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The Application of Set-Based Concurrent Engineering within Lean Agile Product Development Environment at Atlas Copco Henrob

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Abstract

This paper presents the novel Lean-Agile Model for Product Development (LAMPD), which systemically integrates Lean Product Development (LeanPD) with agile methodologies for hardware product development. This paper discusses the successful implementation of the LAMPD model based on a real industrial case study from Atlas Copco Henrob. The case study focuses on the redesign of the air-tube interface, a critical sub-assembly of a Self-Pierce Riveting (SPR) system used for automotive body-in-white applications. The successful implementation validated LAMPD's effectiveness in generating a comprehensive set of alternative design solutions. The two optimal solutions were subsequently validated using Additive Manufacturing (3D-printed) prototypes and rigorous laboratory testing, ultimately demonstrating their superior design quality. The comprehensive evaluation phase leveraged Computational Fluid Dynamics simulation and was augmented by commercially available generative AI CAD, which was used to expand the set of design alternatives.

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Introduction

Lean Product Development (LeanPD) is recognised for its knowledge-driven, systemic approach to early knowledge capture, waste reduction, and disciplined decision-making, notably leveraging Set-Based Concurrent Engineering (SBCE) [1, 2]. However, the model's front-loaded approach and inherent resource intensity can limit flexibility and responsiveness to dynamic requirements and rapid market shifts [3, 4], creating a tension between rigour and agility. Consequently, Agile methodologies, emphasising iterative progress, continuous customer feedback, and responsiveness to change, offer the flexibility required to address this adaptive deficit [5]. Rather than treating Lean and Agile as opposing methodologies, recent efforts have focused on combining their complementary strengths within a unified framework [4]. The Lean-Agile Model for Product Development (LAMPD) is one such approach to product development. This paper presents a case study that applies the integrated LAMPD model to the redesign of an air-tube interface in collaboration with Atlas Copco Henrob, a manufacturer of Self-Pierce Riveting (SPR) systems used in automotive applications [4].

Atlas Copco Henrob's SPR riveting system uses compressed air to move rivets from the Compact Bulk Feeder (CBF) shown in Figure 1-A to the rivet gun. Inside the CBF, a component called an escapement is used, as shown in Figure 1-B and 1-C, which releases one rivet at a time into the T-tube, guiding it toward the rivet gun. If the airflow is not properly directed, the rivet may not travel smoothly, leading to delays, increased air consumption, reduced efficiency, and lower reliability of the joining process. The system layout is illustrated in Figure 1, which shows the SPR system and the critical location of the air-tube interface for pneumatic rivet delivery.

To design and optimise the Air-Tube Interface, the cross-functional team rigorously applied the LAMPD, leveraging the model's systematic derivation and prior validation [4]. The work was carried out using the Scrum framework, which breaks the project into sprint cycles [6]. Each sprint focused on a specific stage of the design, from the early planning to testing. The tasks were planned and completed in steps, and the design was developed and reviewed throughout the process to ensure that it matched the system requirements.

LAMPD is based on SBCE and agile hardware product development. SBCE provides alternative design solutions for each component of the air-tube interface. The component design space was systematically explored using SBCE and progressively narrowed.. Final selections were driven by Key Value Attributes (KVAs), defined in Phase 1 of the model, and evaluated against CFD simulation results from Autodesk Fusion 360.

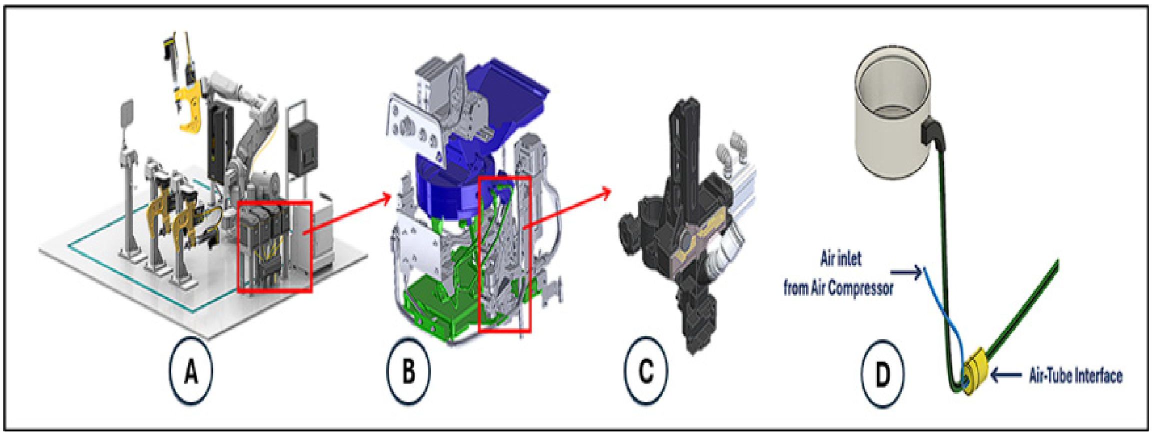


Figure 1: (A) Atlas Copco Henrob's Self-Piercing Riveting system, B) Compact Bulk Feeder, C) Escapement, D) air-tube interface location

Research Methodology

This study was conducted using an exploratory sequential mixed-methods approach [5] involving three integrated phases, focusing on the systematic application of the LAMPD model to industrial hardware development.

