A CHANGE PROCESS:
TRANSITION FROM 2D TO 3D BY MODEL BASED DEFINTION

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Abstract: The purpose of the study is to investigate factors that are important for the transition from 2D to 3D by Model Based Definition (MBD). Within MBD, 3D models are used as sources of information for design, production, distribution, technical documentation, services and the overall product lifecycle. The introduction and development of MBD at Aeronautics can be described in five transitions that illustrate how knowledge enhancement from project to project and between the projects and the linear organization has evolved. The largest challenges have been in the start-up of the transitions, people are gathered with different prerequisites, seeing solutions or problems from different perspectives.

Keywords: Change Process, Organizational change, Implementation, Development, Model Based Definition.

1. INTRODUCTION

Paper drawings have been crucial for decades, they were applied even back when the ancient pyramids were built (Terwiesch et. al., 1999). Drawings are is an engineering way to communicate what to make and how to build it (Di Benedetto, 1999), the purpose is to carry, control and maintain a product's definition, and to decrease the risk of misinterpretation (Surbier et. al., 2010). 3D (three-dimensional) models carry the same expectations as 2D (two-dimensional) paper drawings.

A case study has been performed at Saab Aeronautics, (later referred to as Aeronautics) an aerospace and defense company. The business portfolio involves for example Gripen (fighter aircraft), unmanned aerial systems (UAS) and commercial aeronautics and aero-structure products. Aeronautics has a history of few large programs, tightly coupled to a single customer— the Swedish Air Force. Aeronautics has during the last decades gone through a transformation from one dominating customer to several customers and from unique Swedish to internationally interoperable (Backlund, 2006). The commercial environment for Aeronautics has changed:

- New product development and production programs with shorter turnarounds have been introduced.
- The Gripen program is expanding into a multi-customer, export environment which is forcing Aeronautics to improve its handling of product variants and upgrade programs.
- Customers expect Aeronautics to identify, fund, and develop new capabilities rather than the traditional customer paid development model.
- Market desire to contract for complete systems instead of parts/products, for example, delivering integrated solutions rather than providing aircrafts and support equipment under separate contracts.

As a consequence of the changes identified above, there is a drive to improve engineering productivity and quality. This reasoning is in agreement with Andersson, (2009). Aircraft manufacturing is an industry with small batch sizes, the assembly lines have long and complex work sequences. The operators are dependent on the drawings and the assembly instructions and the repeatability in time is longer compared to many other industries.

However, the strive to improve and enhance the production are as large as in other manufacturing industries. One method to reduce time to market and improve product quality is Model Based Definition (MBD) (Quintanan et. al., 2010). The 3D models in MBD act as sources of information for design as well as production (Alemanni et al., 2011; Nestor & Unroth, 2013). Working more concurrent in the interface between design and production will affect both the quality and the productivity of the company in a positive way (Quintanan et. al., 2010).

1.1 Research Objective

The purpose of the work is to investigate the transition from 2D to 3D by Model Based Definition (MBD), with focus on local challenges at Aeronautics. This to be able to reuse knowledge in similar future operational changes or related research areas. The purpose is divided in three steps.

1) Investigate if it is possible to divide the change process into different transitions.
2) Analyse the organizational learning enhancement through the implementation of MBD.
3) Identify where and how the largest challenges occurred.

2. METHODOLOGY

The case study was performed at Aeronautics focusing on the introduction and development of MBD. The first step of the study was a literature study; this provided an understanding of existing research within the area. For this research, a single-case study design was chosen (Yin, 2003). Some benefits of using one company are that the uniqueness is highlighted, the research is easier to apply and more in-depth knowledge is visualized. Some challenges can be that the result is difficult to generalize, that single events may be overanalysed and that the case may be isolated (Yin, 2003).

To collect data, ten open-ended interviews and continuous observations were performed. Open-ended interviews allow the researcher to pose certain questions within a specific theme, but at the same time allowing the interview to change direction. A lower scale of structure can give the interviewee more space to express their knowledge within the subject. One risk is that the interview can take long time, and be indistinct; it can be difficult to extract results (Alvesson, 2010). Interviews were conducted from January 2013 to March 2014 with managers, support staff and engineers within management and development of the MBD methodology at Aeronautics. The length of the interviews varied from one to three hours. Observations have been performed by attending to meetings and in work situations within the research area. Most of the empirical data were digitally documented, meetings and interviews were recorded and important sequences were transcribed. The empirical data was summarized and analyzed based on identified mutual important factors between the transitions. From these mutual factors are the differences and similarities discussed to gain experience from the change process.

