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Foundations towards the future: FUTPRINT50 TLARs an open approach

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Abstract. A hybrid-electric regional aircraft for 50 passengers has challenges in technology, operation and future regulations similar to larger class aircraft. It is thus at the right spot to drive technology, regulations and operational developments in order to accelerate cleaner flight technologies based on propulsion electrification. The FUTPRINT50 team set up Top-Level Aircraft Requirements that aim to be a reference foundation for the development of specific topics handled in this H2020 project but also drive the open collaboration model adopted by FUTPRINT50. In this paper the development of the mission statement will be explained for a hybrid-electric 50 passenger regional aircraft, which builds the framework for the Top-Level Aircraft Requirements. To further support development from these requirements, a mission scenario will be presented for this class of aircraft.

1. The project FUTPRINT50

Future propulsion and integration: towards a hybrid-electric 50-seat regional aircraft – FUTPRINT50 – is a European funded project within the Horizon 2020 Research and Innovation programme. The FUTPRINT50 consortium joins fourteen international partners, led by University of Stuttgart and is formed to accelerate the entry into service (EIS) of a hybrid-electric regional aircraft with up to 50 passengers. Estimated EIS for this kind of hybrid-electric regional aircraft is 2035/2040 and it should enable an eco-friendly regional/short range travel option by air. New challenges for the aircraft configuration and systems design will be introduced through the electrification of the propulsion system which will allow for cleaner aviation operations. Therefore, in-depth state of the art analysis and feasibility studies are performed with the help of open-source aircraft design tools which are publicly available or developed within FUTPRINT50. Along with the electrification, additional subsystems are introduced into the aircraft and new systems interdependencies are identified and created. To take these challenges into account, FUTPRINT50 is focusing specially on new disruptive technologies for energy storage, energy harvesting and thermal management.

The hybrid-electric approach is opening various new design spaces in aviation. To ensure certifiability, the consortium is performing multiple component failure scenarios analyses. Furthermore,



a space allocation study will allow for a feasible aircraft design where every subsystem is integrated in compliance with its installation requirements.

As a final major result, FUTPRINT50 will create a roadmap for development of its key technologies with regulatory aspects, experimental infrastructure and future demonstrators to support the achievement of a European Clean Aviation expressed in the goals of the Flightpath 2050 [1]. Finally, the project's open approach allows to align future research activities and aviation stakeholders to accelerate the emergence of a future European hybrid-electric regional aviation.

2. Introduction

In the recent years an increasing awareness of the environmental impact of air travel became apparent. Climate initiatives like the European Union's Flightpath 2050 or the ICAO's CORSIA [2] are setting new emission goals to be met by the aviation industry in the next two decades.

The reduction of emissions does not only include by-products from the combustion process but also noise. Within Flightpath 2050 highly ambitious goals have been set. In relation to a typical year 2000 aircraft, CO₂ emissions should be reduced by 75% and NO_x emissions by 90%. Noise emissions, especially harmful for the environment near airports, shall be reduced by 65%. For conventional aircraft designs the potential for improvement is expected to be limited below these requirements. Therefore, new paths for aircraft design must be explored to close these gaps and additional synergies between subsystems need to be investigated to improve the overall efficiency of the aircraft.

Further on, Flightpath 2050 requires that all aircraft movements on ground while taxiing have to be performed emission-free. For a hybrid-electric aircraft this can be easily fulfilled, whereas in case of a conventional aircraft two main options are available: Either an electric tow truck that pulls the aircraft to the runway or additional electric motors for example within the landing gear of the aircraft. The first option requires a suitable infrastructure at every serviced airport, while the second option introduces a weight penalty for the aircraft solely for the purpose of emission free taxiing.

Another requirement of Flightpath 2050 is that the aircraft is designed with recycling in mind. This includes not only the material used for the aircraft itself but also all aspects of the manufacturing process and the overall life-cycle. Therefore, a Systems Engineering approach was selected for FUTPRINT50.

