

Numerical simulation methods involve the use of mathematical models to simulate the the physical and chemical processes in combustion chambers. The chosen method is built on a simplified 1D engine system model which is based on energy and mass balances. The limitations imposed by the constructive concept or the usage regime determine optimal usage intervals of a combustion chamber, limitations highlighted in the parametric analyses in this paper.

The paper aims to quantify the operating performance using parametric numerical analyses for the combustion chambers of jet engines for theoretical conditions of software instrumentation using GasTurb. For the parametric numerical analyses, a series of variables in the operation of the combustion chambers can be considered, such as: fuel heating value (FHV), burner part load constant (BPC), burner design efficiency (BDE), burner exit temperature (BET) or burner pressure ratio (BPR) [1].

1.2 Theoretical

a. Fuel heating value (FHV)

The calorific value (heat value) of the fuel has a direct influence on the operating performance of jet engines. The heat value is the amount of heat released during the combustion of a specified amount of substance.

A number of specialized references (commercial and scientific) provide values of the characteristics of the most relevant fuels used in aviation [2, 4, 5, 6, 7, 9]. According to the specialized references, we present some average reference values in Table 1.

Table 1. Fuels features [2].

Name	POSF	Description	Average formula	MW(g/mol)
A_1	10264	JP8	$C_{10.8}H_{21.6}$	151.9
A_2	10325	JET A	$C_{11.4}H_{21.7}$	158.6
A_3	10289	JP 5	$C_{12.}H_{22.3}$	166.1
C_1	11498	Gevo ATJ	$C_{12.5}H_{27.1}$	178.0
C_2	12223	Bimodal fuel C14/TMB	$C_{12.3}H_{24.6}$	173.0
C_3	12341	High viscosity	$C_{12.8}H_{25}$	179.6
C_4	12344	Low cetane, broad boiling	$C_{11.4}H_{24.7}$	162.2
C_5	12345	Flat boiling	$C_{9.7}H_{18.7}$	135.4
C_6	10279-2	Virend HDO SK	$C_{11.9}H_{23.7}$	166.8

Caloric fuels values can also be calculated using online tools [3, 8]; a series of results can be viewed in Table 2.

Table 2. Fuel heating values (Mj/kg) [3]

Fuel	LHV	HHV	Fuel	LHV	HHV
Hydrogen	119,96	141,88	Methanol	20,09	22,88
Gasoline	43,44	46,52	Ethanol	26,95	29,84
Butane	45,27	49,20	Propane	46,28	50,22

Fuel heating value equation [16], the quantity of heat released (Q) is:

$$Q = m \cdot c_p \cdot \Delta t \quad (1)$$

where: m –mass of the substance
c_p– specific heat capacity

Δt – temperature range

and Gross heating value (GHV) is:

$$GHV = \frac{Q}{m_1} \tag{2}$$

where m_1 –mass unit

Higher heating value (HHV) is:

$$HHV = \frac{GHV}{1 - \frac{M_{ad}}{100}} \tag{3}$$

where M_{ad} –percentage mass of water

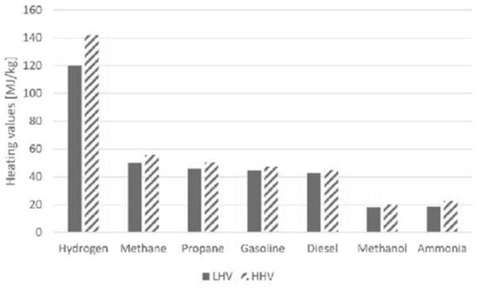

Fig. 1 Fuel heating value, [17]

