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Considerations and Findings During the Conduct of the CONCERTO CS-23 HVD Gap Analysis

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Abstract

The CONCERTO project intends to enable innovation, while maintaining the safety performance of current configurations, by drafting suggestions for new means of compliance within the scope of the three Clean Aviation branches. This paper is drafted within the high-voltage distribution branch of the CONCERTO consortium. It provides an overview of existing considerations about the certifiability of (hybrid-)electric aircraft configurations and presents a structured and methodical approach that has been established while conducting CS-23 regulatory gap analysis for the CS-25-derived CS-23 CONCERTO HVD architecture. A limiting factor when incorporating existing insights into a new regulatory gap analysis is that most studies are based on a specific configuration, limiting their applicability. One key feature of the presented methodical approach is the property-based similarity approach that overcomes this limitation by enabling systematic incorporation of existing project-specific findings into the analysis to be conducted, taking into account the specific properties of different system design and sizing. The structured comparison, based on relevant technological properties, enhances the applicability of the identified critical areas and regulatory gaps of available gap analyses by enabling a systematic transfer of gap findings to other HVD system designs, even with different properties.

Keywords: high-voltage distribution; gap analysis; comparison; safety assessment process; CS-23; certification

1. Introduction

1.1. Motivation

Historically, certification specifications represent current technology requirements and standards that aircraft need to demonstrate compliance with to obtain certification. As elaborated by Schlickenmaier et al. [1] and Jézégou et al. [2], using distributed electric propulsion as an example, current certification standards face difficulties in covering the features of new and potentially disruptive technologies. In such cases, an analysis needs to be conducted to identify gaps in current requirements. To enable later certification of the intended product, these gaps need to be filled to ensure an equivalent level of safety, as required, e.g., by CS.25.1309 [3], or guidance material for aircraft safety analyses, e.g., [4], respectively. Within the European Union's Clean Aviation Joint Undertaking (CAJU), high-voltage distribution (HVD) systems, capable of providing and distributing power not only to conventional loads but also to an electric or hybrid-electric propulsion system, have been identified as one key enabling technology to support climate-neutral aviation. The connection of propulsive loads to the aircraft electrical system brings along elevated power and voltage levels and new functional interrelations that affect both nominal

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and off-nominal system behavior. These differences with respect to conventional aircraft configurations incorporating fuel-based propulsion systems motivate the necessity of a profound gap analysis for all relevant certification requirements. The CONCERTO project features certification gap analyses based on an exemplary HVD system design for CS-23, CS-25, CS-E and applicable battery-related standards. As the availability of certification gap analyses for (hybrid-)electric configurations is growing, valuable resources are already available; however, they are intended for different and specific configurations, respectively. One of the intents of the CONCERTO project is to enable certification of not only one specific configuration but also the complete range of possible configurations. To fulfill this task, one key question to be answered is whether a structured approach can be established that makes results transferable between different aircraft system designs and different technological concepts. This question incorporates considerations about how to assess the comparability of different system designs regarding their certification gap findings, how to transfer results from one project to another by accounting for these differences in system design and sizing, and how to make maximum use of existing knowledge to enhance the quality and robustness of the gap analysis outcome, while potentially expediting the process. To take the first steps in answering these questions, the authors have come up with the "property-based similarity approach" that will be presented in Section 3.4.1. It is part of the complete structured and methodical approach that has been used for conducting the CS-23 gap analysis within the CONCERTO project, which will be presented in detail in the following chapters, together with a summary of the main findings.

1.2. The CONCERTO Project

The acronym CONCERTO stands for "Construction Of Novel CERTification methOds and means of compliance for disruptive technologies". Due to the radical changes to aircraft designs induced by the technologies envisioned in the CA branches [5], the CONCERTO project investigates the certifiability for all three branches envisioned by the CAJU, covering the key enabling technologies. The project focuses on the regulatory framework with the aim not to restrict innovation, whilst maintaining the safety performance of configurations currently in use. The results of the gap analysis shall later be used to establish new means of compliance, or other regulatory material, if deemed necessary [6].

1.3. High-Voltage Distribution Proof of Concept Within CONCERTO

Comparable to the configurations and projects introduced in Section 2, where the gap analyses were conducted with reference to the respective configuration, for the CONCERTO HVD branch, a proof of concept (PoC) was also defined to conduct the gap analysis. To be of best use for the global CA REG branch [5], the CONCERTO HVD PoC was defined in close coordination with other CA REG projects, such as HERA and HECATE. While the resulting HVD distribution was obtained from the HECATE project [7], the parallel hybrid powertrain architecture originated from HERA use case A (UCA) [8]. To protect intellectual property of the related projects, in the following, all values relating to the HVD PoC are given as ranges or are deliberately omitted. For more information on this, the authors of this work refer to the relevant points of contact for the relevant CA project or authors of the references, respectively.

The PoC, as defined within [9], envisions a parallel hybrid propulsion architecture with a combined power ranging between 4 and 10 MW. The high-voltage distribution system, as illustrated in Figure 1, routes electrical power from the storage system to the propulsors (in green), the intermediate voltage system (in blue) and the low-voltage loads (in light blue) within the secondary distribution. The energy source is not defined within the PoC, as both a battery- and fuel-cell-powered electrical system shall be usable. The fraction

of electrical power provided shall be around 40% of the total hybrid-system power. The very-high-voltage direct current (KHVDC) bus introduces a power converter linking to the high-voltage direct current (HVDC) bus. High-voltage loads are connected via solid-state power contactors (SSPCs), which are also used to connect the low-voltage direct current (LVDC) bus and low-voltage loads. Therefore, the isolation of the buses, together with the bonding and grounding, is of utmost importance. The bus design is closely regulated.

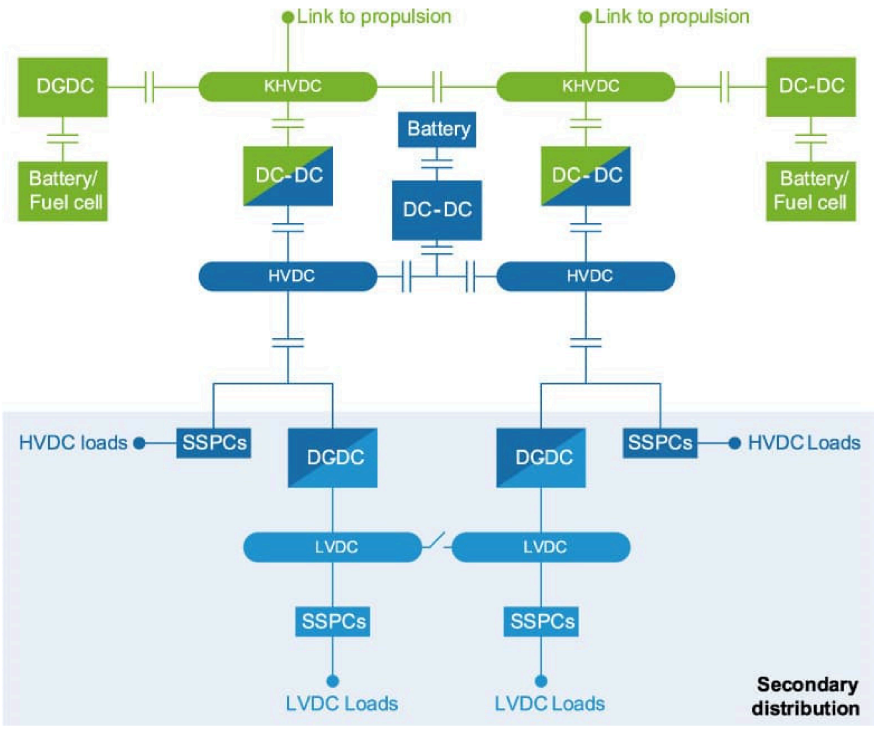


Figure 1. CONCERTO/HECATE HVD architecture [10], (green) very high voltage distribution system, (blue) intermediate voltage distribution system, (light blue) low voltage distribution system.

The non-electrical part of the propulsive system consists of two conventional gas turbines. As depicted in Figure 2, they are electrically boosted by two electric engines via a gearbox, to enable the combination of both power sources driving the propeller. The gas turbine is started by a conventional starter generator. The propulsive architecture foresees two parallel hybrid engines.

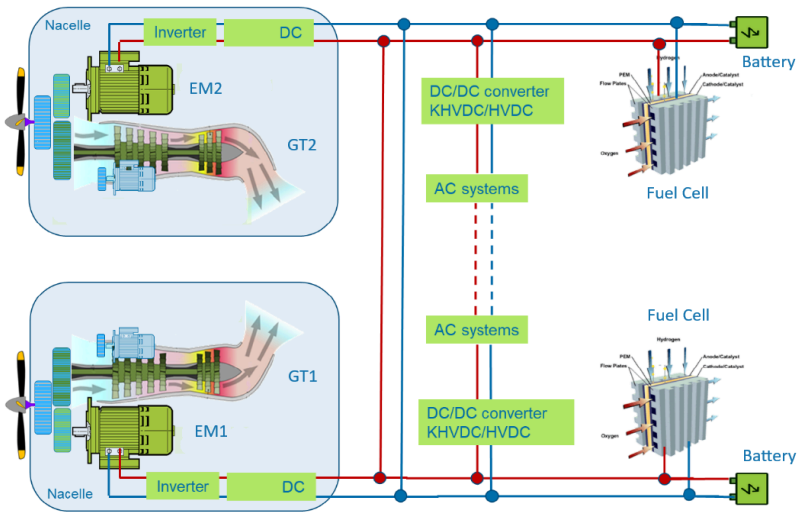


Figure 2. HERA UCA reference architecture [8].

As the CONCERTO project intends to serve the CAJU REG [5] branch in the most efficient way, the PoC envisioned is a CS-25 configuration. This decision in particular results in the chosen voltage and power levels for the KHVDC part. To properly conduct the gap analysis for a CS-23 configuration as well, the PoC needed to be validated for its CS-23 applicability, which initially motivated the comparison and the question of the global applicability of the HVD PoC. To maintain the global notion and to base all further discussions on one PoC, no decisive CS-23 PoC was designed. Instead, the CS-25-intended HVD PoC as depicted in Figure 1 has been re-evaluated regarding the required voltages and power ratings and has been slightly modified.