Systems Engineering (SE) is a methodology where one takes a holistic view and investigates the need, the functions necessary to fulfil that need, and the physical architecture required to perform those functions. SE requires a transdisciplinary approach to position a system in its worldly picture and look at all that are affected within the complete life-cycle of the product. Systems engineering is to enable the realisation of a successful system [3]. As defined by the international council on systems engineering: *"A transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods."* [3].

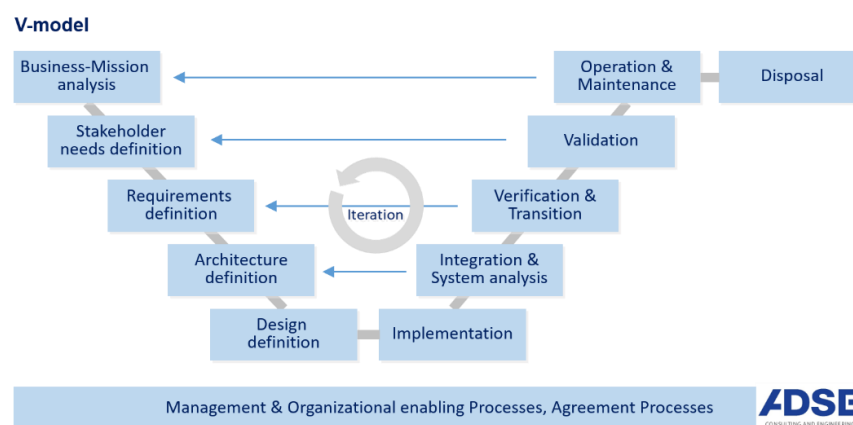


Figure 1. V-model of systems engineering

The SE way of working is best depicted by the V-model (Figure 1). The V-model works from a need and business analysis towards a design definition on the one hand, and from design implementation to actual operation on the other hand (eventually leading to disposal). Important to highlight are the iterations for validation and verification purposes. The analysis and design definition need to align with the actual designed system, fulfilling the identified needs. For the case of a hybrid-electric regional aircraft, the requirements definition aligns with the Top-Level Aircraft Requirements (TLAR).

To start, one needs to define the system and its added value (the goal or need), using the business-mission analysis. In the case of FUTPRINT50 this would initially be: hybrid-electric aircraft design. However, the aircraft in itself is only a way to fulfil the need, more like the architecture or design definition. The goal of the aircraft would be to transport people from one location to another. The purpose of doing that with a hybrid-electric version of an aircraft would be to reduce the negative impact of air travel on society and environment. The need would become to design a regional aircraft which significantly reduces environmental impact.

A stakeholder analysis is used to uncover the needs. Stakeholders are all involved parties that are affected by the system. FUTPRINT50 identified following stakeholders: EU citizen, Authorities, Operator, Airport, Air Traffic Management (ATM), Supplier of energy and the Passenger. The EU citizens are mentioned separately as they are the customer, paying to achieve a more sustainable means of transport to attain climate goals. The passenger will be seen as the user of the system.

The stakeholders uncover the bigger picture, the 'system of systems' (Figure 2). The system definition of the regional aircraft is part of the world transport system. The aircraft and its design will affect multiple stakeholders and their potential needs. It is therefore important not only to create a perfect aircraft design, but to create a design that works seamlessly within the 'system of systems'.

The term 'value proposition' can be used to quantify how the system and the stakeholders align, to highlight beneficial areas for development. Through analysis of the need, the system in which it operates (including stakeholders), the functions and architecture required, the gaps and selling points of the system are revealed. Together these pros and cons make the value proposition.

The system definition together with the stakeholder needs and the following value proposition are the starting point to define the TLARs.

The first two steps in the V-model can be translated into a mission statement. The mission statement is a concise explanation that supports the vision and serves to communicate purpose and direction to all involved. The statement in our case would define what system is to be designed, as well as highlighting the value for the stakeholders.

