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APPLICATION OF AGILE METHODS IN CONCEPTUAL AIRCRAFT DESIGN

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Abstract

Conceptual aircraft design is not only a technical but also an organizational challenge. Especially, the integration of unconventional components into novel system architectures requires fast design iterations including the revision of requirements and an efficient propagation of changes across a diversity of disciplines in order to minimize project risk. Current process models in conceptual aircraft design do not fully address these needs. By contrast, Agile Methods, a family of process models successfully applied in software engineering, have consistently demonstrated that iterative product development and frequent delivery of product increments to the customer are effective for keeping project risk low. Furthermore, the process complexity is deliberately avoided in order to enable the developers to quickly react to changes imposed by the customer or the design. In a recent inter-disciplinary design study at Bauhaus Luftfahrt, the so-called “Scrum” methodology was adopted as a process model. Since Scrum is not solely adept to software development, essential concepts of this Agile Method could be transferred to the given aircraft design task without major obstacles. Based on the observations during and after the project it can be generally concluded that Agile Methods are well applicable to conceptual aircraft design. Especially, the Scrum-specific “time boxing” and an efficient meeting culture applied at various project levels was perceived helpful by all project participants to convey situation awareness (transparency) and to cope with fluctuation of personnel. This positive first experience encourages further investigation with respect to the adoption of Agile Methods in aircraft design, especially regarding the transition from a virtual concept to a physical product.

1 INTRODUCTION

The development of an aircraft is a challenging enterprise of systems engineering. Common collaborative design practice is based on engineering experience and best practices that often rely on conventional mechanisms and interfaces of known system configurations. Therefore, the introduction of advanced technological concepts and system configurations significantly impacts the functional decomposition and the physical interfaces within the system. Owing to the lack of empirical knowledge and the required re-definition of system interfaces, the applicability and effectiveness of classical process models to advanced technological approaches is limited. Hence, despite the demand for breakthrough system design solutions facilitating economically and ecologically sustainable airborne mobility, conceptual aircraft designers often hesitate to elaborate unconventional aircraft concepts and systems with sufficient degree of detail.

Bauhaus Luftfahrt (BHL) is committed to research on long-term drivers of aviation, breakthrough technologies, and integrated air transportation system concepts. An important part of the integrated conceptual design work is constituted by Initial Technical Assessments (ITAs), bringing together the different in-house research disciplines. In order to coordinate BHL’s inter-disciplinary research portfolio, new ways of collaboration throughout the conceptualization of visionary technical concepts are constantly evaluated. Directly addressing the environmental goals for the year 2050 as per the International Air Transport Association (IATA) [1] and the European Commission [2], the conceptual design of a universally-electric, short-range, mid-sized transport aircraft was tackled in a recent ITA. Acknowledging the significant progress and the foreseeable development of electrical energy storage and conversion technologies, and, considering the time frame for the long-term target settings mentioned above, the definition of a best-and-balanced concept solution for an electrically-powered transport aircraft represents a great inter-disciplinary challenge. Due to the dynamic development in electrical component technologies, technically feasible design payload / range capacity of air transport systems strongly depend on the targeted Entry-Into-Service (EIS) year. Since passenger and market requirements also change over time, in combination, significant iteration and inter-disciplinary trade-offs were required, in order to optimally match economic attractiveness and initial feasibility of the electrically-powered aircraft concept. Hence, unlike classic aircraft conceptual design tasks, the determination of appropriate Aircraft Top-Level Requirements (ATLeRs) is required to be part of the iterative design procedure. In summary, the frequent change of design boundary conditions for the referred ITA necessitated a process model which would not only address the iterative nature of the design task but also reinforce multi-disciplinary collaboration. Accordingly, the scope of the research on current methodologies was broadened to other industry sectors developing highly complex systems. Eventually, the decision was made to adopt a process model from the family of “Agile Methods”, namely Scrum, which is commonly applied in the software industry.

This paper reports about the first experience in adopting Scrum at Bauhaus Luftfahrt. Firstly, current practices in aircraft design are reviewed before the basics of agile collaboration and Scrum are introduced. Subsequently, the design challenges and the organizational framework of the project are described, and, details about a Scrum-oriented way of working are provided. To round off, important observations made during and after the project are discussed, and recommendations for future application of Scrum in aircraft conceptual design are given.

2 PROCESS MODELS

Process models are an integral element of aircraft design in order to coordinate the activities of highly specialized individuals developing a reliable and economical mode of transportation. After a brief overview on current practices in aircraft design, a general introduction to Agile Methods and particularly to the Scrum process model is given.

2.1 Current Practice in Aircraft Conceptual Design

Current practices in the development of commercial aircraft at Airbus are described by Pardessus [3]. The structured development cycle forming the basis for commercial programs at Airbus features five major phases, namely, the “Feasibility”, “Concept”, “Definition‘”, “Development”, and “Series” phases, taking of the order of 10 years from the initially established product idea to the end of the basic aircraft development. While development and series production phases are dominated by industrial performance requirements, i.e. the linking of engineering and production, upstream phases of aircraft development, i.e. feasibility and conceptual design stages, are highly interactive and iterative in nature.

