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INTEGRATION OF HYBRID PROPULSION SYSTEM IN A CS23 COMMUTER DESIGN

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Abstract

In this paper an introduction to strategies behind the usage of alternative energy carrier as well as a discussion about efficiencies for different system architectures is provided. Different key figures to describe hybrid propulsion systems are discussed and an enhanced efficiency definition is introduced. Developed capabilities for the initial design of aircraft with hybrid propulsion system and the connection to CPACS [1] *based design environment is presented. Further a design study using the presented methodology is performed and the results are presented in this paper. The aim of the presented approach is to support the assessment capabilities for hybrid propulsion systems to thereby assess the potential towards the flightpath 2050 goals* [2].

1 Introduction to Hybrid Propulsion for aviation applications

Since more than one hundred years internal combustion engines (ICE) are used to power aviation. For general aviation and in the early beginning of commercial aviation, piston engines are and were respectively dominating. Furthermore since more than sixty years jet engines have been used for commercial aviation, and have evolved over time into very well developed technologies. Both types of engines are based on thermodynamic cycles which are physically limited in efficiency due to the maximum reachable difference in temperatures. The Carnot cycle efficiency can be employed, as the upper theoretical limit for the reachable efficiency in thermodynamic cycles. The efficiency is defined by the ratio between cold temperature and hot temperature. The upper temperature is given by the combustion temperature of the used fuel and the lower temperature is defined by the exhaust temperature. One possible solution to reduce the exhaust temperature is to use recuperation [3] but even than the combustion engine is limited in efficiency. Even if we assume a hot temperature of 2200 K and an exhaust temperature of 800 K it is theoretically not possible to achieve more than 64% efficiency. That is still far away from efficiencies which can be achieved with electric components. The reachable efficiency figures of electric components are much higher, usually in the order of more than 90% and could help to increase the overall efficiency. That leads to the main motivations and ideas behind hybrid propulsion concepts:

- High efficiency factors of electric components and systems enable high overall efficiency
- To allow for new integration strategies due to a possible geometric separation of energy system and thrust generation and also due to the beneficial scaling characteristics of electric components.
- To enable optimized thermodynamic cycle / new freedom in cycle design. Some design requirements can be fulfilled with the help of electric components, which means fewer requirements for the thermodynamic cycle.
- To enable the usage of renewable energy due to the use of alternative energy carriers.

- To use alternative propulsion technologies but avoid huge changes in infrastructure. For instance, compared to full electric design, battery exchanges prior to flight can be avoided.

Following this incomplete collection of motivations, it is also important to have the differences in usage of energy systems in mind. There are ideas to use alternative energy carrier and also ideas to enable other technologies or benefits through the new system.

1.1 Basic understanding of energy carrier

As explained above, not all hybrid propulsion systems aim to use an alternative energy system. In general, from the energy point of view, there are two basic underlying concepts for using alternative energy carrier.

- The first concept is the real replacement of fuel by an alternative energy carrier. Due to the in some cases not sufficient energy density of the alternative a hybrid system is chosen. Or if the alternative energy carrier has other limitations like for instance limited dynamic in power withdrawal, a hybrid system can be applied as well.
- The second concept is to use the fuel with higher efficiency, so hybrid propulsion can also be used as an enabler for higher efficiencies of the thermodynamic cycle. It can for example increase the bypass ratio due to the separation of energy conversion (thermodynamic cycle plus generator) and thrust generation. In this case it is not primary objective to include an alternative energy carrier, but mostly needed.

1.2 Basic understanding of efficiency

If additional electric components are added to a conventional fuel based system there are only two fundamental ways to implement an electric system. The starting point is the conventional turboprop with the efficiency of the gas turbine and the propulsion unit (eq. 1). The first way is to multiply by an additional efficiency factor, which means series hybrid architectures (eq. 2). The second way is to add the additional efficiency factor what will give a parallel hybrid propulsion system (eq. 3).

$$\eta_{total} = \eta_{GT} * \eta_{porp} \qquad (1)$$

$$\eta_{total} = \eta_{elec} * \eta_{GT} * \eta_{porp} \qquad (2)$$

$$\eta_{total} = (f * \eta_{GT} + (1 - f) * \eta_{elec}) * \eta_{porp} \qquad (3)$$

To increase the total efficiency of these two architectures, there are only certain ways.

- If the components are placed in series, we need to improve the already before existing efficiencies by enabling other advantages, such as improving the aerodynamics by realizing boundary layer ingestion (BLI).
- If the components are placed in parallel the total efficiency can be improved by increasing the proportion of the energy path with higher efficiency, but this usually also means an increasing mass. Otherwise the existing efficiency factors can be improved as well.

