# Key elements to navigate sustainable product development in aerospace



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# Key elements to navigate sustainable product development in aerospace

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**ABSTRACT:** Product development is critical for sustainable development, yet sustainable design practices remain under-implemented in the industry. This paper explores the aerospace sector, addressing its specific barriers and enablers to sustainable design. Through a comprehensive literature review, group discussions, and expert group interviews, this study introduces an impact model with essential elements for enabling sustainable product development in aerospace and explains their causal relations. Five key elements were identified: business drive, sustainability implementation, knowledge, ownership, and collaboration. In addition to the impact model, the paper discusses aerospace-specific challenges and opportunities for sustainable product development. Findings from this study offer a practical framework for practitioners and researchers to plan and implement interventions in organizations.

**KEYWORDS:** sustainable product development, aerospace, sustainability, new product development, design for x (DfX)

## 1. Introduction

The production and consumption of products significantly impact society and the environment. The role of product design for sustainable development has been a research area that has developed considerably over the last 30 years (Bhamra & Hernandez, 2021). Considering ecological, social, and economic dimensions altogether is essential for the transition to a sustainable society (Broman & Robèrt, 2017), which can be achieved by developing products that better meet fundamental sustainability principles (Hallstedt, 2017). This is a complex but necessary task in which manufacturing companies must participate to develop solutions that preserve natural and social systems while enhancing long-term success and competitiveness (Maxwell & van der Vorst, 2003). This, in turn, calls for increasing capabilities to be resilient (Urbaniec, 2014) and the ability to create value for stakeholders (Li et al., 2021).
Several design methods and tools have been developed to support the manufacturing industry in the sustainability transition. However, the implementation of these methods remains low (Faludi et al., 2020; Vilochani et al., 2024). Mallalieu et al. (2024) raise several factors that influence an organization's ability to appropriately adopt such design methods and tools, where the contextual complexity of design method adoption is one of the key barriers. Design methods are seldom 'plug-and-play', and there is always a need to adapt a design method to fit the existing organizational context. Further research is therefore needed to study the implementation gap and better support companies integrating sustainability into their product development activities.
The need for further research is particularly evident in industries with complex product lifecycles, such as aerospace. Although affected by the COVID-19 pandemic, the aviation sector is projected to grow significantly, with emissions projected to double by 2050 in business-as-usual scenarios (ICAO, 2022). Aviation stakeholders form a complex, multi-level decision-making hierarchy (Al Sarrah et al., 2020).

Consequently, key stakeholders, such as regulatory committees, aerospace manufacturers, and airlines often delay decisions regarding environmental sustainability or pass on their responsibility 'to one another' (Singh et al., 2022).
Aerospace systems are costly and technologically advanced to design, develop, and produce, which causes typically long development cycles and operational lifespans. To significantly improve the sustainability impact, there is a need to welcome radical technology shifts without compromising flight safety and business risk (Hallstedt et al., 2023). This industry also faces slow development in technologies and materials that support a circular economy (Rodrigues Dias et al., 2022). To integrate sustainability into aerospace design processes, research is developing tools such as decision-making support that integrate both sustainability criteria and technical product requirements (Filippatos et al., 2024). However, despite a growing awareness of sustainability issues and need to address them, the aerospace industry experiences a lack of economic incentives to accelerate the development of more sustainable solutions (Léonard et al., 2024).
Considering these previous findings, this research aims to shed light on the aerospace industry within the aviation and aeronautics sectors and its relation to sustainable product development. More specifically:

a) Understanding what sustainability challenges and trade-offs are encountered in aerospace product development;
b) Describing key elements to sustainable product development within the aerospace industry and proposing solutions to overcome barriers.

In this article, design for sustainability is considered an umbrella term that includes initiatives to support the development of products towards sustainable development, such as eco-design, sustainable product development, and a circular economy. Terms such as sustainable products are used in this paper to designate solutions (e.g., product technologies and system solutions) that reduce the environmental and social impacts compared to previous or similar solutions.
The research questions that guided the design and execution of this study are the following:

**RQ1:** What are the key elements needed to design for sustainability in the aerospace industry?
**RQ2:** What strategies can further enable the development of sustainable solutions in aerospace technology product development projects?

