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CONCEPTUAL STUDIES OF DIFFERENT TYPE OF HYBRID ELECTRIC PROPULSION SYSTEMS FOR COMMUTER AIRLINERS

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Abstract

The paper presents estimation of different type of hybrid electric propulsion system for 19 passenger capacity commuter airliner efficiency. The advanced turboprop propulsion system (with technology level of 2030), serial hybrid electric propulsion system, parallel hybrid electric propulsion system based on hybrid turboprop engines (with integrated reversible electric machine), partially turboelectric and an all-electric propulsion are compared.

Keywords: commuter airliner, hybrid/ turboelectric electric propulsion system, design architecture

1. Introduction

Reconsideration of conceptual architecture of the conventional gas turbine propulsion system is required because of the tightening up of emission limits in airport areas. The Brighton cycle limits doesn't allow to decrease harmful emissions in accordance with the future requirements of ICAO. The main innovative way for aviation industry development is the primary using of aircraft hybrid electric propulsion systems. Theoretically their using helps to decrease fuel consumption and, consequentally, harmful emissions. As the further research shows, for commuter airplanes sized up to 19 passengers, these concepts can ensure some benefits even at the current level of technology.

Due to short flight distance of 300 – 400 km and in order to make the aircraft lighter and reduce its cost, the cabin is non-hermetic. This leads to the flight altitude up to 3000-3500 m only. Such aircrafts are often use short and ground runways. The propulsion system is often over-sized because of short takeoff and landing requirement. As a result, propulsion systems of commuter non-hermetic aircraft have the following features:

- The power required at cruise speed is more than twice less than maximum continuous power of each of the 2 turboprop engine. It means that the throttle ratio is less than 50%. This impairs the fuel usage effectiveness, because at a small throttle ratio the specific fuel consumption increases significantly (20-40%).
- The maximum engine power is required only for 1-3 minutes to provide the short takeoff and climb.

Earlier in the work [1], the authors conducted a study on the evaluation of the efficiency of a serial hybrid electric propulsion system for a passenger commuter airliner with a maximum take-off weight of 6,100 kg. The prototype plane was Evektor EV-55 Outback. The propulsion system considered in [1] consist of two electric motors rotating propellers. The electric power is provided by a power unit that consists of batteries and one or two turbo-generators. At take-off mode the electric motors are supplied by batteries and generators simultaneously. Gas-turbine generators should provide enough power for cruise flight and batteries charging at minimal fuel consumption. The modelling of typical airplane flight cycle with hybrid propulsion system characteristics predicted for the time period of 2025-2030 shows 10-12% increase in fuel efficiency for one-turbogenerator case in comparison with turboprop at the same take-off weight [1].

The main idea of hybridization is to use the batteries to create additional power during take-off and climbing, which allows to use turboshaft gas turbine engine rotating generator adopted for cruise flight conditions. It means a decrease in its mass and specific fuel consumption.

Current work continues [1]. Unlike [1], here the aircraft L-410 was chosen as a prototype with maximum take-off weight of 7200kg and 19 passengers. In addition to the serial hybrid propulsion and conventional turboprop, a parallel hybrid electric, a partially turboelectric and an all-electric propulsion systems are considered here.

During evaluations the mass of the propulsion system and the mass of fuel are varied while maintaining the value of their sum ($M_{fuel} + M_{PS} = const$). Thus, an increase in the mass of a hybrid propulsion system in compare with a conventional propulsion system leads to fuel mass decrease. However, when evaluating flight performance by reducing the fuel consumption of the engine in the main engine operating modes, you can get a gain in the flight range of the aircraft. One more varying parameter is the degree of hybridization, i.e. the share of power at maximum mode is taken from the batteries.

In present work we have developed the conceptual designs of a perspective turboprop, turboshaft engines and hybrid turboprop engines with the same core. The best option for an engine of considered dimension (around 1000hp) is the simplest design architecture with a minimum number of blade machines, including the following main components: one or two-stage centrifugal compressor; annular inclined combustion chamber; uncooled single-stage compressor turbine; uncooled single or two stage power turbine.

2. Efficiency assessment approach

The distinguishing feature of proposed methodology is the close association of "aircraft-related" and "engine-related" engineering and design aspects, the opportunity of using external (experimental) characteristics of both engine elements, propulsion system and aircraft aerodynamic performance, the instrument of visualization and results analysis and, finally, the organic interaction with multiparameter and multicriteria optimization software.

Assessing impact of a large amount of aircraft-related and engine-related factors (from several decades to several hundreds depending on the complexity of mathematical models) on the "aircraft-propulsion system" parameters it is practically impossible to derive simple analytical dependencies of the aircraft takeoff mass, flight distance and other characteristics on considered (variable) parameters. In this case the only possible way is aircraft performance and distance calculation with given flight mission with certain takeoff mass accounting for solving of equations of volumes existence and conformance. The next step is iterative definition of the takeoff mass G_0, contributing to proposed requirements, such as maximum flight distance.

The effectiveness research of propulsion system application (conventional, hybrid, electric and others) as part of an aircraft according to determinated criteria comes down to the propulsion system rational design formation, i.e. the propulsion system design to assure the best aircraft performance indicators. The following performance indicators list is characteristic of a passenger aircraft:

– Aircraft flight distance (with the fixed takeoff mass and the fixed passengers amount);

– Aircraft fuel effectiveness;

– Transport performance;

– Harmful emissions rate;

– Noise rate;

– Cost indicators (aircraft propulsion system development, manufacturing and operation costs) and others.

