SETTING THE AVIONICS RESEARCH AGENDA FOR ZERO-EMISSION FLIGHT

U. Durak*, H. von Viebahn*
* German Aerospace Center (DLR), Institute of Flight Systems, Lilienthalplatz 7, 38108 Braunschweig, Germany

Abstract

As the expected growth in air traffic for the next two decades almost approaches the 4% mark a year, decarbonization is pronounced loud as the key to sustainability in aviation. Aircraft-related technology and standards are in the International Civil Aviation Organization (ICAO) basket of measures to achieve carbon-neutral growth. This position paper renders the current advances in aviation toward zero-emission flight, identifies the key requirements for future avionics systems, and introduces the avionics research agenda of the Institute of Flight Systems in the German Aerospace Center (DLR).

Keywords
Avionics; Sustainability; Platform Engineering; X-by-Construction

1. INTRODUCTION

The International Civil Aviation Organization (ICAO) recently adopted its Long Term Global Aspirational Goal (LTAG) of achieving net-zero carbon emissions by 2050 [1]. To attain this objective, it is crucial to prioritize technological advancements, operational enhancements, and the utilization of sustainable aviation fuels. Additionally, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [2] has been introduced to offset the unavoidable CO_2 emissions.

This paper discusses the impact of avionics on the anticipated technological advancements for future aircraft and their operations. These developments are projected to play a significant role in realizing the net-zero carbon goal by 2050, contributing to more than 15% of the overall reduction.

Radically new propulsion technologies are at the heart of the next quantum leap toward zero-emission flight. Electrified aircraft propulsion, in both hybrid-electric and all-electric configurations, will drive significant changes. Their power sources will involve high-performance batteries or hydrogen-powered fuel cells. Conventional combustion engines will also remain in operation, but they will be fed with carbon-neutral generated fuels. Then comes the advanced aircraft configurations that exercise radically new aerodynamic, structural design, and flight control architectures. Besides many non-conventional electric Vertical Takeoff and Landing (eVTOL) configurations in the Advanced Air Mobility (AAM) segment, blended wing, and strut-braced wings are worth mentioning for the conventional CS-25 aircraft. The options in optimizing aircraft operations in general for zero-emission are diverse. If we concentrate on the flight, generating and following minimum-emission routes is an approach, which promises significant reductions in fuel consumption. These new approaches include trajectory-based operations, formation flight, performance-based navigation, and flexible tracks.

Although it has not been stressed as much as propulsion technologies, advanced aircraft configurations, and minimum-emission routes, innovative high-performance avionics is highly relevant for realizing carbon-neutral aircraft since this technology is the enabler of all three that are previously mentioned. They all will increase the number of software-defined functions on the aircraft and will require complex network topologies, even extending the boundaries of a single aircraft. Furthermore, some of the future functions such as Remaining Useful Lifetime (RUL) estimation for batteries or online route planning will require high-performance onboard computing. Artificial Intelligence (AI) based functions, such as autonomous operations for air taxis will require totally new means of compliance to ensure safe operation. Beyond all, software-defined functions for the next-generation propulsion systems, aircraft configurations, or navigation procedures are yet to be defined. Neither the technologies themselves, nor the functions are mature today. Hence, a steep learning curve will be observed, and the full performance of the systems will be achieved gradually, as many functions will initially be available only within tight limits and restrictions due to safety reasons. However, through continuous software and hardware updates, the new systems will progressively attain their full capabilities. The major challenge for avionics technology is to enable these rapid feedback cycles through software