## 2. Research methodology

This study has been designed following the iterative process proposed by Maxwell for qualitative research (Maxwell, 2013). A literature review was conducted to define the research questions and the methods to collect empirical data. The research approach is inductive and structured in four phases as highlighted in Figure 1. The methods employed are further described in the following sub-sections.

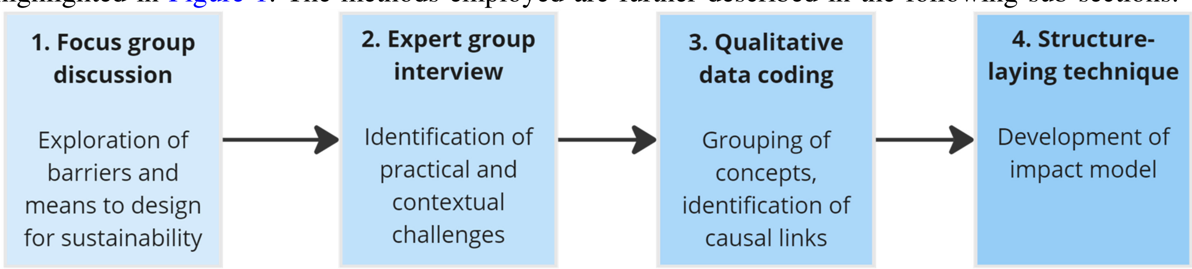


**Figure 1. Research methodology**

### 2.1. Phase 1: focus groups discussion

Six focus group discussions with experts from the aerospace industry and researchers within design for sustainability (see Table 1) were used to explore barriers and means to design for sustainability in aerospace. The focus group discussion format developed for the purpose of this study is a mix of focus group and group discussion methods (Flick, 2009). The aim of this mixed format is to encourage an exchange of opinions and to allow participants to correct each other, only after receiving a specific introduction (Flick, 2009). The focus group discussions were facilitated by a moderator and lasted between 1-2 hours each. The discussions among groups 1 and 2 were conducted at GKN Aerospace, Sweden, in September 2024 with participants working within the industry at GKN Aerospace and SAAB. Both companies are established Tier 1 suppliers and have design responsibility for critical aerospace components and systems. The focus group discussions for groups 3, 4, 5, and 6 were conducted at the European Aeronautics Science Networking (EASN) conference in Thessaloniki, Greece, in October 2024.

**Table 1. Roles of group discussion participants**

| Group | 1 | 2 | 3 |
|---|---|---|---|
| Role of participants (other than research group) | Sustainability specialist (3)<br>Business analytics specialist (2) | Sustainability specialist (2) | Researcher (4)<br>Educator (2) |
| Group | 4 | 5 | 6 |
| Role of participants (other than research group) | Researcher (3)<br>PhD student (1) | Researcher (4) | Researcher (2)<br>Student (2) |

The focus group discussions were conducted in several phases. First, the groups were introduced to the concepts of systemic and strategic sustainability perspective (see e.g., Broman & Robèrt, 2017), multi-criteria trade-off analysis in aerospace and sustainability, and value-driven design of aerospace solutions (see e.g., Isaksson, 2014). Then, participants brainstormed barriers, benefits, conflicting trends, and synergies with regards to "design for sustainability". They were asked to categorize findings in three themes, namely product & technology, processes & practices, and business & behavior. This approach aimed to address the systemic and complex nature of sustainability challenges and encourage participants to adopt innovative thinking. Finally, the participants were asked to reflect on stakeholder needs and trade-offs. The main outcomes and results from each focus group discussion were captured on A3 sheets and later transcribed to digital documentation.

## 2.2. Phase 2: expert group interview

A two-hour expert group interview was conducted with two industry specialists having a pivotal role in implementing sustainable product development at their companies (denoted as experts A and B), from GKN Aerospace and SAAB. A semi-structured interview approach was used to further describe key contextual barriers and enablers to design for sustainability and serves as a complementary method to the focus group discussions described in section 2.1 (Flick, 2009). A mix of open, research-driven, and confrontational questions were used to address the experts' occasional presumptions about design for sustainability. The group format was used instead of individual interviews to encourage discussion eventual contradicting opinions and perspectives. The interview was divided into four themes and examples of asked questions are listed below:

c) **Sustainability approach:** Do you think there is a lack of a common approach to sustainability in aerospace?
d) **Sustainability assessments:** How can product sustainability assessments support your company towards the development of sustainable solutions?
e) **Pace and need of transition:** How can project management practices evolve to overcome barriers to the development of sustainable solutions?
f) **Conflicting interests between stakeholders:** What is dysfunctional in product development projects at your company that prevents the development of solutions towards sustainability?