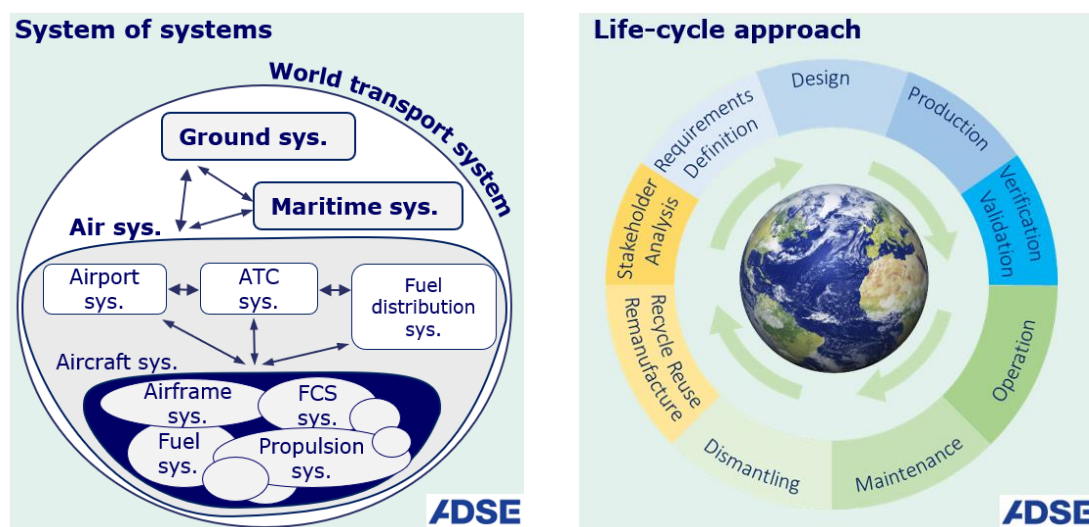


Figure 2. The 'system of systems' (left) and the life-cycle approach (right)

The current FUTPRINT50 mission statement is as follows:

“To develop a synergetic aircraft design for a commercial regional hybrid-electric aircraft up to 50 seats for entry into service by 2035/2040, to identify key enabling technologies and a roadmap for regulatory aspects. The clean sheet aircraft design shall help accelerate and integrate hybrid-electric aircraft and technologies to achieve a sustainable competitive aviation growth, as well as acting as a disruptor to regulators, ATM and energy suppliers.”

The clean sheet aircraft design shall:

- have class leading emissions and noise,
- include technologies that ensure (operational) safety,
- offer a competitive operational cost,
- offer operational improvements during exploitation compared to current regional aircraft,
- not enforce expensive changes to the current infrastructure.

The V-model is strong as it recommends to iterate after every step. The current mission statement is based on the mission analysis and stakeholder definition as is seen now. After iterations this view might change, consequently the mission statement might be further refined. The ability to be agile can be the key to success, where it should always be in a structured and organised manner to prevent one from losing track.

This mission statement provides the framework for the TLARs. The requirement of feasibility until the EIS in 2035/2040 stands above all in this case, followed by a high influence regarding the environmental aspects defined within Flightpath 2050 objectives. The TLARs should provide reference requirements to understand and develop a robust roadmap for the hybrid-electric regional aircraft. This class of aircraft is located in the sweet spot allowing technology readiness within the required timeframe and furthermore for a good transferability onto larger aircraft by facing similar challenges. Other influencing aspects are current operations within the regional market as well as possible future transport networks. In the future new operation modes might emerge by exploiting novel technology enablers. Increasing autonomy which allows less personnel in the cockpit or even unmanned operation might open up new markets. Remote tower airports will allow for a denser, more decentralised network with increased coverage. Together with potential other changes this further might allow to deal with current technical limitations encountered by hybrid-electric regional aircraft, like the limited range for example.