3. THEORETICAL FRAME

The theoretical framework presents an introduction to the main areas in the study: Model Based Definition (MBD) and organizational change.

3.1. Model Based Definition (MBD)

Model based definition (MBD) can be explained by the practice of using 3D digital data within 3D Computer Aided Design (CAD) software to provide specifications for individual components and product assemblies. In MBD a 3D-model carries all the information that used to be communicated through 2D-drawings (Alemanni et. al., 2011; Quintana et. al., 2010). The purpose of a 2D drawing is to communicate requirements and information to decrease the risk for misinterpretation or assumption (Bourguignon et. al., 2001). A MBD dataset contains the 3D geometry and 3D annotations of the product's dimensions, tolerances and parts/notes lists for a complete product definition (Quintana et. al., 2010). MBD aims to: suppress 2D documents and drawings, give better data consistency, give better product/process virtualization, and provide better support for all computer-aided tasks within engineering and manufacturing disciplines. MBD as a method is not connected to any CAD-program in specific, the company that choses to work with MBD can choose their software (Alemanni et. al., 2011). The information (3D CAD model) is accessible downstream from integrated systems and applications. The data is created once then re-used; the product structure is less hierarchical than before, the digital mock-up is on everyone's desk. In the MBD way of working the same 3D models that the designers create will be applied by the operators in the manufacturing areas and also used by different engineering disciplines, for example: stress-, flow-, -weight and balance analysis. The 3D models can be presented in a light weight format on different types of media; this means that no more paper drawings will come from the 3D models (OnTime, 2013). Aerospace industries apply the MBD concept to compose, detail and annotate views of 3D models for downstream application, such as manufacturing, planning, product services and procurement (Versprille, 2008).

3.2. Organizational Change

One theoretical approach to illustrate the introduction of MBD at Aeronautics is through the thoughts of Pettigrew (1987). Pettigrew based his research in referenced article by discussing the content, context and process of change. Content refers to the specific chosen areas that undergo the transformation. The content is often identified by answering the question what? The content can be exemplified by a product, a technology or geographical positioning (Pettigrew, 1987). The context can be divided into outer and inner context. Outer context often connects to the social, economic and political surrounding of the company. The inner context is connected to the company's culture, structure and political context. The content can be described as the answer to the question "why the change has occurred?"(Pettigrew, 1987). The process of change is related to the actions, reactions and interaction, actually "how" the company is moved from present stage to the future stage after the change is performed (Pettigrew, 1987).

Organizational change can be described in various vocabularies, there is no general agreement on attributes or characteristics that can best describe the different types of change (Maes & Van Hootegem, 2011). Herein is some of the commonly used vocabulary briefly introduced. This, to understand the descriptions of the changes or transformations described in the empirical data.

Planned change can be an iterative process problem description, action and assessment (Cummings & Worley, 2009). Planned change is based on logic and that there exist a rational way to solve problems, it should be scheduled and executed in a systematic way (Senior & Swailes, 2010). In planned change it is assumed that managers have enough knowledge to be able to predict the result of the change (DeCock & Rickards, 1996).

Emergent change, is continuous and dynamic, it appears unpredictable and unplanned (Burnes, 2004). Emergent change can only exist in action, it cannot be planned or foreseen (Mintzberg & Waters, 1985). Such change occur when people, in their daily work, adapt or change from improvements or other opportunities. This cycle does not have a beginning or an end (Weick, 2000; Feldman & Pentland, 2003).

Inertia can be defined as a tendency to repeat actions as a routine and create a pattern of activities (Jansen, 2004). For an organization inertia can be described as an inability to change in accordance with the environment (Hannan & Freeman, 1984). It is a type of resistance to change (Pardo Del Val& Martinez Fuentes, 2003).

Continuous change is a gradual adaption to the changed conditions (Burnes, 2004), it occurs in an uninterrupted flow of events (Stickland, 1998). Brown and Eisenhardt (1997) stated that companies most often have to undergo change continuously to survive. The degree of continuous change is high where the structure is low, the freedom is high and intensive interaction between employees is allowed (Brown & Eisenhardt, 1997).