The result is illustrated in Figure 3, which mainly aligns with the CONCERTO CS-25 HVD PoC, as introduced in [9]. As, according to [11], both the propulsive and non-propulsive power requirements are considerably lower, no intermediate power level is required; hence, only the KHVDC bus (for propulsion) and the LVDC bus (for LV loads) are considered relevant for the derived CS-23 architecture. Although for the majority of CS-23-only-sized projects lower bus voltages have been considered more adequate, even in the CS-23 certification framework, projects exist with comparatively high voltage levels, comparable to the envisioned CS-25 values [12]. Thus, we conservatively assume identical voltage levels for the CS-23 and CS-25 architectures. Additionally, the authors assume that other functions, such as the provision and distribution of power, will first be regulated on a CS-25 basis, due to the requirements for infrastructure and part availability. Therefore, it must be noted that one specific PoC as the CS-23 HVD PoC derivative, illustrated in Figure 3, cannot provide coverage of the complete design space and might lead to over-restrictive results by being too conservative. This emphasizes the necessity of a structured comparison approach capable of transferring insights from one system design to another by accounting for different properties, e.g., different voltage and power levels.

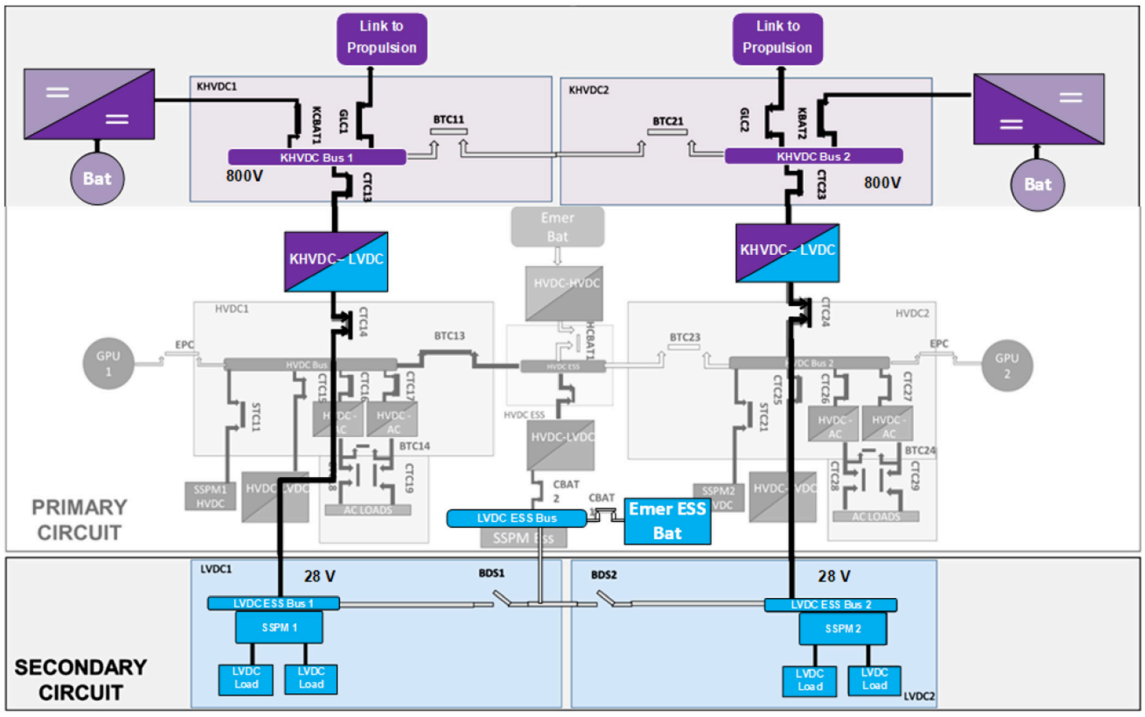


Figure 3. CONCERTO CS-23 resized HVD architecture, (purple) very high voltage distribution system (green, in Figure 1), (light blue) low voltage distribution system.

2. Review of Work Conducted and Technological State of the Art

Electric and hybrid-electric propulsion system (EHPS) concepts evolve fast, with the aim of fulfilling global emission goals and decarbonizing aviation. Due to architecture- and component-inherent challenges, the configurations currently certified or considered close to certification mainly target the replacement of single-engine piston aircraft. The Pipistrel® Velis Electro may be globally considered the first electric aircraft to obtain certification [13]. In the meantime, the Electra Solar Trainer is also certified under the German LTF-UL [14]. Diamond Aircraft is currently (2026) seeking certification of its DAe40 as the first electric aircraft to be certified within CS-23 [12]. Whereas the first electric certification undertaking certified all components as "part of the aircraft", or in SC-E19 terms, within an "aircraft approach" [15], in 2025 the first electric engines were certified separately. In February, the Safran enGenius100 engine obtained its EASA Type Certificate (TC) [16]. It was followed by the issuing of a G-1 Issue paper by the FAA for the Ampaire AMP-H570 in May 2025. This achievement may be seen as a step towards a Supplemental Type Certificate (STC) [17].

These ultra-light or single-engine piston (SEP) equivalent configurations indicate that the transition to hybrid or fully electric propulsive architectures for up to CS-23 Level 2 aircraft is already on-going. Larger aircraft categories are still predominately examined on a theoretical basis targeting feasibility and usability. Due to the technological drawbacks that result from replacing carbon-based fuels with alternative energy sources, such as the significantly reduced energy density and the increased complexity and number of components, most of the studies intend to use all synergy effects available, to reduce the primary energy demand as much as possible. Therefore, the number of larger-scale designs using electric or hybrid-electric powertrains is currently limited. The retrofitted Dash 8-300 by Universal Hydrogen or the retrofitted Do228 by ZeroAvia may be seen as examples of this. According to a study conducted by Abu-Gyamfi and Good [18], most of them seem "over-optimistic" regarding the "stringent certification requirements" and the timeline regarding the availability and readiness level of the envisioned technologies and the maximum usage of synergy effects, as introduced above. In addition, Abu-Gyamfi and Good indicate [18] that Eviation® has postponed the entry into service (EIS) of its Alice aircraft from 2019 until 2025, and possibly even further; as of today, no sign of activity within the company is yet available.

The specific aspects of all-electrical and hybrid-electrical powertrains widen the design space significantly. Formerly complex integration of propulsion systems at disruptive locations is now enabled due to the high power density of electric engines, together with the extension of fuel distribution systems to remote locations. This enables improved conventional but also disruptive configurations to intentionally break the conventional separation of aircraft functions, such as control, high lift and propulsion, from their formerly allocated systems by making use of aero-propulsive synergy effects [18]. To understand the challenges regarding certifiability, a general understanding of the new configurations and their differences from current configurations needs to be established. To approach this topic in a structured manner, within this paper a first overview of the technical features and the newly introduced effects shall be presented. The CONCERTO project and its related projects are introduced in Section 1.3. Thereafter, within Section 2, a selected overview of configurations currently under investigation, within certification, or flying as a prototype shall be given. The discussion of configuration specific peculiarities and hence the overall question of comparability and applicability is addressed within the methodology part, in Section 3, and in particular using the property-based similarity approach within Section 3.4.1. The results, regarding the specific findings for the CS-23 certification gap analysis, together with the usability of the methodology introduced within this paper, are presented in Section 4.

2.1. What Is Specific to an HVD Configuration?

In the beginning, the question arises of what an HVD actually is and how it differs from current aircraft energy supply and distribution architectures. To elaborate on this, first it needs to be discussed how current configurations are powered in contrast to hybrid-electric architectures. For most of the configurations, the HVD system is one part of a hybrid architecture. The integration and operation of electric propulsors and its complementary power source can be compared to the hybrid architectures of the automotive sector. There are parallel, serial, and combined hybrid architectures, depending on the interaction of the engines. All of them have in common that one part of the energy is converted to electricity prior to the propulsors, using electric energy to move the aircraft. A complementary energy source may be liquid hydrogen, conventional fuel, possibly enriched by synthetic drop-in fuels, or even methane-based alternatives. In any case, a hybrid architecture features different energy sources and energy converters, and, for serial hybrids, might even be propelled entirely by electricity. In this case, the complementary energy source is also used to generate electric power, while enabling higher combined energy densities than pure battery electric systems. According to Raymer, "the aircraft fuel system includes the fuel tanks, fuel lines, fuel pumps, vents and fuel-management controls" [19]. This description is the fuel-based equivalent of the HVD system, as it provides, controls and distributes the fuel flow according to the aircraft's requirements. However, in a conventional fuel system, the system is basically capable of transferring the fuel to any point in the system where it is needed. This is done by increasing the pressure through air inlets to slightly pressurize the fuel tanks [19], then followed by (sometimes motive-flow-driven) fuel (tank) pumps, where the initial flow comes from mechanical-engine-driven pumps and finally distributed via electrically operated valves.

In contrast to an HVD system, a conventional fuel system is dependent on pressure gradients rather than voltage differences. Flowback can be inhibited mechanically by backflow valves. All in all, a conventional fuel system is a complex but well-understood and proven system in an aircraft. The newly introduced propulsive dependency on the HVD systems, on the other hand, together with its high dependency on complex soft- and hardware and the additional features of the system itself, necessitates an intense research effort to provide an understanding of these systems that ultimately enables manufacturers and certification bodies to ensure a comparable level of safety for hybrid-electric and all-electric architectures.

2.2. Review of Work Conducted Within the Scope of HVD Gap Analysis

After the initial introduction of hybrid-electric systems and their key differences, a range of all-electric and hybrid-electric configurations shall be introduced, presented in Figure 4. Some have been investigated on a theoretical basis [20–22] to evaluate the implications for overall aircraft design. Some are already flying and serve as flying testbeds [23,24]. The configurations presented give a coarse overview of research and work conducted and are introduced to demonstrate the design space envisioned for electric and hybrid-electric architectures. For some configurations, a specific gap analysis was even conducted within their projects [1,25,26]. As indicated in Section 3, these results were also evaluated within the scope of the CONCERTO HVD PoC gap analysis and served to question our own results or widen the coverage of affected requirements.