2 Taxonomy of hybrid Architectures

To accomplish one or more of the presented levers for improvement it is necessary to compare different architectures of propulsion systems and choose the most promising for the selected mission.

2.1 Series hybrid architectures

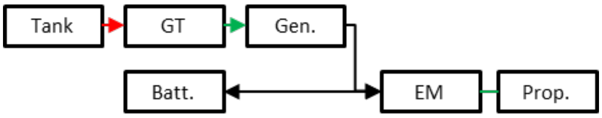


Fig. 1 Simplified visualization of a series hybrid architecture using gas turbines and batteries

The idea of series hybrid propulsion is mainly to use an electric propulsion system combined with an energy system which can provide more energy density than simply batteries. Therefore all electric components need to be sized to the maximum power.

A series hybrid propulsion system usually offers the possibility to divide into an electric energy providing system and a system which is converting electricity into thrust. Out of that, new design possibilities of the propulsion system can be gained. For example by enabling BLI or distributed propulsion.

Based on these pure series hybrids, an additional battery is used in parallel in most cases. However, it's commonly still named as series hybrid system. The idea is to cover load peaks with energy out of the battery and to use the battery for reserve or alternate mission energy.

2.2 Parallel hybrid architectures

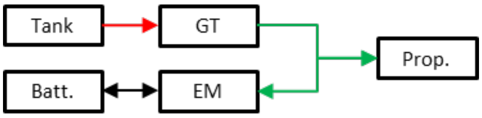


Fig. 2 Simplified visualization of a parallel hybrid architecture using gas turbine and electric motor

The idea of parallel hybrid propulsion systems is to take a conventional drivetrain and connect an electric motor mechanically to the shaft. Its advantage is to keep the direct drive without multiplying with other efficiency factors. Also for the sizing of the electric components it is beneficial because they do not need to be sized for the full power. Otherwise it is difficult to change the configuration of the aircraft due to the still coupled energy conversion and the thrust generation.

2.3 Power-split hybrid architectures

Power-split hybrids are variations, respectively combinations of parallel hybrids or parallel hybrids and series hybrids. They are not explicitly discussed in this paper, because most fundamentals for these are given by series or parallel architectures.

3 Indicators of hybridization

To characterise the propulsion system in use, usually further indicators are given to the architecture of the system. Widely used is the energy or power specific degree of hybridisation. In the following paragraphs these indicators among others are discussed and an additional new indicator is proposed.

3.1 Power specific degree of hybridization

Meanwhile the degree of hybridization with respect to power is one of the most commonly used indicators to specify the properties of a hybrid propulsion system. Various definitions are used the presented (eq. 4) is following the definition given by Lorenz et. al. [4], where P_{em} is the power of the installed electric motor power and P_{tot} the total installed power.

$$H_P = \frac{\mathrm{P_{em}}}{P_{tot}} \qquad (4)$$

In general there is only information about the sizing of the different components included. But together with information about the architecture a first impression about the operating and sizing strategy can be gained. However, the definition of type of energy is used in which phase of the mission as well as how good the system is, is not included in these kind of figure. Furthermore it is not a design parameter as long as the aim is to improve fuel based systems. It is much more the result of the sizing for a certain operating strategy. Only if mission energy is stored in batteries and a fuel based system acts mainly as range extender it can be handled as design parameter, but even than it is usually given by the design process for the certain mission. (Compare paragraph 1.1)

If the indicator is interpreted without consideration of additional information or the architecture it can be misleading. For example if we have a value of one it seems to be both: Pure electric or series hybrid using only fuel. In case it is a series hybrid based on fuel it can happen that it is even less fuel efficient than a conventional fuel based system.

3.2 Energy specific degree of hybridization

Complementary to the power specific degree of hybridization an energy specific degree of hybridization can be given as an indicator about how much of what kind of energy is used. There are also several definitions published in literature. As example the definition given by Lorenz et. al. [4] is shown in (eq. 5). It is comparing the energy stored as electricity compared to the total stored energy. This indicator can give an impression on how much of the mission energy is stored in which storage and how they are sized.

$$H_E = \frac{E_{\mathrm{el}}}{E_{tot}} \qquad (5)$$

Together with information about the architecture and the power specific degree of hybridization already a quite good characterisation of the propulsion system can be given.