A number of approaches to improve the efficiency of collaboration during concept and later product development have been established in the aerospace industry and are considered to be state-of-the-art in the present context: Concurrent Engineering practices address the management of complexity, the synchronisation of the development cycle, the control of design domain interfaces, cross-company collaboration, and the traceability of product information throughout product development. Concurrent Engineering is process-oriented, hence, processes have higher priority than methods and tools. This includes the analysis of how design teams actually cooperate, how information is exchanged, and, how design changes are handled, eventually, targeting streamlined overall work flows and maximizing process quality [3]. The challenge of coupled intra- and inter-disciplinary design complexity is tackled by multifaceted research activities embraced by the term Multidisciplinary Design Optimisation (MDO). A number of MDO approaches aim for a problem-oriented decomposition of complex design tasks in order to optimally utilize the disciplinary expertise and productiveness of the human experts through efficient work clustering and process parallelization [4, 5, 6]. Commercial software solutions are available and in use for the handling and exchange of model information in collaborative environments [7, 8, 9]. New collaborative procedures involving MDO across enterprise firewalls were explored as part of the Virtual Aeronautical Collaborative Enterprise (VIVACE) project [10]. Methodological development in collaborative engineering has also addressed the challenge of ensuring the convergence of stakeholder design activities through systematic communication of decision-critical information, and thus, facilitating an improved organization of the coupled decision making process during complex product development [11].

Considering more radical long-term-oriented design tasks, the challenge of matching economic target scenarios and technological availabilities has become more important. The resultant strong interdependency of ATLeRs projected, technology availability, and correspondingly optimal system configurations require a high level of flexibility and agility in team organization and collaboration. Despite the fact that its relevance is widely accepted, the organization of the daily research and development work within an interdisciplinary team of conceptual aircraft designers is rarely addressed in the literature.

2.2 An Introduction to Agile Methods

Agile Methods are driven by the idea that a team of developers delivers benefit to the customer by its ability to efficiently react even on late changes. In that context, changes can be extrinsic, like changes of requirements or prioritization by the customer, but also intrinsic, like changes of the required effort for achieving development goals or technological requirements for a chosen system design.

The Agile Manifesto [12] is a condensate of the core principles of Agile Methods. Direct interactions between individuals contribute to the success of the project more than processes and tools. Maintaining an integrated working product has higher priority than providing consistent documentation. Establishing a productive and close relationship to the customer has higher priority than negotiating a contract. The capability to efficiently react even to late changes is valued higher than the organizational ability to follow a plan.

These principles are based on assumptions regarding incompleteness of information and the integration of the product. Proponents of Agile Methods claim that the customer cannot completely define all requirements at the beginning of the process. Accordingly, the development process and the final product cannot be completely defined at the beginning. To tackle this issue they recommend to integrate as yet rudimentary components of a complex product early in the process in order to validate assumptions and design decisions. Furthermore, early integration enables frequent feedback cycles with the customer helping to identify and handle project risks through direct communication rather than formalized exchange of documents. Direct communication implies that a large amount of information exchange and decision making is done informally. While proponents of Agile Methods value informal processes as a key enabler for agility, they generally acknowledge that technological and organizational improvement requires developers to act according to or at least exhibit a rational process [13].

In essence, Agile Methods, are less plan driven, more lightweight regarding process complexity, and more iterative than current process models in aircraft design.

In a review of empirical studies of Agile Methods in software development Dybå and Dingsøyr [14] list several instances of Agile Methods:

- Crystal Methodologies,
- Dynamic Software Engineering Method,
- Feature-driven Development,
- Lean Software Development,
- Scrum, and
- Extreme Programming.

On the one hand, these process models have adopted principles that are proven in other industries. For instance, Lean Software Development reuses principles and nomenclature from Lean Production. On the other hand, Agile Methods are currently designed for application in software engineering. For instance, Extreme Programming and Feature-driven Development are closely tied to typical tasks and processes of software engineering. Glas and Ziemer [15] reasoned theoretically about the challenges of a general application of Agile Methods to the aviation industry due to fundamental differences between software engineering and aircraft design. However, in the conceptual design phase of aircraft, limitations such as scale, certification, and geographical distribution of development are less critical compared to efficient adaption of tools and methods, the exploitation of design freedom, and the dealing with limited knowledge. Therefore, the application of Agile Methods to conceptual aircraft design was reasonable. For the design project, Scrum was selected as an existing process model less tied to programming. As Scrum promised to be adaptable to the context of aircraft design without substantial changes, this strategy would allow a better correlation of experiences with existing studies in software engineering.

2.3 Scrum

An early publication about agile product development [16] describes this new practice as a "rugby" style process in which the team of developers stand closely together in order to move forward. In rugby, such a tactical formation is called a "scrum". In the original publication Schwaber [17] continued the rugby analogy and called his new agile process model Scrum. He claims that waterfall-like process models are based on the assumption that the development process of a new product can be fully defined. Under that assumption, theoretical methods can be applied to plan and execute the process. By contrast, Schwaber considers a development process a black box which requires empirical methods of measurements throughout the process in order to control it. In the following, concepts of Scrum are described which are most relevant for the context of conceptual aircraft design.