The task of propulsion system design formation as an integral part of an aircraft is closely linked to the mission task (flight with an fixed flight mission) [1-3]. Because the aircraft effectiveness indicators, such as the mass, altitude and velocity, and throttle characteristics, can be gotten only on the base of fully designed propulsion system.

In this work the propulsion system designing was carried out for the accomplished aircraft with fixed performance.

Figure 1 represents the flowchart of the process of designing propulsion system as part of an aircraft. The task is solved by a number of iterations, each of them making the result more precise in compasion with the previous calculations.

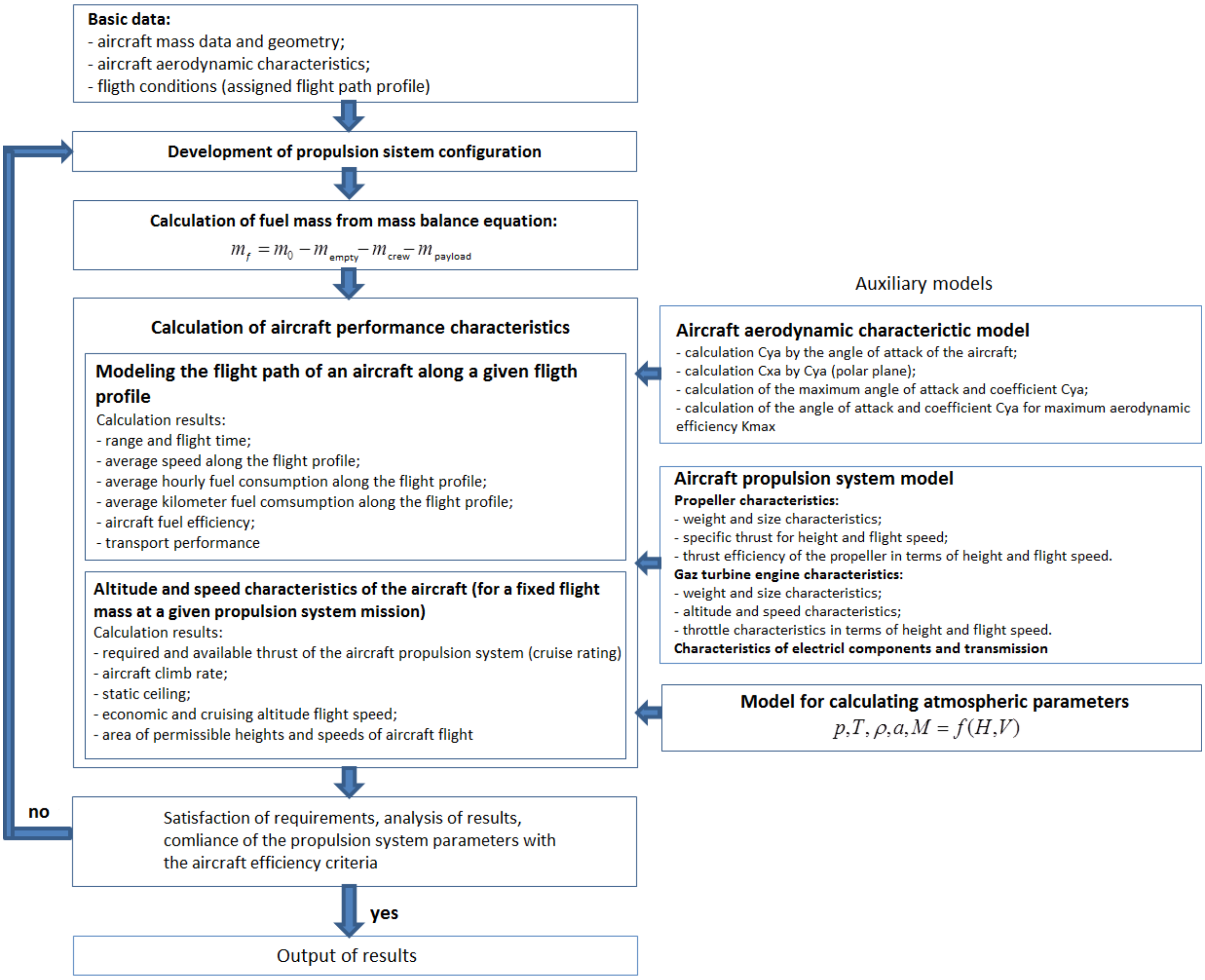


Figure 1 – The flowchart of designing the propulsion system as part of an aircraft

Mathematical models, attributes of thermal engines and electrical components designing, as well as the flight mission, are represented in works [1-3].

Relative parameters of the gas turbine propulsion system electrical components were defined according to [4]. Design research of various electric machines for commuter airplanes were also conducted with the authors of this piece of work involved. These results were also taken into consideration while performing the analysis.

3. The base airplane

The object of research is the 19-passenger commuter airplane Let -410UVP (Figure 2) with engines GE H-80.