Phase 1: Literature Review

The literature review targeted best practices in pneumatic system design and CFD simulation for achieving stable pressure, uniform air delivery, and reduced energy loss in the context of rivet transfer. This study investigated the applications and capabilities of commercial generative AutoCAD Fusion 360 for geometric modelling and CFD simulation analysis. In addition, the literature review covered the study of LAMPD to understand how iterative and knowledge-based processes can enhance engineering decision-making.

Phase 2: The Application of LAMPD on Air-Tube Interface

Task 2.1. Define Scrum and Sprint Product Backlogs. The LAMPD's integrated activities constitute the Product Backlog (the 'what'), defining the scope and sequenced tasks required for the air-tube interface redesign. In line with the Scrum framework, these activities were grouped into Sprint Backlogs (the 'how much') and executed within a fixed two-week cadence to ensure predictable progress. The Sprint definitions are illustrated in Figure 4.

Task 2.2. Ensure Continuous Integration of Stakeholder Feedback. Regular Scrum meetings were held with Atlas Copco Henrob's supervisors to discuss sprint progress, review the findings, and shape development direction. Feedback on performance expectations, manufacturability, and testing feasibility was integrated into subsequent sprints to maintain continuous alignment with industrial needs.

Task 2.3. Augment SBCE's Ideation Phase using Generative AI-Enabled CAD. AutoCAD and generative-design tools were used to explore alternative geometries of the air-tube interface at the concept level and produce an expansive set of design alternatives for both CAD modelling and CFD simulation. The generated variations were analysed to study potential improvements in airflow direction, pressure stability, and assembly fit, forming the basis for subsequent evaluation and optimisation.

Phase 3: Trade-Off Curve Development. Generating data-driven trade-off curves directly from the CFD simulation results for each alternative. These plots compare key performance features, such as rivet propulsion, force, air velocity, flow rate, and blow time, to identify the Pareto-optimal region for design convergence.

Phase 4: Air-Tube Interface Laboratory Testing. The top two alternative designs were produced via Additive Manufacturing and subjected to rigorous laboratory performance testing at Atlas Copco Henrob's US facility. This final validation informed the release of the optimal design specifications.

Literature Review

SBCE plays an important role in LeanPD, particularly in fostering radical innovation, enhancing knowledge re-use, and improving disciplined decision-making [4, 7]. Instead of selecting a single design option early in the process, it encourages the simultaneous development of multiple alternatives at the same time. These options are gradually reduced through testing, comparison, and validation. This approach helps avoid early design lock-ins and allows for more informed decisions later in the process.

SBCE also fosters better cross-functional collaboration and knowledge management by creating an environment in which design insights are shared and continuously improved [7, 8]. It focuses on value creation and encourages processes that support collaboration and flexibility. In complex projects, this method helps delay key decisions until sufficient knowledge is available, which reduces risk and leads to better outcomes. Although many frameworks mention SBCE as part of LeanPD, only a few empirically validated studies detail its practical applications [9, 10].

LeanPD focuses on maximising value while reducing waste during design and development processes [11, 8]. It aims to improve decision-making and reduce delays by structuring work into phases in which tasks and evaluations are clearly defined. One of the key elements of LeanPD is learning from early-stage ideas and allowing flexibility before final decisions are made.

SBCE is a key component of this approach. Instead of selecting a single concept early in the process, multiple design alternatives are created and explored in parallel [12]. These designs are gradually narrowed down through evaluation, testing, and comparison with system requirements. This method allows teams to work with more confidence because decisions are based on analysis and not on assumptions. It also helps avoid unnecessary redesigns by filtering out less effective solutions before proceeding. This approach is particularly effective for complex engineering problems in which the correct solution is not known at the beginning. This ensures that all feasible possibilities are considered and only the most suitable options are selected for final development. In this project, SBCE helped the team create and assess multiple design variations of the air-tube interface before selecting the most promising ones for final testing [4].

Agile methodologies promote iterative development, structured around short sprint cycles (typically 1-4 weeks), which enable rapid adaptation to new requirements, enhanced progress transparency, and minimisation of development rework [5]. This intentional responsiveness enhances a firm's capacity to adjust to market and technical volatility [8]. The Scrum framework is a specific method of applying agile principles. In Scrum, the project is divided into sprint cycles, each lasting one or two weeks. At the beginning of each sprint, specific tasks are planned, and by the end of the sprint, progress is reviewed. This helps teams respond to new information, make decisions faster, and adjust their plans based on results [13].