Like other Agile Methods, Scrum addresses the organizational capability to react to changes efficiently and to systematically reduce project risk. Accordingly, Scrum lays emphasis on simplicity and low technical requirements for the process infrastructure. It defines roles, meetings, documents, and a general process. Scrum is a team- and product-oriented process model. A team should assemble persons from different professional background in order to cover a range of required skills. Scrum-specific roles are depicted in Figure 1. One team member invests the role of the Product Owner which is responsible for conveying a shared vision of the product as well as its delivery on time and with quality. In that function the Product Owner represents the team and its product as the main contact person to external stakeholders. The Scrum Master as an organizational adviser is responsible for the team's compliance to the Scrum method and for removing productivity impediments for the team. The Scrum Master works closely with the team as a trainer and does not have to be exclusively assigned to one team. It is important for the success of the project that the respective persons are entitled to exercise their designated roles to the full extent.

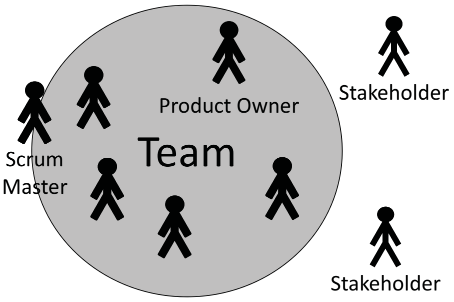

Figure 1: The Scrum roles adapted from Gloger [18]

Scrum aims at reducing complexity of organizational documents. Therefore, it defines only a few essential documents including the Product Backlog, the Sprint Backlog and the Burn Down Chart. The Product Backlog is a list of tasks each having a category, a priority, and an estimated effort. As the Product Owner represents the team to the stakeholders, he is also responsible for prioritization. The effort, however, is estimated by the team members. This bottom-up approach of effort estimation not only conveys better self-estimation. Group discussions on required effort also elicit any misunderstandings and reinforce best practices. Scrum encourages setting up these documents on a "pen-and-paper" basis to lower the technological barrier of adoption and aims to effect a high level of quality by sharing a "definition of done" between team and stakeholders, and not delivering any "half-done" products. Figure 2 illustrates how the product development process is divided into several Sprints. Each sprint is a development period which leads to a potentially shippable product. In a Sprint the developer team commits to realizing a Sprint Backlog which is a slice of the Product Backlog.

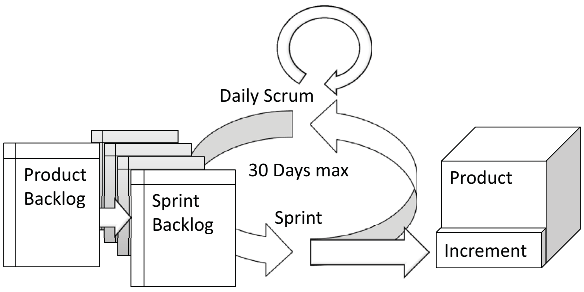

Figure 2: The Scrum process adapted from Pichler [19]

The Product Owner creates a Burn Down Chart which depicts the decrease of the estimated effort required to complete open tasks over the duration of the Sprint. For better orientation a Burn Down Chart as depicted in Figure 3 is overlaid with an ideal, constant burn down rate. The team meets regularly every day at the same time and place to a Daily Scrum in order to discuss the current status, next steps, and impediments. Thereby, the Burn Down Chart is updated in order to track the progress and adjust estimated effort as soon as possible. Budgeting time is addressed by “time boxing” on different scales. Accordingly, not only the development iteration cycles, so-called Sprints, have a predefined hard deadline but also Daily Scrum meetings always end after 15 min.

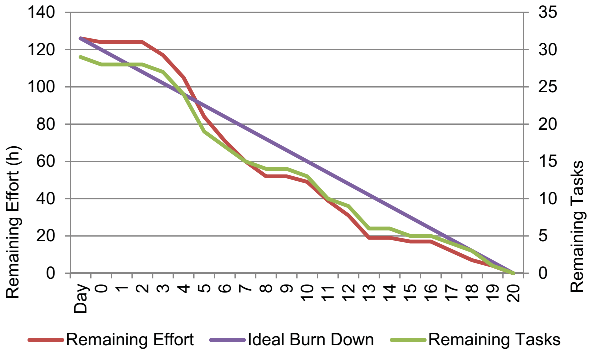

Figure 3: A sample Burn Down Chart

The aforementioned concepts of Scrum enable a developer team as a small, effective, and wholly collaborative working unit. According to Schwaber and Sutherland [20], a team ideally consists of 7 ± 2 persons. Scrum of Scrums is a regular meeting where delegates from different teams discuss overlapping issues. Thereby, the Scrum methodology is scaled in order to coordinate the collaboration of several teams in a multi-team project.

According to experience reports Scrum is usually introduced into organizations [21, 22] in pilot projects with voluntary pilot teams.

