IOP Conference Series: Materials Science and Engineering, Volume 642, Number 1, 2019
DOI: 10.1088/1757-899X/642/1/012008

Investigation of aircraft engine performance utilizing various alternative fuels

Mahammadsalman Wariman[1], Azami M.H[2], Mark Savill[3], Yi-Guang Li[4], S. A. Khan[5], Ahmad Faris Ismail[6]

[1,2,5,6]Department of Mechanical Engineering,IIUM,Kuala Lumpur,Malaysia
[3,4] Centre for Propulsion Engineering, Cranfield University, United Kingdom

Corresponding author e-mail:hanafiazami@iium.edu.my

Abstract. The airlines are subjected to the energy crisis and have raised environmental issues at the same time. Future engine technology advances could decrease the effect on the environment and energy consumption. Alternative fuelspotentially assist in the reduction of engine emissions and hence lower the energy-related issues. This study presents analysis of the efficiency of aircraft engines as a function of thrust force, flow of the and specific fuel consumption (SFC) at distinct mixing ratios (40% and 100%)of African natural gas, Algae, Camelina, Jatropa, Diesel, Hydrogen, Synthetic paraffinic kerosene, UK natural gas at cruising altitude. In – house Cranfield University simulation codes, PYTHIA & TURBOMATCH have been used to investigate and model a three-shaft high bypass engine analogous to RB211 - 524. The engine model has been certified and authenticated in commercial aircraft with open works found in the Bio - Synthetic Paraffinic Kerosene test program.Blended fuel of Kerosene & hydrogen (KE+HY) fuels gives values of 331.6 KN,1.2577KG/S, and 6.9512 kg/kwh for net thrust force,the flow of fuel and specific fuel feastingat mingling ratio of 40 % respectively. However, at mixing ratio of 100% Blended fuel of Kerosene & hydrogen (KE+HY) fuels gives values of 339.01 KN, 0.800KG/S, and 4.333 kg/kwh for net thrust, fuel flow, and specific fuel consumption respectively.It is found that blended fuel of Kerosene &hydrogen (KE+HY) fuels give better engine performances as compared to other alternative fuels. However, Kerosene &diesel (KE+DI) fuels have shown a slight reduction in engine performance.

1. Introduction

A biofuel is a fuel material derived from renewable biomass resources that are widely used as an alternative, cleaner fuel [1].It isdescribed as a fuel composed of long-chain mono-alkyl esters of renewable fatty acids which can be generated by a chemical procedure called transesterification [2].Various liquid biofuels such as biodiesel, bio-ethanol, and bio-oil can be produced from biomass. Biomass was converted into distinct kinds of fuel using thermo-chemical and bio-chemical paths [3].Bio jet fuels consist of a blend of C9–C16 hydrocarbons typically created through transesterification and later hydroprocessing of plant and animal oils to generate fuel with many of the characteristics of petroleum-derived jet fuels [4]. Jatropha, Camelina, and Algae are promising plant-based feedstocks for future aviation biofuels [4].Microalgae have a significant stake in producing biofuels of the next generation that are indistinguishable based on their characteristics from petroleum fuels. This is because the use of microalgae to produce biofuels would have less adverse effects on food supply and other agriculture as they can be grown on non-arable soil using fresh, waste or saline water sources and allow more effective recycling of nutrients and greater productivity [7]. Green (Chlorophyta), red (Rhodophyta), and brown algae (Phaeophyta) are the most prevalent form of algae. Because of the high lipid content, green microalgae are more appropriate for biofuel manufacturing than other microalgae [8].As we understand, aircraft use has proliferated over the past few years. More than six billion individuals travel around the globe each year by aircraft [5].In the past decade, there has been a huge growth of technology in the direction of alternative fuels. Aircraft can be fueled with synthetic jet fuels or jet biofuels nowadays [6].However, the demand for fuel in the world has risen gradually every day, owing to fast population growth [7]. According to literature, petroleum consumption in 2012 was estimated at 89 million barrels per day across the globe, and nearly half of this was used in gasoline manufacturing [8]. The oil resources are expected to run out at this pace in the next 50 years [8].H. D. Banu *et al.*[9].Reported that at current rates of consumption, it is estimated at a 95% probability that the worlds remaining oil resources will last 63 years and a 5% chance that they will last 95 years. Research on alternative aircraft fuels is therefore of paramount significance for the long term [9].As oil fossil fuel decrease or a significant carbon tax on fossil fuels is imposed globally, liquid fuels from biomass-based on carbon will become widely competitive [10]. Growth in fuel usage rises by around 2.9% annually, in aviation fuels by around 4%[11]. It is projected that crude oil production will be maximum in 2020. Total emissions of carbon dioxide are expected to rise by more than 60%[11].Depleting fossil fuels and pollution induced by the combustion of petroleum base makes the world look to renewable energy as an alternative fuel to meet energy demand for economic development [12].The aviation sector is researching fuel availability issues in response to increasing environmental needs [13]. It is advisable to generate energy from renewable sources such as solar, hydro, tidal, wind, biomass and geothermal power that do not produce environmentally pollution and are accessible in large quantities [14].One of the most significant study subjects is the search for an alternative fuel independent of carbon-based fossil fuels [15]. Alternative fuels were suggested as one of the alternatives to decrease the greenhouse gas (GHG) footprint of aviation [16].It is possible to convert agricultural, industrial and domestic waste into biodiesel, biogas using various methods [17].Biofuel's usefulness in aerospace fuel these days owing to biofuel characteristics. Biofuel will be commonly used in the near future as an aviation fuel [18].Biofuels are other alternative kinds of fuel to decrease worldwide emissions [5]. These energy resources give a number of benefits over non-renewable fossil fuels [8].The benefits of using biofuels would be their balanced effect CO_2on the environment and their ability to become a sustainable fuel.Their use can also lead to reduced emissions from the engine.If sustainability, efficiency, and cost liabilities can be overcome, the aim is to mix biofuels with synthetic jet or Jet-Aviation fuels [19].Synthetic jet fuels are produced from coal, gas, or other hydrocarbon feed stocks using a Fischer-Tropsch process. The efficiency of these fuels is very comparable to standard jet fuel, but they contain almost zero sulfur and aromatics. This may lead in reduced exhaust emissions. Furthermore, synthetic fuels have outstanding low temperature characteristics, keeping low viscosity at reduced ambient temperatures[19]. The primary motivation for this research has provided rise to a desire for more secure fuel supplies for aircraft in the future from renewable and sustainable energy sources obtained from renewable fuel sources.