Atlas Copco Henrob's Lean Agile Model for Product Development

Atlas Copco Henrob's current PD process consists of five phases: Phase 1: Project Definition, Phase 2: Project Feasibility, Phase 3: Project Realisation, Phase 4: Project Launch, and Phase 5: Serial Production. The application of the LAMPD model is restricted to the first three phases.

Figure 2 shows the mapping of the 1st phase of its PD process, called 'PD Definition', against the SBCE 1st phase, 'Define Value', resulting in the Atlas Copco Henrob's Lean PD Phase 1: Project Definition. The new LeanPD model follows the phases of SBCE with detailed activities that need to be performed to obtain the right results that are needed during the design review stage. The activities highlighted in blue came from the best practices of SBCE, while those highlighted in white came from Atlas Copco Henrob's current PD process. Similarly, the Phases of 'Project Feasibility' and 'Project Realisation' were transformed into a LeanPD environment.

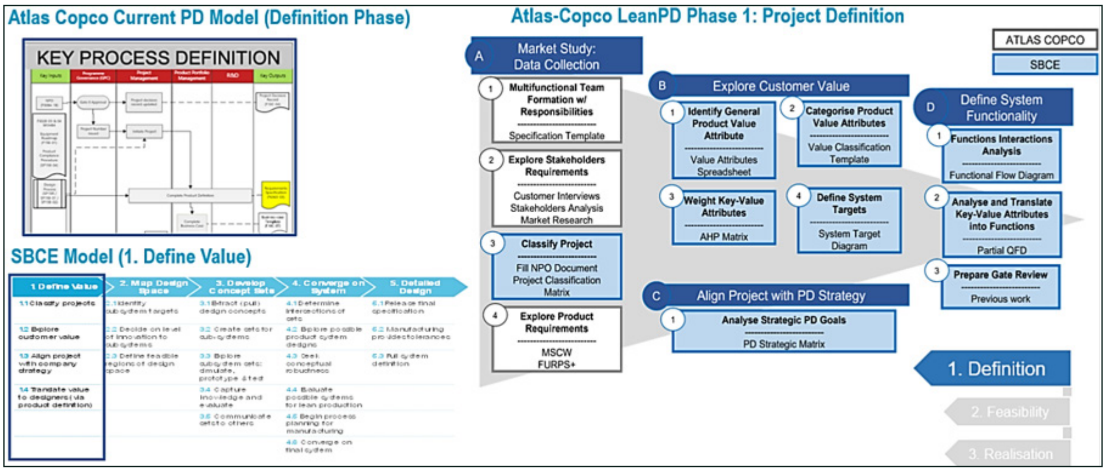


Figure 2: Mapping of Atlas Copco Henrob's Current product Development with the SBCE Model to Generate the LeanPD Process Model Phase 1: Project Definition

The integration of the developed Atlas Copco Henrob LeanPD process model with the agile approach using the scrum framework is illustrated at Figure 3. This shows that the scrum product backlog is defined by the detailed activity of the developed LeanPD model. In addition, it shows that the sprint backlog is a selection of certain activities from the defined new LeanPD model, in this case, the activities related to exploring customer values: 1) identify general product value attributes, 2) categorise product value attributes, 3) weight KVAs, and 4) define system targets. In this research, it was agreed that the sprint is of two weeks' duration. Similarly, LeanPD Project Feasibility and Project Realisation are integrated with an agile approach using the Scrum framework.

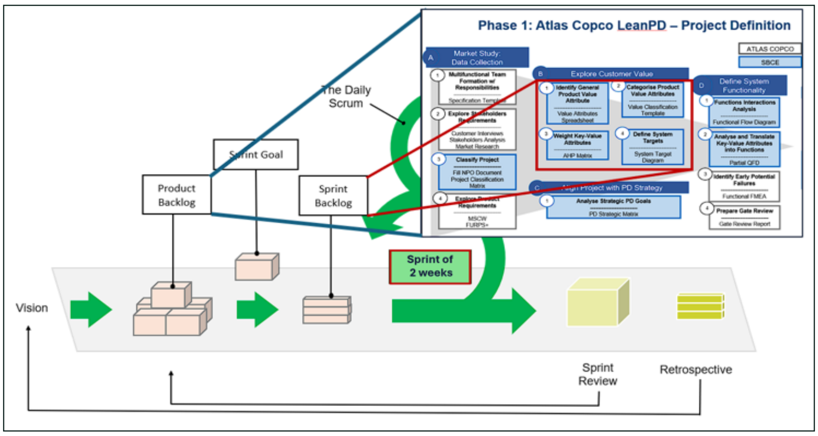


Figure 3: Integration of the LeanPD model with the Agile Scrum framework

Figure 4 shows the final development of the Lean-Agile Product Development Process models of Project Definition, Feasibility, and Realisation. Figure 4 also shows the sprint backlogs in each phase, highlighted in red boxes, where each sprint backlog was conducted over two weeks.