3 AN INSIGHTFUL PILOT PROJECT

The long-term environmental targets set for air transportation [1, 2] elevate the demand of exploiting revolutionary technological and methodological approaches to aircraft conceptual design. As a possible means of in-flight zero-emission air transport, the task of establishing the initial technical feasibility of an electrically-powered transport aircraft was tackled as an inter-disciplinary group design project involving more than 20 researchers from all research departments of Bauhaus Luftfahrt. During project setup, lessons learned from a previous group design project, such as the necessity of precise market requirement specification, information transparency, situation awareness, and improved integration of the inter-disciplinary expertise, were recapitulated. Moreover, due to the strong interdependence of electrical technology with respect to aircraft system integration, and economical utilization potential intrinsic to the newly encountered design task, a highly iterative and interdisciplinary procedure was required. Acknowledging this strongly iterative and interactive nature of the overall activity, the Scrum approach was considered adequate in order to meet the required agility in collaboration throughout the project. In the following, the nature of the conceptual design task given, the project organizational structure, and important aspects of the daily way of working using Scrum are discussed in more detail.

3.1 The Design Task

In view of an in-flight zero emission operation and acknowledging the step changes in electrical storage and conversion technologies that have occurred during the last decade, the prospect of utilizing electrical motive power is currently starting to be seriously considered for aerospace vehicle design and integration [23, 24].

To this end, an ambitious mission statement was formulated for the present conceptual design task:

> *"Perform the conceptual design and initial technical assessment of a short range aircraft application featuring electro-motive systems."*

Classical aircraft conceptualization and feasibility analysis is triggered by the specification of a transport task, i.e. range for a given payload, accompanied by a set of performance, economical and ecological goals, as well as certification-related requirements. Combined with the considerable complexity of an air transport system, this leads to a challenging design task in establishing a best and balanced, feasible aircraft concept. If advanced technological and architectural solutions need to be incorporated in the system design concept, the design challenge is considerably elevated. In the present design study, the complexity of the aircraft design and definition problem are driven by the initial lack of knowledge on the involved electrical component technologies, and, the necessary deviation from classical system sizing and optimisation procedures. The challenge, here, is greatly enriched by the moving design target scenario due to the strong interdependency of technological and economical concept feasibility as a function of the potential EIS year, as shown in Figure 4.

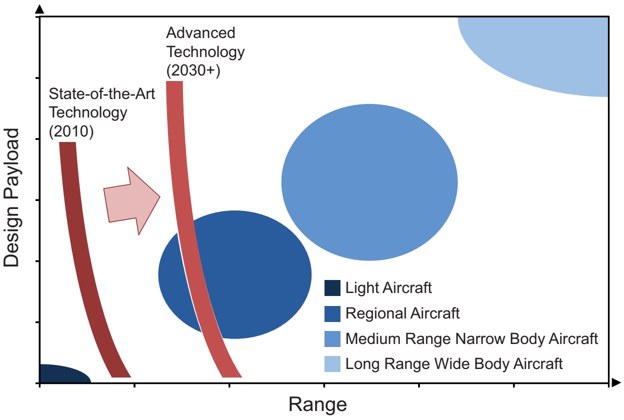

Figure 4: Design target space based on full-electric motive power

Conventionally powered transport aircraft exceed payload masses of 100 t featuring ranges that allow point-to-point connections around the entire globe. In spite of the high standard of state-of-the-art structural, aerodynamic and propulsion system technologies, a key enabler of this is the high gravimetric and volumetric energy density of the kerosene fuel used. When considering universal-electrically powered transport aircraft, achievable payload and range capacities are strongly limited by the gravimetric energy and power densities of the system components for electrical energy storage and conversion. However, significant progress in electrical energy and power densities is predicted in the mid-term future [25]. In Figure 4, a qualitative visualization of the expected progress in key electric technologies and the corresponding impact on economic utilization potentials is given. As can be seen for advanced technology (2030+), an economic use case for electrically-powered transport aircraft seems conceivable. However, the strong technological dependency of transport capacity and the trade-off between payload and range for a given technology status emphasizes the highly iterative nature of the given design task in order to produce a feasible design concept for maximum economic utilization at a reasonable EIS date. Different from classical aircraft conceptual design tasks, the definition of ATLeRs is required to be part of the iteration.

3.2 Organization of the Project

The given design task was executed in the frame of an inter-disciplinary group design project within 16 calendar weeks. Essential facets of the collaborative work performed are discussed in the following. This includes project planning aspects, the forming of task-oriented teams within the project, the organization of roles and responsibilities within these teams, formalized cross-team collaboration, as well as the daily way of working procedures.

The collaborative work was performed by four inter-disciplinary working groups, called Inter-disciplinary Project Teams (IPTs), involving a total number of 22 researchers, supplemented by the Technical Coordinator, the Chief Engineer, and the overall Product Customer. The role of the Technical Coordinator included the task of managing scope, time and resources of the project, as well as the organization of proper collaboration in the multi-disciplinary team. The Chief Engineer acted as a senior technical adviser, while both, the Chief Engineer and the overall Product Customer, represented the critical review authority within the project. The range of expertise in the overall project team covered multiple scientific disciplines including aerospace engineering (17), physics (2), economics (3), computer science (2), and industrial design (1).