doi: 10.25967/610068

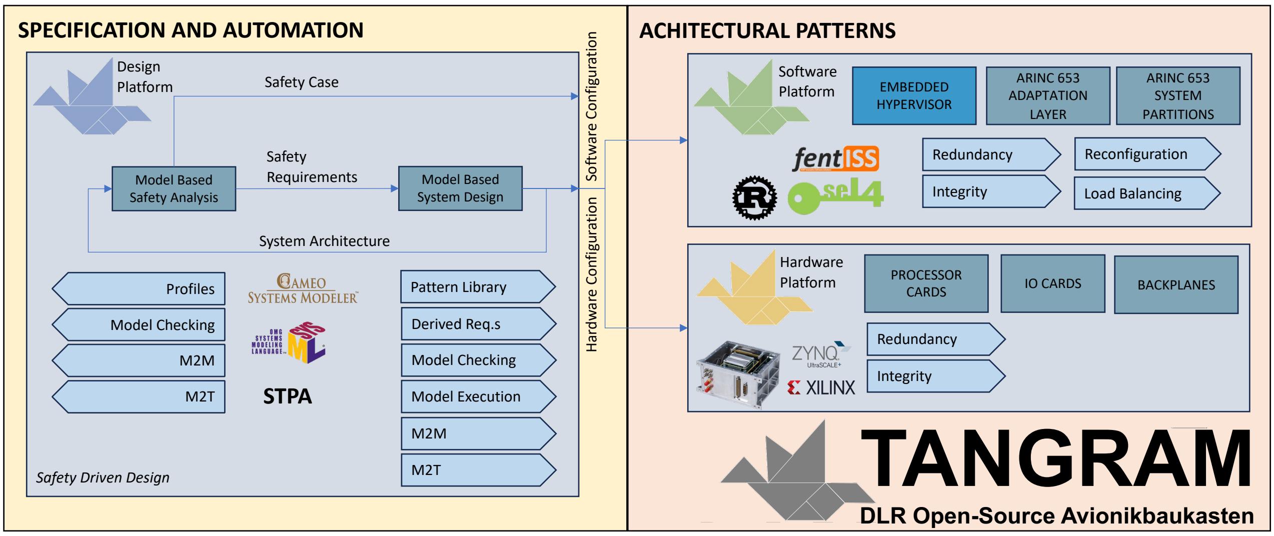


FIG 1. TANGRAM DLR Open-Source Avionikbaukasten

and hardware updates through a modular, versatile high-performance computing platform and efficient processes.

2. TECHNOLOGY LANDSCAPE

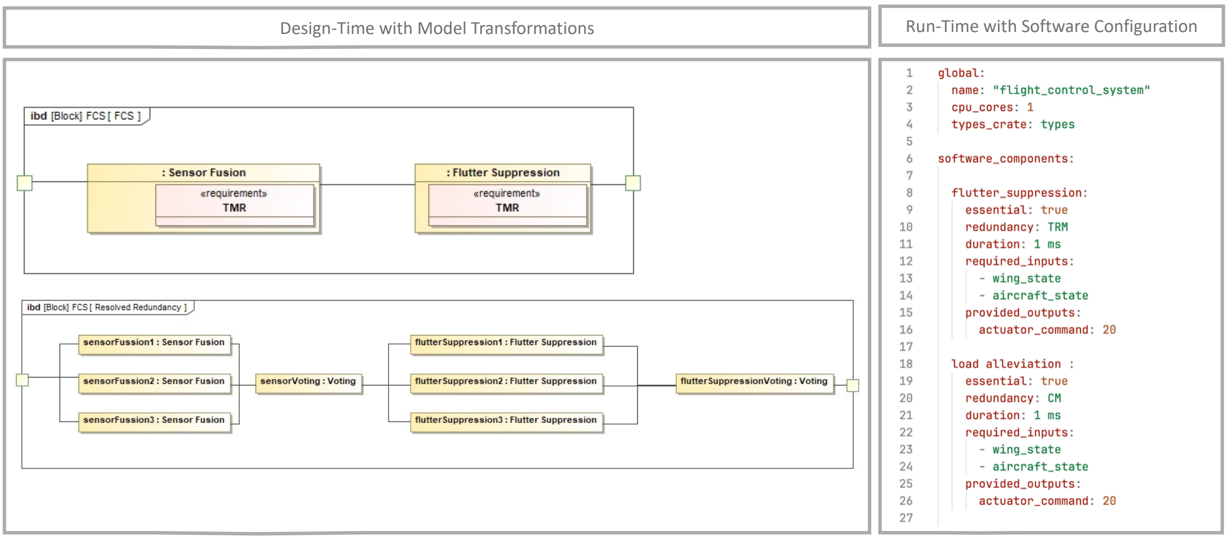
Like many other technical systems, the future of aircraft is becoming increasingly software-defined. The concept of Software-Defined Vehicles (SDVs) has been developed and extensively employed in the automotive industry [3–6]. This concept pertains to vehicles whose characteristics are primarily shaped by software-defined functions. In this context, vehicles are no longer solely characterized by their hardware components, such as their engines, but predominantly by their software-driven features, such as Advanced Driving Assistance Systems (ADAS). Notably, vehicle manufacturers are now setting themselves apart more through their software innovations rather than hardware distinctions [3].