Figure 2 – The commuter airplane Let -410UVP

Table 1 represents the main aircraft characteristics

Table 1 – The main aircraft characteristics

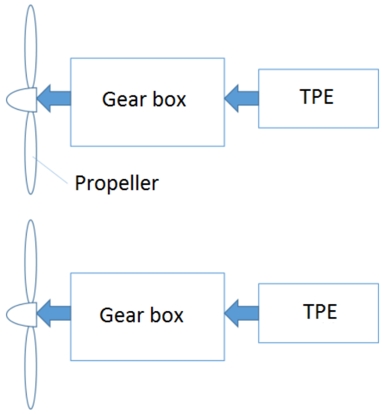
Name	**Value**
Modification	L410UVP-E20
Crew	2 pilots
Payload	19 passengers or 1800 kg
Engine's type	2 × TPE GE H80-200
Takeoff power, hp	2 × 800
Propeller type	2 × Avia AV-725
Number of blades	5
Propeller diameter, m	2,3
Wingspan, m	19,98
Aircraft length, m	14,42
Aircraft height, m	5,83
Wing area, m2	34,86
Empty aircraft weight, kg	4050
Maximum takeoff weight, kg	6600
Fuel capacity in main tanks, kg	1000
Fuel capacity in tip tanks, kg	313,8
Cruising speed, km / h (corresponds to the minimum kilometer fuel consumption of aircraft propulsion system)	270
Cruising altitude, m	3050
Practical ceiling, m	4200

4. Propulsion system architectures

4.1. Conventional propulsion system (Scheme 1)

Propulsion system consists of two turboprop engines. Each of engines drives the propeller rotating by mechanic transmission. Propulsion system also has fuel and oil systems.

Such propulsion system architecture is presented in figure 3.

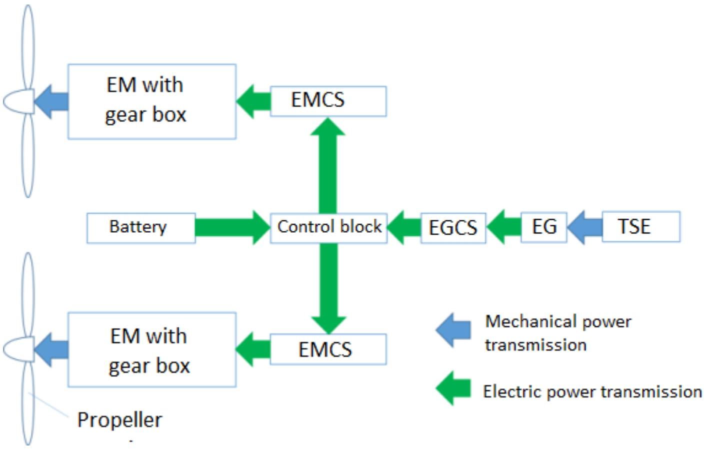


TPE- turboprop engine

Figure 3 – Conventional turboprop propulsion system (architecture 1)

4.2. Serial hybrid electric propulsion system (architecture 2)

The architecture of serial hybrid electric propulsion system with one turboshaft engine is shown in figure 4. Such architecture was also shown in [1]. This work also shows that the use of two turbo generators is impractical, as it increases the mass of the propulsion systems and doesn't contribute to specific fuel consumption decrease. Therefore it is not considered further.



TSE - turboshaft engine; EG - electric generator; EGCS - electric generator control system; EM - electric motor; EMCS - electric motor control system.

Figure 4 – Serial hybrid electric propulsion system (architecture 2)

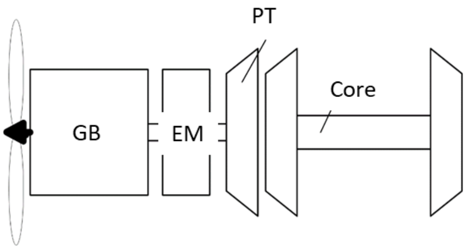
Hybrid electric propulsion system include one turboshaft engine, rotating the electric generator. The turboshaft engine generates only power at output shaft, but it generates no reactive thrust. Electric energy from the generator is driven onto two electric engines, rotating the two propellers. It makes the main difference of this architecture from others (excluding the fully electrical architecture), as they drive the engine power to the propeller mechanically, by transmission.

This architecture has the largest mass and size of electrical components among the considered architectures.

Besides the turbo generator the hybrid electric propulsion system includes an additional source of electric power – a rechargeable battery. It is normally decharged only at the aircraft takeoff mode. At cruising the rechargeable battery is charged from the turbo generator. The rechargeable battery available electrical power would compensate for the turbo generator failure at takeoff mode. The rechargeable battery available energy would assure the flight operation during the predefined period of time in all flight phases in case of turbo generator is drop out. The question is the distance supplied by the energy resource.

4.3. Parallel hybrid electric propulsion system (architecture 3)

Hybrid electric propulsion system this type has two hybrid turboprop engines with integrated reversible electric machines. It means they can work both as electric engines and electric generator. There are different ways to locate electric machine, for example, on the free turbine shaft (see figure 5). Such configuration leads to rotation frequency of electric machine to be nearly 30000 rpm, and its mass and size is minimum. It can drive the rotation to the propeller both independently and together with the power turbine. In generator mode it takes away part of mechanic power from the free turbine shaft.