## 2.3. Phase 3: qualitative data analysis

The expert group interview was recorded and transcribed, and qualitative data was later collected in the format of in-vivo, i.e. using the actual words or phrases spoken from the interview, and analyzed using a mix of several coding techniques (Miles et al., 2018):

- **Hypothesis coding:** to link the data with the themes from phase 1 and 2;
- **Concept coding:** to classify ideas and theories beyond the initial discussion topics;
- **Causal coding:** to understand the links between different concepts.

The analysis results were displayed in a flowchart, illustrating the identified codes and their causal relationships.

### 2.4. Phase 4: structure-laying technique

A second group interview was conducted with experts A and B to assess and refine the outcome from phase 3, and the structure-laying technique was utilized to support this procedure. The participants were presented with the flowchart resulting from phase 3. A moderator exposed the narrative behind the flowchart and asked follow-up questions when explanations or data were lacking in specific areas. Furthermore, the participants and were asked to assess and further structure the concepts and had the opportunity to alter or further develop key statements from the expert group interview. This method is especially suitable for revealing and organizing existing knowledge, as well as shaping the contents of subjective theory (Flick, 2009).

## 3. Results

This section presents the main findings from this study in relation to the research questions. Section 3.1 presents relevant results from group discussions and Section 3.2 presents the results from the expert group interview, qualitative data analysis and structure-laying technique.

### 3.1. Exploration of barriers and means to design for sustainability

The qualitative data collected from the six focus group discussions was compiled into a table with topics, including a large set of barriers and means to design for sustainability. The focus group discussions captured ideas related to a broad range of topics, revealing several stakeholders needs that specifically focus on aerospace companies, research, and actors in the aerospace value chain. Figure 2 shows the different topics covered during the focus group discussions. However, due the scope of this paper, results from three of the eight topics will be presented, namely, "Stakeholder needs", "Sustainable product development" and "Time perspective and priorities" (i.e., the highlighted boxes in Figure 2).


**Figure 2. Topics discussed during the focus group discussions**

Key findings related to the contextual challenges of the aerospace industry within these three topics are presented below.

- **Sustainable product development - sustainability approach.** Some groups expressed concern about the lack of a common approach to design for sustainability within the industry. Establishing clear standards and guidelines would encourage companies to (i) procrastinate less on implementing sustainable design practices, and (ii) gain capability in addressing sustainability-related trade-offs.
- **Time perspective and priorities - pace of transition.** Technology and product development is arguably moving too slowly to meet sustainability goals, such as achieving net zero by 2050. One key reason for this slow pace is the industry's strict safety standards, which prevent the rapid implementation of innovative technologies. Moreover, most aerospace companies continue to prioritize short-term profit over sustainability. The high cost of product development discourages the proactive development of more sustainable products due to the high risk of failure. While major industry players do invest in some "green" aviation technologies, these investments remain insufficient to drive a timely sustainability transition.
- **Time perspective and priorities - need of transition**. There is a lack of consensus on the urgency of transitioning to a more sustainable aerospace industry. To meet societal demands, companies need to become more disruptive and further invest in sustainable technologies. The groups also

discussed differences in approaches between continents. In Europe, the aviation industry is well-established, not expected to grow significantly and increasingly targeted by country or EU-based regulations. In contrast, regions such as China and India are experiencing rapid aviation growth, and the priority lies more in establishing this industry rather than investing in the exploration of more sustainable designs.

- **Stakeholder needs and conflicting interests**. Aviation organizations project not only for the industry to grow, but also to improve passenger experience, with air travel always becoming faster, quieter, and more affordable. However, this conflicts with the fact that many technologies and approaches towards environmental sustainability (such as flying lower and at slower speeds) could make air travel less comfortable and more expensive. These potential solutions, while beneficial for the environment, conflict with the industry's social sustainability goals to make air travel accessible for all. Aerospace sustainability goals might need to be reconsidered to ensure they do not cause harm to the planet and society.