2. Previous works on alternative fuels

Previous laboratory and ground test experiments using bio-based fuels or synthetic Fischer – Tropsch fuels generated from natural gas and coal feedstocks indicate that the lack of sulfur and aromatic species in the fuel significantly decreases airplane engine sulfate and black carbon emissions[4].M. Z. W. Yahya *et al.*analyzed liquid hydrogen and found that hydrogen is better than kerosene fuel. The hydrogen performs better in term of performance and also in reducing overall emission [20].M. H. Azami *et al.* proved that biofuels based on jatropha are one of the most potential plants in biofuels [21].A. J. Beyersdorf *et al.* used conventional oil JP-8 fuel, pure synthetic fuels generated from natural gas and coal feed stocks using the Fischer–Tropsch (FT) method, and 50% of both fuel mixtures were tested on a DC-8 airplane in the CFM-56 motors. A positive effect of alternative jet fuels is a reduction in particulate and gas emissions [22].M. H. Azami *et al.* showed that Jatropha biofuel works much better in gross thrust, fuel flow, and SFC than camelina biofuel[22].X. Hui *et al.* in there research utilized conventional Jet-A and six alternative jet fuels, including three Fischer – Tropsch Synthetic Paraffinic Kerosene (SPK) fuels and three Hydrotreated Renewable Jet (HRJ) fuelsand tested to acquire their basic combustion properties[23].R. O. Price *et al.* researched the use of liquid hydrogen as a replacement commercial aviation fuel offering enhancement in air quality [24].Two kinds of fuel were tested by B. Gawron *et al.* Aviation fuel (Jet A-1) and a combination of aviation fuel with HEFA synthetic element (hydro-processed esters and fatty acids) from camelina feedstock [25].S. B. Amgad *et al.* showed that FT jet fuel from natural gas, coal, and biomass.Bio-jet fuels from fast pyrolysis ofbiomassand hydro processed renewable jet fuel from vegetable and algal oil reduced emission[26].Mohdnoh *et al.* reviewed that enhanced composition in bio-jet fuel to be compared with conventional fuel creating more advantages in term of carbon emissions, fuel efficiencies, components wear andtear and reduction in fuel cost and maintenance in prolong future [27]. Fig.1displays the relative CO_2 emissions generated by different fuels during their life cycles, using present jet fuel as the basis. FT fuels can only be regarded a feasible alternative to petroleum if the CO_2 emissions produced during manufacturing can be captured and sequestered continuously [19].Achieving deep CO_2 reductions will also require a shift to very low-carbon energy carriers, of which the three most likely to play a prominent role are electricity, biofuels, and hydrogen [28]. Sustainable bio-jet fuels are a promising route for mitigating greenhouse gas emissions [4].