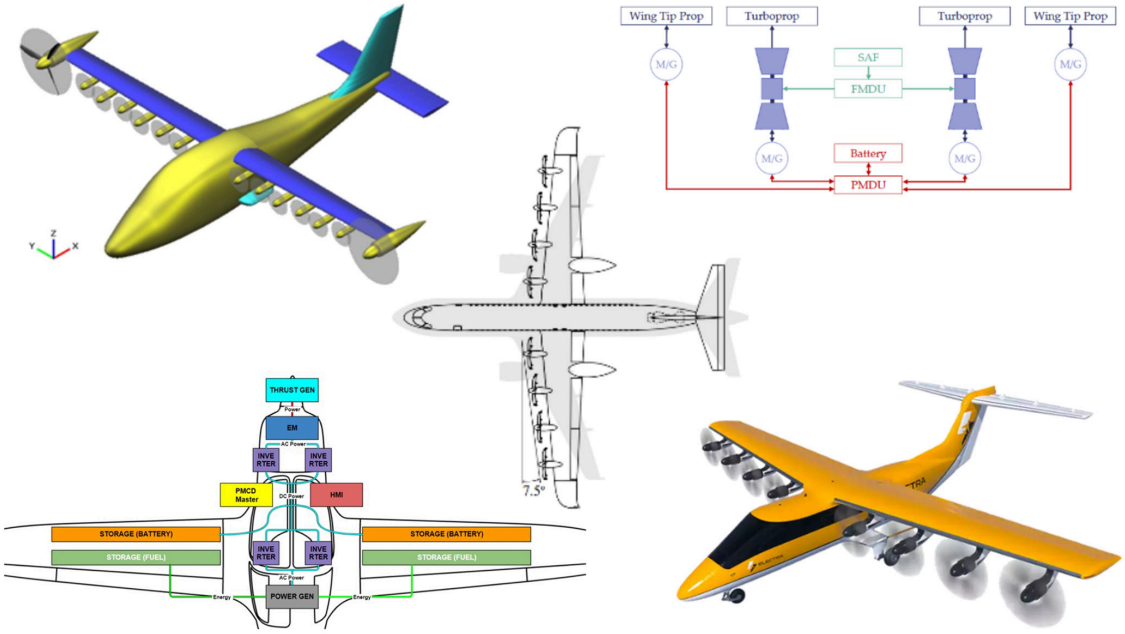


Figure 4. Selected overview of (hybrid-)electric aircraft designs (top left) NASA X-57 Maxwell [20]; (top right) FutPrint50 Parallel-Serial Hybrid Architecture [21]; (mid) Elysian E9x [22]; (bottom left) MAHEPA Project Pipistrel Panthera Hybrid [23]; (bottom right) Electra.aero EL9 [24].

Figure 4 provides a selected overview of aircraft designs that have been investigated within this study. The selection demonstrates the different use cases and energy sources of (hybrid-)electric propulsion. Top left: NASA X-57; bottom left: Pipistrel Panthera MAHEPA; center: Elysian Aircraft E9x; top right: FutPrint50; bottom right: Electra.aero EL9.

2.2.1. NASA Certification Gap Analysis/NASA X-57

The NASA X-57 "Maxwell" was foreseen as an all-electric experimental aircraft, or X-plane. The Maxwell concept was primarily intended to generate insights into an "electric-propulsion-focused design". The understanding generated during the project should have been used to discuss the airworthiness process with regulators to advance certification approaches for distributed electric propulsion concepts [20]. The investigation was planned to be conducted within several configurations. The third and final one, as illustrated in the top-left corner of Figure 4, featured fourteen electric propulsors fitted to a highly efficient high-aspect-ratio wing fitted to a Tecnam® P2006T airframe. Twelve of the fourteen propulsors are distributed along the wingspan for high lift, with two large wing-tip propulsors (WTPs) for cruise.

Initial results of the accelerated airflow behind the propellers indicated a doubling of the lift [20]. The batteries were designed to power the entire flight profile and were able to prevent temperature increases from spreading through the battery system and hence limit thermal runaway propagation. The specifications of the configuration are summarized in Table 1.

Table 1. TLAR and powertrain overview—NASA X-57 Maxwell [20].

Range [Nm]	Seating Capacity [Seats]	MTOM [t]	Architecture	Engine(s)	Battery/Power Source
86	2	1.4	14 electrical propulsors: 2 WTPs for cruise 12 DEPs for high lift	2 electric propulsors for cruise 14 electric propulsors for TO TO: 0.246	69.1 kWh Li-ion battery system

2.2.2. FutPrint50

The FutPrint50 project was a research project conducted under Horizon2020, based on an ATR42 aircraft. The project mainly focuses on energy storage, energy harvesting and thermal management, and integration of these at system and aircraft level [27]. As the configuration is based on an ATR42, the final FutPrint50 configuration is a high wing design with a combined serial–parallel hybrid-electric propulsion system with a bus voltage of 800 V. It transports 50 passengers over a design range of 215Nm [21]. The powertrain architecture, which may be seen as the most disruptive outcome of the project, is presented in the top-right corner of Figure 4, whereas the technical data for comparison is summarized in Table 2.

Table 2. Top-level aircraft requirement (TLAR) and powertrain overview—FUTPRINT50 Project [21].

Range [Nm]	Seating Capacity [Seats]	MTOM [t]	Architecture	Engine(s)	Battery/Power Source
215	50	18.2	Serial–parallel hybrid	2 electric propulsors 2 turbo-generators TO: 4.6 MW	Max 0.8t battery Assumed 500 Wh/kg Max 400 kWh

2.2.3. MAHEPA Project/Pipistrel Panthera

The MAHEPA project was also funded under the EU's Horizon2020 program. The acronym stands for a "Modular Approach to Hybrid-Electric Propulsion Architecture" and is intended to mature electric and hybrid-electric propulsion for future aircraft designs [23]. The MAHEPA project has investigated two variants of hybrid-electric propulsive architecture that have been advanced to TRL6. Both variants have been tested in two different four-seater aircraft designs. In the following, the conventional hybrid-electric configuration, based on a Pipistrel® Panthera, is presented. It combines a commercial off-the-shelf internal combustion engine (COTS ICE) from Rotax® driving a Compact Dynamics® generator. This system basically serves as a range extender. The electrical engine is also designed and manufactured by Compact Dynamics®. The Pipistrel® Alpha Electro derived battery packs feature improved thermal runaway propagation (TRP) suppression and cooling and are fitted inside the wings [28]. An overview of the system is given visually in the bottom-left corner of Figure 4 and as a fact-sheet overview in Table 3.

Table 3. TLAR and powertrain overview—MAHEPA Panthera [23,28].

Range [Nm]	Seating Capacity [Seats]	MTOM [t]	Architecture	Engine(s)	Battery/Power Source
350	1-2	1.3	Single electrical propulsor serial hybrid	1 electrical engine 1 piston engine TO: 300 kW MCT: 200 kW	Based on Pipistrel Alpha Electro with improved TRP and cooling; around 21 kWh

2.2.4. Elysian E9x

The Elysian E9x is a project originating from research conducted at TU Delft [22,29] and foreseen for certification within CS-25. The configuration is driven by distributed electric propulsion, combined with a sleek fuselage, a low wing design and efficient landing gear integration to spare additional weight and drag. Its take-off, climb, cruise and descent are powered by wing-integrated batteries. The reserve energy is stored as conventional fuel and converted via a range extender system [30]. Hence, the environmental impact is neglectable, but due to the high gravimetric energy density of conventional fuels, or SAF, the system is weight efficient.

In total, the Elysian E9x shall carry up to 90 passengers for up to 800 km, or 432 Nm, in a configuration roughly of the size of an Airbus A320, as illustrated in gray, in the three-side view, within the center of Figure 4. According to [22], its battery is used down to a state of health (SOH) of 90%. Due to the off-design usage of airlines, according to [22], where the system is not always operated within a 100% to 0% state of charge (SOC) range, de Vries et al. estimate the degradation during a mixture of use cases to result in a yearly battery exchange. An overview of the Elysian E9x performance figures is presented in Table 4.

Table 4. TLAR and powertrain overview—Elysian E9x.

Range [Nm]	Seating Capacity [Seats]	MTOM [t]	Architecture	Engine(s)	Battery/Power Source
Up to 432	90	76	Distributed electric propulsion, incl. gas turbo-generator driven reserve energy system	8 electric propulsors TO: 13.5 MW CONT: 11.2 MW	35t Battery—@ 360 Wh/kg: 12.6 MWh

2.2.5. Electra.aero EL9

As depicted in the bottom-right corner of Figure 4, the Electra.aero EL9 is a high wing configuration. It utilizes eight electric propulsors, powered by a hybrid propulsion system, consisting of a battery and a turbo generator [31]. The EL9 is intended to present an alternative to widely researched vertical take-off and landing (VTOL), offering more range as the configuration is more efficient in terms of lift generation. Therefore, the EL9's overall goal is to minimize the required take-off and landing distance using the aero-propulsive effects of its fully blown wing [24]. According to Electra.aero [31], it can take off from a runway the size of a soccer field. In December 2025, Electra.aero filed an application to the Federal Aviation Administration (FAA) for part 23 type certification of the hybrid-electric EL9 aircraft [24]. Its key figures are summarized in Table 5.

Table 5. TLAR and powertrain overview–Electra.aero EL9.

Range [Nm]	Seating Capacity [Seats]	MTOM [t]	Architecture	Engine(s)	Battery/Power Source
330	1 (/2) Crew + 9 Pax or 3000 lbs cargo		Distributed electric propulsion, incl. gas turbine reserve energy	8 distributed electrical propulsors	600 kW hybrid-electric; 50 kWh battery electric [32]

3. Method for the CONCERTO HVD Gap Analysis

Certification gap analyses generally involve significant efforts to generate valid, meaningful and complete results. The process is neither strictly mathematical nor exactly prescribed and requires engineering judgement as well as experience. It is not unlikely that different analysts may obtain different resulting gap findings or focus on different specific technological aspects. According to the judgement of the authors, the main risk when conducting gap analyses with the intent to promote the certifiability of novel disruptive technologies in aviation can be seen in missing important aspects or underestimating the relevance of certain gaps. Consequences of failure to identify gaps or correctly assess their impact may lead to expensive and time-consuming design corrections as well as missing the certification basis or means of compliance. Even operational consequences including incidents and accidents are possible when specific risks are misjudged or overlooked entirely, even in later development stages. To provide a profound gap analysis for the CONCERTO project and to generate benefits beyond the examination of the specific system design, it has been decided to define a structured systematic approach for the complete analysis.

The process has been designed such that it is reproducible independently of the system under consideration and that it is able to incorporate existing knowledge in the form of gap analysis results of similar projects.