Application of Lean agile Product Development Process Model on air-Tube Interface

This section demonstrates the application of the Lean Agile Product Development process model to develop the air-tube interface. This is to demonstrate the effectiveness of the developed new model in developing novel and real engineering applications to enhance the energy efficiency of the overall system of the self-piercing riveting system. The case study is redesigning an air-tube interface to reduce air usage and improve rivet delivery, while retaining the capability to fit the assembly into the existing system without major modifications (see Figure 1-D). The air-tube interface was broken down into components, and alternative design ideas were explored, modelled, and tested using CFD of Autodesk Fusion 360. The following paragraph presents the implementation of the activities within the sprint backlog, as shown in Figure 4.

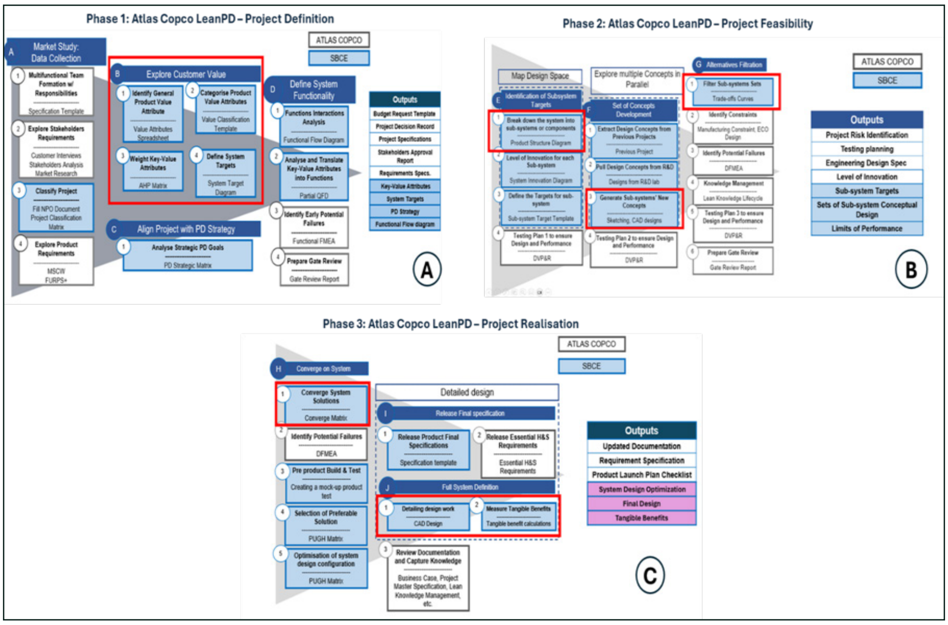


Figure 4: Atlas Copco Henrob's Lean Agile model for the Product Development Process

Phase 1. Project Definition: B-Explore Customer Value

Activity B1: Identify general product value attributes (Figure 5.B1), was identified by brainstorming the values that the air-tube interface should have to meet the required performance and address inefficiencies such as excess air usage and inconsistent rivet delivery.

Activity B2: Categories of Product Value Attributes. Categories of Product Value Attributes. This activity categorises the defined values (Figure 5.B2), which are design performance, operational performance, manufacturing feasibility, system integration, cost, and sustainability.

Activity B3: Weight Key-Value Attributes, as shown in Figure. 5-B3 prioritised the classified value attributes using the Analytical Hierarchy Process (AHP). The AHP matrix was developed by comparing each attribute pairwise based on the engineering priorities and system-level requirements of the company. Six categories were evaluated: design performance (31.1%), operational performance (18.6%), manufacturing feasibility (5.3%), system integration (10%), cost considerations (3%), and sustainability (31.4%). Based on these scores, the final KVAs were defined with the following weightings: sustainability (35%), design performance (30%), operational performance (20%), and system integration (15%). These priorities were used to guide design decisions and establish the foundation for system-level evaluation.