In addition to contextual challenges, recurring topics of discussion when it comes to design for sustainability were described:

- **Sustainable product development - sustainability assessment.** There is a need to develop capabilities to assess sustainability was discussed by several groups. Evaluating technologies early in their development is essential to gauge their potential to contribute to long-term sustainability goals and mitigate other impacts. It was proposed that the sustainability impact of complex products should be assessed using impact categories and complemented with sustainability risk assessments on product development projects.
- **Sustainable product development - sustainability implementation.** Opportunities to implement sustainable practices in design were discussed by the participants, with an emphasis on the need to include sustainability in product requirements.

## 3.2. Key elements towards the development of sustainable solutions

This study resulted in the identification of five key elements to enable sustainable solutions in aerospace. Those elements and main empirical evidence are displayed in figure 3. This section further describes these key elements and their causal relations.

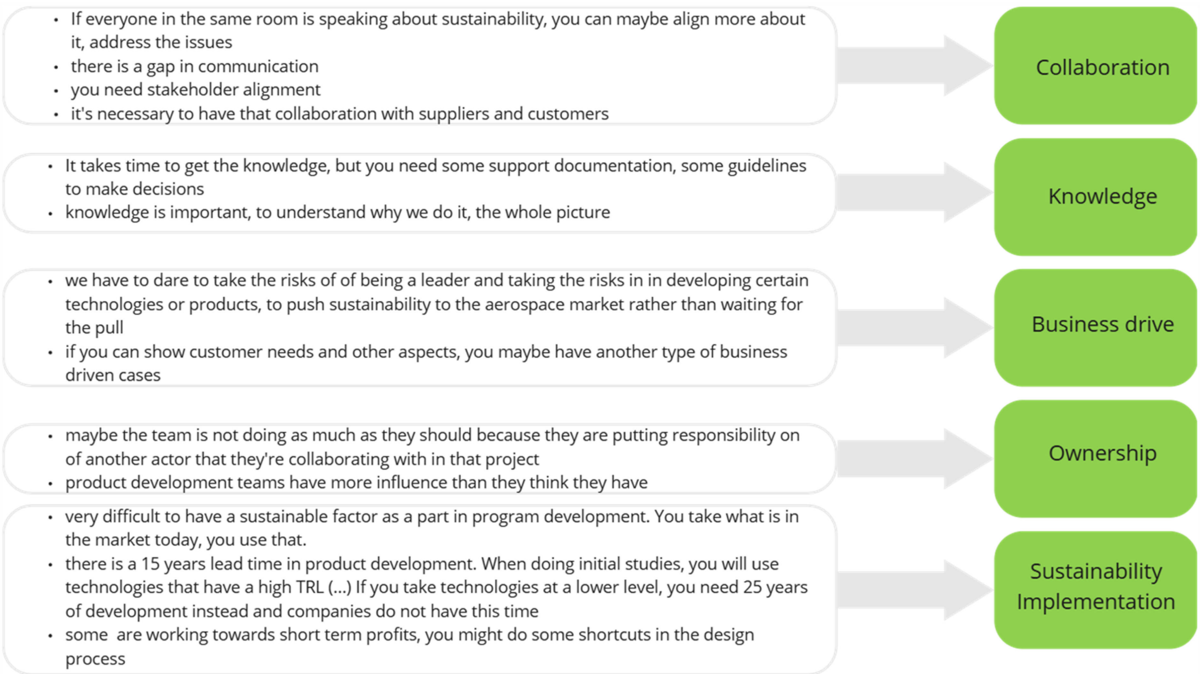


**Figure 3. Empirical data (quotations from interviews, left) and interpreted key elements (right)**

### 3.2.1. Business drive

Business drive is what encourages decision-makers to choose an alternative over others. Businesses are typically profit-driven or compliance-driven, both having the potential to lead businesses towards a more sustainable future. The business case of aero engines was further discussed during the interview, and expert A stated that "*Circularity is a very important aspect when it comes to business models and sustainability*". Most aero engines are designed, repaired and maintained to be able to have an extended lifecycle, a core aspect of circularity.

Regulations play an essential role in shaping the aerospace industry, but those aimed at sustainable development are not yet very stringent and typically result from agreements between regulatory bodies and industry. The interviewed experts believe that sustainability-leading companies are showcasing what it is possible to achieve. This might accelerate the instalment sustainability-related of regulations and additionally, these companies will have an easier time complying as they already lead the way.