3.1. Overview of All Loops of the Systematic Approach

The overall chosen approach is provided in a flow chart format in Figure 5. The analysis is divided into three subsequent loops. Each loop contributes to the obtained final results by increasing the level of detail and scope of considered inputs stepwise, thereby maturing the gap-finding results along the process and increasing the certification readiness level, as introduced within [33]. Each loop generates its own specific outputs that may serve as input for subsequent loops, ultimately leading to the final results in the form of the improved gap analysis table after Loop 3.

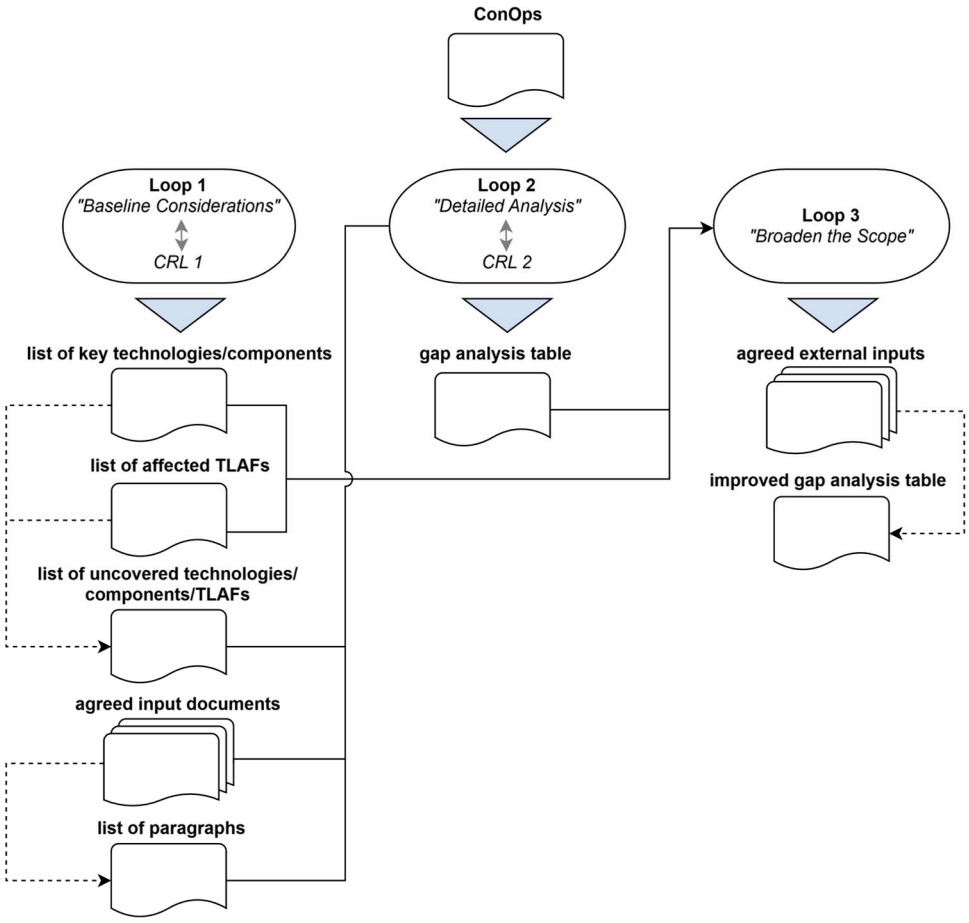


Figure 5. Overview of the systematic approach.

Loops 1 and 2 are confined to project-internal evaluations, meaning that they focus on the specific design the gap analysis is based on. In contrast, the objective of Loop 3 is to incorporate existing insights from external projects into the analysis to further improve the quality of the attained results. It is intentionally conducted after the completion of project-internal considerations to avoid any bias in the results and to ensure the independence of the obtained findings of the respective loops. In this way, this contributes to a higher robustness of the process in the sense that the likelihood of missing important aspects is reduced by making use of all available resources.

3.2. First Loop "Baseline Considerations"

Figure 6 illustrates the procedure that constitutes Loop 1. It can be initiated as soon as the basic system description is available, including architectural design as well as agreement on technologies and components to be used, thus corresponding to Certification Readiness Level CRL 1 according to [33].

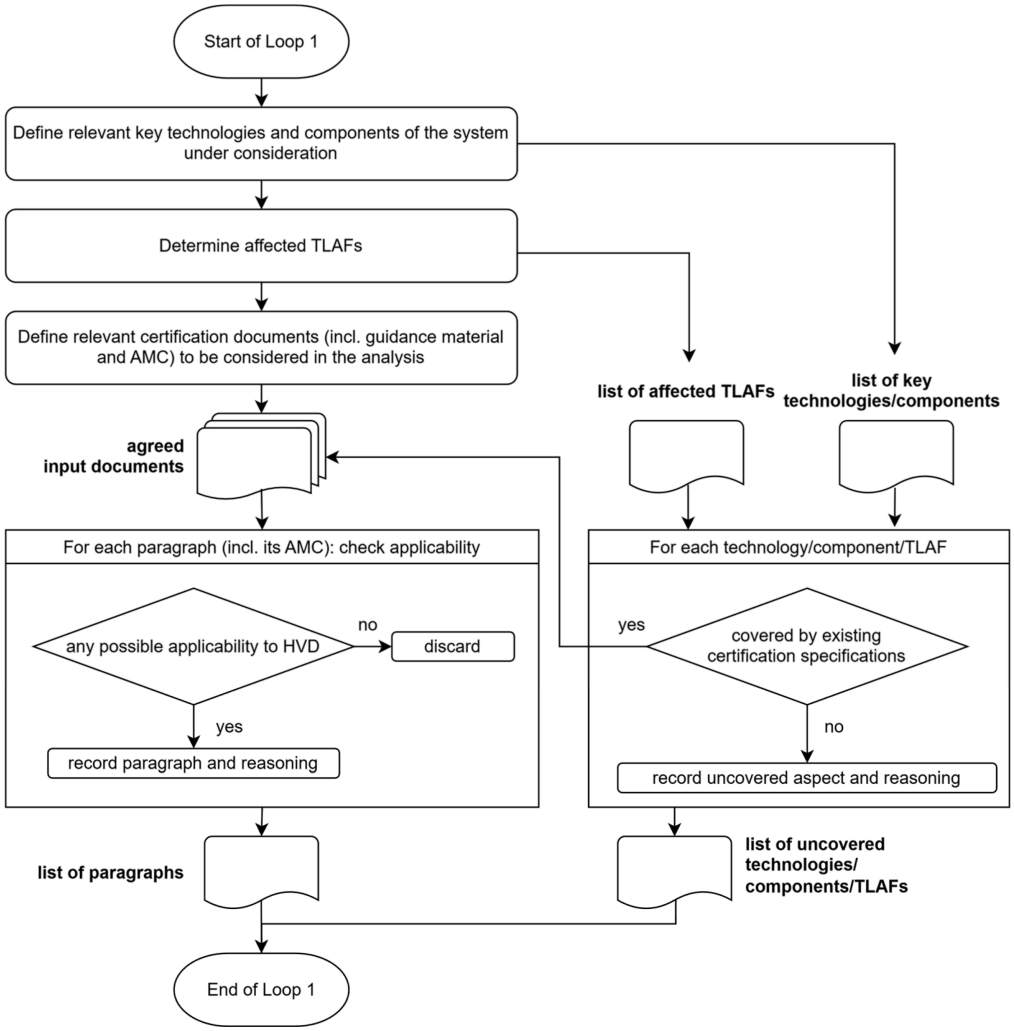


Figure 6. Flow chart for Loop 1.

The purpose of this first loop is to establish a reliable baseline for the actual gap-finding process. The procedure starts with determination of the key technologies and components of the system under consideration and assessment of its disruptive nature. The novelty of a system may originate from using entirely new technologies, new type or size of components or by interactions of the system or subsystems with top-level aircraft functions (TLAFs) that differ from conventional existing configurations. This step can be seen as an important precondition to allow these technologies, components or even aircraft functions that are not covered by any currently used certification baseline, and thus need to be reviewed within the second loop, to be found. Here the necessity of the introduction of new requirements and guidance material to ensure adequate overall system safety and reliability is assessed. Furthermore, existing certification documents must be examined to establish a baseline of agreed input documents together with the relevant paragraphs or subsections in these documents with relevance for the system under consideration. Several outputs are generated during Loop 1, which are summarized and explained in Table 6.

Table 6. Outputs of Loop 1.

Output	Description
List of key technologies/components	List of technologies and/or components that can be either regarded as novel in type or sizing or are used in a novel way different from existing conventional configurations
List of affected TLAFs	List of all affected top-level aircraft functions that are affected by nominal or off-nominal behavior of the system under consideration
List of uncovered technologies/components/TLAFs	List of technologies/components/TLAFs that are not covered in any way by existing regulations/AMC due to their disruptive nature
Agreed input documents	All existing certification specifications, AMC and guidance material deemed relevant for the analysis
List of paragraphs	List of all paragraphs or subsections within the agreed input documents that may have relevance for the system under consideration

Examples for Loop 1

One of the most relevant technological aspects of the Concerto HVD system is that in contrast to conventional aircraft designs, the electrical power system is not only used to provide electrical power to equipment and systems but also to supply the electrical part of the propulsive system. This introduces new types and sizes of components, e.g., fuel cells or high-capacity batteries. At the same time, new functional relations are created. By supplying the aircraft propulsion system with electrical power, nominal and off-nominal operation of the high-voltage distribution systems need to be evaluated regarding the effect on top-level aircraft functions, such as "Generate Thrust" and "Control Flight Path". The latter may be adversely affected by thrust asymmetry resulting from failures in the HVD distribution. Whenever distributed propulsion systems are conceivable, this leads to an interaction of thrust availability with lift generation, due to the aero-propulsive effect of the propeller slipstream. Therefore, the top-level function "Generate Lift" may also be affected. Tables 7 and 8 provide examples for and excerpts from the Loop 1 output documents that are related to the above-stated examples.

Table 7. Examples of key technologies/components.

Technology/Component	Reasoning
Fuel Cells	HVD may be supplied by fuel cells
High-Capacity Batteries	HVD may be supplied by high-capacity batteries

Table 8. Excerpts from list of affected TLAFs.

TLAF	Reasoning
Generate Thrust	The HVD system is used to supply the propulsion system.
Control Flight Path	Failures in the HVD system may induce propulsion asymmetry and therefore may affect yaw and roll control.
Generate Lift	Using distributed propulsion may lead to a significant coupling between lift and thrust generation, leading to the possibility that failures in the HVD will affect the amount of lift that can be generated.