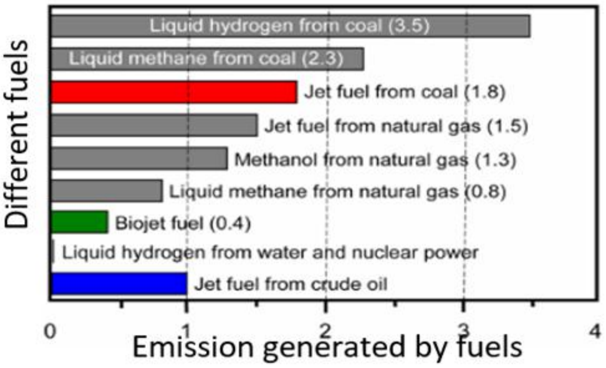


Fig. 1: Co_2 emission by different fuels (JET A) [19].

3. Present work

This research emphasizes the effect of mixed alternative fuels on the effectiveness of aircraft engines specifically on gross thrust, and specific fuel ingestion (SFC) at distinctly mixed mixing ratio percentages. Alternative fuels such as African natural gas, Algae, Camelina, Jatropa, Diesel, Hydrogen, Synthetic paraffinic kerosene, UK natural gas biofuel are evaluated blended with kerosene (C_12 H_24) at 40% and 100%. Engine model RB211-524 was used for verification during the evaluation using available engine constraints.Authentication of a variant RB211 and comparison is done with Rahmes et al. research work [29]. For computational analysis, our native code was used.PYTHIA uses a modified Newton-Raphson convergence method is used for designing and PYTHIA is also used in the zero-dimensional steady-state modelto compute numerous gas turbine devices for both design and off-design themes.It can also assist as ananalyticaldevice for examining deterioration and enables map scrambling for off-design situations. PYTHIA is united with our actassessment program TURBOMATCH. PYTHIA demands for the TURBOMATCH program FORTRAN-coded to reiterate the energy & mass equilibriumof every engine constituent. PYTHIA is easy to use and has a newengine component choicefor the interface. PYTHIA is the abilityofindustrialized gas turbines to aero-gas turbines has been assessed &validated for many years. The newestform of PYTHIA can change the type of fuel &the ratio of amalgamatedfraternization ratio while preserving the same engine design as the conventional kerosene.This is crucial if fit for use fuels for the actual engine at different working points are to be evaluated. This research can, therefore, serve as an expansion of work of Azami, M.H.*et al.* [30]. Work using a previous form of PYTHIA that for original design conditions could only provide comparison for separate pure fuels. These latest findings not only support earlier outcomes but also go beyond them as more abilities have been put in new PYTHIA variant, such as assessing added alternate fuel choices under separate off-design circumstances.

4. Methods

The RB211-524 engine is selected for research. From library data of PYTHIA selected engine configuration was specified and arrangements made for defaulting situations. The classical engine arrangements are shown in Fig. 2. Kerosene is selected as a baseline fuel. Each engine model component is labeled as a brick and has its own functionality. The inputs were allocated in the INTAKE brick, agreeing to the suggested flying requirements such as altitude, flight velocity, mass flow, pressure recovery, deviation of pressure, and relative humidity. For the pressure ratio is 2.0, and the stator angle is 10o for the first compressor, the maximum for the first compressor, the maximum pressure ratio is 2.0, and the stator angle is -10 °. The previous HP compressors have a maximum pressure ratio of 11.0 with stator angle of -10o. But it is anticipated that only the HP compressors will have bleeding air. By setting the complete relate variations of mass movement and overall pressure, PREMAS bricks are used to determine the outlet circumstances of parts such as splitters, bleeds, bypass ducts or jet pipes. The burner does not have water flow. In the meantime, MIXEES brick is used to determine the outlet circumstances causing from steady two-flow blending without the total pressure loss allowance & after TURBINE brick information, MIXFUL brick data is used to calculate outlet requirements from steady mixing area flows with total allowance for complete pressure shift due to momentum equilibrium. The 0.04 ratio of the maximum enthalpy drop and the turbine inlet temperature for all turbines is set at 1580K. These turbines also have a 10o angle position and are choked at low velocity. The NOZZLE brick selects a convergent nozzle. Tabulated in Table 1, the engine parameter results, and the baseline fuel efficiency. The PYTHIA method flowchart is presented in Fig. 3. It starts with inputs defined by the user. TURBOMATCH is called for reiteration in mass & energy balance relation (i.e., Eq. 1 & 2). Equations must and should be contented between consecutive apparatuses. Before the iteration method, values for pressure ratio, temperature, and rotation swiftness must be guessed. A high-level computer programming language FORTRAN is used to code TURBOMATCH. TURBOMATCH is Cranfield's software for Gas Turbine Performance Simulation. For the method of mass balance iteration, compressor and turbine maps were required. For the assessment of thermochemical fuel characteristics, NASA Chemical Equilibrium Analysis (CEA) is used. In the TURBOMATCH library information, these correlations are stored. Before the iteration method converges, several guess values will be required. Finally, the data were performed and submitted for data analysis to the Excel spreadsheet. Table 1 shown the design condition for the engine parameters and performance utilizing kerosene fuel as the baseline. These values are obtained through iterations for every brick used in the schematic diagram (Fig. 2).