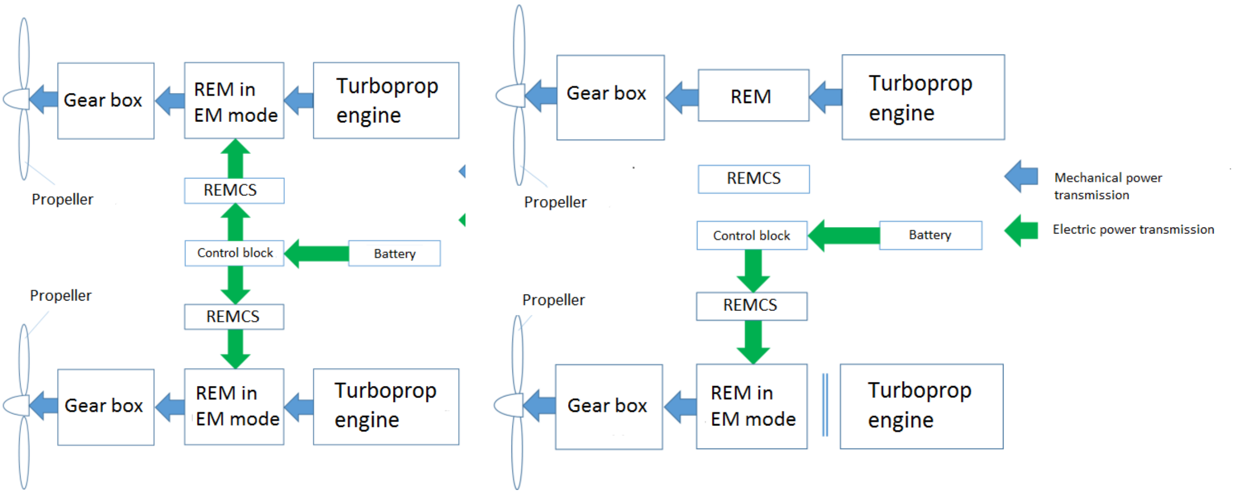


GB – gear box, EM – reversible electric machine, PT – power turbine

Figure 5 – One possible architecture of a reversible electric machine installation into a hybrid turboprop engine

The propulsion system also includes an additional source of electric power in rechargeable battery. It provides a short time increase of power at an aircraft takeoff by ensuring defined requirements of the takeoff distance both normal and continued with gas turbine engine failure.

Figure 6 shows the hybrid electric propulsion system operation mode at rechargeable battery decharging.



a) b)

REM – reversible electric machine; REMCS – reversible electric machine control system; EM - electric motor; a) normal climb; b) a case of continued aircraft climb with one of gas turbine part of one of engines failure.

Figure 6 – Architecture of hybrid electric propulsion system with two gas turbine engines and rechargeable batteries

It should be noted that the Hybrid Electric propulsion system mass exceeds the mass of conventional propulsion system, which means an increase in the aircraft landing mass and consequently, an increase to the aircraft landing distance compared to the reference aircraft L-410UVP. In case of the aircraft landing distance exceeds the predefined runway length, it necessitates working out recovery measures to assure more intensive airplane slowdown at landing.

At aircraft continued takeoff (takeoff with gas turbine engine failure), all the rechargeable battery power is driven to the propeller at the side of the failed engine.

In case assuring of equal propellers thrust is needed both at the aircraft climb and at cruising speed with gas turbine part of one of the hybrid electric propulsion systems failure, partially the power of working gas turbine engine can be redirected to the failed engine side propeller.

At cruising level the rechargeable battery is charged during the preset time (1 hour) with turboprop engines operate at increased power to ensure charging of the rechargeable battery. Rechargeable battery doesn’t operate at other phases of flight (excluding climb).

4.4. Partially turboelectric propulsion system based on hybrid turboprop engines (architecture 4)

The propulsion system is based on two hybrid turboprop engine as the parallel hybrid turboprop engine (architecture 3, section 3.3). It differs from the previous propulsion system by no rechargeable battery block. It means that the gas turbine part of the hybrid turboprop engines has as much power as the propulsion system of the conventional engines for the reference aircraft. It means that the power of gas turbine part of the two engines is sufficient for takeoff with preset approach and cruising distance.

The main idea of this propulsion system is that after the takeoff and climb at cruising speed the gas turbine part of one of the engines turns off with the gas turbine part of the second engine turned on at maximum continued speed. Partially the power of the free turbine of this engine (a little less than half) is driven to the propeller and the remaining part of it is spent on the reversible electric machine operation in a generator mode. The electric energy worked out is driven onto the reversible electric machine, operating in a motor mode of an engine, operating with its gas turbine part turned off. This electric machine rotates the propeller. As a result the mechanic power of the free turbine of one hybrid turboprop engine is driven onto the two propellers. In one case it turns out through mechanic transmission, in the other case through electric transmission. This is the reason to call this architecture partially turbo electric. The architecture of such an engine is presented at Figure 7.