The scope of work was defined by the Technical Coordinator, and, reviewed and approved by the Chief Engineer and the overall Product Customer as part of an upfront project planning. Four essential streams of tasks were characterized:

- the setup of an efficient, formalized aircraft design process,
- the definition of a feasible air transport application,
- the definition of the aircraft system and technology configuration, as well as,
- the modelling, integration and simulation of the aircraft concept.

For each stream of tasks, an individual IPT was formed prior to project kick-off, reflecting a problem-oriented build-up of the time-dependent requirements and availability of human resources and individual expertise. As an upfront risk mitigation measure, IPT constituency was tailored to minimize resource conflicts with other projects running in parallel. The work objectives of the four IPTs are characterized in Tables 1,2, 3, and 4.

Definition of Transport Application (DTA)
Identification of meaningful EIS and corresponding economic scenario
Identification of initial technological scenario for targeted EIS
Harmonization of technological availabilities, economic sanity, and best utilization perspectives
Definition of Aircraft Top Level Requirements (ATLeRs)
Declaration of reference aircraft
Monitoring of ATLeRs conformity during concept refinement

Table 1: Objectives of Team DTA

Aircraft Design Process (ADP)
Harmonization of BHL-available engineering software tools
Identification and implementation of (partial) tool chains
Development of concepts for the efficient data exchange between expert models
Definition of (multi-tier) aircraft conceptual design process
Definition of central data model applicable to the aircraft design task

Table 2: Objectives of Team ADP

Modelling Integration and Sizing (MIS)
Mapping of important physics of selected technologies, aircraft components and system architectures
Implementation and validation of required models
Harmonization of applied disciplinary and component-specific models
Model integration and simulation
Aircraft sizing and optimization
Computer aided design and visualization of the product

Table 3: Objectives of Team MIS

Technology and Configuration Definition (TCD)
Evaluation and down select of useful technologies
Definition of aircraft layout and central design features
Definition of systems architectures

Table 4: Objectives of Team TCD

In order to resolve the significant interdependence of the parallelized streams of tasks, an efficient task coordination was required. This was partly realized through sequential separation of individual tasks by upfront planning. Accordingly, the project was separated into six consecutive phases or time boxes, i.e.

1. initialization of study,
2. technology survey and down-selection, definition of processes and aircraft configuration,
3. modelling of technologies and system components,
4. aircraft-level integration of models,
5. aircraft design sizing and optimisation, and
6. formal reviews and documentation.

The six consecutive phases of the project and the work package contributions of the individual IPTs were planned and monitored using classical Gantt chart visualization.

3.3 Mapping Scrum to Inter-disciplinary Aircraft Design

The principles of Scrum were utilized in order to resolve the highly iterative and interrelated nature of simultaneous IPT tasks, e.g. the identification of a meaningful EIS and corresponding technological scenario (Team DTA) and the evaluation and down selection of useful technologies (Team TCD). An organizational diagram of the collaborative work flow and IPT interdependencies during the project is shown in Figure 5.

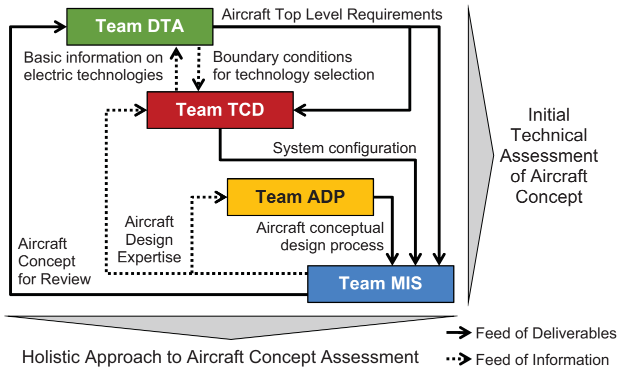

Figure 5: Schematic of IPT collaboration

The figure highlights the basic interrelationships of the IPTs, i.e. the information flow and the feed of deliverables, as well as the expected main products, the initial technical assessment of the aspired universally-electric short-range transport aircraft, and a reinforced holistic approach to aircraft conceptual design.

As a pragmatic approach to handle the volatility of boundary conditions and a well-established collaboration method to deliver virtual products in a timely manner, Scrum was employed and explored for the organization of IPT work. In each of the IPTs, a Product Owner (PO) and a Scrum Master (SM) were designated during team formation. Since most members of the overall project team were inexperienced in agile process models, Scrum was first introduced through a primer IPT, Team ADP, who explored Scrum best practices and gave training courses to the POs and SMs of the other IPTs. Sprints of the Scrum primer IPT were planned according to predefined Product Backlogs, conducted and reviewed in order to maintain conformity with the given timeboxes (phases) of the overall project plan, thereby ensuring well-defined interfaces to subsequent, dependent tasks. The detailed work scopes for the Sprints were negotiated between the teams and the corresponding customers during IPT constituent meetings, i.e. Release Planning Meetings. During Sprints, Daily Scrum meetings were held, adhering to the recommended procedures, i.e. same time and place for every daily meeting, a maximum meeting duration of 15 min and the delegation of detailed discussions to off-line conversation.