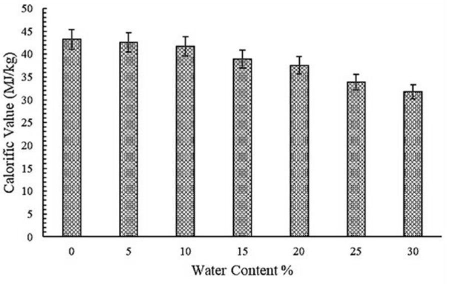

Fig. 2 Fuel heating value vs water percent, [18]

and Lower heating value (LHV), is:

$$LHV = HHV - r \cdot (W^r + 8{,}94 \cdot H_2^r) \tag{4}$$

where r –heat of vaporization of water

W^r–percentage of water in fuel

b. Overall efficiency

Overall efficiency (η_o) of a propulsion system according to [1], is the ratio between the mechanical work performed and the energy content of the fuel (see figure 3) and is given by the following the equation:

$$\eta_o = \frac{F \cdot V_0}{W_f \cdot FHV} \tag{5}$$

where F-traction

V_0-air speed

W_f-fuel flow

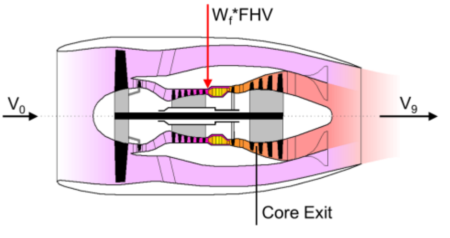

Fig. 3 Overall efficiency data, [1]

or

$$\eta_o = \frac{V_0}{SFC \cdot FHV} \tag{6}$$

where SFC – specific fuel consumption

c. Burner fuel flow (BFF)

This is determined by the air-fuel ratio and the engine air mass flow rate. The air-fuel ratio (f) is influenced by the desired outlet temperature of the combustion chamber (T_4) and the calorific value of the fuel (FHV), while the air flow rate is a design characteristic of the engine [1, 19]. The equation is:

$$f = \frac{\left(\frac{T_4}{T_3}\right) - 1}{\frac{\eta_b \cdot Q}{c_p \cdot T_3} - \left(\frac{T_4}{T_3}\right)} \tag{7}$$

where T_4*-turbine inlet temperature*
T_3*-combustor inlet temperature*
η_b*-adiabatic efficiency*
c_p*-average specific heat capacity (coefficient)*
Q-fuel heating value (FHV)

2. METHODS AND TOOLS OF ANALYSIS

GasTurb is a software tool used for numerical analysis (Figure 4) of the characteristics and operating performances of the most important constructive types of aircraft propulsion systems (turbojet, turboprop, turbo-engine, ramjet, etc.).

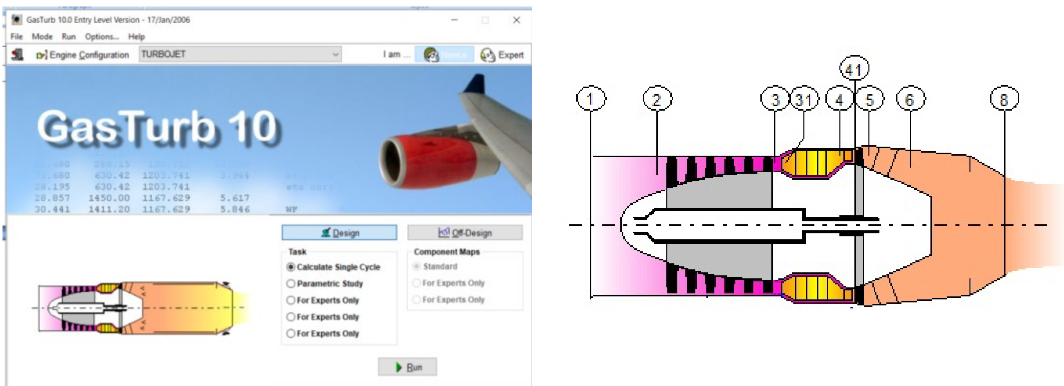

Fig. 4 GasTurb software GUI, [1]

GasTurb offers a series of modular analysis tools for: aerodynamic cycle analysis (parameter evaluations), parametric analysis (detailed analysis), off-design (analysis of the influences of external factors), fault diagnosis (cause identification analysis), [1, 10-14] or for comparative analysis of external results [15].