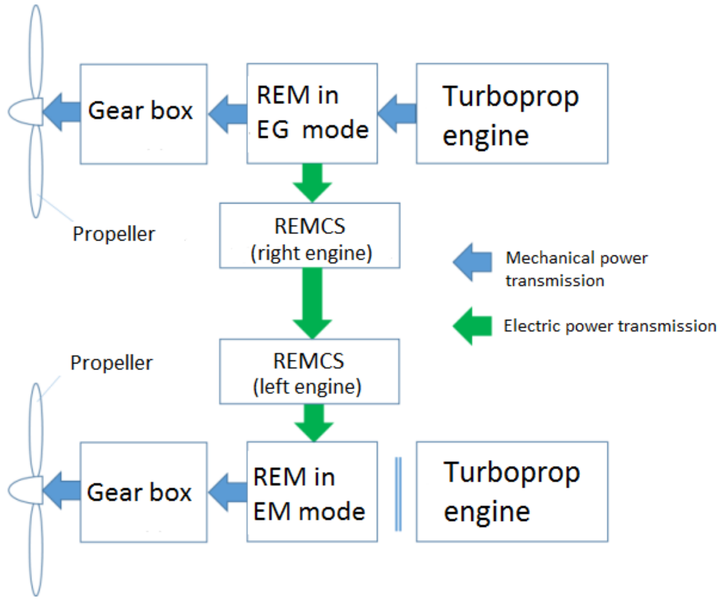


Figure 7 – Partially turboelectric propulsion system (architecture 4)

In this architecture the throttle ratio of one operating gas turbine engine is 90-95% in contrast with the throttle rate of two operating engines of 42-45%. It means exactly one engine is optimum and contributes to minimum fuel consumption.

4.5. Full electric propulsion system

This propulsion system consists of two electric engines, rotating propellers. Electric energy onto engines is driven from the accumulator battery block.

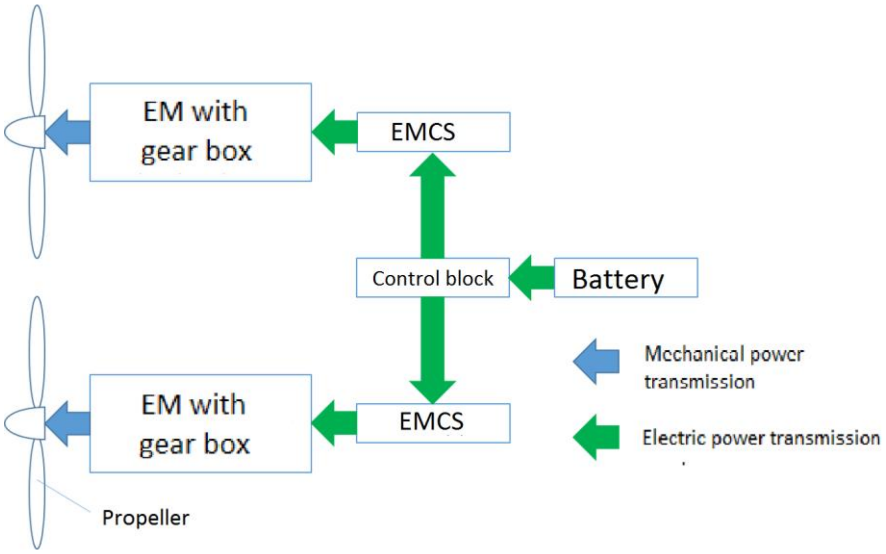


Figure 8 – Full electric propulsion system (architecture 5)

5. Efficiency assessment results of various propulsion systems as part of commuter airplanes

5.1. Conventional propulsion system aircraft

The conventional propulsion system was designed, and turboprop engines characteristics were assessed for 2020 year level (TPE-800-2020) and 2030 year (TPE-800-2030) [2]. The comparative throttle characteristics of these TP for cruising conditions (H=3050 м, V=270 kmph) are illustrated at the graph (Figure 9). Comparison is drawn up of the characteristics of engine GE H-80-200, which is installed on L-410 airplane.

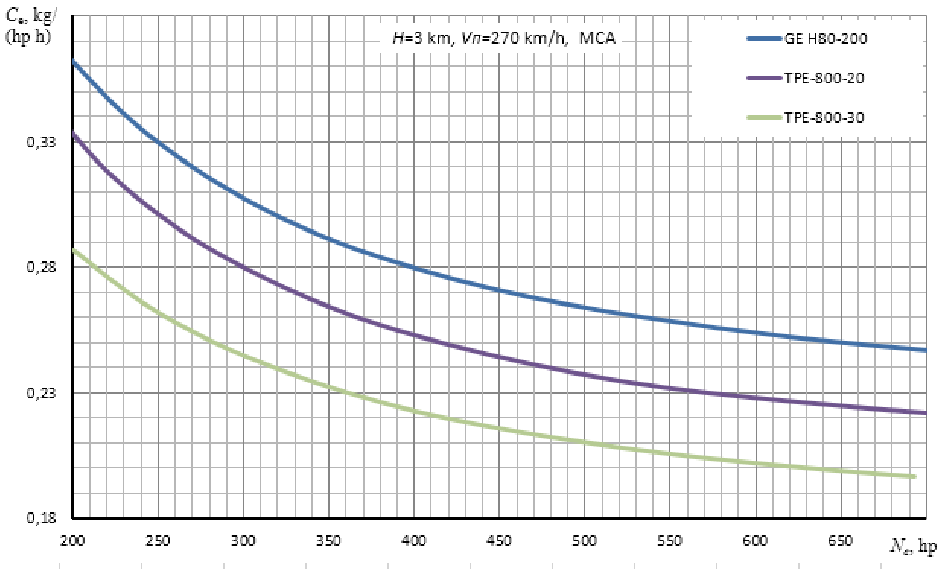


Figure 9 – Comparative throttle characteristics of a range of TP in cruise conditions

The results of modeling of L-410UVP airplane performance with conventional propulsion system with various turboprop engines are presented in Table 2.