A disadvantage of this indicator is that it is not very intuitive due to the huge differences in energy density and completely different efficiency factors while using this energy. That makes it hard to asses comparing two different types of energy systems. Fuel has much higher energy density than batteries but additionally the efficiency is typically much lower, so it can happen that from the value of this fraction it seems that nearly no electric energy is used but in real the friction of for propulsive used energy (exergy) is much higher.

For instance a value of 0.5 gives as first impression that half of the thrust is generated out of fuel. If typical total efficiencies of 25% for fuel based system and 80% for electric system are assumed, it results that ca. 76% of thrust is generated out of electricity. So this indicator needs to be interpreted with care otherwise it can be misleading.

3.4 Exergy specific degree of hybridization

An alternative to the prior described figures and to get a better understanding about the propulsion system the relation between exergy can be taken. That makes it much easier to understand where the energy of thrust is coming from. And it is a good metric to understand how much the secondary energy path is contributing to the propulsion. The degree of hybridization in terms of exergy can be defined similar to the power or energy specific ones. Where the exergy stored as electricity is compared to the total exergy (eq. 6).

$$H_{Ex} = \frac{E_{\mathrm{el}}}{E_{tot}} \qquad (6)$$

Accordingly, a value of 0.5 means that 50% of the thrust is generated out of fuel and 50% out of electricity. That seems to be a good option to compare or classify the propulsion systems.

But it is still not possible to make any comment on the energy efficiency of the transportation mission. For instance, the aircraft could be very heavy with only small remaining payload and the total amount of energy could be more than for a fuel based, lighter aircraft with same payload.

3.5 Usefulness of Energy systems (UoE)

All the previous discussed indicators for hybridization can only give an idea on how the hybrid system looks like and how the components are sized. All these indicators together with some information about the architecture should be given to get a better impression of the system. But for many stakeholders it is not of interest to see the technical details of such a system, as they are only interested to know how much better the system is compared to other systems. Today usually energy is taken as the metric for comparison.

Due to the incompleteness of information in all these prior discussed indicators the following new indicator is introduced in this paper. The new indicators will not replace the already used indicators but provide an easier method to assess and to derive a comparable value about energy efficiency. The new indicator is mainly designed for battery-fuel hybrid systems, but an application to other kinds of propulsion systems is possible.

The main disadvantage of batteries is usually that the mass is incredible high compared to fuel, that means it will generate a lot of effort to carry only the batteries themselves. Also the additional components of an electric propulsion system are sometimes much heavier compared to, for instance gas turbines. So the first required step is to find a ratio between the stored energy and the energy required due to the mass (eq. 7). If this ratio is higher than one potentially an additional transport mission could be done.

$$E = \frac{Energy_{stored}}{Energy_{reqiured}} \qquad (7)$$

But it’s still misleading because due to the system in which the energy is stored can only use the energy with the installed components, which means with the installed efficiency. Hence to characterize we need to give the required exergy to move the whole system compared to the total stored energy of the resulting system consisting out of electric as well as fuel based parts. If exergy is defined as energy times the total efficiency we will get the equation (eq. 8) for the usefulness of the invested energy (UoE).

$$UoE = \frac{(Exergy_{stored} - Exergy_{required})}{Energy_{stored}} \qquad (8)$$

For propulsion systems with constant masses the equation (eq. 9) can be given, which includes certain assumptions about the aircraft and mission, such as a lift to drag ratio and a mission distance etc.

$$UoE = \frac{E_{sp} * \eta_{total} * L/D - g * d}{E_{sp} * L/D} \qquad (9)$$

With:

E_sp	[J/kg]	specific energy density of whole system
η_{total}	[-]	total efficiency of the total propulsion system
L/D	[-]	Lift to drag
g	[m/s2]	gravitational constant
d	[m]	mission distance

For propulsion systems with mass losses over the mission (fuel burn) it is more challenging to give such an equation because the operating strategy has influence. It can be different depending on when the fuel is burned and how the mass is developing over the mission.

The UoE is mainly a new efficiency figure for the propulsion system taking also the mass of the propulsion system into account. A higher value means a reduction in total used energy.

If the resulting UoE number is divided by the total efficiency the resulting number (PoE) will give information about the potential payload. A PoE close to one it means a lot of energy can be used to transport a payload. If the PoE figure is close to zero it means a lot of energy is used to carry the energy storage and propulsion system itself, without capabilities for payload.

The derived methodology of hybrid architecture assessment is demonstrated in an aircraft design use case. Values for UoE and PoE of the design study are given in paragraph 6.6.