Based on the collection of HVD-system-related TLAFs, technological aspects and components, available certification and regulatory resources have been carefully examined as prescribed by the formalized procedure of Loop 1 to establish the agreed input documents as a baseline for further analysis. In general, due to its generic nature, a great range of certification documents are related to certain aspects of the CONCERTO HVD system design and its intended use cases, ranging from certification specification CS-23 to CS-25, with associated AMC and including the provisions given by CS-E, SC E-19, as well as industry standards concerning battery technology. However, since the scope of this publication is bound to the CS-23 part of the gap analysis, Table 9 provides an excerpt of the associated entries within the list of agreed input documents established within Loop 1.

Table 9. Excerpts from list of agreed input documents.

Document	Title
EASA CS-23	Certification Specifications for Normal Category Aeroplanes
ASTM F2490-20	Standard Guide for Aircraft Electrical Load and Power Source Capacity
ASTM F3066/F3066M-18	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation

After establishment of the agreed input documents, they were scanned according to Loop 1 to determine for each paragraph or subsection whether the respective provisions have any applicability to the Concerto HVD concept. Table 10 illustrates the results for two different paragraphs from CS-23, one of which has been found to be applicable to HVD systems.

Table 10. Excerpts from list of paragraphs.

Paragraph	Applicable	Reasoning
CS-23.2135 "Controllability"	Yes	HVD system may affect type and top-level effects on controllability of "likely propulsion system failures"
CS-23.2210 "Structural Design Loads"	No	Not related to HVD system

3.3. Second Loop "Detailed Analysis"

Loop 2 builds on the outputs generated within Loop 1. It is illustrated in Figure 7. Loop 2 can be initiated as soon as Certification Readiness Level CRL 2 has been reached, meaning that a fully drafted concept of operation (ConOps) for the system is agreed upon by all stakeholders. Beyond the results of Loop 1, the ConOps can be seen as fundamental input for the gap-finding process in Loop 2. To enable a systematic gap-finding approach, each item of the list of paragraphs is evaluated together with the ConOps in order to evaluate whether the existing specifications adequately cover the associated aspects of the system under consideration ("no gap"), or whether changes at the means of compliance Level ("impact low") or even at the requirement level ("impact high") are necessary. Whenever no other safety objectives or constraints are given by the ConOps, the principle of demanding an equivalent level of safety compared to existing configurations has been used for the present analysis for judging the need for amendments or adaptation. This is in line with today's safety assessment principles and their related requirements, such as CS-25.1309, or for CS-23, CS-23.2500 and CS-23.2510, respectively. In addition to the list of paragraphs, the list of uncovered technologies/components/TLAFs is systematically reviewed. The intent of this step is to elaborate on the need and extent of additional AMCs or requirements to satisfy either the safety objectives defined within the ConOps or to ensure an equivalent

level of safety as for conventional configurations. The results of both steps are merged into a single gap analysis table that constitutes the final output of Loop 2. In the gap analysis table, all findings are recorded (including the "no gap" findings) together with their categorization and the reasoning behind it. The end of Loop 2 represents the completion of all considerations and analyses that are restricted to the system under consideration without any reference to external results or projects.

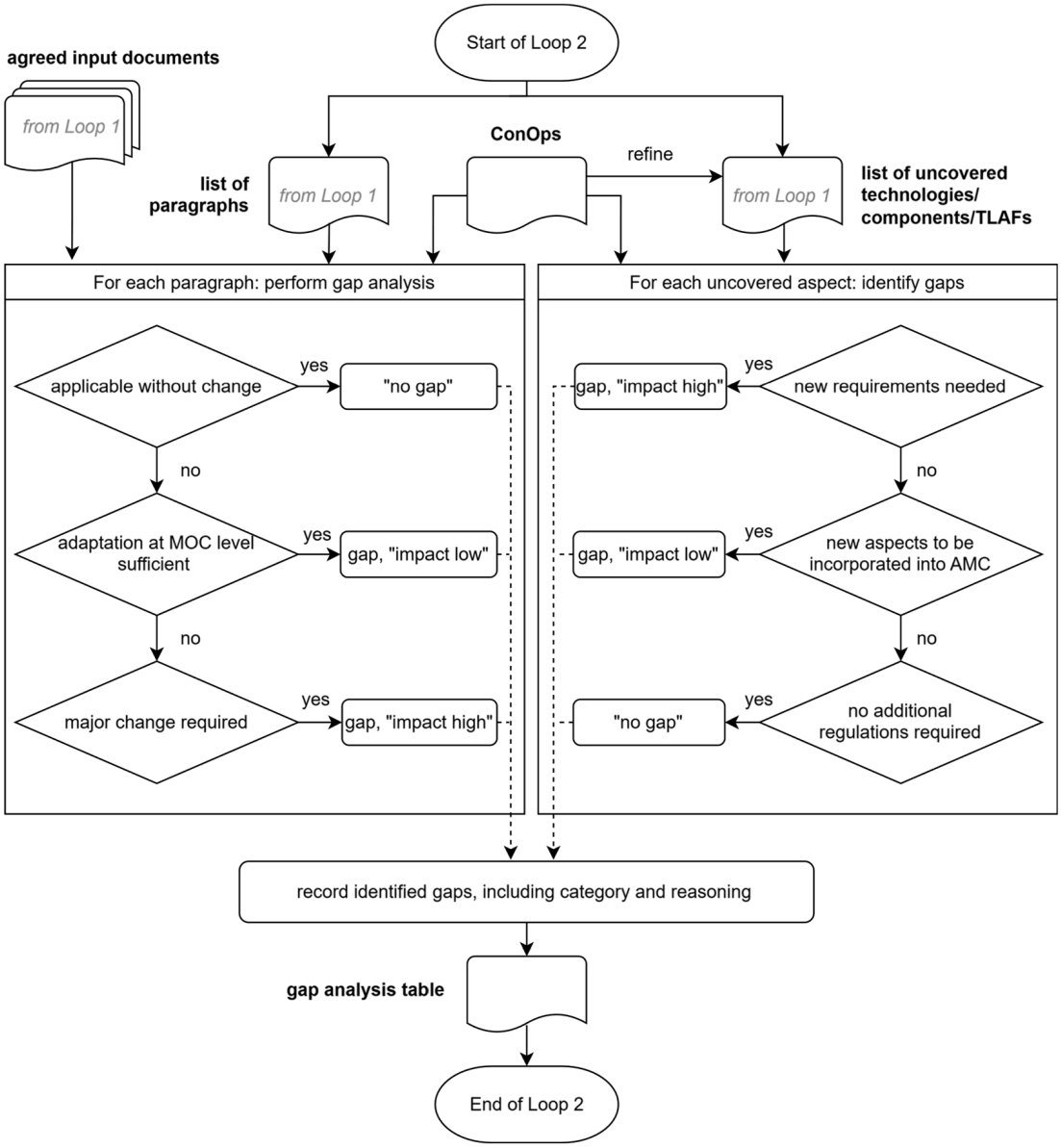


Figure 7. Flow chart for Loop 2.

Examples for Loop 2

To provide an example for the formalized gap-finding process, paragraph 23.2135 from CS-23, as already given in Section "Examples for Loop 1", has been chosen. As it is part of the list of paragraphs originating from Loop 1, it is processed through the left side of the Loop 2 flow chart, as illustrated in Figure 7. Among other requirements, the paragraph demands the airplane to be controllable within the operating envelope in the presence of "likely propulsion system failures" [34]. As no further specification of the failures is given at the requirement level, further substantiation is allocated to the AMC level. In the ASTM standard F3173/F3173M-21a ("Standard Specification for Aircraft

Handling Characteristics", [35]), the focus lies on one specific critical loss of thrust scenario. In previous research of the authors, it has been shown, that with complex disruptive propulsive architectures, as envisioned to be used with HVD distribution systems, a profound safety assessment regarding controllability in the presence of thrust asymmetry should not be restricted to a single critical failure scenario but cover the complete range of relevant failure scenarios with different likelihood and top-level effects. Therefore, a gap has been identified at the AMC level for this paragraph. This leads to the categorization with "impact low", according to Figure 7. Table 11 shows how this finding is documented in the gap analysis table that constitutes the primary output of Loop 2.

Table 11. Exemplary gap finding.

Paragraph	Impact	Reasoning
CS-23.2135 "Controllability"	Low	The coupling of HVD with the propulsion system may lead to complex failure scenarios with different likelihoods and effects on thrust asymmetry and therefore controllability. Definition of performance requirements for only one "critical loss of thrust" scenario as in current AMC may not be adequate to ensure an equivalent level of safety compared to conventional configurations.

3.4. Third Loop "Broaden the Scope"

The third loop intends to incorporate existing knowledge into the findings from Loop 2. On the one hand, the increasing number of available projects, designs studies and associated certifiability considerations can be seen as promising resources to improve quality and completeness of the attained findings; on the other hand, care must be exercised when transferring insights from one system to another. Although various systems may be similar in certain aspects, they still may exhibit differences, e.g., in system parts, subsystems or in component numbers and sizing. A valid transfer of knowledge must therefore systematically check for relevant differences and account for them in a suitable manner. A key concept that has been established by the authors to respond to this challenge is the so called "property-based similarity approach", which will be introduced in Section 3.4.1. The complete process chosen for Loop 3 is illustrated in Figure 8. Generally, Loop 3 consists of two major steps. In the first step, available external projects are examined and compared to the list of key technologies/components as well as the list of affected TLAFs, element by element, to confirm relevant overlaps regarding the novelty or disruptive design characteristics of the system under consideration. Only if relevant overlaps can be confirmed are the certifiability-related findings of the external projects added to the agreed external inputs elementwise. In the second step, identified gaps for each external project are extracted from the corresponding documentation, and based on the property-based similarity approach, the insights are systematically reviewed and either discarded where irrelevant or transferred to the gap analysis table resulting from Loop 2. The result of this process is an improved gap analysis table that constitutes the primary output of Loop 3.