Table 2 – The main performance indicators of conventional propulsion system airplane L-410UVP.

Name	**GE H80-200** **(2010)**	**TPE-800-2020**	**TPE-800-2030**
The mass of a TP including systems and mounting elements, kg	239,4	217,8	173,7
Fuel capacity, kg	590,1	633,3	721,6
Mass of aeronavigation fuel reserve, kg	128,7	119,6	103,8
Mass of fuel used in flight mission, kg	461,4	513,7	617,8
Depth of throttle of TPE in cruise flight (relative of maximum continuous mode)	0,41	0,42	0,47
Design takeoff distance (up to 10,7 m), m	620	629	627
Design takeoff distance with one of TP failure, m	905	969	962
Climb time of cruising level, min	7,1	7,6	9,6
Aircraft landing mass, kg	6141	6089	5985
Flight distance, km	**680**	**819**	**1141**
Fuel effectiveness, g/(pax-km)	**35,7**	**33,0**	**28,5**
Kilometer fuel consumption of propulsion system, medium at cruising phase, kg/km	**0,65**	**0,60**	**0,52**

The data given show that TP engines of L-410 airplane have the depth of throttle in cruising conditions (engine power relative to TP available power in nominal mode) equal to 0,4-0,47. It means that cruising mode has significant power reserve.

5.2. Serial hybrid electric propulsion aircraft

As the generator drive of serial hybrid electric propulsion (figure 4) a series of turboshaft engines with differing power from 950 to 1300 horsepower were discussed. It actually means the varying of hybridization degree of HEP, i.e. the share of total power worked out by rechargeable battery only.

A specific design case of turoshaft engine failure at aircraft takeoff was discussed. The failure detection by the crew was reckoned to take place at the worst considered moment, namely at decision speed of 150 kmph (as in Flight manual of L-410). At the momentof turboshaft engine failure the rechargeable battery is driven into emergency rating with maximum acceptable power N_{BatER}. This N_{BatER}. is defined by calculating depending on the turboshaft engine power (up to the limit), the power of decharging of rechargeable battery up to the limit and preset limitations of approach and takeoff distance.

After the aircraft continued flight is performed with the turboshaft engine failure, rechargeable battery remains single source of energy as part of HEP and it must assure for all the consequential flight phases up to landing:

Aircraft lift to 100 m;

Roundabout flight and approach to landing at 100 m with constant speed at climb wing configuration ($\delta_{п} = 15^{\circ}, \delta_{з} = 18^{\circ}$) with landing gear taken out;

Gliding and landing.

Comparative results of serial HEP performance design for the year 2030 technology level are shown in table 3.

Table 3 – Results of L-410 serial HEP aeroplane performance modeling AT THE YEAR 2030 technology level for turboshaft engines of varying power.

TP power, hp.	950	1000	1100	1200	1300
Aircraft takeoff mass, kg	6600	6600	6600	6600	6600
Rechargeable battery decharging power at normal takeoff, hp	250	200	100	0	0
Rechargeable battery decharging power at prolonged takeoff with turbo propeller propulsion system failure, hpr	945	945	945	945	900
Rechargeable battery electric work at aircraft prolonged takeoff considering roundabout flight and landing, kW*ph	27,8	27,6	27,2	26,8	26,9
Rechargeable battery decharging power aircraft lift, hp (with turboprop propulsion system operating in nominal mode)	70	30	0	0	0
Rechargeable battery electric work at aircraft lift, kW*ph	20,5	8,4	0	0	0
Turboprop propulsion system mass with systems and mounting elements, kg (one)	144	151	163	175	187
Turboprop engine rotation speed (free turbine), rpm	32119	31470	30259	29249	28366
Relative power of a reversible electric machine, kW/kg	18,5	18,2	17,6	17,3	17,2
Rechargeable battery mass, kg	128,8	127,8	125,9	123,9	124,3
Electric generator mass, kg	31,37	33,6	38,2	42,3	46,2
Electric generator control system mass, kg	22,59	23,7	26,1	28,5	30,9
Electric motor mass, kg(one)	24,91	24,9	24,9	25	27,0
Electric motor control system mass, kg (one)	14,9	14,9	14,9	15	16,2
Power conversion control system mass, kg	22,4	22,4	22,4	22,5	24,3
Mass of hybrid electric propulsion system equipment and cables, kg	22,4	22,4	22,4	22,5	24,3
Total mass of HEP electric components, kg	307,4	309,9	315,1	319,8	337
Fuel capacity, kg	616,6	607,8	590,3	573,6	544,7
Fuel mass of aeronautical fuel reserve, kg	91,7	92	92,7	93,3	94
Fuel mass used in predefined flight mission, kg	525	515,8	497,6	480,3	450,7
Run-up distance, m (considering taxiing area of 50 m)	643,3	644,4	646,6	649	599,4
Aircraft takeoff distance, m	853,9	855,2	858	861	799,8
Takeoff distance of aircraft continued takeoff with turbo propeller propulsion system failure, m	993	994	996	998	992
Time of aircraft climb at cruising level, min	28,85	27,9	21,5	15,9	12,1
Aircraft landing mass, kg	6077	6087	6105	6122	6152
Landing distance, m					
Predefined flight mission distance, km	1085	1056	1012	975	910
Fuel effectiveness, g/pax*km	25,45	25,69	25,86	25,92	26
Kilometer fuel consumption of propulsion system, average at cruising flight mode, kg/km	0,462	0,464	0,467	0,469	0,47

The optimum variant of serial HEP assuring maximum aircraft flight distance (1086 km) combined with the highest fuel efficiency (24,45 g/(pax-km)), relates to serial HEP with turboshaft engine of 950 horsepower. Such propulsion system assures a 10-12% lower relative fuel consumption than conventional propulsion system based on two turboprops of the 2030 year level(see table 3). But it is necessary to note that the rechargeable battery capacity in design cases considered takes account only of turboshaft engine failure at takeoff. To compensate for this engine failure it is necessary at cruising phase to have a large battery reserve, which at preset takeoff mass significantly reduces either flight distance or payload.