Regarding sustainable innovations, technological development steadily reduces carbon emissions in the field of civil aerospace propulsion. As a result, aircraft and aero engines from the previous generation pollute more than the newer generations. But due to the high cost of development and manufacturing, these are not systematically replaced when a more efficient solution comes in the market. Expert A stated that "*One way to improve sustainability in the aero engines business model could be to actually shorten their (use-)life*". Such an approach however would reduce circularity for the profit of climate change reduction. The experts expressed the need to gain a further understanding of what a sustainable business model for aerospace could be, when accounting for the systemic nature of sustainability.

The challenge of aerospace legacy solutions was also discussed, and expert B stated that "*When solutions are in development, we use tools and assessment to identify hotspots, but most of their features derives from our legacy systems that are being used again and again. What can we do to truly improve their sustainability impact? Nothing.*". In other words, as most of the solutions being developed in aerospace derive from previous designs, there is little room for radical changes, and it is unclear what can be done to improve the sustainability impact of the solution.

### 3.2.2. Sustainability Implementation

The implementation of sustainability in engineering practices was highlighted as a pivotal element to enable the development of sustainable aerospace solutions by the interviewed experts. The development of aerospace solutions follows strict processes that ensure airworthiness of innovations. Technology and product development are typically two separate divisions in the organization, with separate management processes: "*We have two different managements systems within the company, a strategic management looking ahead and product management that looks at product development*" (expert B). During the interview, the experts confirmed the problem of long development cycles within aerospace: "*There is a 15 years lead time in product development. When doing initial studies, you will use technologies that have a high TRL (technology readiness level) (...) If you take technologies at a lower level, you need 25 years of development instead and companies do not have this time*" (expert B).

A problem, however, is encountered when people do not rigorously follow processes in place. "*I know that some companies are working towards short term profits. In this context, you might do some shortcuts in the design process*" (expert B). Technology and product development teams might see sustainability as time-consuming, costly and bringing little value to the overall solution in development, leading teams to not follow the established procedure. Decision-makers in this context would likely agree with the shortcuts taken as they are aligned with short-term profit goals.

Requirements were specifically discussed as strong means to implement sustainability in engineering practices and they are difficult to skip once they are in place. In Aerospace, requirements start to be defined on a high level (aircraft system, engine system) based on the business model. These are later detailed down to component level. Including sustainability in the requirement list would ensure consideration and prioritization of sustainability criteria from early development stages.

The experts also discussed the need to include holistic sustainability assessments in technology and product development processes, which supports findings from focus group discussions (see Section 3.1). Different methods are needed at different stages of product development and for different type of analysis, e.g. technology, system, and concept analysis. But the main challenge resides handling the outcomes of sustainability assessments: not only should they address a variety of impact categories, but these results should be included with other engineering assessments for decision-making. It is particularly challenging as sustainability is often too complex to be displayed as one value, and is often approached qualitatively in early innovation stages.

### 3.2.3. Knowledge

Knowledge about the sustainability implications of the solution in development will encourage engineers and specialists to adopt a broader perspective in their work beyond their usual expertise. It is not only about "what" the impact is but also "why" it is important and should not be disregarded. Knowledge about sustainability will support reducing shortcuts taken as mentioned in Section 3.2.2, which might happen despite successful implementation, as it will be easier to understand the work needed to be done. Sustainability assessments are essential elements for product developers to gain knowledge: "*Making sustainability assessments might not directly create change, but it creates a lot of knowledge regarding the challenges that lie ahead. ( . . . ) It has made us handle these challenges earlier and led to further investigations*" (expert A). Gaining sustainability knowledge would also support product development teams in navigating trade-off situations, such as potential conflicts between different social and environmental aspects (see Section 3.1), or circularity versus carbon footprint (see Section 3.2.1). The experts highlighted though the lack of appropriate methods to address sustainability at system level and early innovation stages. For sustainability assessments on component level, a wide range of tools and methods exist, but still present numerous challenges, such as involving right people, acquiring data and communication of the results.

### 3.2.4. Ownership

This element was considered important at the company level and product development team level. The systemic nature of sustainability requires companies to take ownership of sustainability impacts beyond the walls of their organization, adopting a lifecycle perspective. Experts A and B claimed that the lack of individual ownership is a recurring issue on a product development team level. The responsibility to "work with sustainability" tends to be placed on other people or teams in the organization, when at the same time, the core team is in power to influence how sustainable the product, technology, or system will be. Individuals should, therefore, be encouraged to take more ownership. Moreover, an increased knowledge of sustainability can enable ownership as individuals would better understand their role and the importance of improving the sustainability impact of a solution.