This trend remains consistent in the aviation industry, which is traditionally driven by Commercial Air Transport (CAT). Recent advances in AAM including Unmanned Air Vehicles (UAV), Urban Air Mobility (UAM), Regional Air Mobility (RAM), and Regional Air Transportation (RAT) led to a diverse wave of technological innovation. Particularly within the emerging AAM sector, and equally applicable to CAT and General Aviation / Aerial Work (GA/AW), software-defined functionalities are becoming the pivotal distinguishing factor. In all segments, from passenger comfort to safety and the efficiency of flight, there exists a stronger than ever connection to the digital capabilities of the aircraft. Examples of recent innovations are VoloIQ and Airpace Link. VoloIQ of Volocopter is a far-reaching example digital backbone for the future software-defined functions from UAM [7]. The Airspace Link of Airbus is an example from the CAT category. It is developed as the digital backbone of the cabin experience [8].

SDV is today positioned as the key [6] to push technologies that enable the vehicles to evolve during their life-cycle, particularly with adding new features and optimizing the existing ones through software updates and upgrades, in real-time. This paper is to highlight SDV, or Software Defined Aircraft as another key for future zero-emission flight. To stress what was once introduced in the previous section, many of the technologies, from embedded high-performance computing to onboard machine learning, and software-defined functions, from route optimization to energy management are yet to be developed and optimized. SDV technologies will be enablers towards zero emission flight.

SDV, respectively Software-Defined Aircraft will be supported by platforms for faster development, integration, and eventually certification [9]. Platform engineering is a new discipline for developing infrastructure, tools, and workflows to modernize the delivery of software-intensive systems [10]. It can be pronounced as the focal point of the avionics technology landscape to enable accelerated development, optimization, and certification of climate-friendly aircraft functions.

Not to forget the underlying hardware platforms, the trend is pushing increasingly more integrated solutions, that are dense and performant. Consumer electronics, due to large volumes, is driving the hardware technology for embedded platforms. Safety-critical domains are on developing methods



```
global:
  name: "flight_control_system"
  cpu_cores: 1
  types_crate: types

software_components:

  flutter_suppression:
    essential: true
    redundancy: TRM
    duration: 1 ms
    required_inputs:
      - wing_state
      - aircraft_state
    provided_outputs:
      actuator_command: 20

  load alleviation :
    essential: true
    redundancy: CM
    duration: 1 ms
    required_inputs:
      - wing_state
      - aircraft_state
    provided_outputs:
      actuator_command: 20

```

FIG 2. Resolving Redundancy Requirements

and open standards that will enable larger utilization of these general-purpose hardware platforms.

3. RESEARCH AGENDA

Well-established avionics systems development processes have long been providing low-risk and proven design assurance practices [11]. They comply well with the current regulatory framework. There is widespread and mature tooling support. However, the automation of the legacy process is almost at its limits. While there is promising potential in contemporary AI-based software engineering practices, the significant hurdle lies in the realm of tool qualification considerations before their adoption.