While the depth of Scrum adoption during internal work of the other IPTs was left to IPT-internal decision, in the first instance, the organization of project-level collaboration adhered to Scrum best practices. Thereby, all project team members were able to experience agile collaboration. Central pillars of the agile collaborative model used throughout the project involved:

I. Project Weekly Meetings

Preamble:

> *The project weekly meeting is the central forum for the exchange of the latest information and design innovation for all stakeholders of the project.*

The project weekly meetings were timeboxed to one hour, always being guided through the following agenda:

- IPT status reports (5 min each)
- Latest aircraft 3-view and design specification (5 min)
- House-keeping items (5 min)
- Important technical decision making (30 min)

The project weekly meeting represented an important means of maximizing the transparency and inspection of the results produced during the project. The key personnel of the project weekly meetings involved all project team members, customers and stakeholders.

II. The Role of the Product Owners

The IPT Product Owners acted as interfaces to other IPTs, the Technical Coordinator, and the Product Costumers. In turn, the PO of an IPT being the recipient of the deliverable of another IPT (cf. Figure 5) became a stakeholder of the delivering IPT, thereby ensuring the compatibility and consistency of consecutive work conducted within the project.

III. Weekly Product Owners Meeting

Preamble:

> *The weekly PO meeting is the central instance for the coordination of the IPT goals and interfaces, the methodological standardisation, and the organizational administration of the overall project.*

This meeting was also time-boxed to one hour and involved only the IPT POs and SMs, as well as the Technical Coordinator. Weekly PO meetings, thereby, formed an analogy to the Scrum of Scrums known from Scrum best practices.

VI: Project Documentation

Important parts of the project documentation were performed on a collaborative Wiki (web-based) platform. This included a project manual offering important organizational information on the project and functioning as a root document linking to the work and mission documentation of the individual IPTs. The Wiki platform was also used to document the aircraft systems description, the methods developed, as well as the project lessons learned, i.e. findings of Sprint Retrospectives and best practices for future Scrum application. In order to minimize deployment effort, the existing Wiki system of Bauhaus Luftfahrt was used. However, the authors were advised to assign all project relevant articles to a designated Wiki category.

4 RESULTS AND OBSERVATIONS

In the following, the experiences made using Scrum in the inter-disciplinary ITA are discussed and reflected. The presented discussion incorporates observations made during the execution of the project, as well as, post-project analyses of the available project documentation, and a survey performed among the project participants six months after the end of the project. The survey covered the individual perspectives of the IPT members and stakeholders, addressing the perceived team performance, personal job satisfaction, the application of Scrum in general, and Scrum specific methods in particular. The IPT member questionnaires were designed to enable cross-check with complementary questions on the stakeholder questionnaire and with the aforementioned project management related documentation in order to supplement the observations during the project.

4.1 In-Project Observations

A first and paramount observation made during the project was that the final product, i.e. the conceptual design and initial technical assessment of a universally-electric, short-range, mid-sized aircraft, was presented to and approved by the customer on time, at the last Sprint review meeting. A detailed documentation of the aircraft characteristics is given in an internal report [26].

The project was a pilot application study of Scrum. The implemented Scrum rollout strategy was based on the project-level introduction of frequent periodic instances of information exchange and feedback, namely, the project weekly meetings and the Weekly Product Owners Meetings. Moreover, the exploration of the novel collaborative model at the working team level was introduced through a primer IPT, Team ADP, taking care of meta-contents-oriented towards process optimisation in the project. As a major product of Team ADP's work, an Inter-disciplinary Design Process (IDP) was developed [27] that is compatible to multi-tier product conceptual design processes used in industry, but simultaneously is tailored to the practices in agile collaboration. The developed IDP, finally, served as a macro structure for aircraft conceptualization and initial feasibility assessment in the ITA, while Scrum provided the corresponding micro structure for work organization. Team APD gained experience in Scrum-oriented ways of daily work organization, thereby, producing template artifacts and transferring methodological expertise to the other IPTs through training sessions. The dissemination of methodological experience was enhanced by Team ADP members who also served in other IPTs.

At the project level, the project weekly meetings proved as an important pillar for the situation awareness of all project stakeholders, i.e. the IPT members, POs and customers. Every week, an updated product data sheet and the latest aircraft 3-view drawing was presented and discussed. Dedicated time during every project weekly meeting was spent to discuss and review important product design decisions. These meetings, thus, emerged to be a rigorous means of progress monitoring and customer feedback, and thus, represented an efficient means of ensuring transparency, inspection and adaptation throughout the project. The Project Owners weekly meetings established as an efficient means for IPT interfacing, and project control. The convening IPT Daily Scrum meetings proved to be a key enabler of situation awareness within the IPTs. Due to the daily information update, the whole team was aware of past design decisions in every involved expert discipline, corresponding current work status, and, the prioritized roadmap towards product release.