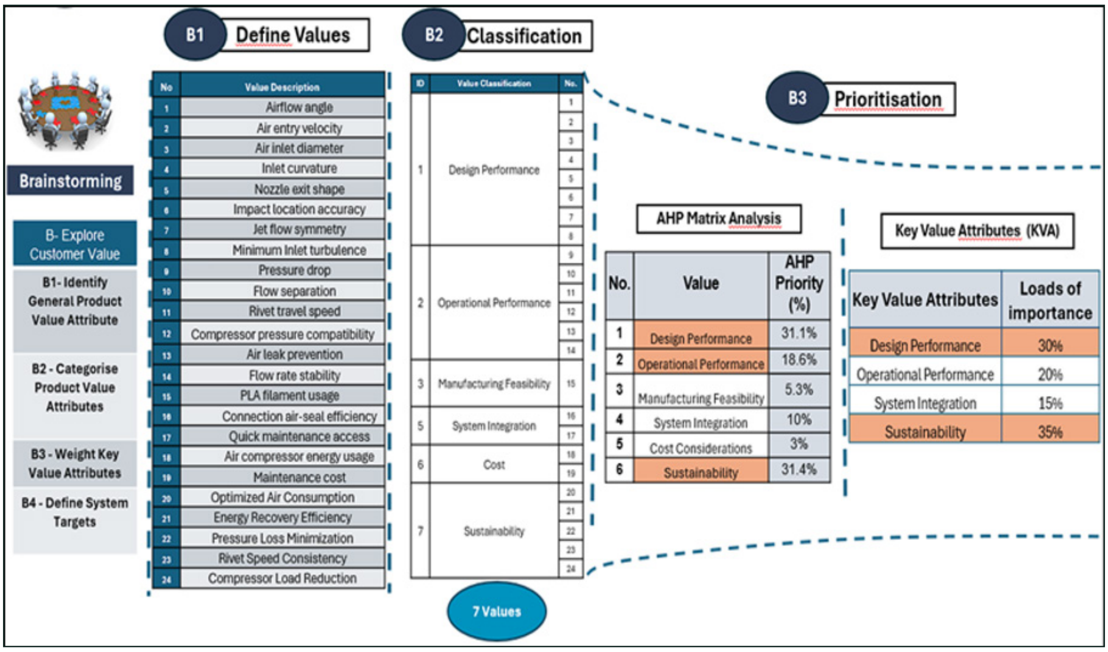


Figure 5: Activity B: Explore Customer Value of air-tube Interface

Activity B4: Define system targets, this activity translated the prioritised Key Value Attributes into measurable system-level targets. Each selected KVA was linked to specific design objectives; for example, sustainability was associated with reduced air consumption, Design Performance with rivet propulsion force, Operational Performance with delivery consistency, and System Integration with interface compatibility. These system targets were used as evaluation criteria for selecting and validating the concepts in the later phases of development.

Phase 2. Project Feasibility: E- Identification of subsystem targets.

Activity E1: Breakdown the system into subsystems or components - Figure 6 shows, Air-Tube interface is divided into following key features: nozzle shapes, air-tube path, number of air entry inlets, number of air inlets to the T-tube, position of air entry, and length of the test part. The application of LAMPD is to generate a set of alternative solutions for each of these features.

Phase 2- Project Feasibility: F- Set of concepts development.

Activity F3: Generate sub-systems into new concepts. This activity, shown in Figure 6, generated the following alternative designs for each feature: nozzle shapes (seven options), air-tube path (three options), number of air entry inlets (two), number of air inlets to the T-tube (two), position of air entry (two), and length of the test part (two). The combination of these features resulted in 336 possible configurations.