There is a recent discussion about how the well-established assurance framework in airborne software is hindering the potential for innovation and agile development, such as in [12]. On the one hand, there are efforts that propose an alternative certification method. The intention is to extend the current framework that adapts a process-based means of compliance with a property-based approach, the Overarching Properties [13–18]. On the other hand, X-by-Construction (XbC) is emerging as a promising approach for both property and process-based approaches. It highlights the automation from specification to implementation that “by construction satisfy specific non-functional properties concerning security, dependability, reliability or resource/energy efficiency” [19]. Given the specification is done with models, these properties can be guaranteed using formal methods [20–22], or dynamic model execution [23]; can be transformed into refined models, code, or configurations [24]; and can be resolved in implementation by well-established design decisions as design patterns [25–27].

This paper sets XbC avionics platform engineering in the research agenda for zero-emission flight. Only when the certification-relevant safety and security properties are guaranteed by the platform, the development, integration, and certification can be accelerated. It is of utmost importance to conduct research into design platforms that enable specifying the relevant safety and security properties, provide formal guarantees that they hold, and help resolving them in implementation through model transformations and design pattern libraries. It is also required to investigate beyond state-of-the-art pattern-rich hardware and software platforms that provide the implementations.

German Aerospace Center (DLR) Institute of Flight Systems has initiated the effort to develop their avionics platform, TANGRAM DLR Open-Source Avionikbaukasten (Fig.1), and investigating XbC techniques on the Design Platform, supported by pattern-rich Hardware and Software Platforms.

TANGRAM Design Platform extends the Model-Based Systems Engineering (MBSE) infrastructures that utilize the Systems Modeling Language (SysML). The platform is being developed for a safety-driven design approach [28], where the System Theoretical Process Analysis (STPA) is promoted as the integrated method to conduct safety and security assessments; thereby, automatically generate safety and security requirements [21], and provide traceability and coverage guarantees [22]. The toolbox *ModelBasedSTPA* is implemented for CAMEO Systems Modeler and

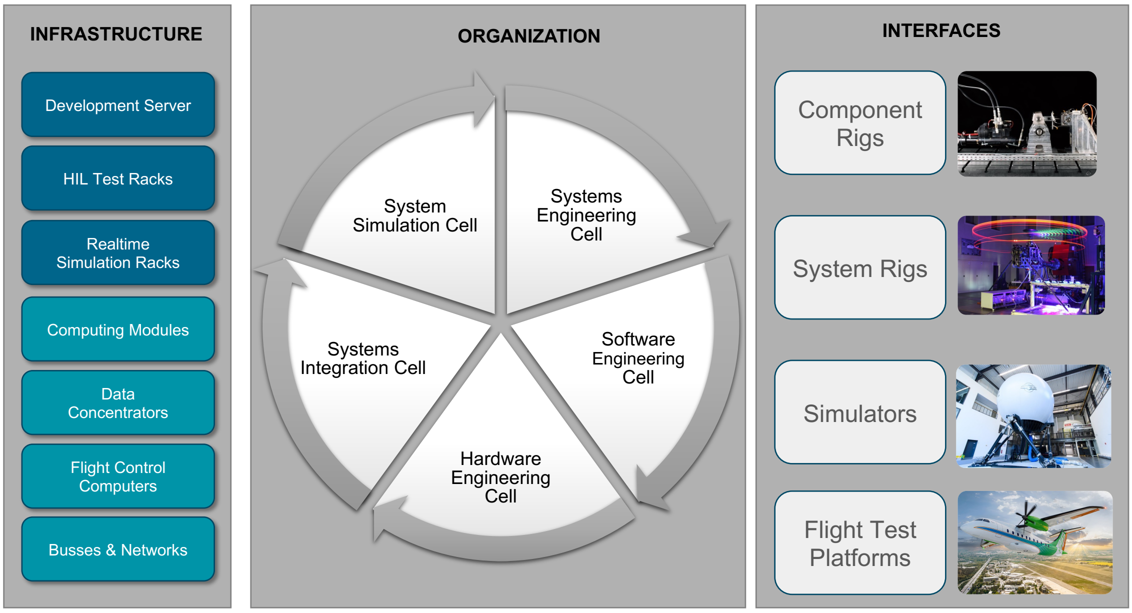


FIG 3. AVIL Overview

open-sourced at Github[1]. The safety and security requirements may then be resolved by the patterns that are annotated to the model elements as architectural requirements. Examples are timing requirements or availability requirements for a particular software component [26]. Architectural requirements can then be resolved through model transformations. For example, as shown in Fig.2, the design platform can resolve an availability requirement for sensor fusion and active flutter suppression using Triple Modular Redundancy (TMR) with three redundant deployments with a voter. Or they can be reflected in the configuration of the software or the hardware platform. As in the example case, the availability requirement can also be a configuration of the hypervisor where the software components are mapped to hypervisor partitions. TMR can be automatically realized by the hypervisor for the software component that was annotated [27].