Incremental change is a step-by-step movement based on the precedent (Kindler, 1979). Incremental change means that the organization should continue working without radical change in culture or hierarchy, the change is an accumulation of small changes (Kindler, 1997; Hope Hailey & Balgoum, 2002; Dunphy et al., 2002).

Radical change can be described as a transformational change in a short period of time that usually necessitates revolutionary change tactics (Stoddard & Jarvenpaa, 1995). Radical organizational change is often referred to as "frame-bending"; the organizations often diverge from existing orientation, often occurring sudden and dramatic after a long period of equilibrium (Romanelli & Tushman, 1994).

4. THE INTRODUCTION OF MBD AT AERONAUTICS

Herein is the empirical data presented, at first is the content, context and process of the change described, later is each transition in the change process presented.

4.1. The Change Process

Aeronautics has been working with 3D-models since the end of the 20th century. Commercial aircraft programs at Aeronautics were signed in the beginning of the 21th century. Aeronautics became a partner in developing MBD to further rationalize data flow and reuse of data throughout design, process planning and workshops. The aim was to limit human errors in the information chain and improve the visualization of work instruction. Before and parallel to the introduction of MBD, the production structure (MBOM, Manufacturing Bill Of Material) was defined within the design documentation. The production documentation was created parallel to the design documentation and the interaction between these parallel tracks was not always good. Reports, regulations, requirements and analysis documentation were filed in binders (On Time, 2013). After introducing MBD, the product requirements are within the design models. It is possible to review the production technique and methodology within the digital models before the actual production starts. Dimensions and regulations are directly connected to the solid model, and product and requirement documentations are stored in a database. This provides an opportunity for reuse of design between projects and products. The change process, how MBD has developed at Aeronautics is illustrated in figure 1.

The content of the change process (Pettigrew, 1987) is the introduction of a new method, MBD, connected both to product development and the manufacturing of products. The new method will be applied in projects at first and then further applied in the organizational structure.
The outer context (Pettigrew, 1987) is that Aeronautics design and manufacture aircrafts, both military and commercial. The aircraft industry often have low batch volumes in combination with complex processes and at the same time, advanced technology is applied. On to that is systematic traceability and configuration management to control all inner and outer requirements on safety and security added. When introducing new technology or methods, it is not possible to have test batches, the change is "live" from star, the complex processes further increase the difficulty of implementation.

The inner context (Pettigrew, 1987) is Aeronautics, the company. At Aeronautics, projects are powerful; since the batch volume is low and complex the product development (included in projects) is a process that can span several years. The projects can be larger than the line organization. The line organization has a crosscutting substructure including:

- Process, methods and tools (PM&T) (including education programme)
- Technology development (including research)
- Quality (in operations)

The project organization is an interwoven structure responsible for product quality, declaration, and certification. A beholder outside the company can see the matrix of the line and project organizations as a bit diffuse. This affects the introduction of new methods, the projects state their needs and the line organization is responsible to provide.
The process (Pettigrew, 1987) of change can be described in five transitions, shown in figure 1.

Transition 1. Commercial aircraft business contracts were signed in the beginning of the 21th century. The commercial aircraft industry had good progress in developing and applying MBD. The Commercial Aircrafts projects/programs at Aeronautics develops and manufactures aircraft structures with systems included, primarily for the commercial market, they have a Tier 1 position for Airbus and Boeing. The knowledge created during the commercial projects set a foundation for future work with MBD at Aeronautics. Transition 1 is a methodology change evolving the use of 3D models; it is a large change that affect the company from design to production. 2D Paper drawings will no longer be the leading production documentation. The operators were used to work with paper drawing and over all the computer experience and competence were quite low. This project was the first out for MBD at Aeronautics and came to set an example for future projects within MBD.