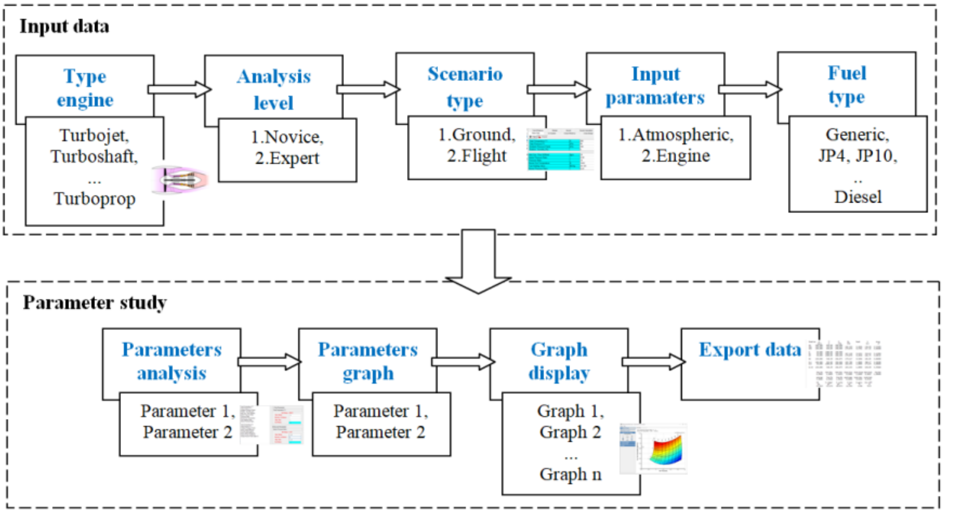

Fig. 5 GasTurb parameter analysis diagram

Detailed parametric analysis with GasTurb involves the following steps (see figure 5): selecting the engine type (e.g. turbojet, turboshaft); selecting the analysis level (e.g. basic, advanced); defining the analysis scenario (e.g. ground, in flight); entering atmospheric parameters and engine operating characteristics; selecting the fuel type (e.g. generic, JP-4, hydrogen); defining the parametric analysis values (parameter 1, parameter 2); defining the graphic export parameters (parameter 1, parameter 2); displaying the parametric graphic results; exporting numerical data.

3. PARAMETRIC ANALYSES ON THE COMBUSTION PROCESS

3.1 Input data analysis

The method instrumentation was performed with the parametric analysis module of the GasTurb software for predefined data of a theoretical turbojet engine (see table 3).

Table 3. General theoretical characteristics of turbojet engine

Parameter	Value	Parameter	Value
Total temperature T_1	280K	Total pressure P_1	99 kPa
Environmental pressure P_{amb}	100 kPa	Relative humidity	0%
Air flow	32 kg/sec	Inlet pressure	0,99
Intake pressure ratio	12	Burner exit temp	1450 K
Burner part load constant	1.6	FHV (reference)	43.124
Mechanical efficiency	0.97	Burner Pressure ratio	0.97
Isentropic compressor efficiency	0.85	Nominal spool speed compressor	14000
Isentropic turbine efficiency	0.89	Nozzle exit petal angle	20^o

To quantify the influence of combustion performance of a combustor, we used a series of input data of two groups of parameters: atmospheric and operating. These parameters are: atmospheric temperature (T1), atmospheric pressure (P1), burner design efficiency (BDE), combustion process pressure ratio (BPR), combustor outlet temperature (BET), fuel calorific value (FHV), burner fuel flow (BFF). The numerical analysis cases are indicated according to table 4.

Table 4. GasTurb numerical analysis cases

Cases	Feature 1	Feature 2	Feature 3	Goal
a	FHV	BPR	BFF	NT
b	FHV	BET	BFF	NT
c	FHV	T_1	BFF	NT
d	FHV	P_1	BFF	NT
e	FHV	BDE	BFF	NT

3.2 Software analysis cases

a. Fuel heating value (FHV)-burner pressure ratio (BPR)– burner fuel flow (BFF).