TANGRAM Software Platform attempts to achieve third-generation Integrated Modular Avionics (IMA). It adapts modern distributed computing concepts from Cloud-Native Technologies to provide interoperability, scalability and dependability patterns [29]. The aim is to extend the state of the art in ARINC 653 [30] hypervisors with system partitions for providing architectural patterns to address safety and security requirements. Architectural patterns include hypervisor-based redundancy and dynamic reconfiguration, such as the reconfiguration of the schedule or reconfiguration of the communication [31]. As an example, an availability requirement on data is resolved by a configurable routing partition that manages the data traffic. The adaptation layer, namely *a653-rs* which is already open-sourced at Github [2], is being developed to provide a hypervisor-independent solution.

TANGRAM Hardware Platform is being designed as a product line of avionics computer building blocks that can be configured and integrated based on architectural requirements. The focus is particularly set on diverse processor cards with heterogeneous multi-core processors that will provide a multitude of redundancy mechanisms. IO cards and backplanes will answer diverse requirements.

4. TECHNOLOGY TESTBED

Advancing avionics engineering for zero-emission flight requires technology test-beds to demonstrate and evaluate, not only the methods, tools, and infrastructures, like what was mentioned in the previous section, but also the innovative software-defined aircraft functions that will reduce the carbon footprint of aviation.

In the Aeronautics Research Program (LuFo) context, the Federal Ministry for Economic Affairs and Climate is founding extensively the realization of testbeds, necessary for the development of future technology for zero-emission aircraft. DLR participates in the program with the UpLift project, which aims to provide ground-based test facilities for electrically propelled aircraft. In this project, the DLR Institute of Flight Systems is establishing the Avionics Innovation Laboratory (AVIL) at its facilities in Braunschweig. AVIL fits into and perfectly complements the existing DLR infrastructure, amongst other testbeds and facilities,

---

[1] https://github.com/DLR-FT/ModelBasedSTPA

[2] https://github.com/DLR-FT/a653rs

simulators for fixed and rotary-wing aircraft as well as the DLR research fleet. It will be equipped with Hardware-in-the-loop (HIL) and real-time simulation racks, a multitude of latest technology avionics computers and networks, measuring equipment, and a consistent and comprehensive set of tools for system and software development, testing, and deployment. The devices can be connected to the component and system rigs as well as to the simulation facilities. The integration in one of the numerous flying testbeds of DLR is typically the final step in evaluating the outcome of the AVIL.

5. CONLUSION

The paper briefly introduced the current context regarding zero-emission flight. In that context, it highlighted the importance of avionics as the means of innovative software-defined aircraft functions that helps to reduce emission. It gave a brief overview of the current avionics research agenda of the Institute of Flight Systems in the German Aerospace Center (DLR). The key is avionics platform engineering to enable fast iteration and enhancement of software-defined functions throughout the aircraft lifecycle. The paper finally presented the DLR Avionics Innovation Laboratory (AVIL) that is being established in Braunschweig as the avionics technology testbed. The future work includes developing demonstrators at AVIL on how the platform engineering approaches can help the agile development of future zero-emission aircraft.

Acknowlegement

This work was funded by the Federal Ministry for Economic Affairs and Climate Action (*Bundesamt für Wirtschaft und Klimaschutz*) of the German government based on a resolution of the Bundestag. The project UpLift-Bodenprüfstände Elektrisches Fliegen (20M2266) is part of the Federal Aeronautical Research Program (LuFo).