4 Conceptual Aircraft design

Starting from these prior described fundamental investigations, the next step is to create conceptual designs taking the whole aircraft into account. And generate the corresponding data in such a way that they can be used within further preliminary design processes.

4.1 VAMPzero and CPACS

To initialize aircraft design project and also to generate conceptual aircraft designs, DLR developed the conceptual design tool VAMPzero [5]. The structures of VAMPzero, supports a categorization into components and disciplines, that allows to easily extend with new technologies, methods or complete new components. This extensibility was for example shown for the conceptual design of strut braced aircraft, where an additional component with the respective disciplines was successfully integrated [6].

To allow the further usage of the generated data the output of VAMPzero is given in the “Common parametric aircraft design schema” (CPACS) [1]. CPACS is an XML based data format to describe an overall aircraft. Meanwhile it is well established standard within the European aircraft design community. The usage of CPACS allows to easily collaborate and to use tools and capabilities developed throughout this community.

4.2 VAMPzero^{hy}

For the initial design of aircraft with hybrid propulsion systems such an approach is also needed. Due to the open structure of VAMPzero it was decided to make further extensions for it.

To Asses hybrid propulsion systems on aircraft level using an overall conceptual design tool it is necessary to make appropriate modification respectively extensions to it. In case of VAMPzero a classic fuel based approach was implemented. For hybrid propulsion systems a change towards a more physical, energy based approach was needed. All aspects in the mission simulation part has been changed and the calculation back from energy to fuel is done to assess the respectively masses. So the essential function to design fuel based aircraft isn’t changed only the intern methodology has been changed toward more flexibility.

The second main change is the implementation of the new component “Hybridsystem” into the VAMPzero tool. All characterizing parameters and methods for hybrid propulsion systems are stored in there, divided into the disciplines:

- **Center of Gravity** (CoG), where the positioning of the center of gravities of all parts are defined with respect to the aircraft
- **Geometry** is the discipline where the dimensions and volumes are defined
- **Mass** holds the corresponding masses for the in CoG defined positions
- **Performance** holds all performance related parameters for the components

All these parameters are fully integrated into the other methods, for example in the overall CoG calculation. That allows assessing the geometrical integration on basis of the knowledgebase or predefined positioning.

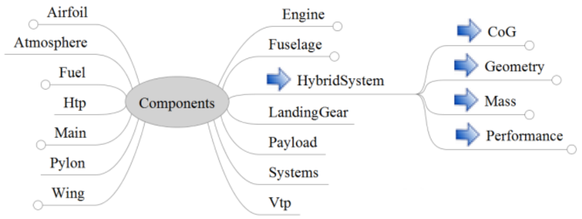


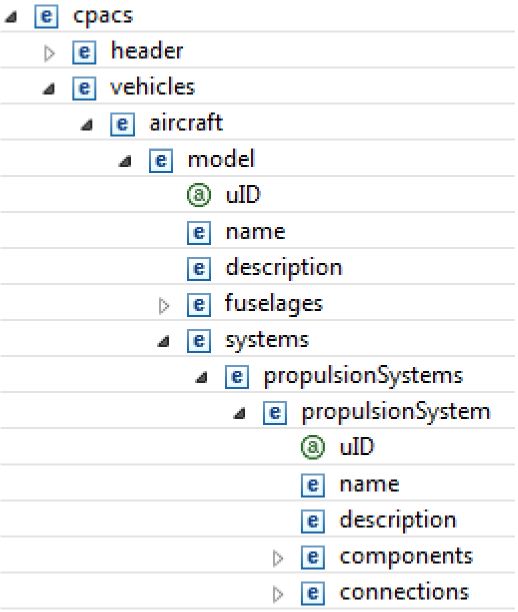
Fig. 3 Overview of VAMPzero components and the disciplines of the included hybrid system

For a conceptual design process which is usually used to initialize more detailed approaches, it's sufficient to base the sizing on simplified, empirical or statistical methods. The methods in this version of VAMPzero are based on fundamental performance indicators like specific energy, power or efficiency figures etc. All these figures have default values for two different technology scenarios but can also be defined within the input file. That simplifies the usage for different scenarios. Or to calculate which technology scenario is needed to get an improvement for a certain mission.

To select between different architectures and their appropriate operating strategies, predefined architectures can be selected via a parameter in the input file. A fast and simple implementation of further architectures is also possible if needed, due to the open and extensible structure of VAMPzero. With a selected architecture, a sizing of propulsion system and an overall aircraft synthesis can be done, taking all snowball effects into consideration. This approach will give a first conceptual design with the aircraft related data like geometry, masses, performance etc. See also results in paragraph 6.6.