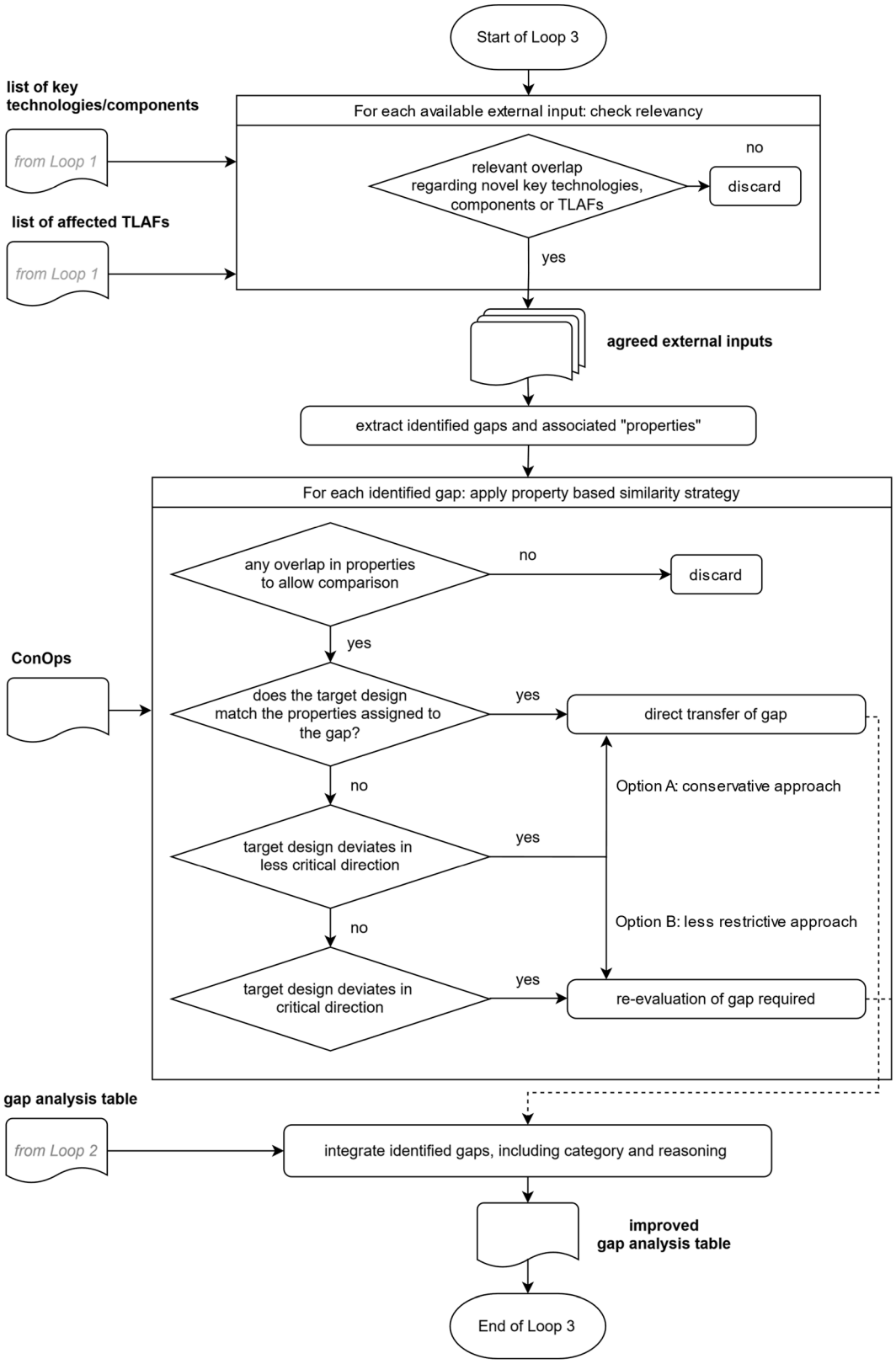


Figure 8. Flow chart for Loop 3.

3.4.1. Property-Based Similarity Approach

The aim of the property-based similarity approach is to allow systematic transfer of gap findings from external projects ("source system") to the system under consideration ("target system"), in the specific case of this paper, from external high-voltage distribution

designs to the CONCERT HVD PoC. The idea for the methodical approach is rooted within the fundamental principle of aircraft design methodology, dating back to early approaches, to establish a design foundation in providing an empirical formula to calculate, e.g., control derivatives for similar aircraft designs, such as the DATCOM Studies [36]. Generally, as elaborated in [37,38], conventional aircraft design relies on similarity assumptions. Examples are the statistical calculation of fragment weights, performance considerations or empennage sizing, which only remain valid as long as the underlying physical drivers remain invariant within the defined domain of applicability. Comparative studies on conventional and unconventional configurations define the limit of established design methods, due to changes in underlying physics, such as flow distribution and derived coefficients [38,39]. In other words, the comparability of configurations is determined by shared scaling laws, comparable mechanisms and—more fundamentally—a comparable physical model behind the analysis. To make use of this practice, first the underlying properties must be defined, to search for configurations where similar governing phenomena remain invariant to enable comparison of architectures within a new part of the design space. The resulting property-based similarity approach assumes that requirements and related gap findings can be associated with certain specifics or "properties" of the analyzed system. If a set of "properties" can be determined that characterize the specific aspect of the source system, which constitutes the need of adaptation of regulatory material, these properties can be used to determine whether the identified gap finding is relevant for the target system design. If relevance is confirmed, properties can be compared between the source system and target system to verify whether the findings can be taken directly or whether they need to be reviewed and adapted to the specifics of the target system. Within the underlying work motivating the property-based similarity comparison, three types of properties have been shown to be useful to capture relevant system design specifics, namely "Architectural Properties", "Dimensional Properties" and "Non-Dimensional Properties". These terms are elaborated in Table 12. Dimensional properties are complemented with information on the direction in which a deviation of the parameter on a continuous scale can be regarded as non-critical, and hence similar, concerning the associated gap finding. For example, for a high voltage requirement, it is likely that increasing the voltage level of a system under consideration might lead to a situation where the original requirement formulation is insufficient to provide adequate safety, whereas a deviation in the direction of lower voltage levels can be regarded as non-critical.

Table 12. Types of properties.

Type	Description	Examples
Architectural Property	Architecture describing, qualitative property.	"contains lithium battery -> yes"/"distributed propulsion system envisioned -> no"
Dimensional Property	Dimensioning figure, describing, e.g., magnitude of a relevant quantity, sizing of components or position of the system on a continuous scale. Non-critical direction given in brackets.	"maximum voltage level -> 750V(-)"/ "power rating -> 4MW(-)"/ "number of passengers -> 50(-)"
Non-Dimensional Property	Non-dimensionalized figure, describing a certain characteristic of a system. Non-critical direction given in brackets.	"max. non-dimensionalized failure induced yaw moment -> 0.8 (-)"

As new design considerations for propulsive system components feature the utilization of aero-propulsive effects, or in general, a combination of aircraft functions within multi-top-level aircraft functions, the "non-dimensionalized properties" have been intro-

duced, in [40], as an additional metric for a property-based similarity approach. As the classical aircraft design relies on functional decomposition, disruptive concepts challenge these assumptions by introducing strong, non-linear interdependency between formerly independent functions. This is particularly critical if trajectory-relevant functions, such as controllability, are affected: for propulsion-system-failure-induced influence on lift distribution, control authority or possibly load alleviation related functions, the underlying assumption of separability—not only relevant for a preliminary aircraft design, but also for determining the baseline for the safety assessment process, as introduced in CS25.1309, CS23.2510 or the ARPs 4761 and 4754—is limited. The safety assessment process currently used in aircraft certification is a top-down approach, as introduced in Figure 9, starting at the function identification and classification at an aircraft level. However, for HVD architectures with an intensive use of aero-propulsive synergy effects, the allocation of those functions to systems, as introduced in [41], is increasingly demanding and further complicated by the possible use of hybrid energy sources. Therefore, the non-dimensionalized properties, as already introduced within Kiess et al. [40], are suggested to enable a comparison of possible multi-function aircraft level effects of the underlying aircraft designs, on which the certification gap analysis is based.

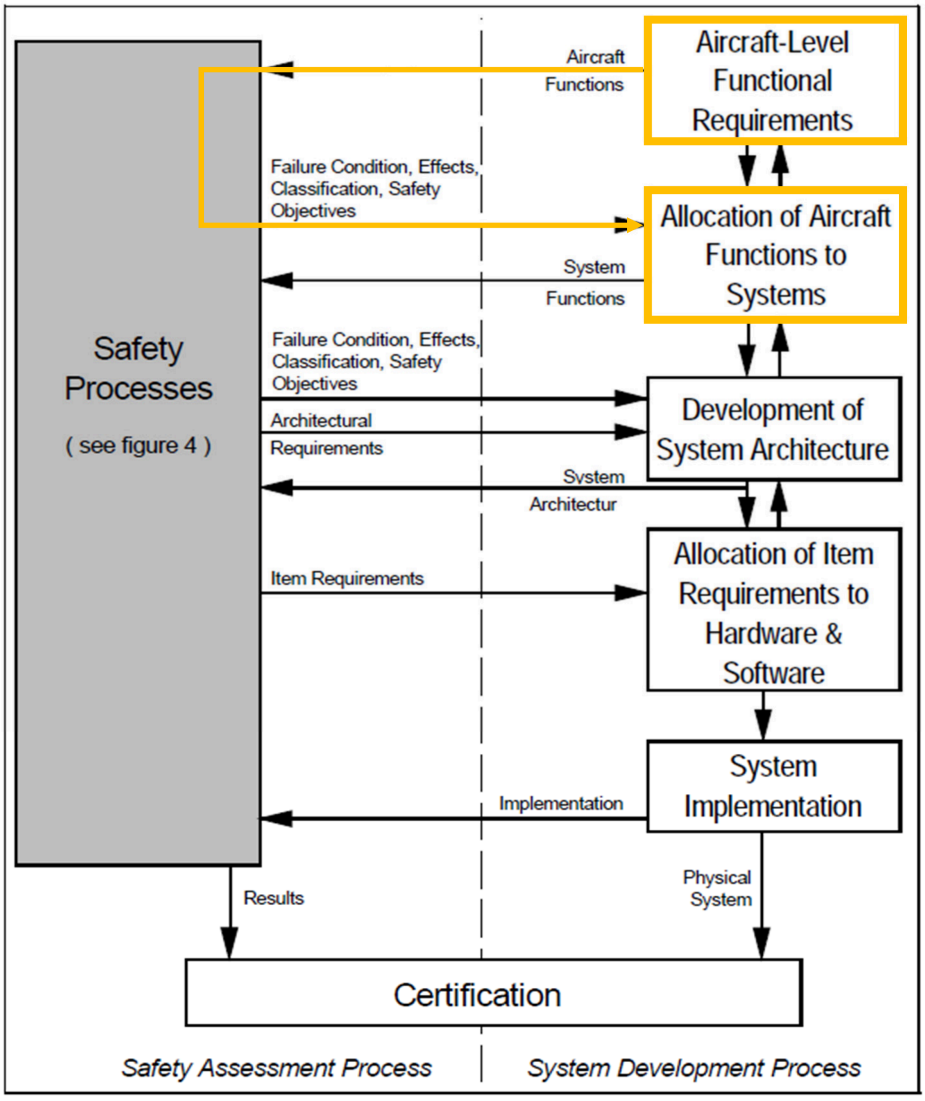


Figure 9. System development process model, with the first loop highlighted [4].