Contact address:

umut.durak@dlr.de

References

[1] International Civil Aviation Organization (ICAO). Report on the Feasibility of a Long-Term Aspirational Goal (LTAG) for International Civil Aviation CO2 Emission Reduction. Report, Mar. 2022.

[2] ICAO. Carbon offsetting and reduction scheme for international aviation (corsia), 2023. https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx.

[3] APTIV. What is a software-defined vehicle?, 2023. https://www.aptiv.com/en/insights/article/what-is-a-software-defined-vehicle.

[4] Bosch. The software-defined vehicle, 2023. https://www.bosch-mobility.com/en/mobility-topics/software-defined-vehicle/.

[5] Continental. From road to cloud – from virtual to real: Our software-defined vehicle approach, 2023. https://www.continental-automotive.com/en-gl/Passenger-Cars/Technology-Trends/software-defined-vehicles.

[6] RenaultGroup. All about software defined vehicle, 2023. https://www.renaultgroup.com/en/news-on-air/news/all-about-software-defined-vehicle/#:~:text=The%20Software%20Defined%20Vehicle%20(SDV,applications%20to%20enhance%20its%20functions.

[7] Volocopter. VOLOIQ Behind-the-scenes support, 2023. https://www.volocopter.com/solutions/voloiq/.

[8] Airbus. Airspace Link – bringing the connected vision to reality, 2023. https://www.airbus.com/en/newsroom/stories/2022-06-airspace-link-bringing-the-connected-vision-to-reality.

[9] Deloitte. Software-Defined Vehicles – A Forthcoming Industrial Evolution, 2023. https://www2.deloitte.com/cn/en/pages/consumer-business/articles/software-defined-cars-industrial-revolution-on-the-arrow.html.

[10] Luca Galante. What is platform engineering?, 2023. https://platformengineering.org/blog/what-is-platform-engineering.

[11] Wanja Zaeske and Umut Durak. *DevOps for Airborne Software: Exploring Modern Approaches*. Springer Nature, 2022.

[12] Jaiden David Kennedy and Massood Towhidnejad. Innovation and certification in aviation software. In *2017 Integrated Communications, Navigation and Surveillance Conference (ICNS)*, pages 3D3–1. IEEE, 2017.

[13] J. Chelini, Jean-Louis Camus, C. Comar, Duncan Brown, A. Porte, Miguel de Almeida, and H. Delseny. Avionics Certification: Back to Fundamentals with Overarching Properties. In *ERTS2018*, 2018.

[14] Michael Holloway. Understanding the Overarching Properties: First Steps. Technical Report, Sept. 2018.

[15] Tim Loveless. Overarching Properties: An Alternative to DO-178. https://www.lynx.com/embedded-systems-learning-center/overarching-properties-alternative-to-do-178.

[16] Edward A. Lester. Risk-based alternatives to the do-178c software design assurance process. In *2015 IEEE/AIAA 34th Digital Avionics Systems Conference (DASC)*, pages 8B2–1–8B2–13, 2015. DOI: 10.1109/DASC.2015.7311470.

[17] Mohamad Ibrahim and Umut Durak. Streamlining the airborne systems certification. In *2021 IEEE/AIAA 40th Digital Avionics Systems Conference (DASC)*, pages 1–6. IEEE, 2021.

[18] Mohamad Ibrahim, Umut Durak, Alexander Ahlbrecht, Oliver Oey, and Timo Stripf. Chasing the rainbow: Streamlined tool qualification. In *AIAA SCITECH 2023 Forum*, page 1128, 2023.

[19] Maurice H ter Beek, Loek Cleophas, Ina Schaefer, and Bruce W Watson. X-by-construction. In *Leveraging Applications of Formal Methods, Verification and Validation. Modeling: 8th International Symposium, ISoLA 2018, Limassol, Cyprus, November 5-9, 2018, Proceedings, Part I 8*, pages 359–364. Springer, 2018.