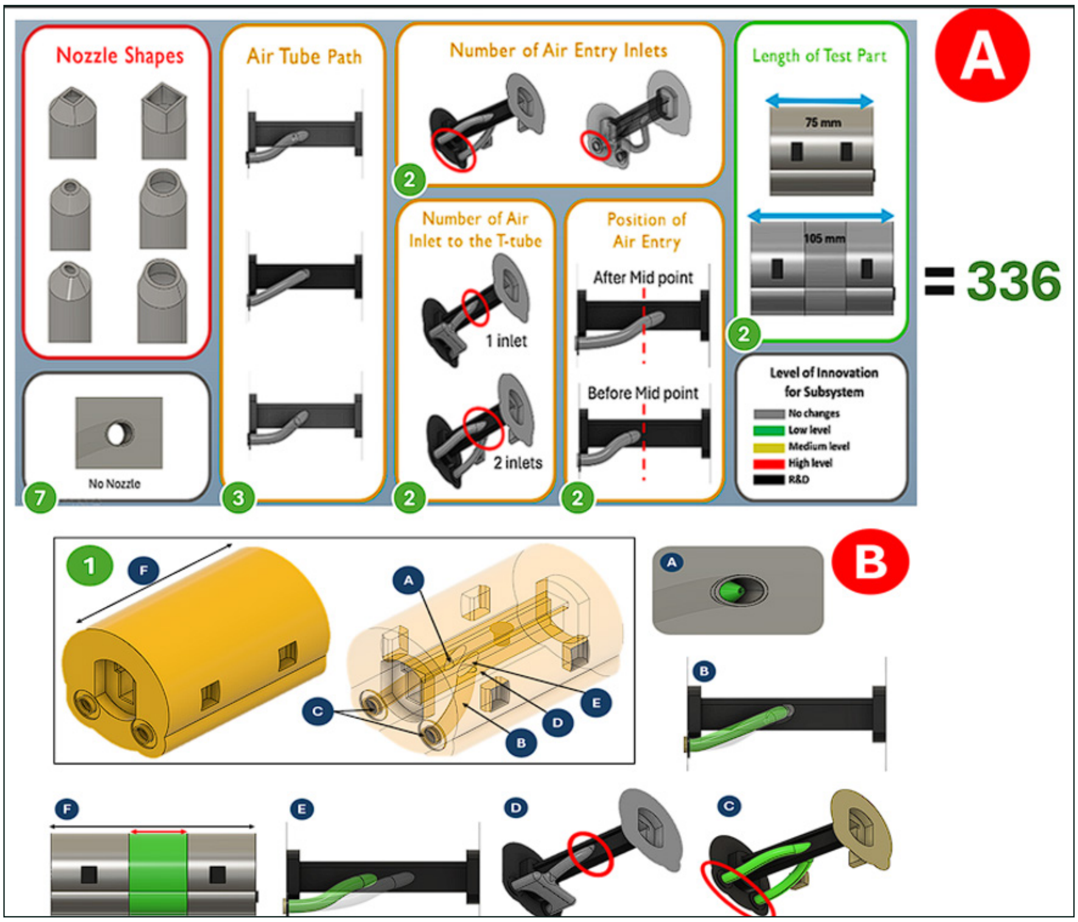
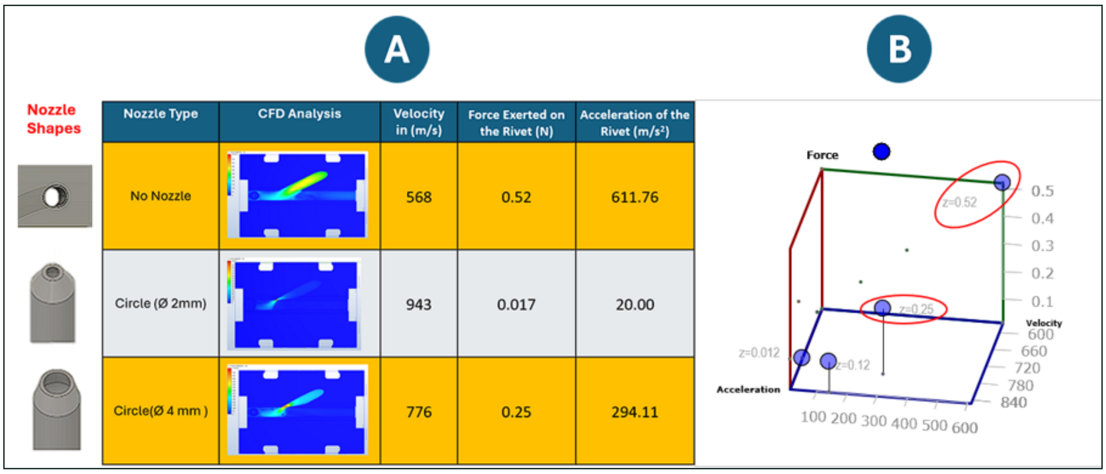


Figure6-A: Air-tube Interface Broken down into Component levels Highlighting the Innovation Level Using Colour code 7 different Nozzle shapes x3 Air-tube paths x2 Different air Entry inlets x2 inlets to T-tube x2 position of air entry Inlets Horizontally x2 Different Lengths, total Combinations = 336. Figure 6-B. Different Features of the Air-Tube Interface.

Phase 2. Project Feasibility: G-Alternatives Filtration

Activity G1: Filter sub-system sets: The CFD tool is used to simulate the air flow on the proposed alternative solutions shown in Figure 6-A, under standard conditions (4 bar, 2.5 $L \cdot s^{-1}$). The key measures were riveting force, airflow quality, and manufacturability potential. Concepts that did not meet the system targets (listed in Figure 5-B4) were removed. Therefore Figure 6-B, is illustrating the selected good design features that were used for further detailed CFD analysis, as shown in Figures 8 and 9. From the CFD results, a trade-off curve, shown in Figure 7, was generated to support the narrowing down of the alternative design solutions.

The trade-off curves shown in Figure 7 were plotted directly from the CFD results for each configuration using the force, air velocity, flow rate, and blow time. For each subsystem (nozzle shape, pathway, inlet number/ position, and length), the plotted data showed the feasible region where the rivet speed and air consumption met the system targets. This enabled the rapid elimination of weak alternative design solutions while retaining variants with the best balance. In the nozzle feature of the air-tube interface, for example, only three shapes achieved the desired force-velocity combination of (0.52N, 568 m/s and 0.25N, 776 m/s), as listed in Figure 7-A. The same approach was then applied to the remaining features of the air-tube interface. This helped narrow the 336 alternative design solutions to 12 solutions.