After assignment of properties to each external gap finding, these properties are used as a baseline for a formalized comparison and decision logic that defines the way in which the transfer of insights from external projects can be conducted. This decision logic is visualized in Figure 8. For each external gap finding, the following steps are conducted: First, all properties of the source system that are assigned to the gap finding under evaluation will be compared to the equivalent properties of the target system. In the case that the target system does not have any of the assigned properties, the conclusion is that the examined external finding is not relevant for the target system and therefore will be discarded. If there is any overlap in properties, a comparison is made to decide on the next steps. Three scenarios are possible as the outcome of the comparison: In the simplest case, the target system matches the properties of the source system, meaning that a direct transfer of the gaps related to the finding is possible. If at least one of the target system properties deviates in the critical direction, no guarantee can be given that the gap finding related to the source system adequately covers the target system. Thus, a re-evaluation of the gap finding is necessary, to determine whether and which adaptations are necessary for consistent transfer of the finding to match the target system's properties. Whenever all properties of the target system deviate in the non-critical direction, two options are provided. The simplest way is the conservative approach, meaning that the gap finding is transferred directly into the gap-finding analysis for the target system. This is plausible, since the confirmation that all relevant properties deviate in the non-critical direction ensures that, considering the attained gap finding directly, the resulting safety level of the source system is either matched or exceeded by the target system. The drawback when choosing the conservative approach is that it may be over-restrictive, thus possibly leading to sub-optimal designs and inefficiencies in later project stages. As an alternative, a second option is offered by conducting a re-evaluation of the gap finding with the intention to find a less restrictive formulation that matches the properties of the target system without negatively affecting its safety properties.

3.4.2. Examples for Loop 3

For the CONCERTO project, after applying the top part of the flow chart in Figure 8, several external projects have been identified with sufficient overlap regarding envisioned technologies, components and their relation to top-level aircraft functions to incorporate the corresponding certification considerations into the CONCERTO CS-23 gap analysis. A major advantage of the systematic property-based similarity concept as introduced above is that it enables transfer of findings accounting for different architectural properties, as well as different dimensioning and sizing of components. Consequently, this allows incorporation of knowledge originating from CS-25 designs into the CS-23 analysis as well. Therefore, the list of agreed external inputs also includes gap findings of the FUTPRINT50 project gap analysis as well as the CONCERTO internal results of the CS-25 gap analysis, which were available to the authors at the time of initiation of Loop 3. The complete list of agreed external inputs is given in Table 13.

To demonstrate the procedural application of the property-based similarity decision logic, one example of processing gap findings from the NASA X-57 certification gap analysis as well as one example illustrating the process of transferring CONCERTO CS25 gap analysis results into the CS23 gap analysis will be detailed in the following.

Table 13. List of agreed external inputs.

Project	Relevant Documents
GNOSIS	Certification Gap Analysis
NASA X-57	Certification Gap Analysis [1]
MAHEPA	"Concept of Modular Architecture for Hybrid Electric Propulsion of Aircraft", "Certification basis composition report" [25]
FUTPRINT50	Certification Gap Analysis for CS-25 [42]
CONCERTO	HVD Certification Gap Analysis for CS-25 [43]

Figure 10 shows how the property-based similarity concept as illustrated in Figure 8 is applied to an example originating from the NASA X-57 project gap analysis results. The analysis concludes that the stall speed requirements as prescribed by FAR 23.2110 or equivalently CS 23.2110 do not adequately cover designs with significant lift augmentation by propulsion as in e.g. distributed propulsion concepts. The analysis states that the concept of a fixed value for stall speed does not account for the influence of aero-propulsive coupling due to propulsion system lift contribution. This gap finding can be directly attributed to the property "Lift Augmentation by Propulsion -> yes". As one of the use-cases envisioned to be used with the Concerto HVD architecture is based on a distributed propulsion concept as well, the property-based similarity approach yields the result that the properties of the considered systems are comparable and align such that the gap finding can be directly transferred.

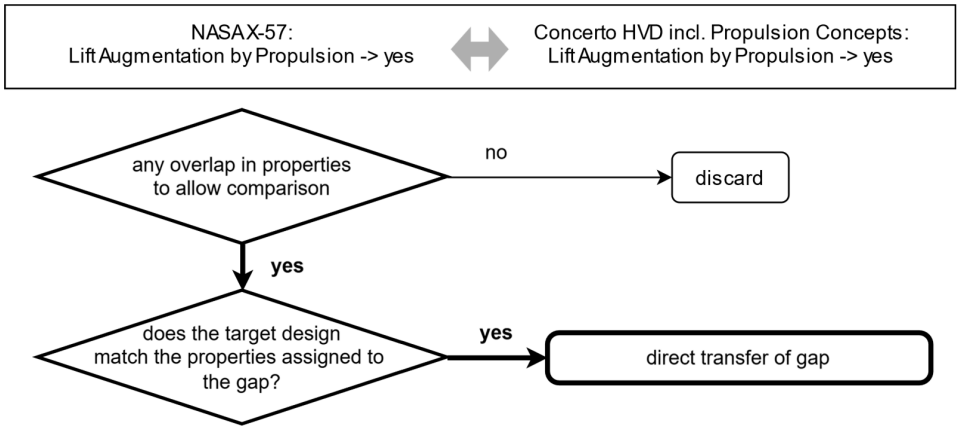


Figure 10. Property-based similarity example A.

Figure 11 illustrates an example of transferring insights from the CONCERTO internal CS25 HVD gap analysis to the CS23 gap analysis results via the property-based similarity concept. One finding of the CS25 gap analysis when evaluating the requirements on electric equipment and installation (CS 25.1353) has been that they may not be adequate to ensure occupant protection from harmful effects of high intensity electromagnetic fields. Whereas the strength of electric fields depends on the maximum voltage rating the magnetic field strength is related to the utilized maximum current values. Thus, the maximum voltage and current values have been chosen as dimensional properties to be associated with the CS25 gap finding. The evaluation of the corresponding properties of the CS23 version of the CONCERTO HVD system shows, that their values deviate in non-critical direction, thus leaving the analyst with the ability to choose between the conservative approach (Option A) and the less restrictive approach (Option B). In the present study the authors have decided to choose the conservative option by directly transferring the gap from the

CS25 evaluation to the CS23 analysis. This was motivated by the fact that although current values are significantly lower for CS23 designs, voltage values in the CS23 domain are expected to cover a wide range, reaching up to the values associated with CS25 designs.

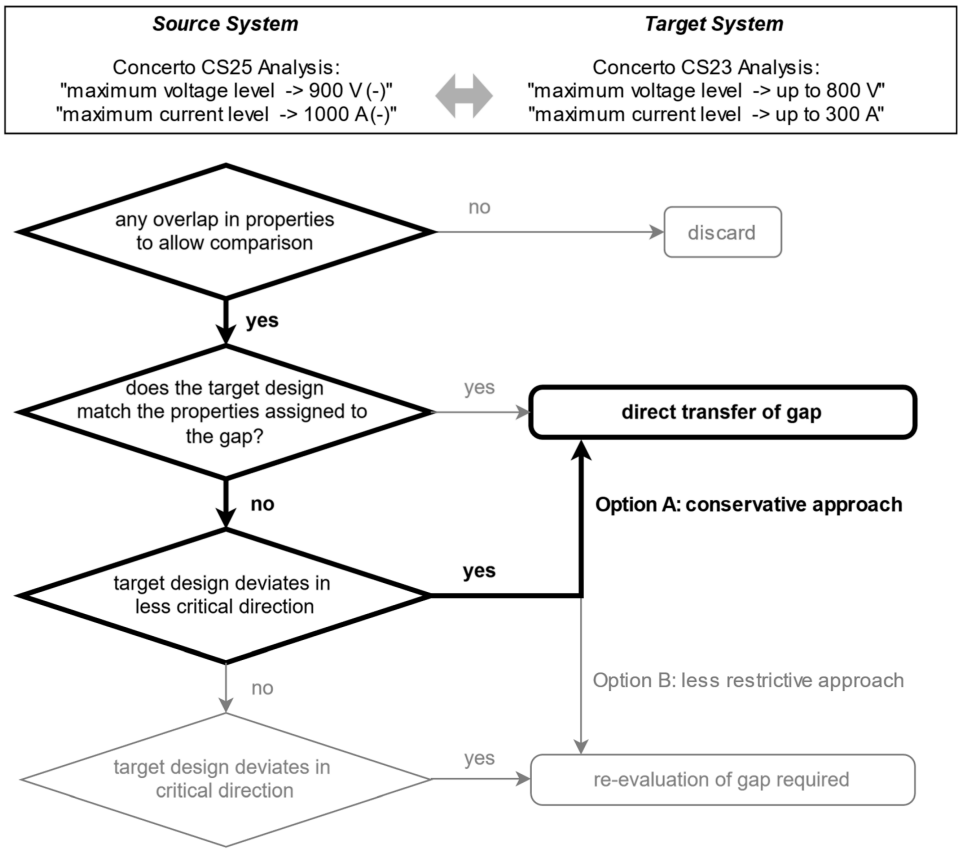


Figure 11. Property-based similarity example B.

4. Results

In this chapter, the combined results of the work conducted within the CONCERTO HVD PoC gap analysis shall be introduced. Firstly, the targeted goal of the respective gap analysis work package within the CONCERTO undertaking is the establishment of a gap analysis for the envisioned configuration as a foundation, to further process the findings within subsequent tasks for possible rulemaking suggestions. Therefore, in Section 4.1, the results of the certification gap analysis for CS-23 are summarized per subpart in Table 14. As the CS-23 gap analysis has been conducted assessing a derivative of the CONCERTO CS-25 HVD PoC (Section 1.3), a comparison of the CS-23 gap analysis, in contrast to the CS-25 findings, is discussed in Section 4.2.