5.3. Parallel HEP aircraft

During research of parallel HEP effectiveness (figure 5, section 4.3) as part of an aircraft a range of gas turbine parts of hybrid HEP was developed, their power varying from 500 to 750 hp for the year 2030 technology level [2]. Rechargeable battery gives away its energy only at takeoff and climb. It is recharged at cruising phase. Table 4 presents the results of aircraft performance modelling.

Table 4 – Modelling results of L-410 parallel HEP aircraft performance based on two hybrid turboprops for the year 2030 technology level.

Name	GTPE-550-2030	GTPE-600-2030	GTPE-650-2030	GTPE-700-2030	GTPE-750-2030
TP throttle depth in cruising mode (related to maximum prolonged mode) with power takeoff for battery charging	0,61	0,56	0,52	0,48	0,45
TP throttle depth in cruising mode (related to maximum continuous mode) with no energy takeoff for battery charging	0,60	0,55	0,51	0,47	0,44
Turbopropeller engine mass with systems and mounting elements, kg (one)	137,2	146,3	155,1	164,1	172,8
Turboprop engine rotation speed (free turbine), rpm	39800	38500	37400	36400	35500
Reversible electric machine power at aircraft takeoff, hp (with tolerable overload coefficient 1.2)	233	180	131	86	37
Reversible electric machine power in cruising mode with one turboprop engine turned off, hp	–	–	–	–	–
Rechargeable battery decharging power at aircraft takeoff, hp.	285	220	160	105	45
Rechargeable battery mass, kg	58,2	44,9	32,7	21,5	9,2
Reversible electric machine mass (one), kg	10	8	6	4	2
Control system mass of a reversible electric machine (one), kg	6	4	3	2	1
Power conversion control system mass, kg	9	7	5	3	1
HEP equipment and cables mass, kg	8	6	4	3	1
Total mass of HEP electric components, kg	107	83	61	40	17
Fuel capacity, kg	6871	693	698	700	706
Fuel mass of aeronautical fuel reserve, kg	102	103	104	105	106
Fuel mass used in predefined flight mission, kg	585,4	590,1	594,0	595,2	599,3
Predefined flight mission distance, km	1090	1093	1095	1086	1084
Fuel effectiveness, g/pax*km	28,3	28,4	28,5	28,9	29,1
Kilometer fuel consumption of propulsion system, average at cruising flight mode, kg/km	0,52	0,52	0,53	0,53	0,54

Modelling results show that hybridization degree (power of battery related to additional power of the propulsion system) in takeoff mode of parallel HEP for the year 2030 technology level has practically no effect on fuel effectiveness and flight distance. Also compared to conventional propulsion system of the year 2030 technology level it has relatively shorter flight distance at the same takeoff mass.

5.4. Partially turbo electric propulsion system aircraft

Effectiveness calculations of partially turbo electric propulsion systems for the year 2020 and 2030 level technology were carried out. Calculation results and their comparison with conventional propulsion systems based on TP are presented in table 5.

Table 5 – Modelling results of L-410 two HEP aircraft performance with one engine turned off in cruising flight mode

Name	TPE-800-2020	GTPE-800 2020	TPE-800-2030	GTPE-800-2030
Turboprop engine mass, kg (one)	217,8	218,8	173,7	173,7
Turboprop engine rotation speed (free turbine), rpm	28000		34700	
Relative power of a reversible electric machine, kW/kg	-	9,6	-	15,0
Reversible electric machine mass (one), kg	-	24,4	-	14,8
Control system mass of a reversible electric machine (one), kg	-	11,3	-	7,2
Power conversion control system mass, kg	-	7,6	-	5,4
Cables mass, kg	-	5,7	-	4,3
Total mass of HEP electric components, kg	-	84,8	-	53,7
Total fuel capacity, kg	633,3	548,5	721,6	667,9
Fuel mass of aeronautical fuel reserve, kg	119,6	101,4	103,8	87,9
Fuel mass used in predefined flight mission, kg	513,7	447,1	617,8	580,0
TP throttle depth in cruising mode (related to maximum continuous mode) with no energy takeoff for battery charging	0,42	0,88	0,47	0,98
Design takeoff distance (up to 10.7 m), m	629	629	627	627
Design takeoff distance with one of turboprop engines failed, m	969	970	962	962
Time of aircraft climb at cruising level, min	7,6	7,6	9,6	9,6
Aircraft landing mass, kg	6089	6156	5985	6023
Flight distance, km	819	827	1141	1251
Fuel effectiveness, g/(pax-km)	33,0	28,4	28,5	24,4
Kilometer fuel consumption of propulsion system, average at cruising flight mode, kg/km	0,60	0,51	0,52	0,44

The results presented show that partially turbo electric propulsion system based on two HEP with gas generator of one of them turned off in cruising mode assure reduction of fuel consumption by 15-16 % and a minor increase in flight distance (see table 5) compared to conventional propulsion systems based on two TP (see table 1). It is correct for both the year 2020 level technology and the year 2030.