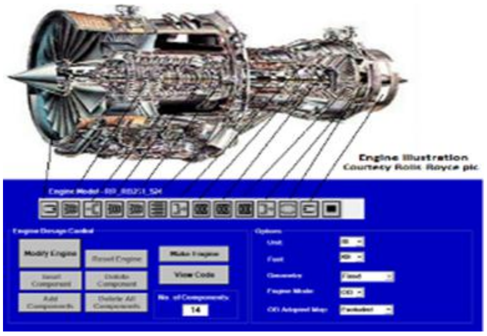


Fig. 2: PYTHIA engine model schematic diagram.

Table1. Engine performance and parameters for baseline fuel.

INTAKE		COMBUSTORS		TURBINE				NOZZLE		ENGINE PERFORMANCE	
Altitude (m)	10588	Efficiency	0.99		1	2	3	Area (m²)	2.25	Bypass Pressure Ratio	4.3
Intake of mass flow (kg/s)	670	Drop in pressure (atm)	1.29	Efficiency	0.91	0.92	0.92	Exit Velocity (m/s)	394.0	Gross Thrust (kN)	293.38
Relative Humidity (%)	60	Flow of fuel (kg/s)	2.18	T_{total}(K)	1580	1499	1240	Nozzle Coefficient	0.98	Specific Thrust (N/kg. s)	154.71
Momentum Drag (kN)	189.72	LHV (MJ/kg)	43.12	P_{total}(atm)	31.04	31.04	12.44	T_{total}(K)	464.39	Fuel Flow (kg/s)	2.18
Flight Mach Number	0.84	P_{total}(atm)	31.04	Mass flow rate (kg/s)	112.18	128.61	128.61	P_{total}(atm)	1.58	SFC (kg/N. s)	21.07
		Fuel-to-air Ratio	0.02								

$$\frac{W_n\sqrt{T_n}}{P_n} = \frac{W_{n+1}\sqrt{T_{n+1}}}{P_{n+1}} \quad (1) \qquad TurbineWork(TW) = CompressorWork\,(CW)$$

(2)

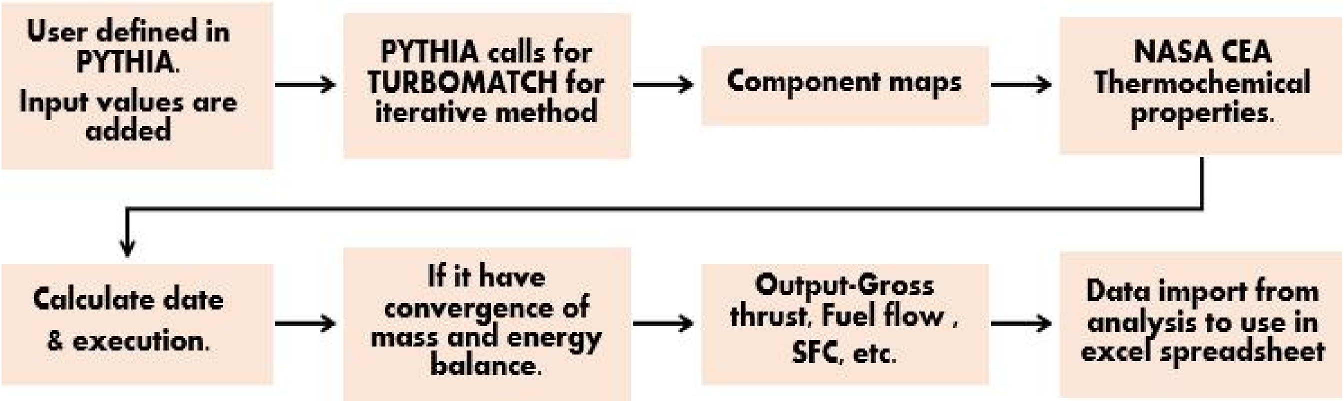


Fig. 3.PYTHIA data process flowchart.