4.3 Propulsion system definition in CPACS

For hybrid propulsion systems a definition is not available in CPACS at this point. To define a parametric structure to store this kind of information, it's highly important to know as many use cases as possible and the requirements of all disciplines depending on this information. To go towards such a definition a prototype data structure within CPACS is introduced to identify the degree of suitability. The prototype is defined in such a way that any architecture can be described, which keeps its definition as generic as possible.


- cpacs
  - header
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        - name
        - description
        - fuselages
        - systems
          - propulsionSystems
            - propulsionSystem
              - uID
              - name
              - description
              - components
              - connections

Fig. 4 Integration of propulsion systems into the CPACS structure

Therefore under the systems node of the aircraft the new „propulsionSystems“ node is defined. Where several independent propulsion systems can be stored. The propulsion system is then a collection of components and connections. Also some additional information for the propulsion system can be given such as name or description. A uID is defined to identify the unique system.

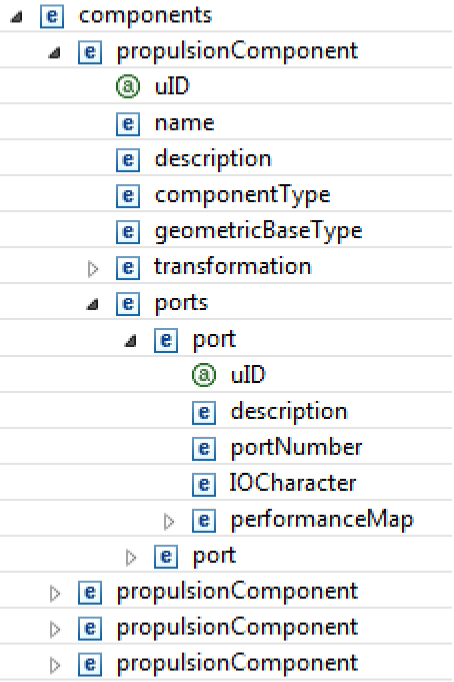

Fig. 5 Integration of propulsion components into the components node

Inside the component node all components of the propulsion system can be stored. The level of detail is free in this stage so it is possible to define a propulsion system without any cables, plugs or anything but it is also possible to define these tiny things like plugs as components. All components are defined by some describing parameters. The "componentType" gives information on what kind of component is installed, that can be used by further tools to select the appropriate modelling methods. The geometric base type gives a normalized geometry like cuboid, cylinder etc. In the transformation node accordingly the translation, rotation and scaling is done to define position, orientation and dimensions of the component. Accordingly the CPACS definition the component mass is stored in the mass section of CPACS and not explicit given in the component. The performance of the components is defined inside the port nodes. A component can have several ports to define different connections. For example a main functionality with mechanical output and electrical input and also secondary things like cooling etc. can be defined. For each port an "IOCharacter" is given to define the type of connection. The "IOCharacter" is also defining what parameters are in the performance map. All parameters in the performance map are defined as vectors, so for a certain entry in the performance map of one port the appropriate entry in the other ports can be found.

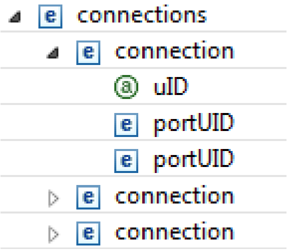

Fig. 6 Realization of connections inside the connections node

To connect different components the connections node holds all connection between ports defined by the uID's of these ports. The "IOCharacter" needs to be same for these two components. The requirements of one can then be found in the other performance map.

5 Hybrid Propulsion in distributed design environment

To use the results of the conceptual initial sizing process it is needed to have an initial data set and a common data format. Both is realized for the design of hybrid propulsion system. Also the integration into the Remote Control Environment (RCE) [7] is realized.

RCE is a distributed integration environment where tools of different partners can be shared and connected into workflows for the analysis, design and optimization.

So the data set of a conceptual hybrid powered aircraft can be used for further calculations. Calculations which are not taking the propulsion into account can be used without any changes, for example clean aerodynamic. For further design or analysis of parts are depending on the propulsion system corresponding adaptions are required.

The by VAMPzero generated and in CPACS stored data, are also input for the under development "Alternative Propulsion System Design Tool" (APSDT). The within these tool calculated performance maps for the propulsion system will then be used for more detailed investigations like mission simulation.