The initial data selected for numerical analysis are highlighted in Table 5.

Table 5. Parametric analysis input data BPR-FHV-BFF

Parameter	Value	Parameter	Value
Burner pressure ratio	0.64÷1	Number value/Step size BPR	10/0.04
Fuel heating value	20÷140 MJ/kg	Number value/Step size FHV	13/10
Burner fuel flow	0,2÷1,6 kg/s	Step size BFF	0,2

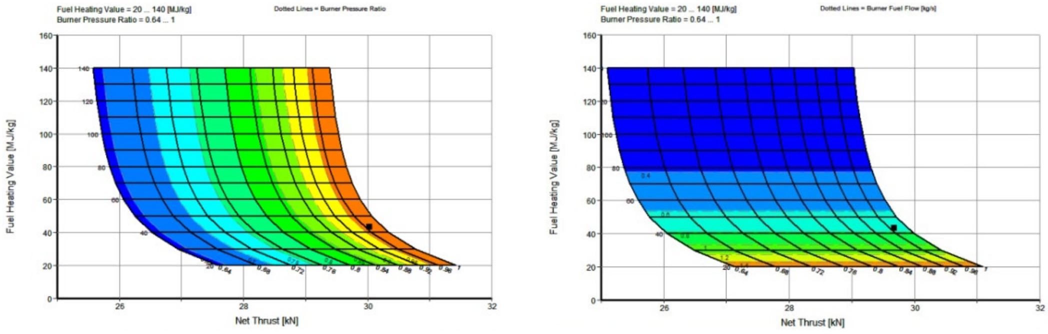

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Fig. 6 Parametric analysis: a. burner pressure ratio (BPR)–fuel heating value (FHV) vs net thrust (NT), b. burner pressure ratio (BPR)–fuel heating value (FHV)- burner fuel flow (BFF) vs net thrust (NT)

Figure 6 shows the influence of increasing burner pressure ratio, i.e. decreasing pressure losses (BPR), on increasing net thrust (NT) values, with the design point at NT=30.1 kN for BPR=0.97 and FHV=43.1 Mj/kg and the values NT_{max}=31.5 kN (fig. 6a) vs NT_{max}=31.1 kN (fig. 6b), so minimizing pressure losses (BPR) leads to increasing overall engine efficiency (NT) for a fixed value of FHV.

b. Fuel heating value (FHV)- exit temperature (BET)-burner fuel flow (BFF).

The initial data selected for numerical analysis are highlighted in Table 6.

Table 6. Parametric analysis inputdataFHV–BET-BFF

Parameter	Value	Parameter	Value
Burner exit temp	1150÷1600 °K	Number value/Step size BET	10/50
Fuel heating value	20÷140 MJ/kg	Number value/Step size FHV	13/10
Burner fuel flow	0,2÷1,6 kg/s	Step size BFF	0,2

According to figure 7, the influence of the fuel heating value (FHV) on the net thrust values is observed, with the design value of NT=30.1 kN at a burner exit temperature (BET) of T=1400k and the values NT_{max}=34.1 kN (fig. 7a) vs NT_{max}=34.0 kN (fig. 7b).