[20] Thomas Given-Wilson and Axel Legay. X-by-c: non-functional security challenges. In *Leveraging Applications of Formal Methods, Verification and Validation. Modeling: 8th International Symposium, ISoLA 2018, Limassol, Cyprus, November 5-9, 2018, Proceedings, Part I 8*, pages 486–501. Springer, 2018.

[21] Alexander Ahlbrecht and Umut Durak. Integrating safety into mbse processes with formal methods. In *2021 IEEE/AIAA 40th Digital Avionics Systems Conference (DASC)*, pages 1–9. IEEE, 2021.

[22] Alexander Ahlbrecht and Umut Durak. Model-based stpa: Enabling safety analysis coverage assessment with formalization. In *2022 IEEE/AIAA 41st Digital Avionics Systems Conference (DASC)*, pages 1–10. IEEE, 2022.

[23] Tobias Dörr, Florian Schade, Alexander Ahlbrecht, Wanja Zaeske, Leonard Masing, Umut Durak, and Juergen Becker. A behavior specification and simulation methodology for embedded real-time software. In *2022 IEEE/ACM 26th International Symposium on Distributed Simulation and Real Time Applications (DS-RT)*, pages 151–159. IEEE, 2022.

[24] Michael Lybecait, Dawid Kopetzki, and Bernhard Steffen. Design for 'x'through model transformation. In *Leveraging Applications of Formal Methods, Verification and Validation. Modeling: 8th International Symposium, ISoLA 2018, Limassol, Cyprus, November 5-9, 2018, Proceedings, Part I 8*, pages 381–398. Springer, 2018.

[25] Dominique Méry. Modelling by patterns for correct-by-construction process. In *International Symposium on Leveraging Applications of Formal Methods*, pages 399–423. Springer, 2018.

[26] Leonard Masing, Tobias Dörr, Florian Schade, Juergen Becker, Georgios Keramidas, Christos P. Antonopoulos, Michail Mavropoulos, Efstratios Tiganourias, Vasilios Kelefouras, Konstantinos Antonopoulos, Nikolaos Voros, Umut Durak, Alexander Ahlbrecht, Wanja Zaeske, Christos Panagiotou, Dimitris Karadimas, Nico Adler, Andreas Sailer, Raphael Weber, Thomas Wilhelm, Geza Nemeth, Fahad Siddiqui, Rafiullah Khan, Vahid Garousi, Sakir Sezer, and Victor Morales. Xandar: Exploiting the x-by-construction paradigm in model-based development of safety-critical systems. In *2022 Design, Automation Test in Europe Conference Exhibition (DATE)*, pages 1–5, 2022. DOI: 10.23919/DATE54114.2022.9774534.

[27] Tobias Dörr, Florian Schade, Leonard Masing, Jürgen Becker, Georgios Keramidas, Christos P. Antonopoulos, Michail Mavropoulos, Vasilios Kelefouras, and Nikolaos Voros. Safety by construction: Pattern-based application of safety mechanisms in xandar. In *2022 IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, pages 369–370, 2022. DOI: 10.1109/ISVLSI54635.2022.00081.

[28] Alexander Ahlbrecht, Wanja Zaeske, and Umut Durak. Model-based stpa: Towards agile safety-guided design with formalization. In *2022 IEEE International Symposium on Systems Engineering (ISSE)*, pages 1–8. IEEE, 2022.

[29] Christian Rebischke, Wanja Zaeske, and Umut Durak. From the cloud to the clouds: Rethinking integrated modular avionics with cloud-native technologies. In *AIAA SCITECH 2023 Forum*, page 1122, 2023.

[30] Paul J. Prisaznuk. Arinc 653 role in integrated modular avionics (ima). In *2008 IEEE/AIAA 27th Digital Avionics Systems Conference*, pages 1.E.5–1–1.E.5–10, 2008. DOI: 10.1109/DASC.2008.4702770.

[31] Wanja Zaeske, Clemens-Alexander Brust, Andreas Lund, and Umut Durak. Towards enabling level 3a ai in avionic platforms. In *Software Engineering 2023 Workshops*, pages 189–207. Gesellschaft für Informatik e.V., Bonn, 2023.