6 CS23 Commuter design study

As use case for the implemented conceptual functionality a CS23 [8] aircraft was studied. The CS23 allows a maximum of 19 passengers and a maximum takeoff weight of 8618 kg. The design mission is chosen as a commuter or regional scenario with 400 km range and a payload of 2000 kg, flown with Ma=0.4 in 3000m altitude. For this mission the integration of four different hybrid architectures and the reference case with conventional turboprop engines are studied. Technologies like distributed propulsion and Boundary layer ingestion are not considered in this stage. The aim of the study is to show the general capability to create initial designs with hybrid propulsion drive trains for the use in distributed design environments. The configuration itself is selected as a high wing with t-Tail. Two propellers are mounted to the main wing independent what type of propulsion system is used. The propulsion systems are placed at the same position on the wing, for series hybrid the energy system is placed in the aft fuselage. This mostly conventional configuration is chosen to show the short/midterm potential for hybrid propulsion systems. With the developed conceptual approach a full aircraft synthesis is possible to get all snowball effects into the loop. The considered technology scenario is oriented on todays and for the next 5 years expected technology, Table 1 gives some sample values.

Table 1 Assumed performance values for electric components (sample)

Component	Value	Unit
Electric motor	3,5	kW/kg
Generator	3,5	kW/kg
Batteries	0,22	kWh/kg
Inverter/Rectifier	10	kW/kg
DC to DC converter	7,5	kW/kg

6.1 Reference Architecture: Turboprop

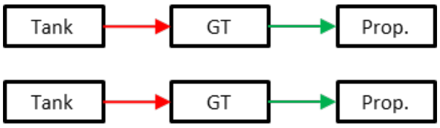

Fig. 7 Conventional turboprop architecture as reference use case

The reference architecture is a classical turboprop propulsion system using two gas turbines to drive the propellers mounted at the wing. This architecture is used as the reference case.

6.2 Architecture 1: Series system using one gas turbine

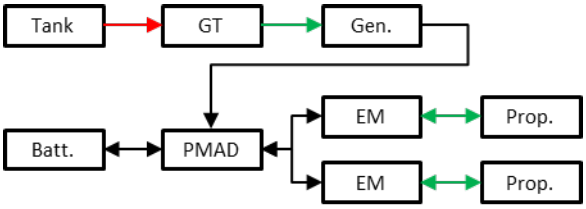

Fig. 8 Series architecture with one gas turbine and two electric driven propeller units

Architecture 1 is a series hybrid propulsion system which has a gas turbine generator unit as well as a battery to power the two electric motors providing shaft power to the propellers. The battery is used to supply power during take-off and climb as well as to cover peak power loads. Also in terms of redundancy the battery is used in case of a gas turbine failure. For this architecture the electric motors are attached to the wing, the battery is also integrated to the wing and the energy system out of gas turbine and generator is located in the aft fuselage.

6.3 Architecture 2: Series system based on two gas turbine generator units

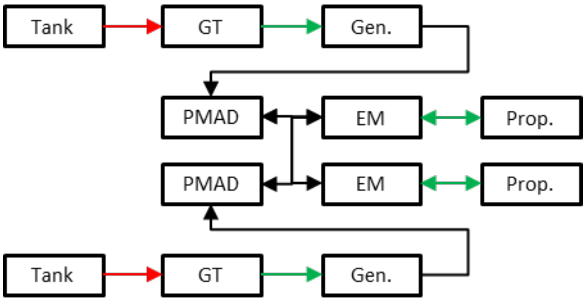

Fig. 9 Series hybrid architecture with two gas turbines

Architecture 2 is a series hybrid propulsion system with two gas turbines running generators to feed the propeller driving electric motors. Due to the not considered potential benefit for the gas turbine there is no reduction in fuel burn expected for this configuration. The electric motors are located on the wing and the energy system with two gas turbines is placed in the aft fuselage.

6.4 Architecture 3: Parallel system using two gas turbines combined with electric motors

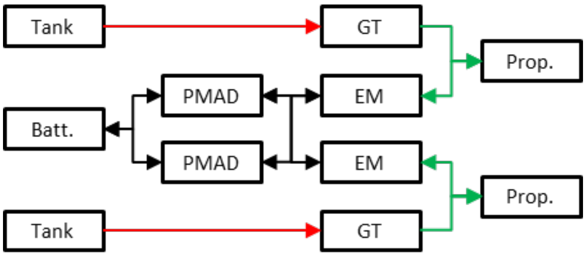

Fig. 10 Parallel hybrid architecture with electric motors connected to the propeller shafts

Architecture 3 is a parallel hybrid configuration where the wing mounted engines are supported by mechanically to the driveshaft attached electric motors. The gas turbines will be sized to cruise with 100% and the additional takeoff and climb power will be provided by the electric system. That will ensure that the efficiency during cruise is not influenced by any additional efficiency and the gas turbine efficiency could be improved as well due to the reduction of design requirements. Only the penalty of additional mass needs to be balanced. The system is mounted to the wings and the Batteries are inside the wing.