Air travel provides differentiated and complementary benefits to other modes of transport. The travel times are drastically reduced by its speed advantage and flight path, less encumbered by geography than other modals. Furthermore, the infrastructure cost of air travel is usually lower than road or rail. The minimum requirements are an airstrip at departure and destination. In between no roads, tunnels or railroads are needed to connect two points. This not only reduces cost for building the infrastructure but also maintaining it. Equally interesting are the possibilities of accessing more remote regions. Here, connecting several points by other modes of transport is often challenging or simply not cost-efficient.

As already shown by the ‘system of systems’, air travel is only a part of the overall picture. One of the goals within Flightpath 2050 is also “that 90% of Europeans citizens should be able to travel door to door within 4 hours”. This will only be possible with an integrated, intelligent, intermodal transport system, allowing synergic and seamless transfer between modes of transport in order to achieve this European vision.

3. FUTPRINT50 top-level aircraft requirements

Close to 40 TLARs are defined within FUTPRINT50 for a hybrid-electric regional 50 passenger aircraft in relation to flight performance, operational aspects, market requirements as well as environmental improvements and regulatory standards.

The technology readiness of all components should allow for a feasible EIS in 2035/2040. As design payload 5300 kg is selected, characterised by the aircraft’s capacity of up to 50 passengers, where each is estimated 106 kg including baggage. For the maximum payload an additional 500 kg of cargo is

defined. Following Flightpath 2050, the ATR-42 was selected as a 'typical year 2000 reference aircraft' and the project will also generate a conventional reference aircraft for year 2040.

The design range is set to 400 km (plus reserves). According to our studies, using a world flight database for year 2019, as well other references, as Brdnik et. al. [4], this represents approximately 70% of today's flights with regional turboprops within the European region. The TLARs would thus target an optimization for the largest market share within the reasonable expectations for the technology.

Still, there are regions where a higher range is essential. One example would be Russia, where cities are often more separated. To address this and to allow more flexibility for the operators, the maximum range is specified at 800 km (plus reserves). This enables them to fly two standard missions without refuelling or to connect more remote regions. Reserves are separately defined to be 185 km and 30 min of additional holding. In the future these requirements will be further investigated and adaptations for different regions may be performed as required.

As shown by the design mission distance, the typical duration of one flight is rather short. Therefore, a design cruise speed of 450 km/h up to 550 km/h is defined. This is comparable to current turboprop aircraft. Reducing this speed would reduce the number of dispatches per day and thus affect the productivity of the aircraft.

Another important aspect, especially for accessing remote regions, is the take-off and landing performance of the aircraft. The take-off length is set to 1000 m in ISA conditions at sea-level on a paved runway. Additionally, the aircraft is required to take-off within 800 m with minimum 80% passengers on board. Required landing field-length is usually shorter for aircraft that are losing weight/burning fuel on the way. Therefore, no special condition was set for landing field-length. This would need revision when for example lithium-air batteries are used, which accumulate oxygen while discharging and therefore increase landing weight of the aircraft [5].

Maximum operational altitude is defined as FL 250 which is typical for current turboprop aircraft. Similar to the design cruise speed, the flight duration is relatively short where a most efficient and for the passengers more pleasant flight profile will be at lower altitudes to reduce overall climb time. Furthermore, in this altitude it is expected that no contrails or aviation induced cloudiness is formed [6]. For them, current research predicts a significant negative impact on global warming which will be eliminated by the lower cruise altitude [7].

As already explained in the previous section, the TLARs are highly driven by environmental aspects defined within Flightpath 2050. So, all the emission-based criteria like CO₂, NO_x and noise as well as recycling and emission free taxiing are specifically included within the TLARs.

4. Design Missions

Several reference missions have been designed to represent all aspects of the TLARs. The different types are based on aspects like range, temperature and terrain.