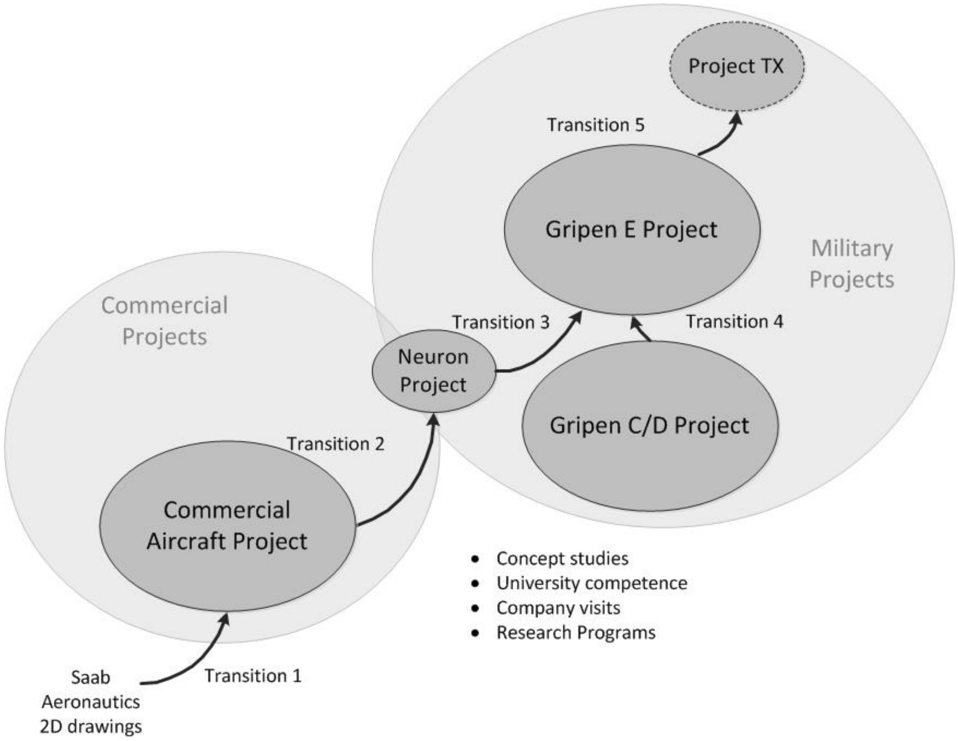

Fig. 1. The development of MBD at Aeronautics.

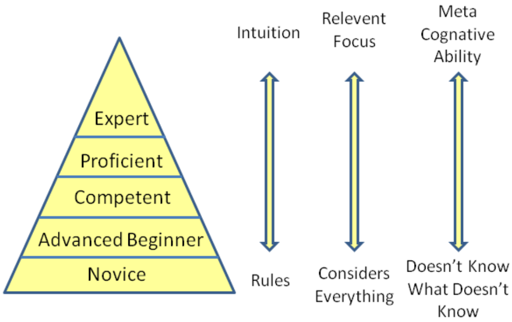

Fig. 2. Dreyfus model (Dreyfus & Dreyfus, 1986).

Transition 2. Neuron is an Unmanned Combat Aerial Vehicle (UCAV), a demonstrator to show military technology, it will never be in military operation. It was a European cooperation project with France and Sweden as leading countries with the intention to evaluate future cutting-edge technology, for example; advanced avionics, autonomy and stealth technology. Since it was a European project, much communication and production documentation were in English. The MBD implementation started around 2005 and Neuron was only manufactured once (a demonstrator), the configuration management was downsized regarding product lifecycle management. Transition 2 was a change to go from a customer driven implementation of MBD to another project, still with a customer driven demand of MBD. However, the customer is in the form of a partner in-between commercial and military. The lead of applying MBD was set at Aeronautics, the software used was chosen by Aeronautics and the interface was designed to fit Aeronautics needs and requirements. The software Delmia was used in production, which set high requirements on the computer hardware, and this evolved to be a problem, it turned into a heavy operated dilemma. The project members were chosen both from the commercial and the military side, still was MBD new for many. The project management had the possibility to choose project members with long experience e.g. experts (see figure 2). Figure 2, is a model developed from Dreyfus & Dreyfus (1986) that illustrates development of skills or competencies.