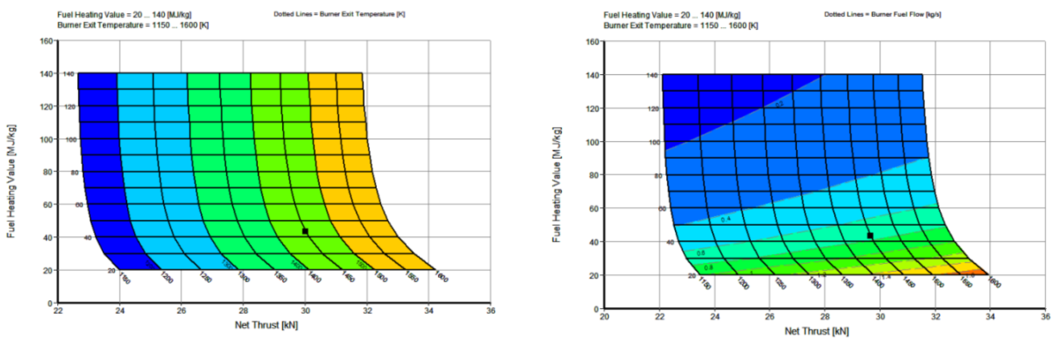

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Fig. 7 Parametric analysis: a. fuel heating value (FHV)-burner exit temperature (BET)vs net thrust (NT), b. fuel heating value (FHV)-burner exit temperature (BET)-)- *burner fuel flow (BFF)* vs net thrust (NT)

c. Fuel heating value (FHV)-temperature T_1 –burner fuel flow (BFF).

The initial data selected for numerical analysis are highlighted in Table 7.

Table 7. Parametric analysis input dataT_1–FHV-BFF

Parameter	Value	Parameter	Value
Temp T_1	250÷330 ºK	Number value/Step size T_1	5/20
Fuel heating value	20÷140 MJ/kg	Number value/Step size FHV	10/13
Burner fuel flow	0,2÷1,6 kg/s	Step size BFF	0,2

According to figure 8, the influence of the increase in temperature T_1 on the increase in net traction values is observed, with the construction point at T_1=280K for 30.1 kN and the values NT_{max}=34.2 kN (fig. 8a) vs NT_{max}=34.0 kN (fig. 8b).

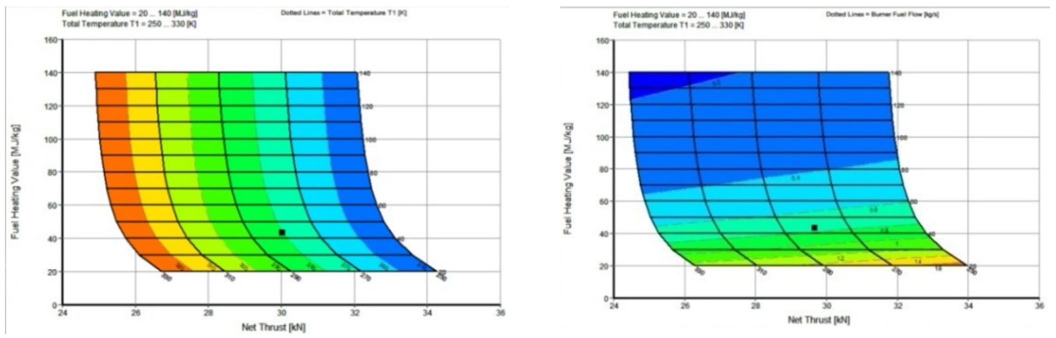

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Fig. 8 Parametric analysis: a. fuel heating value (FHV-temperature T_1 vs net thrust (NT), b. fuel heating value (FHV)-temperature T_1 –burner fuel flow (BFF) vs net thrust (NT),

d. Fuel heating value (FHV)-total pressure(P_1)–burner fuel flow (BFF).

The initial data selected for numerical analysis are highlighted in Table 8.

Table 8. Parametric analysis input data P_1– FHV-BFF

Parameter	Value	Parameter	Value
Total pressure	90÷110 kPa	Number value/Step P_1	3/5
Fuel heating value	20÷140 MJ/kg	Number value/Step size FHV	10/13
Burner fuel flow	0,2÷1,6 kg/s	Step size BFF	0,2

According to figure 9, the influence of the increase in total pressure P_1 on the increase in net traction values is observed, with the construction point at P_1=90 kPa for NT=30.1 kN and the values NT_{max}=31.5 kN (fig. 9a) vs NT_{max}=30.8 kN (fig. 9b).

