NUMERICAL EVALUATION OF THE IMPACT OF THE OPERATIONAL CONDITIONS ON THE FUEL CONSUMPTION OF AN ALTERNATIVE AUXILIARY POWER UNIT

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Abstract:

The aim of this effort was to continue the PhD thesis research "Boosted Diesel Engine as an Auxiliary Power Unit for Commercial Transport Aircraft" conducted by one of the coauthors. The calculation algorithms were slightly improved. The number of calculation cases was significantly increased, allowing more in depth analysis of the impact of the operational conditions on the fuel efficiency of a passenger airplane equipped with a diesel auxiliary power unit.

Keywords: *auxiliary power unit (APU), diesel engine, gas turbine engine, specific fuel consumption (SFC), specific power, basic flight, alternate airport*

1. Introduction

The presented work is an evaluation of the feasibility of a boosted diesel engine (Diesel) based auxiliary power unit (APU) and the impact in the current generation of narrow body passenger jet airplanes. It is based on PhD thesis research "Boosted Diesel Engine as an Auxiliary Power Unit for Commercial Transport Aircraft" conducted by Vladimir Serbezov. The mathematical model of the aircraft, its systems and the engines described in the thesis are used. There are additional features aimed at automation of the software and therefore the errors caused by human factor in the different calculations are reduced to a minimum.

2. Model Description

The Airbus A319 was chosen as a base aircraft for the study. The characteristics of the base aircraft and its engines were identified with the use of records of regular flights from the aircraft digital flight data recorder. The aircraft characteristics were incorporated in a flight dynamics performance model, realized in Matlab.

Supplementing the system with the units, recreating the work of the Diesel APU, will include a unit that is taking into account the energy consumption of the systems whose power is transferred to the Diesel APU. Another unit is necessary that takes into account the

impact of the reduced load on the main engine characteristics (supplemental engine model – SEM).
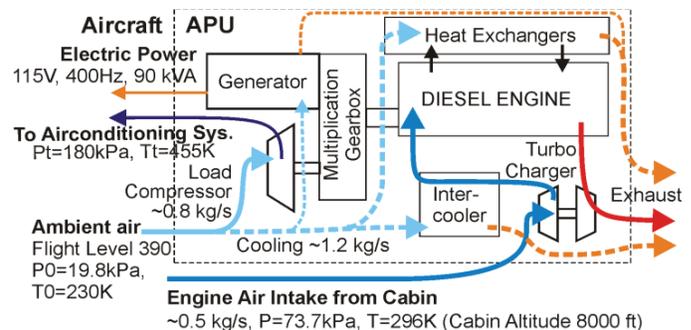

Fig. 2.1. Structure of the Diesel APU

In order to cover a sufficiently wide range of operating conditions of the aircraft six different flight scenarios are simulated.

1a. slightly below average distance flight (2000 km) and 80% load (14.4 t).

1b. slightly below average distance flight (2000 km) and maximum payload (18 t).

2a. middle distance flight (2500 km) and 80% load (14.4 t).

2b. middle distance flight (2500 km) and maximum payload (18 t).

3a. large distance flight (3500 km) and 80% load (14.4 t).

3b. large distance flight (3500 km) and maximum payload (18 t).

The selected flight scenarios allow inferring the relationship between the effectiveness of using Diesel APU, flight distance and loading of the airplane. The calculations for each scenario were made to the base plane with gas turbine APU and Diesel APU within the whole area of the control parameters of the study - specific fuel consumption and specific weight of the Diesel engine.

The flight stages and the indications of mass of the airplane at the beginning and end of each stage are given on fig.2.2. The parameters of each of the stages are selected in accordance with the aircraft documentation and are given in table 2.1. for the main flight and table 2.2. for the flight to an alternate airport.
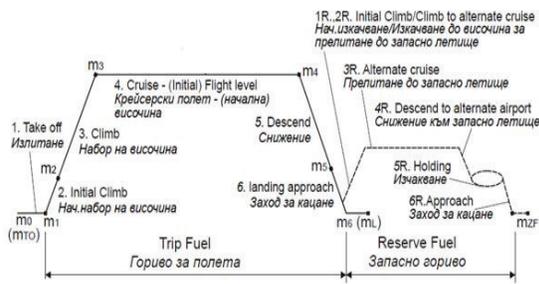