Secondly, the conduct of the gap analysis as foreseen within the CONCERTO HVD PoC motivated the utilization of research already available on high-voltage configurations and led to the necessity to compare the configurations the external gap analyses have been built on. This motivated the development of the analysis loops and the property-based similarity approach to assess the significance of already-existing research for new designs. Therefore, the major contribution this paper intends to provide is more the methodology of the property-based similarity approach than providing the pure results of the holistic gap analysis within the CONCERTO project. The utilization of loops with different levels of detail inherently arose from the design of the CONCORTO consortium and its linkages to other CAJU projects. Working with the reduced material at hand during the different stages of the design process enables a rapid screening of the relevant requirements, already

for early stages of the aircraft design process within Loop 1. Once the configurations matures, during later stages of the process, Loop 2 can be used to reassess and classify the requirements identified within Loop 1. Loop 3 can then be used to ensure all critical aspects of the aircraft design are covered and systematically convert already-existing certification gap analyses into an analysis of the configuration under investigation. This procedure not only promises guidance ensuring nothing is overlooked but is mostly intended to reduce the amount of duplicate effort needed while repeating the analysis already conducted by other projects for a component or design that fulfills the property-based similarity requirement. Due to the design-specific comparison, the amount of effort spared is not quantifiable, as it varies highly in the number of property-based similarities.

Table 14. Summary of results.

Subpart	HVD-Related Sections	Summary of Gap Findings
A—General	CS 23.2010	No gaps
B—Flight	CS 23.2105 CS 23.2135 CS 23.2140 CS 23.2150 CS 23.2155	Performance- and controllability-related requirements are limited to critical loss of thrust scenarios. There is no further definition of a critical loss of thrust. Hence, this may not be adequate to cover the complete range of possible failure scenarios for disruptive propulsion systems with multiple components and complex electric distribution systems.
C—Structures	CS 23.2215 CS 23.2250 CS 23.2255 CS 23.2260 CS 23.2270	It must be ensured that protection against high-voltage-related hazards and battery thermal runaway for lithium-ion-based propulsion batteries is adequately addressed in these paragraphs. This includes controlling adverse effects like arcing or EMI as well as occupant protection against HVD-related hazards.
D—Design and Construction	CS 23.2320 CS 23.2325 CS 23.2330 CS 23.2335 CS 23.2340	Electrification of propulsion systems and usage of higher voltage and power ratings can make the system more susceptible to lightning strikes and may increase fire hazard. For an equivalent safety compared to conventional configurations, additional regulations will be required to sufficiently mitigate associated risks.
E—Powerplant Installation	CS 23.2400 CS 23.2405 CS 23.2415 CS 23.2425 CS 23.2430 CS 23.2440 CS 23.2445	Large parts of related AMC are tailored to conventional fuel and propulsion systems. It is likely that additional risks will be introduced by using HVD in conjunction with electric propulsion that are not covered by the existing AMCs. Failure scenarios concerning powerplant installations and their effects may be considerably different compared to conventional powerplants, in particular, regarding the power quality on the electrical distribution network for the remaining propulsors. In comparison to CS-25 regulations, EWIS-related considerations are far less detailed in CS-23.
F—Systems and Equipment	CS 23.2500 CS 23.2505 CS 23.2510 CS 23.2515 CS 23.2520 CS 23.2525 CS 23.2540	Current AMCs are tailored to electrical systems powered by generators/alternators driven by a conventional powertrain. Amendment is necessary to fully cover HVD systems. High voltage level and propulsion system electrification may increase HIRF- and lightning-related hazards and may require additional regulations and guidance material.
G—Flight Crew Interface and Other Information	CS 23.2600 CS 23.2605 CS 23.2610 CS 23.2615 CS 23.2620 CS 23.2625	Part of the AMCs applicable to powerplant installations and instruments are specifically related to conventional powerplant installations and thus cannot be directly applied to HVD installations. AMCs need to be reviewed and amended to fully cover electric energy and propulsion as well as novel components (e.g., fuel cells) in conjunction with HVD.

4.1. Results of the HVD Gap Analysis

Considering the difference of hybrid-electric propulsive systems as introduced in Section 2 to conventional systems, the focus of the analysis lies on the assessment and understanding of the effects and the level of complexity induced by the usage of HVD systems. This affects the interaction and definition of possible fire zones during an evacuation. This requirement is particularly affected by a battery thermal runaway. Other zonal effects may be induced by EMI of the HVD system. Both topics, however, need to be assessed individually on a configuration- and integration-specific basis. The results presented are summarized in [43].

Additional effects by higher voltages regarding high-intensity radiated fields (HIRFs) and electromagnetic compatibility, lighting protection and bonding for high voltages, power quality requirements, fault detection and isolation, partial breakdown and insulation are common for all intended architectures and might therefore be globally assessed.

Propulsive batteries require accessibility for maintenance, or their exchange once their SOC drops below the critical limit for the intended flight profile. This requires the surroundings and the mounting of the battery to be designed accordingly. If the battery packs already provide high voltages, this poses a threat to maintenance personnel and people surrounding it. Consequently, signaling and safety measures must be defined and implemented to account for the high voltage and energy levels.

The CS-23 requirements identified by Loop 1, and thereafter further investigated within Loop 2 and Loop 3, align with the overall considerations, as introduced above. The requirements are summarized per subpart and presented within Table 14.

4.2. Comparison of the Results of the CS-25 to CS-23 Gap Analysis

The number of requirements affected within the CS-23 gap analysis exceeds the number of affected requirements of the CS-25 gap analysis by far. Although contradictory at first, there are several reasons for this difference:

- Current in-service CS-25 aircraft typically already operate at higher electrical power ratings, with more complex electrical systems and most of them with higher voltages and current levels than current CS-23 designs. Therefore, the introduction of HVD systems is, voltage- and current-wise, a smaller step. Additionally, CS-25 already considers the failure effects of electrical systems.
- Within Amendment 5 of the CS-25, the certification specification for large airplanes, in 2008, a dedicated electrical wiring and insulation systems (EWIS) subpart was introduced. This subpart already covers many aspects associated with HVD system specifics.
- Generally, the scope of CS-25 clearly exceeds the scope of CS-23 in terms of regulations and more restrictive requirements. This also applies for aspects relevant for HVD systems, namely power plant system installation, system safety assessment and airworthiness instructions. CS-25 may therefore be considered more suitable to account for the increased complexity and inherent safety aspects of incorporating high-power electronics and complex distribution systems.

The key implication is that considerably more effort is to be expected to compile the necessary amendments and adaptions for incorporating HVD systems in CS-23 applications. Additionally, it seems likely that some aspects to be addressed prior to entry into market, such as the definition of recharging infrastructure and its requirements, will first be introduced in, and hence covered by, CS-25-based applications. Once a sufficient marked share is achieved, CS-23 configurations may rely on the standards already established. Therefore, some CS-23 considerations have probably already been solved on a CS-25 basis.

As for the EWIS subchapter within CS-25, these new considerations, once established within CS-25, need to be transferred to a CS-23 baseline.

5. Summary and Outlook

Within this paper, the authors have presented a methodical approach for conducting gap analyses for disruptive aircraft system designs by accounting for existing resources via a property-based similarity approach. Application of this structured approach within the scope of the CS-23 certification gap analysis for the CONCERTO project high-voltage distribution proof of concept has led to the insights as presented in Section 4.

During the process of the gap analysis, the question of applicability and comparability for a gap analysis only conducted for specific configurations arose, which basically applies to all configurations previously assessed in other work conducted (Section 2). Therefore, within the CONCERTO HVD PoC gap analysis, the authors strived to enable a global comparison, even though the CONCERTO gap analysis was also intended to be based on the respective HVD PoC configuration. The search for other architectures and the comparison of other gap analyses conducted on those other architectures, together with the CONCERTO inherent derivation of the CS-25 configuration to a CS-23 derivative, led to the property-based similarity approach, as introduced in Section 3.4.1. It was used to structure the comparison of the vast variety of configurations and reduce the assessment to parameters relevant to describe the phenomena newly introduced by the new technologies.

The application of the property-based similarity concept has been shown to be a valuable tool for integration of external project insights into the own gap analysis results, thus improving the quality and coverage, whilst reducing the risk of overlooking important aspects. In a similar way, the same methodical approach provides the capability of future transferal of the CONCERTO-based findings to other projects and more generally enables inter-project knowledge transfer to reduce the number of resources required to conduct a gap analysis for a newly envisioned design. The assignment of unambiguous properties to certification gap findings can also help keep track of which findings may be influenced by design changes in later project stages. In times of rapid technological advancements that significantly widen the design space for future propulsion concepts, the capability to transfer certification gap analysis findings from one system to another can be seen as a valuable contribution. It creates the opportunity to reduce required efforts for future analysis while at the same time improving the results and minimizing the costly risk of overlooking important aspects.

The structured comparison approach by the formalized definition of architectural, dimensional and non-dimensionalized properties also offers the possibility to create databases with gap-finding results and associate properties from various projects, which encourages further research in this area. Once such a database is available, possibly even including gap-fillers, or adequate means of compliance have been found for the projects so far assessed, relevant findings could be extracted for any new configuration with suitably defined properties that in the end determine which of the existing findings are applicable, irrelevant or need further review.

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Data Availability Statement: Please understand that the data availability regarding the CONCERTO project is limited due to the intellectual property of several Clean Aviation projects affected. All external sources are available via the links or publications referred to in the references. For questions, please do not hesitate to contact the authors.

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Abbreviations

The following abbreviations are used in this manuscript:

CA	Clean Aviation
COTS ICE	Commercial Off-the-Shelf Internal Combustion Engine
CS	Certification Specification
D(e)P	Distributed (electric) Propulsion
EASA	European Union Aviation Safety Agency
EIS	Entry Into Service
EHPS	Electric Hybrid Propulsion System
FAA	Federal Aviation Administration
HVD	High-Voltage Distribution
MOC	Means of Compliance
POC	Proof of Concept
SEP	Single-Engine Piston
SC	Special Condition
STC	Supplemental Type Certificate
TC	Type Certificate
TLAR	Top-Level Aircraft Requirement
TRL	Technology Readiness Level
VTOL	Vertical Take-Off and Landing
WTP	Wing Tip Propulsor

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