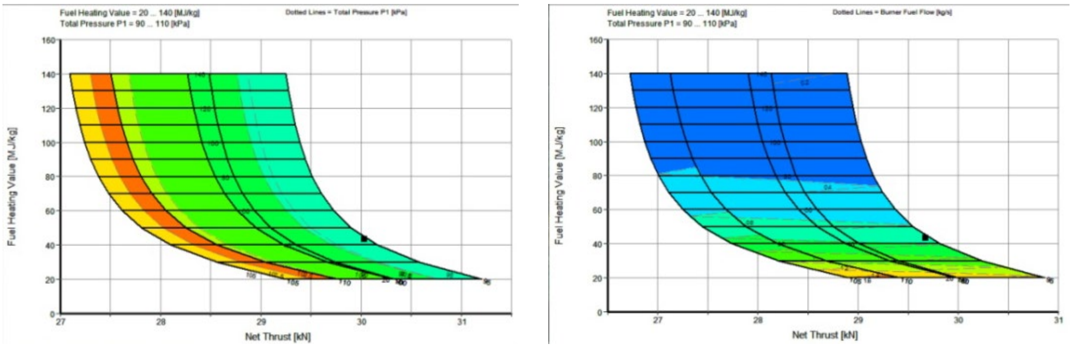

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Fig. 9 Parameter analysis: a. total pressure (P_1)–fuel heating value (FHV) vs net thrust (NT),
b. total pressure (P_1)–fuel heating value (FHV)-burner fuel flow (BFF) vs net thrust (NT)

e. Fuel heating value (FHV)-burner design efficiency (BDE)– burner fuel flow (BFF).

The initial data selected for numerical analysis are highlighted in Table 9.

Table 9. Parametric analysis input data BDE-FHV-BFF

Parameter	Value	Parameter	Value
Burner design efficiency	0.6÷1	Number value/Step size BDE	5/0.1
Fuel heating value	20÷140 MJ/kg	Number value/Step size FHV	10/13
Burner fuel flow	0,2÷1,6 kg/s	Step size BFF	0,2

According to figure 10, the influence of the increase in the combustion chamber design efficiency (BDE) on the net thrust (NT) values is observed, with the design point at BDE=1 for NT=29.7 kN and the similar values NT_{max}=32.4 kN (Fig. 10a and Fig. 10b).

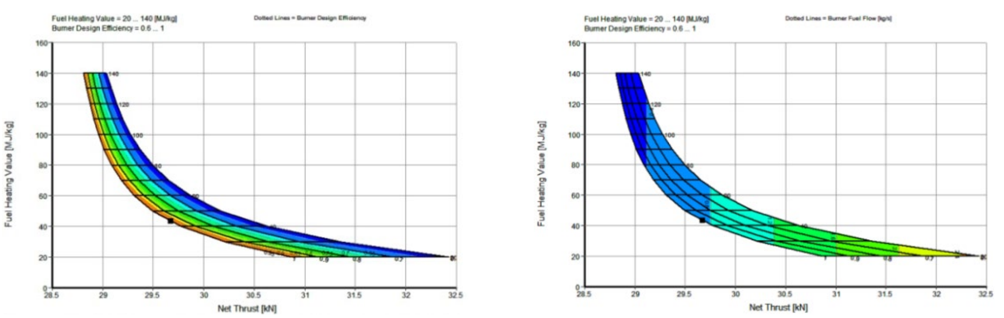

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Fig. 10 Paramatric analysis: a. fuel heating value (FHV)–burner design efficiency (BDE) vs net thrust (NT) b. a. fuel heating value (FHV) – burner design efficiency (BDE) - burner fuel flow (BFF) vs net thrust (NT)

3.3 Parametric numerical results

Numerical simulations performed based on the selected construction parameters and analysis conditions generated the results according to Figure 11. As expected, all parameters considered have an influence on the maximum net traction (NT_{max}) values compared to the reference values of the construction points (figure 11a).