Besides essential fuel effectiveness this propulsion system design offers the following benefits:

Safety in case of gas turbine part of one of engines failure;

Resource economy of the engine turned off.

5.5. Full electric propulsion system aircraft

During calculations of full electric propulsion system aircraft performance it was accepted that relative energy of rechargeable battery assembly of the year 2020 technology level equals to 200 W h/kg, for the year 2030 technology level it equals to 350 W h/kg. Also the mass of the target load was varied (the number of passengers), which helps to vary the rechargeable battery energy supply (battery mass) at predefined aircraft takeoff mass.

Figure 9 presents the modelling results of full electric propulsion system aircraft performance for the year 2020 and 2030.

For full electric propulsion system aircraft of the 2020 year level (figure 9) the predefined flight mission with 19 passengers onboard isn’t realized (rechargeable battery energy is sufficient only for takeoff mode and partially for climb).

Figure 9 also shows that the reduction of the target load mass (number of passengers) results in an increase in aircraft flight distance by predefined flight mission. However, at payload of only 1 passenger the flight distance is 390 km only at the year 2030 level technology.

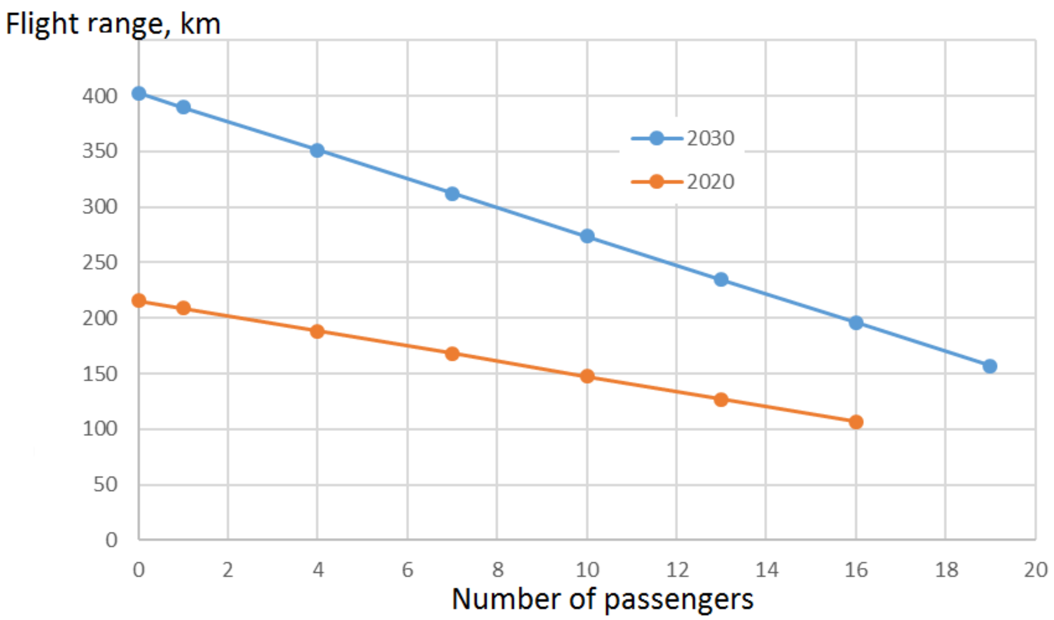


Figure 9 – The modelling results of full electric propulsion system aircraft performance for the year 2020 and 2030

6. Conclusion

This research work includes calculations of the L-410 commuter airplane with 19 passengers on board and propulsion systems varied type. This work addresses conventional turbo propeller propulsion system, serial hybrid electric propulsion system, parallel hybrid electric propulsion system, partially turbo electric propulsion system, full electric propulsion system aircraft.

Modelling shows the following:

Flight distance of GE H80-200 conventional turbopropeller propulsion system aircraft is approximately 20 % worse than TPE-800 conventional turbopropeller propulsion system aircraft of the year 2020 technology level and approximately 68% worse than TPE-800 of the year 2030 technology level.

Serial hybrid electric propulsion system based on one turbo generator for the year 2030 technology level assures a 10% shorter flight distance and 10-12 % smaller fuel consumption compared to conventional propulsion system of the year 2030 level. These results do not take into account the necessary rechargeable battery reserve assuring continued prolonged flight in case of gas turbine engine failure.

Parallel hybrid electric propulsion system based on hybrid turbo propeller propulsion system doesn’t provide for benefit in fuel effectiveness and fuel consumption compared to conventional turboprop propulsion system.

Partially turbo electric propulsion system, providing for turnoff of gas turbine part of one of hybrid turboprop propulsion system, assures 15-16 % benefit in fuel effectiveness and a 10% flight distance increase compared to conventional propulsion system of the year both 2020 and 2030 technology level. Moreover, this architecture results in resource economy of hot engine components.

Full electric propulsion system for the year 2030 technology level provides for flight distance of 150 km only with the payload of 19 passengers. Compared to that the payload of only 1 passenger the flight distance is no longer than 390 km.

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