- Optimum range
- Maximum range
- Cold & extreme cold
- Hot & high
- Island operations
- Mountainous terrain

Each of these missions will drive different design aspects of the aircraft design. The temperature scenarios for example will influence the thermal management as well as available power or thrust and the batteries. Flight performance like take-off and landing field length or climb capabilities will especially affect island operations or missions in mountainous terrain. An example for the optimum range mission is shown in Figure 3, designed as the connection between the two FUTPRINT50 partners, Cranfield University in the UK and ADSE close to Amsterdam in the Netherlands.

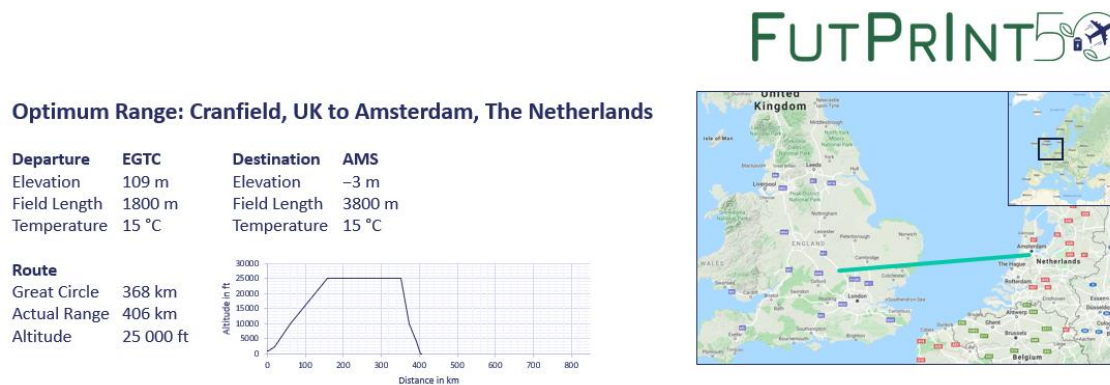


Figure 3. Optimum range mission

5. Upcoming steps

As shown by the V-model, the upcoming steps are the definition of the architecture and design. For the overall aircraft design many options are available, some of which have been already evaluated at a high level. In the ongoing work, detailed assessment and optimisation of different options will take place. To open up the design space a 'FUTPRINT50-Frankenstein' configuration was designed, as shown in Figure 4. It is a concept which includes a large number of technology options and combines them into one single aircraft. The idea behind is to break current aircraft design 'traditions' in an aircraft configuration and design approach. The design itself most certainly is not optimised yet, not the least because of the number of novel propulsion systems integrated, such as high-lift distributed electric propulsion on the main wing, a boundary layer ingesting fan in the rear and hydrogen as fuel for gas turbines that drive electric generators. A converging final design concept in the end will result from a careful down selection, combination and integration of (disruptive) technologies under investigation in the framework of FUTPRINT50.

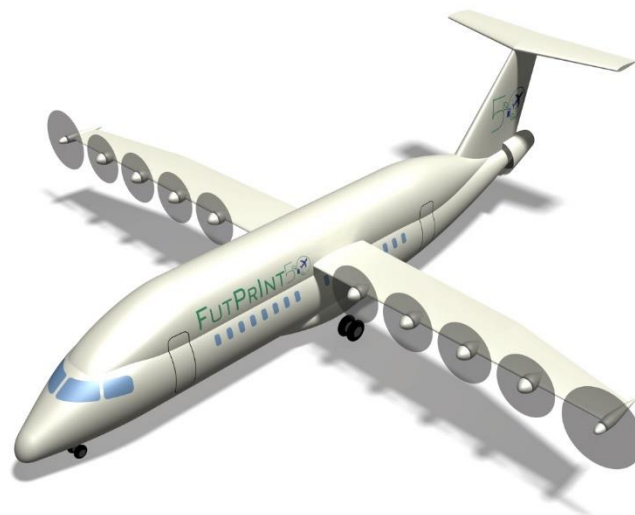


Figure 4. The 'FUTPRINT50-Frankenstein' configuration

Acknowledgments

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