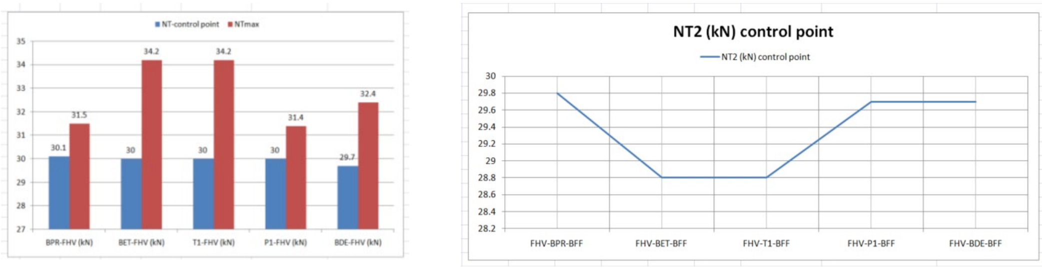

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Fig. 11 Comparative data of parametric analyses, a. NT construction point vs NT_{max},
b. NT_2construction point input parameter

Figure 11b shows variable influences (1kN difference) on the net thrust values (NT_{max}) by the imposed secondary parametric conditions (burner pressure ratio-BPR, burner exit temperature-BET, parameters at section 1-T_1 and P_1, burner design efficiency-BDE).

Figure 12 shows the variation of the influence of the secondary parameters on the 5 analysis cases. The large differences in the tensile values can be observed when the temperature T_1 is involved (value variation of 15%).

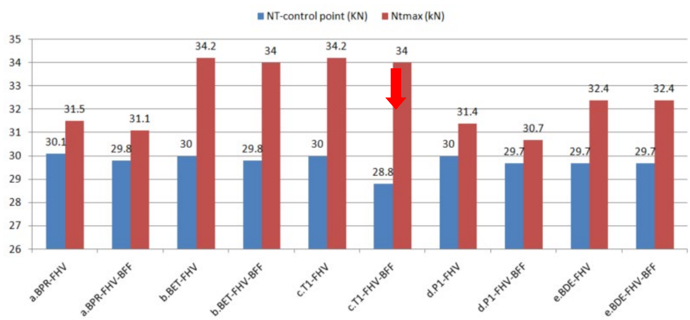

Fig. 12 Comparative data of parametric analyses, NT construction point vs NT_{max}, (5 cases)

4. CONCLUSIONS

The analysis of combustion processes in turbojet engine combustors can be instrumented using numerical simulation methods based on 1D system models (mass and energy estimation) even if they provide few details about local phenomena in the combustion chamber.

The study focused on the analysis of the influence of fuel types (through FHV, BPR, BET, T1, P1, BDE values) on the net thrust (NT) values. The paper provides numerical data on the influence of FHV values that are exposed in 5 analysis cases based on 2 or 3 parameters. The numerical analyses provide an initial perspective of the influence of FHV values on the performance of a theoretical turbojet engine together with a series of secondary parametric factors that augment the maximum net thrust (NT_{max}) value.

To increase the reliability of the results of numerical simulations, with the help of GasTurb, it is necessary to substantiate multiple parametric simulations that take into account the use of both the characteristics and performances of real propulsion systems and the technical specifications of biofuels.

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REFERENCES

[1] * * * GasTurb 13 Design and Off-Design Performance of Gas Turbines, *GasTurb GmbH*, 344p, available at https://www.gasturb.de/Downloads/Manuals/GasTurb13.pdf, 2018.

[2] Rui Xu et all, Thermochemical properties of jet fuels p.23, available at https://web.stanford.edu/group/haiwanglab/HyChem/approach/Report_Jet_Fuel_Thermochemical_Properties_v6.pdf, 2025.

[3] * * * Hydrogen Tools, available at https://h2tools.org/hyarc/calculator-tools/lower-and-higher-heating-values-fuels, accessed at 12.04.2025.

[4] T. J. Bruno et all., Thermodynamic, transport and chemical proprieties of reference JP-8, NUSTIR 6659, National Institute of standards and technology, 152p., 2010 https://www.nist.gov/publications/thermodynamic-transport-and-chemical-properties-reference-jp-8

[5] * * * Aviation fuels. Technical review, Chevron, Products Company, available at https://www.chevron.com/-/media/chevron/operations/documents/aviation-tech-review.pdf, accessed at 16.04.2025, 2007.