5. Results

Fig.4 shows a list of legends used for all graphs described below.

Fig. 4: Legends considered for all graphs shown in paper

5.1. *Varying flight conditions*

The INTAKE block diagram is modifiedto define the flight conditions difference in off-design automatically.This is achieved by changing the speed of the flight. PYTHIA is programmed for various flight circumstances at off-design points.

5.2. *Gross thrust at various mixing ratio at different Mach number*

This portion describes the impacts of mixing 40% and 100% on engine enactment at the sailingcondition. As illustrated in below figures which shows the difference in gross thrust and proportionvariance as related to the baseline fuel. As shown in Fig5. KE+HY shows the maximum value of 331642.4 N gross thrustsmonitored by KE+UKNG and KE+BJ320760.2 N and 317844.7 N at Mach number 0.8 The minimum value of 212735.5N gross thrust shown by KE +DI. And, there is no much gross thrust value difference between KE+AG, KE+BC, KE+BJ. At this gross thrust, there is no considerable percentage difference of fuel with respect to KE.In Fig. 6, the KE+HY shows the maximum value of 339018.66 N gross thrusts followed by KE+UKNG and KE+AFNG of value 325625.4 N & 322372.99 N. The minimum value of gross thrust is shown by KE +DI of value 212554.1N. And, there is no much gross thrust value difference between KE+AG, KE+BC, KE+BJ. In all mixing ratios percentage difference with respect to KE goes on increasing as speed increases. Finally, KE +HY shows the highest increment of gross thrust at a speed of 0.8.

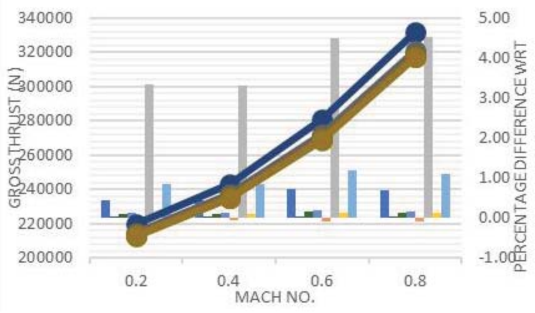


Fig.5: Variation of gross thrust at 40% mixing ratios.

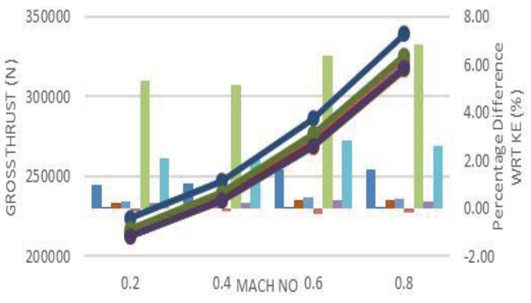


Fig.6: Variation of gross thrust at 100% mixing ratios.

5.3. *Fuel flow at various mixing ratio at different Mach number*

This portion describes the impacts of mixing 40% and 100% on engine enactment at conditions the sailing flight. The ambient and flight circumstances are shown in the below figures, which shows fuel flow difference and fraction variance as related to the standard fuel. As shown in Fig.7. The maximum value of 2.2756KG/S fuel flows at the mixing of 40% shown by the KE+DI followed by KE+AG 2.2696KG/S. The lowest value of fuel flow is by KE +HY and KE+AFNG of value 1.2577& 1.933KG/S.

Fig.8 shows the Maximum value of 2.2888KG/S fuels flows at the mixing of 100% as shown by KE+DI followed by KE+AG 2.2737KG/S. The lowest value of fuel flow is by KE +HY 0.8009 KG/S and KE+AFNG 1.8031KG/S of value. In both different mixing ratios, fuel flow is almost linear at various speeds. There is a slight decrease in fuel flow at the highest speed flow of 0.8. And, the percentage difference with respect to KE goes on increasing as the mixing ratio increases.