Fig. 2.3. Flight profile

Table 2.1. Basic parameters for calculating the fuel for a flight to the main airport

Flight stage	Flight height m	Speed profile
1	0	$0 \rightarrow V_2$
2	-	$V_2 \rightarrow V_{cas} = 250kt$
3	$\rightarrow 11278$	$V_{cas} = 250kt/$ $V_{cas} = 300kt/M = 0.78$
4	11278	$M = 0.78$
5	11278(11887) $\rightarrow 853$	$M = 0.78/$ $V_{cas} = 300kt/$ $V_{cas} = 250kt$
6	$853 \rightarrow 0$	$V_{cas} = 250kt \rightarrow V_{app}$

Table 2.2. Basic parameters for calculating the fuel for a flight to an alternate airport

Flight stage	Flight height, m	Speed profile	Time, min	Distance, km
1R	$305 \rightarrow 6960$	$V_{app} \rightarrow V_{cas} = 250kt$	-	-
2R		$V_{cas} = 250kt \rightarrow V_{cas} = 270kt$	-	-
3R	6960	$V_{cas} = 270kt$	-	370.4
4R	$6960 \rightarrow 457$	$V_{cas} = 270kt \rightarrow V_{cas} = 250kt$	-	-
5R	457	$V_{cas} = 202kt$	30	-
6R	$457 \rightarrow 0$	$V_{cas} = 202kt \rightarrow V_{app}$	-	-

The task is to determine the fuel consumption of the aircraft in flight. For this purpose, a parametric study was conducted with control parameters specific fuel consumption (SFC) and specific power of the diesel engine.

The assay range of values of these parameters is selected so that it corresponds to the values set for existing engines. Specific power (power/mass) vary in the range 0.8 - 1.2 kW/kg, and specific fuel consumption, respectively, 0.23 - 0.2 kg/kWh.

For each flight scenario for basic flight and flight to an alternate airport was calculated the fuel for the whole flight and the fuel for each flight stage. Calculations for the fuel for the flight stages were made for the most favorable and most unfavorable combinations of specific fuel consumption and specific power of the Diesel engine.

3. Results for the fuel consumption for the main flight

The realized fuel economy for different flight ranges and different loads on aircraft using diesel APU is between 0.01% and 0.95% of the total fuel consumed for the basic flight. It is noted that with increasing distance of the flight, the savings increases. By reducing the specific power of Diesel, the benefits of using it decreases exponentially, while increasing the specific fuel consumption of Diesel with 0.01 kg/kWh, the difference in rates between the fuel required for gas turbine APU and Diesel APU grew by about 0.1%. The benefit of using Diesel is more pronounced at 100% load on the plane.

It is important to note that even in the worst case of Diesel (573.33 kg and 0.230 kg/kWh SFC), there is fuel economy compared to the use of gas turbine APU.
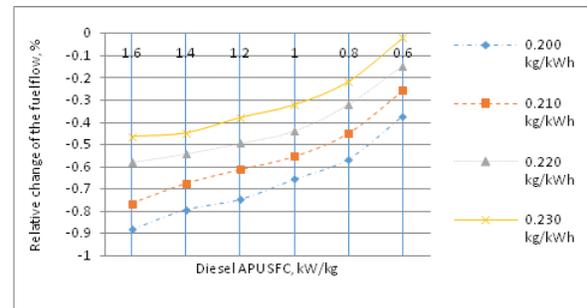

Fig. 3.1. Relative change of fuel consumption of aircraft using Diesel APU, flight of 2000 km, 80% load and standard atmospheric conditions

The dependence of fuel consumption from Diesel APU, SFC and its specific power is showed on fig. 3.1. This is the worst case - a flight of 2000 km and 80% load.

The reserve fuel is determined only by the load of the aircraft so it is compared only for a flight with aircraft with 80% and 100% load.