[6] * * * Aviation fuel, *Shell and MOH Aviation v.1*, available at https://www.shell-moh.com/uploads/media_items/msds-in-english.original.pdf, accessed at 16.04.2025, 2021.

[7] X. Wang, T. Jia, L. Pan, *et al.*, Review on the Relationship Between Liquid Aerospace Fuel Composition and Their Physicochemical Properties, *Trans. Tianjin Univ,* **27**, 87–109 https://doi.org/10.1007/s12209-020-00273-5, 2021.

[8] * * * Natural gas calorific value calculator, available at https://www.unitrove.com /engineering/tools/gas/natural-gas-calorific-value, accessed at 18.04.2025, 2025.

[9] * * * J. T. Edwards, Jet fuel properties, AFRL-RQ-WP-TR=2020-0017, (Fuels & Energy Branch / Turbine Engine Division), Air Force Research laboratory, available at https://apps.dtic.mil/sti/pdfs/AD1093317.pdf, 2020.

[10] Y. S .M. Altarazi, Abd Rahim Abu Talib, E. Gires, J. Yu, J. Lucas, T. Yusaf, Performance and exhaust emissions rate of small-scale turbojet engine running on dual biodiesel blends using Gasturb, *Energy,* Volume **232**, 120971, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2021.120971, 2021.

[11] J. Kurzke, Starting and wind milling simulations using compressor and turbine maps, *Journal of the Global Power and Propulsion Society,***7**: 58–70. https://doi.org/10.33737/jgpps/159372, 2023.

[12] R. Agbadede & B. Kainga, Performance and Techno-Economic Analysis of Inlet Fogging System Implementation in Heavy Duty Industrial Gas Turbines, *International Journal of Thermodynamics*, **24**. 75-81. 10.5541/ijot.782485, 2021.

[13] R. Agbadede & I.Allison, Techno-economic and Performance Analysis of Associated Gas Utilization in Gas Turbines. **2**. 34-42, 2020.

[14] V. Prisacariu, A. Tudosie. Consideration regarding jet engine combustor parameters, *REVIEW OF THE AIR FORCE ACADEMY*, **1**(45), Braşov, Romania, ISSN 1842-9238; e-ISSN 2069-4733, pp.53-62, DOI: 10.19062/1842-9238.2022.20.1.6, 2022.

[15] M. Razmjooei & F. Ommi &Z. Saboohi, Experimental Analysis and Modeling of Gas Turbine Engine Performance: Design Point and Off-Design Insights through System of Equations Solutions, *Results in Engineering*, **23**, https://doi.org/10.1016/j.rineng.2024.102495, 2024.

[16] M. Kalivodová & M. Balas & P. Milčák & H. Lisá & M. Lisý & J. Lachman & P. Kracík &P. Križan & K. Vejrazka, Determination of Higher Heating Value by calculation based on elemental analysis, *Paliva*, 8-20, 10.35933/paliva.2022.01.02, 2022.

[17] D. Hjeij & Y. Bicer & M. Koç, Hydrogen strategy as an energy transition and economic transformation avenue for natural gas exporting countries: Qatar as a case study, *International Journal of Hydrogen Energy*,**47**. 4977-5009. 10.1016/j.ijhydene.2021.11.151., 2022.

[18] H. Alahmer & A. Alahmer & R. Alkhazaleh & M. Alrbai & M. Al-Amayreh, Applied Intelligent Grey Wolf Optimizer (IGWO) to Improve the Performance of CI Engine Running on Emulsion Diesel Fuel Blends. *Journal of Fuels,* **4**. 35-57. 10.3390/fuels4010004., 2023.

[19] * * * Fuel Mass Flow. Glen Research Center, available at https://www.grc.nasa.gov/www/k-12/airplane/fuelfl.html, accessed at 02.06.2025.