In retrospect, the achieved level of agility provided significant support in dealing with unforeseen organizational challenges encountered over the course of the project, such as the *ad hoc* withdrawal of human resources due to external constraints. However, while a deep level of Scrum adoption was explored by the declared primer IPT, a fully Scrum-oriented organization of the daily work in the other IPTs was not realized during this pilot project. In particular, the role of a Scrum Master which requires familiarity with the philosophy and best practices of Scrum, proved to be challenging for the implementation of the method, since most of the IPT members were widely inexperienced in Scrum. The number of meetings, intrinsic to agility and required by the highly iterative project task, was perceived critical by IPT members during Sprint phases. The level of familiarity of the IPT members with the daily procedures in agile collaboration, however, increased significantly over the course of the project, leading to a most productive working environment.

4.2 Evaluation of Project Artifacts

In the aftermath of the project, the available project documentation, Wiki, and the log files of the project Subversion code repository (SVN) was analyzed in order to assess the adoption of the Scrum methodology and agile practices. All IPTs prepared a Backlog in at least one Sprint Planning Meeting. These Backlogs consistently reflected the common understanding of required tasks. From the content of the documents it can be concluded that only two out of four IPTs used the Backlog to coordinate their work during the project. Only the primer IPT created Sprint Backlogs and derived Burn Down Charts on a sophisticated spread sheet. Presumably, due to complexity of the spread sheet the other IPTs did not use it as a template. Two IPTs documented their Sprint Retrospectives, whereas a dedicated retrospective at the overall project level was not performed.

According to one retrospective report, the membership of persons in two IPTs was good for the productivity of the IPT, as it helped to disseminate knowledge. Another IPT saw the problem that double memberships could lead to unclear responsibilities. According to the log of the SVN system, the repository was not purposefully used for concurrent development on the code base. All Wiki articles related to the project were ranked among the top 25% of the most visited articles. In contrast to the SVN, this indicates that the Wiki as a tool enabling agile practice was more intensively adopted by the participants. Every weekly Product Owner meeting was documented by a mind map[1]. The mind maps only contained topics discussed in the respective meeting comprising the status of the IPTs and identified risks and dedicated mitigation strategies. The regularity and range of discussed topics indicates that the weekly PO meeting was an effective implementation of the Scrum of Scrum concept.

To sum up the analysis of the available project documentation it can be concluded that the Scrum methodology was adopted only in rudimentary fashion internally by the IPTs except for the primer IPT. However, the POs widely adopted the Scrum of Scrum concept to coordinate the IPTs.

4.3 Post-Project Observations

Six months after the end of the project a survey was conducted among the IPT members and project stakeholders. Most stakeholders reviewed project internal deliverables. Therefore, the stakeholder survey mostly refers to in-project delivery situations. Table 5 and 6 show a qualitative excerpt of a detailed analysis filed as an internal report [28]. This excerpt depicts the general attitude[2] towards certain aspects of the pilot project, which were derived from answers to statements about these aspects. In the evaluation of the survey, the scale of the answers was represented by numbers from 2 for “strongly agree” to -2 for “strongly disagree”. The median of the results was transformed to a scale from $++$ for “very positive” to $--$ for “very negative”. For every aspect the standard deviation of answers was used to derive a qualitative indication for controversy[3]. In order to increase the contrast, the controversy scale was normalized to the maximum standard deviation of the respective survey. For instance, in the IPT member survey, a maximum standard deviation was measured at the statement, that the time spent on the Daily Scrum Meeting was worthwhile. One IPT member strongly disagreed, whereas the median of all answers agreed.

Project aspect	**Attitude**[2]	**Controversy**[3]
Product quality	$+$	$++$
Timeliness of deliveries	$+$	$++$
Overall project situation awareness	$+$	$+$
Team situation awareness	$+$	$++$
Team budget awareness	$\circ$	$++$
Team meeting efficiency	$+$	$++$
Project meeting efficiency	$+$	$+$
Job satisfaction	$+$	$+$
Importance of Scrum Master	$+$	$+$

Table 5: Qualitative excerpt of the survey results among IPT members

Project aspect	**Attitude**[2]	**Controversy**[3]
Product quality	$+$	$++$
Timeliness of delivery	$\circ$	$++$
Situation awareness	$+$	$++$
Meeting efficiency	$++$	$+$
Observed job satisfaction	$++$	$+$
Product sustainability	$+$	$\circ$
Scrum scalability	$+$	$\circ$
Application of Scrum to later project phases	$\circ$	$++$

Table 6: Qualitative excerpt of the survey results among stakeholders

For most participants, this project was their first experience with Agile Methods. Despite the observation stated above that a Scrum-oriented way of working was fully adopted only by one IPT and at the Scrum of Scrum level, the survey shows that all participants of the pilot study had a positive perception of Scrum.

Both stakeholders and IPT members considered Scrum typical meetings like Daily Scrum very efficient. The weekly overall project meeting was also perceived efficient as well. Sporadically during the project, there were negative comments about the frequency of meetings. Therefore, it can be assumed that in the aftermath of the project the attitudes towards Scrum typical meetings changed to the better. Regarding typical Scrum roles, the Scrum Master was considered important for the success of the project. In the retrospective after six months, the IPT members were satisfied with the product of their IPT. Most stakeholders stated that the products under their responsibility proved sustainable.