At the lighter engines (higher specific power) with a less SFC, the Diesel APU is more economical - within 0.17% to 0.02%, but more severe engines (lower specific power) with a higher SFC it appears that the gas turbine APU is more economical. The Diesel gives higher fuel consumption by 0.02% to 0.50%.
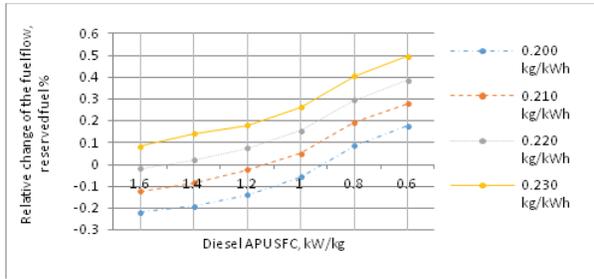
Fig. 3.2. Relative change of fuel consumption of aircraft using Diesel APU for flight to alternate airport and 100% load

4. Results for the fuel consumption on the different flight stages

The most and the least favorable cases of Diesel are simulated. They show most clearly the dependence between weight and SFC of the engine. The parameters of the diesel engines are showed in table 4.1.

Table 4.1. Parameters of the Diesel APU

Weight (specific power) of Diesel, kg (kW/kg)	SFC of Diesel, kg/kWh
260.83 (1.6)	0.200
260.83 (1.6)	0.210
287.62 (1.4)	0.200
287.62 (1.4)	0.210
448.33 (0.8)	0.220
448.33 (0.8)	0.230
573.33 (0.6)	0.220
573.33 (0.6)	0.230

The figures below show the results for each flight stage of the flight to the main airport. All of them are in percentage calculated by the formula below:

$$m_{fuel,\%} = -\frac{m_{fuelTD} - m_{fuelGT}}{m_{fuelTDsum} - m_{fuelGTsum}} * 100\%$$, (4.1)

m_{fuelTD} – fuel mass for the specific flight stage used by Diesel, kg

m_{fuelGT} – fuel mass for the specific flight stage used by gas turbine APU, kg

$m_{fuelTDsum}$ – total flight fuel for aircraft equipped with Diesel, kg;

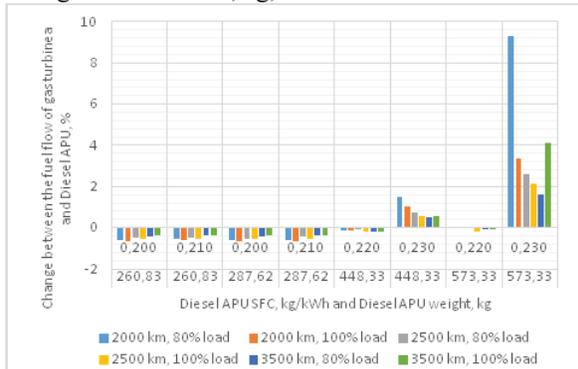$m_{fuelGTsum}$ – total flight fuel for aircraft equipped with gas turbine APU, kg;
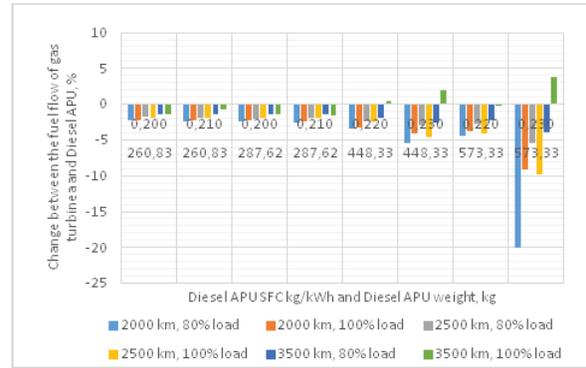