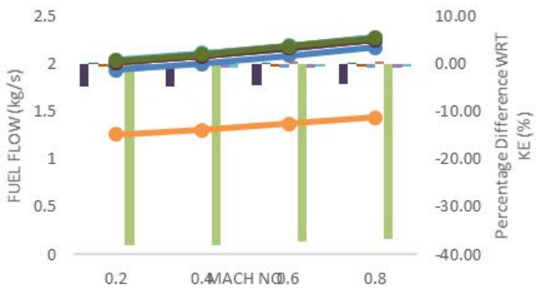


Fig. 7: Variation of fuel flow at 40% mixing ratios.

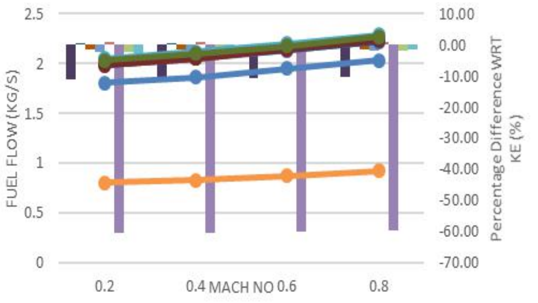


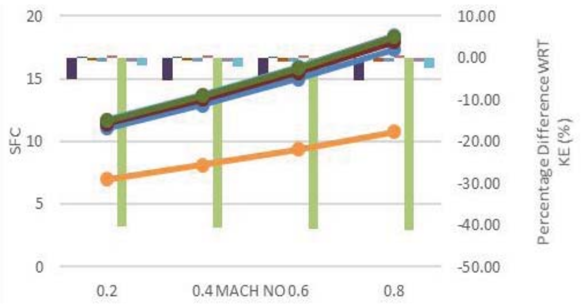
Fig. 8: Variation of fuel flow at 100% mixing ratios.

5.4. SFC atvarious mixing ratio at differentMach number

This portion describes the impacts of mixing of 40% and 100% on engine show at conditionsof the sailing flight. The ambient and flight situations are shown in the below figures, which present the specific fuel consumption deviation and proportion difference as related to the standardfuel. As shown in Fig. 9, the maximum value of SFC Shown by KE +DI 18.4338 KNfollowed by KE+AG18.3593KN&KE+BC 18.1914 KN. The lowest value of 6.9512 KN SFC shown by KE+HY.And, as shown in Fig. 10. The maximum value ofSFC Shown by KE +DI18.5775 KN followed by KE+AG18.39 KN &KE+BC17.9758KN of value. The lowest value of 4.3333 KN SFC showed by KE+HY. In both cases, SFC goes on increases as speed increases. There is no much difference in SFC of KE+AFNG, KE+AG, KE+BC, KE+BJ, KE+SPK, KE+UKNG.Test conducted on various biofuel mixtures like African natural gas, algae, camelina, Jatropa, diesel, hydrogen, synthetic paraffinic kerosene, UK natural gas at an altitude of 2000 feet. Table 2. shows in brief results of fuels which given highest &lowest values for gross thrust, fuel flow, specific fuel consumption. From this work, it is investigated that blended fuel of Kerosene & hydrogen is the best alternative fuel option and Kerosene + diesel not shown good results for net thrust, and specific fuel ingesting. To generate more gross thrust 100% mixing of Kerosene & hydrogen is recommended. For fuel flow & specific fuel feeding, 40% mixing of kerosene & hydrogen gives excellent results comparatively.

Table 2. Maximum &minimum values of gross thrust, fuel flow &specific fuel consumption with respect to base line fuel.

Performance Parameters	Blended Ratio Percentage	Maximum diff in % from base line fuel		Minimum diff in % from base line fuel	
Gross thrust (KN)	40%	KE+HY	4.51	KE+DI	-0.09
	100%	KE+HY	6.83	KE+DI	-0.22
Fuel flow KG/S	40%	KE+HY	-38.04	KE+DI	0.42
	100%	KE+HY	-60.54	KE+DI	1.06
Specific fuel consumption (SFC) kg/kwh	40%	KE+HY	-40.51	KE+DI	-0.52
	100%	KE+HY	-63.62	KE+DI	1.3



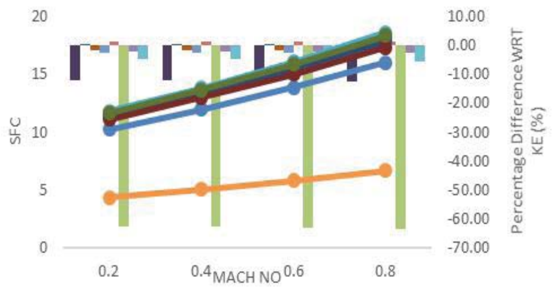


Fig. 9: Variation of SFC at 40% mixing ratios. **Fig. 10:**Variation of SFC at 100% mixingratios.