Nozzle Type	CFD Analysis	Velocity in (m/s)	Force Exerted on the Rivet (N)	Acceleration of the Rivet (m/s²)
No Nozzle		568	0.52	611.76
Circle (Ø 2mm)		943	0.017	20.00
Circle(Ø 4 mm)		776	0.25	294.11

Figure 7-A: Alternative Design of Nozzles with CFD Simulation. Figure 7-B -Trade-off Curves of different Nozzle Shapes

Phase 3. Project Realisation: H- Converge on System - Activity H1: Converge system Solutions.

This activity uses the 12 alternative design solutions to perform further analysis and to narrow it down. Based on the experience of a test engineer from the company, the following parameters were advised to narrow down alternative design solutions. The recommended parameters are as follows: flow rates of approximately 320-330 L/min and pressure of approximately 4 bar. The compressor air blow time in these cases was approximately 1.4 s, allowing the rivet to reach the desired speed range of 15-16 m/s. Specifically, to achieve this speed parameter, the force on the rivet inside the Air-tube Interface was considered (force directly proportional to speed) which was applied to the narrowed 12 alternative design solutions by comparing the value of force on the rivet to achieve the recommended speed of 15-16 m/s.

The narrowed four solutions, shown in Figure 8, had further CFD analysis performed (or: underwent further CFD analysis).

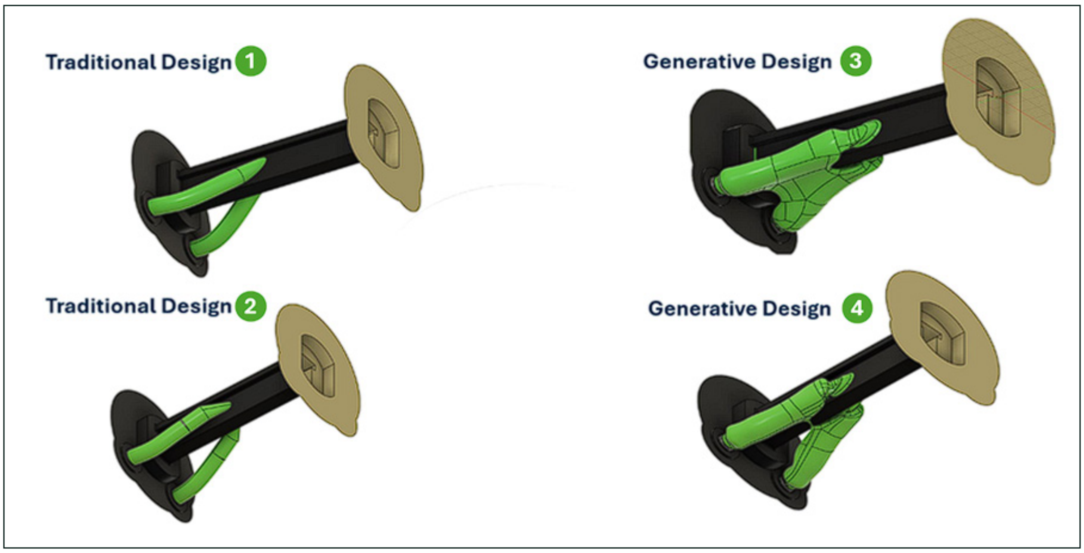


Figure 8: Four Alternative Design Solutions for the Air-Tube Interface

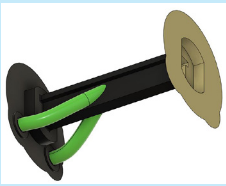
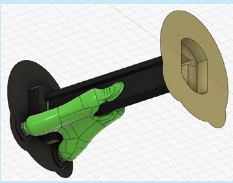
- **Traditional Design 1.** Traditional design 1 was produced using Autodesk Fusion 360, with No Nozzle, two air entry inlets, and two air inlets to the T-tube with a length of 75 mm.
- **Traditional Design 2.** Traditional design 2 produced using Autodesk fusion 360, it is with Nozzle of

4mm, has Two Air entry inlets and Two Air-inlet to T-tube with the Length of 75mm

- **Generative Design 3.** The design was produced using Generative AI commercial CAD of Autodesk fusion 360. A manifold-style internal structure with Two Air entry inlets and two air inlets to the T-tube with a length of 75 mm.
- **Generative Design 4.** The design was produced by Generative AI commercial CAD of Autodesk fusion 360. A manifold-style internal structure having Two Air entry inlets and Two Air-inlet to T-tube with the Length of 75mm

Table 1 shows the CFD results of the four alternative design solutions and highlights the best design solutions, Traditional design 2 and Generative design 3, achieving forces on the rivet of 2.2N and 2.06N, respectively (Figure 9). These are the optimum solutions because they have a high force resulting in high rivet speed, allowing the rivet to reach the desired speed range of 15-16 m/s, as recommended by the company's test engineers.