Fig. 4.1. Take off
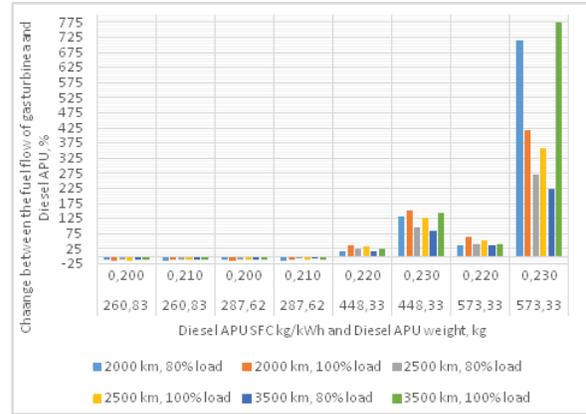

Fig 4.2. Initial climb
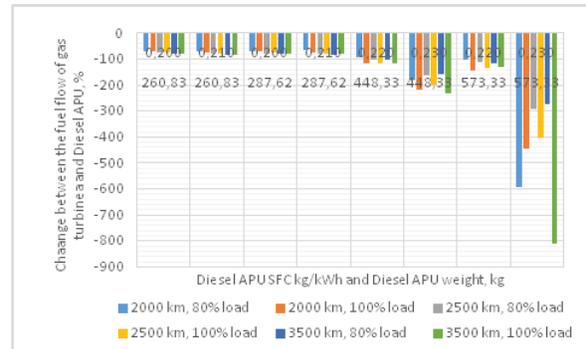

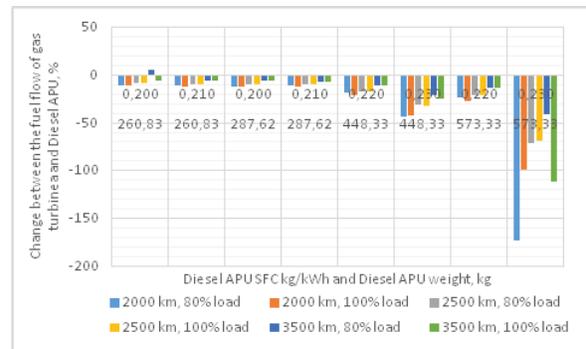*Fig. 4.3. Climb to cruise height*

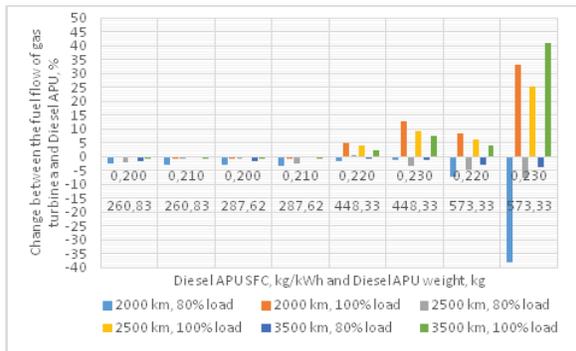*Fig. 4.4. Cruise*

Fig. 4.5. Descent

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Fig. 4.6. Approach

It is seen that at stages "cruise" and "descent" the impact of Diesel APU on the fuel consumption is positive. It is also clearly seen that the results for the first four types of engines (lower SFC and greater specific power) are similar. For the second four types (with a large SFC and lower specific power) there are also similar trends.

For the first four types of engines (lower SFC and high specific power) between 79.18% (83.26 kg) to 81.56% (80.84 kg) of fuel savings are realized at the "cruise" stage of the flight.

For the second group engines 773.08% (23.55 kg) of the total fuel savings are realized at "cruise" stage of the flight. At "climb to cruise height" stage these engine types realize rapid increase of fuel consumption – up to 810% (24.68kg) over the value of the economy.

The dependences that are observed at the flight stages during the main flight are observed at the flight stages of the flight to an alternate airport. The only difference is at stage "holding" which has only negative impact of the fuel consumption.

5. Conclusion

The results of the presented study confirmed the positive effect of boosted diesel engine as APU for narrow-body passenger jet airplanes. The study expands the range of the examined flight cases in [1]. The different flight scenarios with several flight distances, aircraft load and standard atmosphere conditions showed:

- When using contemporary diesel engine in flight as an additional source of energy, relieving the main engines it can be expected fuel economy within the 0.5 - 1%;

- Diesel gives a better overall performance at 100% load on the airplane, which is explained by the higher mode of the main engines and the bleed air for conditioning

system that is with unnecessarily high pressure;

- The results for the flight phases show that Diesel has very good performance at cruise phase of the flight. This means that by increasing the distance of the flight under the same conditions, the savings will grow.

- Analyzing the results of a flight to an alternate airport it is seen an increase in fuel consumption using Diesel APU during flight stage "holding." This can be avoided by switching off the APU at this stage of the flight.

- The results of a total fuel savings of airplane equipped with Diesel APU are fully comparable with those of other alternative APUs as fuel cells.

Examination of the aircraft's flight in its stages gave an opportunity to see the impact of each stage on the total cost of the fuel and to make general conclusions about the possibilities of additionally reducing the fuel consumption by selective use of the Diesel APU only in flight stages when it is mist effective. Final conclusions about the expediency of introducing Diesel APU can be made on the basis of wider feasibility studies.

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