6. Conclusion

The present study has investigated the impact of mixed biofuels on the efficiency of airplane engines in particular on net thrust, the flow of fuel and specific fuel consumption (SFC) at a different speed and at two fraternization ratios. Three biofuels-Algae, Jatropha and Camelina are assessed as a clean fuel and mixed with kerosene($C_{12}H_{24}$) at 40% and 100%. The outcomesshowed that the reduced fuel heating value had a significant impact on engine such as thrust, fuel flow, and SFC at variousblended mixing ratio at altitude 2000 feet. Pure alternative fuels for two mixingratios at altitude 2000 feet were evaluated. KE+HY fuels showed a considerablyimproved engine performance as correlated to all the biofuels. KE+DIfuels presented a very less engine enactment asmatched to all the biofuels.

Acknowledgment

The corresponding author would like to thank and acknowledge International Islamic University Malaysia for the FRGS Grant (FRGS19-063-0671) for this research project.

References

[1] Costa JF, Almeida MF, Alvim-ferraz MCM, Dias JM. Biodiesel production using oil from fish canning industry wastes. Energy Convers Manag 2013;74:17-23. doi:10.1016/j.enconman.2013.04.032.
[2] Giakoumis EG, Rakopoulos CD, Dimaratos AM, Rakopoulos DC. Exhaust emissions of diesel engines operating under transient conditions with biodiesel fuel blends. Prog Energy Combust Sci 2012;38(5):691-715. doi:10.1016/j.pecs.2012.05.002.
[3] Fadhil AB, Ahmed AI, Salih HA. Production of liquid fuels and activated carbons from fish waste.

Fuel 2017;187:435-445. doi:10.1016/j.fuel.2016.09.064.

[4] Moore RH, Thornhill KL, Weinzierl B, et al. Biofuel blending reduces particle emissions from aircraft engines at cruise conditions. Nature 2017;543(7645):411-415. doi:10.1038/nature21420.

[5] Baharozu E, Soykan G, Ozerdem MB. Future aircraft concept in terms of energy efficiency and environmental factors. Energy 2017;140:1-17. doi:10.1016/j.energy.2017.09.007.

[6] Zhukov VP, Sechenov VA, Starikovskiy AY. Autoignition of kerosene (Jet-A)/air mixtures behind reflected shock waves. Fuel 2014;126:169-176. doi:10.1016/j.fuel.2014.02.036.

[7] Yesilyurt MK. The effects of the fuel injection pressure on the performance and emission characteristics of adiesel engine fuelled with waste cooking oil biodiesel-diesel blends. Renew Energy 2019;132:649-666. doi:10.1016/j.renene.2018.08.024.

[8] Banu HD, Shallangwa TB, Joseph I, Magu TO, Hitler L, Ahmed S. Biodiesel Production from Neem Seed (Azadirachta indica) Oil Using Calcium Oxide as Heterogeneous Catalyst. J Phys Chem Biophys 2018;8(2):8-10. doi:10.4172/2161-0398.1000266.

[9] Ebbinghaus A, Wiesen P. Aircraft fuels and their effect upon engine emissions. Air Sp Eur 2002;3:101-103. doi:10.1016/s1290-0958(01)90026-7

[10] Openshaw KA review of. A review of Jatropha curcas: an oil plant of unfulfilled promise. Biomass Bioenergy 19 2000;19:1-15.

[11] Pągowski Z. New perspectives for biofuels in aviation. J KONES Intern Combust Engines 2003;10:1-4. http://ilot.edu.pl/KONES/2003/3-4/28.pdf.

[12] Mechanics A. feasibility study of pulse detonation engine fueled by biogas. Appl Mech Mater 2013;388:257-261. doi:10.4028/www.scientific.net/AMM.388.257

[13] Daggett D, Hadaller O, Hendricks R, Walther R. Alternative Fuels and Their Potential Impact on Aviation. In: The 25th Congress of the International Council of the Aeronautical Sciences (ICAS) 2006:1-8. doi:10.1016/j.vetpar.2012.01.033.

[14] Kirubakaran M, Arul Mozhi Selvan V. A comprehensive review of low cost biodiesel production from waste chicken fat. Renew Sustain Energy Rev 2018;82:390-401.