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[1] Visual relational diagram of ideas or concepts

[2] Attitude scale: $++$ very positive, $+$ positive, $\circ$ unsure, $-$ negative, $--$ very negative

[3] Controversy scale: $++$ high, $+$ middle, $\circ$ low

Both IPT members and stakeholders agreed on having experienced a high level of job satisfaction and team spirit. On the one hand, this is remarkable as most IPT members had to apprehend a new way of working while not being exclusively assigned to this particular project. On the other hand, the observations suggest that this positive experience mostly does not solely originate from Scrum-oriented practice *within* the IPTs. Regarding process scalability, most stakeholders agreed that Scrum could possibly be applied to bigger projects. This concurs with the observation during the pilot project and also with the literature on Scrum adoption in the software industry, that the size of the pilot project organization did not reach a natural limit.

Both IPT members and stakeholders stated that they were aware of the status of their team and the overall project. Most IPT members stated that the budget of the team was not communicated to them and thus was not clear during the project. It was also observed that IPT members assessed quality and timeliness slightly more positive than stakeholders. The fact that most products were delivered on time, however, indicates that the general situation awareness among IPT members regarding the status of the products was well established. However, the measures to convey situation awareness regarding budget were less effective.

Asked about project related tools, 75% of the IPT members stated to have used the project Wiki. These statements concur with the high rankings of project related Wiki articles described above.

5 LESSONS LEARNED

Structuring the project time line in Sprints as iterations delivering a finished product increment was beneficial in multiple ways. Firstly, the moving target problem intrinsic to the given design task was stabilized at hand-over points between teams. Secondly, the time-boxed character of the Sprints facilitated the conformity of task completion with the overall project schedule. Furthermore, frequent and efficient meetings, and encouragement to direct communication was effective to disseminate knowledge, to identify risks early, and to convey situation awareness within and across team boundaries.

The retrospective suggests several improvements in future agile projects, in particular regarding observation practice, method adoption, and fluctuation of personnel. We observed that only the primer team completely set up Scrum during the project, whereas, the other teams adopted Scrum sporadically. In follow-up Scrum projects a single Scrum Master should be assigned to all teams in order to implement Scrum more consistently. Product Owners should not change during Sprints. If a hand-over of responsibility is yet required and predictable, it can be planned in advance. However, a team must be prepared for unforeseeable hand-overs. The ability to transfer implicit knowledge is vital for keeping up not only the focus and spirit of a team but also for maintaining design integrity. A team must also identify mission critical skills and must ensure that these skills are distributed among team members in order to compensate unforeseen fluctuations of resource availability. The applicability of Agile Methods to the full development of large scale critical systems such as aircraft, remains an essential research question not only in aircraft engineering but also in information sciences.

6 CONCLUSION AND OUTLOOK

Efficient inter-disciplinary collaboration and fast design iteration cycles are critical for the success of a conceptual design project especially when advanced ideas and solutions are pursued. In a recent design project Bauhaus Luftfahrt made first experiences with the adoption of Scrum, a process model originally developed for software development. This paper reported on Scrum-oriented way of working and observations during the project complemented with a post-project evaluation of project related artifacts, and a survey among team members and stakeholders.

Based on these observations it can be concluded that Agile Methods are well applicable to conceptual aircraft design. In particular, the adaption of the Scrum methodology to the specific organizational context proved effective to tackle the specific challenges of the conceptual design task. Especially Scrum-specific time boxing and meeting culture led to a high degree of situation awareness of both team members and product stakeholders.

The success of the pilot project encourages to further explore the potential of Agile Methods in future conceptual aircraft design projects. During the pilot study no incompatibilities between Scrum as a process micro structure and the Inter-disciplinary Design Process developed during the project as a conventional process macro structure, could be observed. However, it should be investigated in more detail how a further adoption of Scrum affects this compatibility and how Agile Methods can help small teams to cope with fluctuation of personnel and resources.

A topic for further investigation is the applicability of Agile Methods to later phases of aircraft development. This research would address the development process eventually comprising the transition from a virtual model to a physical product. New insights on this matter would be not only relevant for aviation but also for other industries developing high-value-added, large scale, and safety critical systems.

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DEFINITIONS & GLOSSARY ESSENTIAL TO SCRUM

Roles	
Product Owner	Represents team and its product to the stakeholders
Scrum Master	Helps the team implementing Scrum, removes productivity impediments
Stakeholder	Customer of a product increment
Events	
Sprint	Development iteration period
Sprint Planning Meeting	Convey a common understanding on work to be done within a Sprint
Daily Scrum	Dissemination of status and near term plans and impediments
Sprint Review	Review completed and uncompleted work with the stakeholders, demonstrate finished product increments to stakeholders
Sprint Retrospective	Convey organizational learning
Scrum of Scrums	Share status, near team plans and impediments between teams
Documents	
Product Backlog	Product definition by categorized prioritization of tasks, and rough estimation of the respective effort
Sprint Backlog	Product increment definition by break a slice of the Product Backlog down to manageable tasks, update of effort estimation, and tracking of progress
Burn Down Chart	Progress tracking during a Sprint based on Sprint Backlog