6.5 Architecture 4: Series system based on fuel cell and LH_2

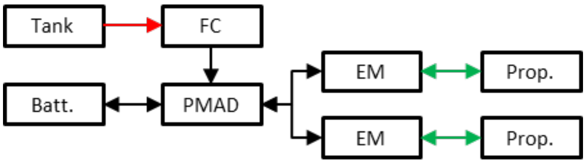

Fig. 11 Series hybrid using hydrogen and a fuel cell for the main energy path and batteries for the secondary path

Architecture 4 is a series hybrid based on a fuel cell and liquid hydrogen storage. Variations in power load are covered by a Battery. The challenge in this case is beside the mass also the volume of the energy storage. The concept considers a fuselage integrated hydrogen storage direct behind the cabin. That's why an increased fuselage length and friction drag is expected. The CoG can be hold in certain limits due to the high mass specific energy of hydrogen, which means only small changes in mass during the flight. Otherwise that means only small benefit on mission fuel due to the mass change over the mission.

6.6 Results from the overall aircraft synthesis

The result of the aircraft design process are five aircraft designs with different propulsion architechtures.

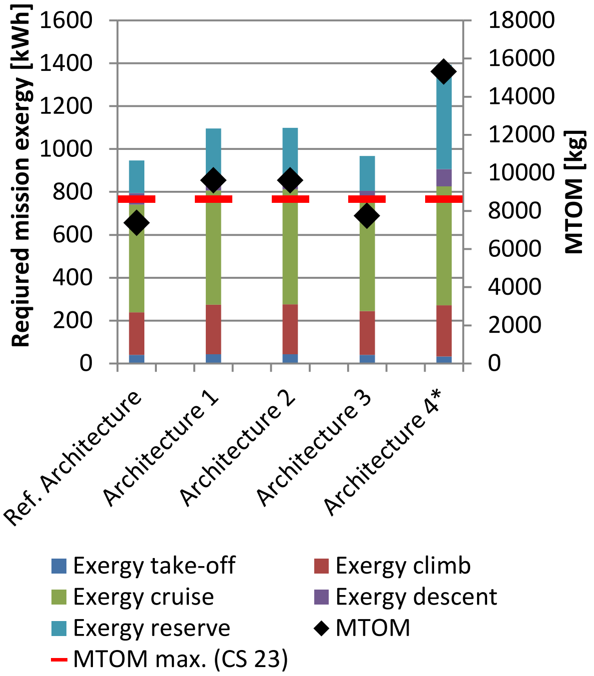

Fig. 12 Resulting MTOM for the designs and the required exergy for the missions. (*Architecture 4 is calculated with different cruise mach number)

The results of the overall aircraft synthesis are shown in [Fig. 12] displayed is the used propulsive energy (exergy) for the prior described mission with in colors divided energy fractions for the different parts of the mission. The used exergy is direct, depending on the mass of the aircraft. It can be seen that the parallel hybrid architecture, from the exergy requirement perspective is pretty close to the reference so it could be beneficial. The other systems are not possible within the CS23 MTOM limit and also the exergy requirement is relatively high already. Architecture 4 is not possible to build for the required mission. To generate at least some data and test the methodology the cruise mach number is reduced to 0.3 for that architecture.

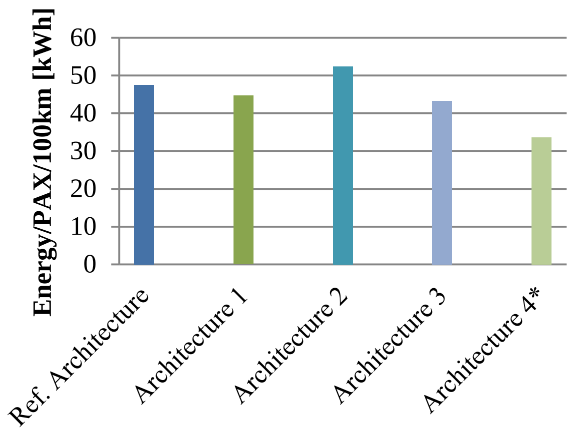

Fig. 13 Energy consumption of the designs per 100 passenger kilometers (*Architecture 4 is calculated with different cruise mach number)

The already observed potential for architecture 3 can be further seen if energy is compared, as it has the lowest total energy requirement. Also architecture 1 has a lower total energy requirement due to the included battery. For architecture 4 the energy consumption is best but it's still not possible to fly the same mission.