[15] Jun Li, Hongyu Huang, Noriyuki Kobayashi ZH and YN. Study on using hydrogen and ammonia as fuels: Combustion characteristics and NOx formation. Int J energy Res 2013;32(32):336-355. doi:10.1002/er.

[16] Pfaender H, Payan AP, Mavris DN. Long-term Alternative Fuels Scenarios. In: AIAA/3AF Aircraft Noise and Emissions Reduction Symposium AIAA2014:1-18. doi:10.2514/6.2014-3165.

[17] Warimani M, Azami MH, Khan SA, Ismail AF. Study Of Feasibility Of Pulse Detonation Engine Powered By Alternative Fuels. Int J Eng Adv Technol 2019;8(January):291-296.

[18] Shimada T, Hayashi AK, Yamada E, Tsuboi N. Numerical Study on Detonation Characteristics Using a Bio-Fuel. In: 49th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition 2011:1-11. doi:10.2514/6.2011-582.

[19] Daggett Hendricks, R.C., Walther, R., Corporan, E. DL. Alternate fuels for use in commercial aircraft. In: 18th ISABE Conference September 2007:1-21.

[20] Yahya MZW, Azami MH, Savill M, Li Y, Khan SA, Salman M. Modelling of a Three - Shaft High - Bypass - Ratio Engine Performance and Emission Prediction Using Hydrogen Fuels. Int J Innov Technol Explor Eng. 2019;8(6S3):484-490.

[21] Azami MH, Noorazman Z, Savill M, Li YG, Hilmi MR. Modelling the performance and emission prediction of RB211 aero-gas turbine engine fuelled by Jatropha-based biofuel. In: IOP Conference Series: Materials Science and Engineering 2019; 488:1-6. doi:10.1088/1757-899X/488/1/012006.

[22] Beyersdorf AJ, Timko MT, Ziemba LD, et al. Reductions in aircraft particulate emissions due to the use of Fischer – Tropsch fuels. Atmos Chem Phys 2014:11-23. doi:10.5194/acp-14-11-2014.

[23] Hui X, Kumar K, Sung C, Edwards T, Gardner D. Experimental studies on the combustion characteristics of alternative jet fuels. Fuel 2012;98:176-182. doi:10.1016/j.fuel.2012.03.040.

[24] Price RO. Liquid hydrogen-an alternative aviation fuel? Int J Hydrogen Energy. 1991;16(8):557-562. doi:10.1016/0360-3199(91)90155-C

[25] Gawron B, Bia T, Janicka A, Zawi M. Exhaust toxicity evaluation in a gas turbine engine fueled by aviation fuel containing synthesized hydrocarbons. Aircr Eng Aerosp Technol. 2019. doi:10.1108/AEAT-11-2018-0277.

[26] Amgad Elgowainy, Jeongwoo Han, Michael Wang, Nicholas Carter, Russell Stratton, James Hileman, Andrew Malwitz and SB. Life-Cycle Analysis Of Alternative Aviation Fuels In Greet 2012:1-76.

[27] H Mohd Noh GAR and NAAR. The adaptation of sustainable biojet fuels and its effect on aircraft engine maintenance. In: IOP Conference Series: Materials Science and Engineering 2016:1-10. doi:10.1088/1757-899X/152/1/012043

[28] Lewis M. Fulton, Lee R. Lynd, Alexander Körner, Nathanael Greene LRT. The need for biofuels as part of a low carbon energy future. Biofuels, Bioprod Biorefining 2015:1-8. doi:10.1002/bbb

[29] Rahmes TF, Kinder JD, Henry TM, et al. Sustainable Bio-Derived Synthetic Paraffinic Kerosene (Bio- SPK) Jet Fuel Flights and Engine Tests Program Results. In: 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO)
and
Air 21 - 23 September 2009, Hilton Head, South Carolina2009:1-19.

[30] Azami MH, Savill M. Comparative study of alternative biofuels on aircraft engine performance. Proc Inst Mech Eng Part G J Aerosp Eng 2017;231(8):1509-1521.

2019-10-24

Investigation of aircraft engine performance utilizing various alternative fuels

Li, Yi-Guang

IOP

Warimani M, Azami MH, Savill M, et al., (2019) Investigation of aircraft engine performance utilizing various alternative fuels. IOP Conference Series: Materials Science and Engineering, Volume 642, Article number 012008

https://doi.org/10.1088/1757-899X/642/1/012008