### 3.2.5. Collaboration

The lack of collaboration among actors in the aerospace value chain when developing new solutions was highlighted as a key element that blocks sustainable outcomes, although this topic was not fully explored during the interview. However, stakeholder collaboration remains important for developing more sustainable and value-creating life cycle solutions. Therefore, further research is needed to better understand the various stakeholders involved in the development of sustainable business models and in which ways collaboration can further enable the development of sustainable solutions.

### 3.2.6. Approach to sustainability

Although not a key element directly enabling the development of more sustainable solutions, the need for a shared vision towards sustainable development was expressed by the industrial experts. This correlates with findings from Section 3.1, as the experts agree that organizations could use the lack of common approach as a reason to procrastinate towards sustainable development. However, companies should be aware of their negative impact on society and the environment, and should use this to define their own sustainability approach, in combination with science-based definitions, to act where it is most needed. It will result in companies having different approaches, but aiming to move towards the same sustainable vision.

## 3.3. Impact model

This study resulted in the creation of an impact model (Figure 4) that displays elements to enable sustainable solutions in aerospace. The five key elements (which are directly connected to the goal to develop more sustainable solutions) are represented in green boxes, while secondary elements are in white boxes.

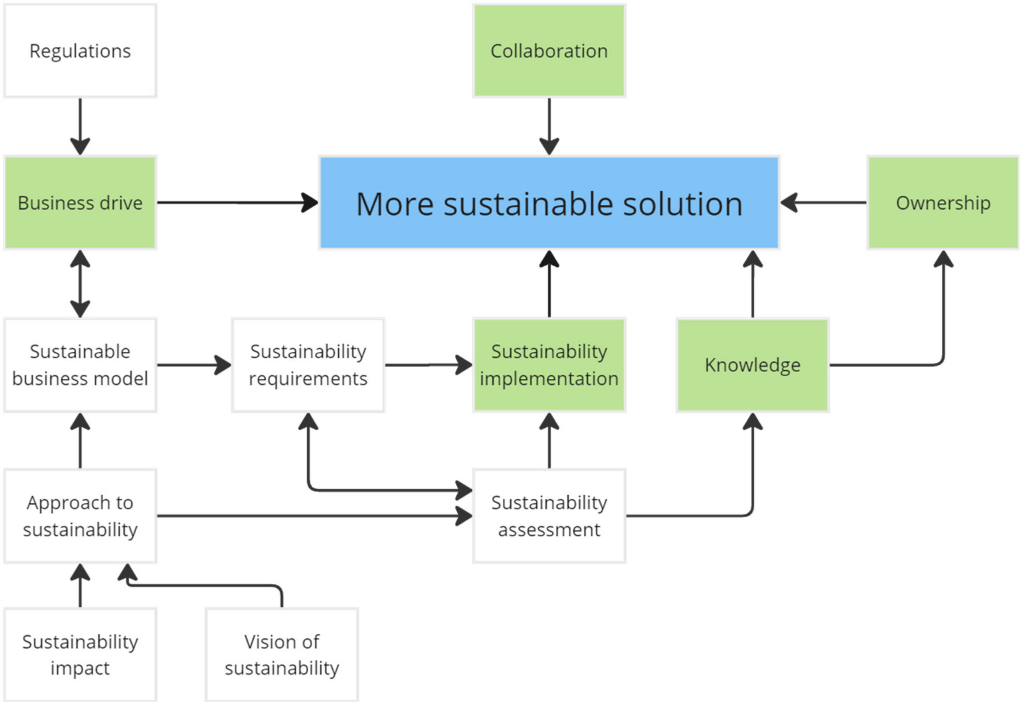


**Figure 4. Proposed impact model with key elements towards sustainable solutions in aerospace, based on findings from this study. An outgoing arrow means an element enables another**