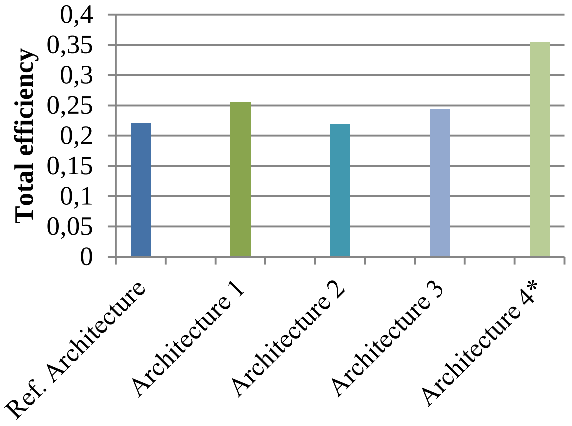

Fig. 14 Resulting total energy consumption of the designs (*Architecture 4 is calculated with different cruise mach number)

Figure [Fig. 14] shows the total efficiency and total used energy for all designs. From the energy point of view we receive already a remarkable benefit for the architecture 1 and 3.That means the penalties due to the higher mass can be equalized by the high efficiency of the electric part although we have to invest more exergy to do the transportation job. But in this context it also needs to be considered that the aircraft is the system border, no indirect energy consumptions are considered.

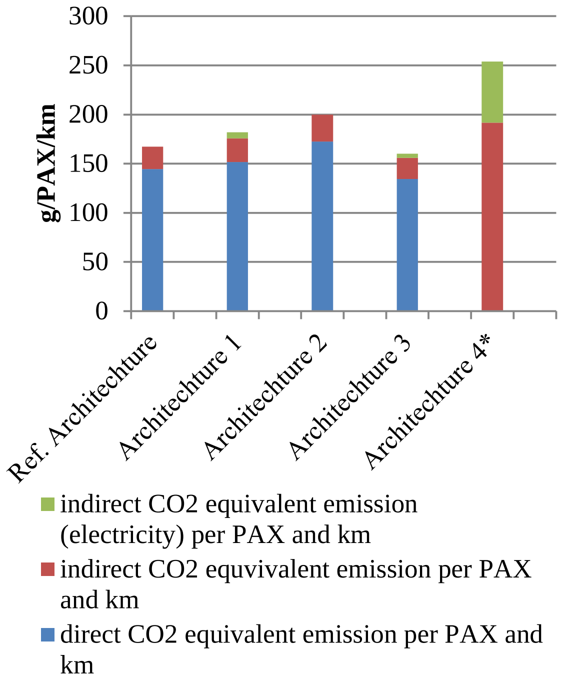

Fig. 15 Direct and indirect emissions of the designs (*Architecture 4 is calculated with different cruise mach number)

If a comparison of emissions is done, also indirect emissions can be considered by using emission factors. In this case data for energy in Germany are taken from the German environmental protection agency [9]. The most emissions are direct and indirect emissions from fuel. The indirect emissions out of the electricity generation are pretty low. The emissions of architecture 4 with fuel cell and hydrogen are very high, due to the nowadays used production based on the use natural gas.

A comparison with prior estimated UoE and PoE figures shows accordance with the results from the conceptual design process [Table 1].

Table 2 Estimated key figures for the selected designs

Architecture	Ref.	1	2	3	4
UoE	0.299	0.229	0.217	0.304	0.259
PoE	0.977	0.844	0.860	0.953	0.576

7 Conclusion and future work

The capability of the introduced indicators UoE and PoE to estimate total mission efficiency and payload capabilities has been verified with results of the developed conceptual design approach. The methodology of the initial design process was proven by performing a design study for a commuter mission with various hybrid propulsion systems and respect to CS 23. The following future works are planned to improve the initial and preliminary design process for aircraft with hybrid propulsion.

- Implementation of further disciplines to the initial design process, in particular thermal aspects.
- Increased set of predefined architectures with different integration strategies.
- Further test and development of the CPACS definition for hybrid propulsion systems.
- Development of preliminary tools for hybrid propulsion systems and integration to the design environment.

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