Table 1: Four Alternative Design Solutions of the Air-Tube Interface with the Detailed Results of the CFD Simulation

Air-Tube Interface Designs	Velocity (m/s)	Mass Flow Rate (litres/sec)	Force on Rivet (N)
 Traditional Design 1	657	2.5	1.9
 Traditional Design 2	698	2.5	2.2
 Generative Design 3	694	2.5	2.06
 Generative Design 4	645	2.5	1.75

Phase 3 - Project Realisation: J- Full system definition, Activity J1: Detailing design work

The two selected air-tube interface designs were 3D printed and tested at Atlas Copco Henrob's US facility. Traditional design 2 outperformed the generative CAD designs in terms of simplicity, ease of integration, and performance under test conditions. The SBCE concepts are more closely aligned with key value attributes and system requirements. All the designs were compatible with the existing test setup and did not require major modifications.

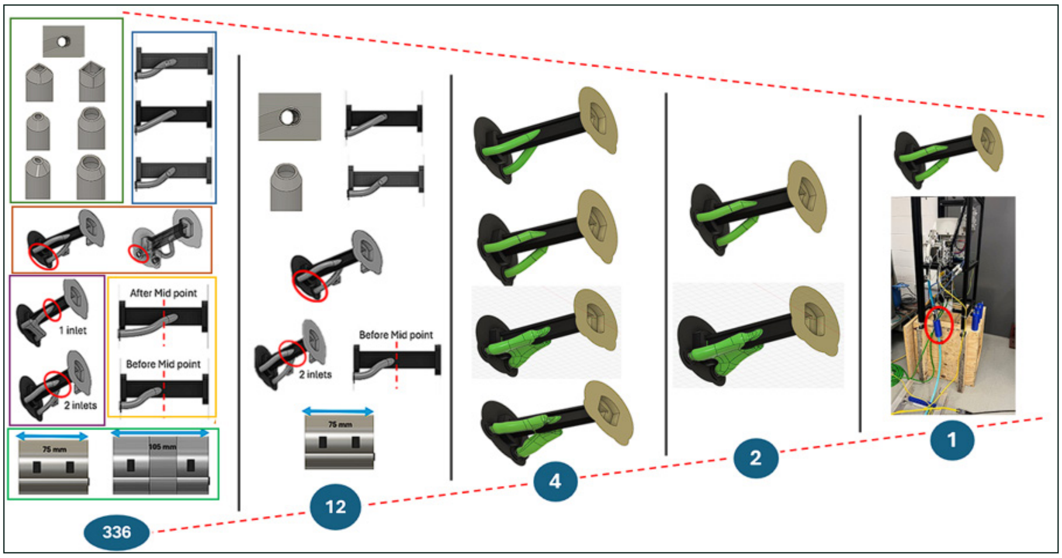


Figure 9: Overall LAMPD Applications and the Convergence of the Air-Tube Interface Design

Conclusions

This study demonstrated that supporting product development processes can be achieved by integrating two different approaches. These are the LeanPD and Agile hardware product developments. The integration of these two approaches provided a clear process model, called LAMPD, that helped address the different aspects of product development. LeanPD, based on SBCE, provides activities and tools to generate alternative design solutions to optimise product design. Agile hardware product development with the application of Scrum and Sprint frameworks provides a mechanism to develop a product in short intervals with clear processes and key activities to follow with clear tangible outputs in each Sprint. Therefore, the proposed LAMPD (Figure 4) is an effective process model for supporting product development and offers a structured, yet adaptive methodology. Expert judgment has validated its functional structure and utility in industrial hardware development [5].

A case study of the air-tube interface (shown in Figure 1-D) which is a subassembly of Henrob's SPR system, demonstrated the ease and smooth implementation of the LAMPD model. The case study showed how the model represents the product backlog in the scrum framework (shown in Figure 3) and how easy it is to select the sprint activities within the defined process model. The implementation of the LAMPD model yielded an initial 336 alternative design solutions (see Figure 9), which were methodically narrowed down to 12, then 4, then 2, leading to the final optimal selection. The use of generative AI directly augments SBCE's exploration phase of SBCE to enable this volume of concept generation [5].

The generative AI commercial CAD system proved effective by producing a component-level alternative design, demonstrating its utility as an SBCE ideation tool in the context of the air-tube interface case study. The SBCE process, embedded within the rigorous LAMPD framework, resulted in the selection of Traditional design 2 as the optimal solution. Critically, while the generative AI CAD system produced novel and topologically optimised alternatives, it demonstrated a suboptimal performance output by likely prioritising shape innovation and material reduction over the explicit fluid performance criteria critical to the SPR application [14-16].

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