# 4. Discussion

This study explored the relationship between the aerospace industry and sustainable product development, aiming to understand the specific sustainability challenges in aerospace product and technology development. The research was guided by two research questions:
**RQ1**: What are the key elements needed to design for sustainability in the aerospace industry?
**RQ2**: What strategies can further enable the design of sustainable solutions in aerospace technology product development projects?
In response to RQ1, this study employed qualitative research methods to explore barriers and enablers to sustainable product development in aerospace. The focus group discussions and expert group interview led to the creation of an impact model (see Figure 4) and the identification of five key elements essential to design for sustainability in aerospace: i) business drive, ii) sustainability implementation, iii) knowledge, iv) ownership, v) collaboration. Currently, companies experience insufficient business drive to prioritize the development of more sustainable solutions. They lack implementation of sustainable practices in their product development processes. Individuals at operational (design engineers) and tactical levels (decision-makers) might lack sustainability knowledge and might not have sufficient ownership to take action. Lastly, collaboration both internally in companies and with the value chain is not established sufficiently to address sustainability challenges. The barriers identified in this study are also encountered in the field of sustainable product development. Examples include the need for sufficient drivers to enable eco-design (Schäfer & Löwer, 2020), the need for implementation of sustainability practices (Faludi et al., 2020) and the impact of human behavior and organizational context (Mallalieu, 2024).
In response to RQ2, several solutions to enable the development of sustainable solutions were identified, providing valuable insights for future research. This study suggests extending stakeholder analysis in the development of business models to move beyond immediate customer needs. Moreover, viable business models are essential to enabling eco-designed products (Schäfer & Löwer, 2020). Considering future trends in this analysis can facilitate the creation of more sustainable business models while ensuring successful solutions. Sustainability should not only be integrated into business model development, but also in management practices, decision-making and day-to-day activities. This requires adjustment of organizational structures, routines (Schäfer & Löwer, 2020), and project phases (Sabini et al., 2019). Adopting a strategic sustainability approach that focuses on opportunities is essential, along with managing trade-off between sustainability aspects and other metrics (Lövdahl

et al., 2024). This paper highlights the importance of further implementing sustainability in projects and product requirements, to ensure timely and holistic assessments. Establishing rigorous follow-up processes and clear expectations through management frameworks could encourage teams to take action after performing such assessments. Sustainability knowledge is also essential, and can be enhanced through competence building and the use of support tools (Hallstedt, 2013). Visualization plays a key role in informing decision-makers and guiding decisions (Backes et al., 2023). Based on this study, a proposal is to support companies to develop their sustainability knowledge at a system level, so system designers will better understand impact of their solutions, and components designers will be encouraged to adopt a broader perspective. Companies need to be proactive, to embrace the role of designers and be capable to handle soft factors such as the behavior of employees (Schäfer & Löwer, 2020). They need better internal cross-functional collaboration, and to involve the value chain in product design. Stakeholder management is also an essential element to more sustainable product development projects (Sabini et al., 2019).

The study presents an initial impact model based on an inductive and qualitative approach, primarily using empirical data collected through interviews. The proposed model requires further refinement, development, validation, and generalization. To address this, a broader study involving additional companies and extended discussion time can be conducted to expand and strengthen these findings.

## 5. Conclusion

This paper sheds light on barriers to sustainable product development in the aerospace context. Strict regulatory background and an overall lack of sustainability proactiveness are examples of such specific challenges. The complexity of the stakeholder landscape in aerospace often leads manufacturing companies to believe that enabling sustainable solutions is beyond their scope, but findings from this study suggest otherwise. Issues that are common in the field of sustainable product development were also identified in this paper, such as implementation issues and lack of business case for sustainable solutions. The focus group discussions and expert group interviews led to the identification of five key elements needed to design for sustainability in aerospace: i) business drive, ii) sustainability implementation, iii) knowledge, iv) ownership, v) collaboration. Several barriers and enablers were identified, such as the usage of sustainability requirements or extending stakeholder analysis when starting projects. This study developed an initial impact model showcasing causal relations between these key elements.

While acknowledging its contributions and limitations, this paper's identification of initial barriers and enabling strategies holds relevant implications for academics and industry practitioners and is a contribution to future research on sustainable product development in aerospace. The identified key elements in this paper can serve as a support for practitioners to inspect their own organization's practices and gaps and plan for efficient intervention. From a research perspective, this study highlighted the industrial need for support for the areas of business drive and sustainability implementation. It underscores the need for researchers to pursue active collaboration with industry. Future research could explore in greater detail the influence of internal and external stakeholders on the sustainability performance of solutions within aerospace product development projects.


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