Transition 3. Gripen E is a large development project (~1500 people); the drivers for the project are high maintainability and low operating costs. The Gripen E product is a multi-role fighter applied for fight, ground attack and reconnaissance. The performance improvement for Gripen E are found primarily on the inside, with a more powerful engine, increased internal fuel capacity, an upgraded cockpit display system and more advanced avionics (aviation electronics). Transition 3 is a change going from a project with one demonstrator as output to serial production. The MBD implementation started before 2010 and the main motivation to the Gripen E project was to save time (money) by applying the method. MBD can help Aeronautics with the concurrent engineering work and to improve their design for manufacturing. MBD is further developed by adding In Process Part Definition (IPPD), IPPD defines parts for detail manufacture such as pre-drilled holes and pilot holes, tooling lugs, and trim allowance. In the Gripen E, Delmia is used as a tool for the Manufacturing Engineer to define the manufacturing bill of material (MBOM) from the engineering bill of material (EBOM). An integrated application of Delmia is used to create and store work instructions in a light weight format. The work instructions are visualized in a 3DVIA player embedded in an Internet Explorer template, for higher usability for the shop floor worker. The project members in the Gripen E project consisted from start of a mix of experience, from all levels in the Dreyfus model (figure 2). The project member from Gripen C/D (described in Transition 4) has within the context of MBD the level of Novice and Advanced beginner. The project members that came from Neuron were either experts or competent to proficient.

Transition 4. The Gripen C/D project is a large project compared both to Neuron and the commercial projects. Version C of the Gripen aircraft family is a single-seater, version D is a two-seater. The drawing kit compiled for Gripen C/D fighter consists of ~10 000 paper drawings and ~50 000 production documents. The designers produced 3D models in CAD, and the information was then transferred to paper drawings and work instructions. The motivation for the change is that the resources have to move to a new project, there was no selection of personnel preformed, everyone was relocated. The C/D project was down-sized and was not estimated to grow again. Transition 4 in figure 1, is when Gripen C/D is downsized and the resources were moved to the Gripen E project. All resources were moved, no selection was performed. MBD in transition 4 can be described as a relatively mature method at a large part of Aeronautics and the supporting PM&T organisation. However, it is still a method that is new to a lot of project members from the Gripen C/D project.

Transition 5. The TX project started early 2013, it is a cooperation project between Saab and an international aircraft company. The objective of the project is to develop and manufacture training aircraft. The project is still in a start-up phase, and all structures, plans and other prerequisites are not open for publication. The project is organized in cross-functional team: manufacturing, design and stress in the same team, to make the development more efficient. MBD provides benefits when working in cross-functional teams. The data in the 3D models are the same all the way through the product flow. It is possible to simulate manufacturing scenarios early in the development. It is the user company of the MBD method that chooses the local software to apply MBD. Companies that cooperate and share design and manufacturing have to find a mutual ways to solve such issues.

Training through the change process. The training was more structured in the beginning; all members were on more or less the same level. In transition 3 and 4, it was more complex, the project members were all on different levels and distinct groups had various training needs. At the same time, the method is evolving which lead to the fact that the training also evolves. This ends up in a large project coordination need with various knowledge levels, and project members entering and leaving the projects. When a project has the possibility to choose project members, people with long experience is often selected. Such experts can make large difference in the progress of the project. To support new team members, the more experienced users with educational qualities serve as mentors. The need for MBD method support nearby the development teams and end users, and also for just-in-time education was identified. Means to fulfil those needs were to strengthen the supporting PM&T (Process, methods and tools) organization.

5. DISCUSSION

5.1. Investigate if it is possible to divide the change process into different transitions

On a macro level, the introduction and development of MBD at Aeronautics can be viewed as a planned change that aims to be incremental, with each project as an increment. In figure 1, the change process was divided in five transitions. Each transition can be seen as an episodic development of MBD as a method, and within the transitions is the development more continuous. Table 1 illustrates a description of the transitions within the change process. The second column describes the major MBD development of respective transition. The third column shows the motivation for the projects. Column four defines the target project for the transition and five illustrates how the project members were recruited. In the sixth column, the definition for a large project is more than 1000 project members, a small project is less than 200 and a medium project is in between. The last column shows the type of change performed. The most important factors in transition 1 was the development, going from 2D to 3D definition, Aeronautics started on a concept level when the commercial contract were signed. These concept studies were beneficial to have in the contract negotiations, maybe even an order winner. The most important step in transition 2 was to move from customer demand to internal, to have lead in the development. The main development of the method has evolved in transition 3, the MBD method was developed to match serial production, maintenance was added in the process chain, and the software was more user-friendly. Transition 4 was driven by economic internal motives; resource relocation. In transition 5, the project have utilized the benefits from the method more efficiently, by for example working in cross-functional teams to make the development more efficient and inspired. Another important factor is the cooperation with an international partner, the user company of MBD chooses the local software to apply MBD, the partners have to make an agreement.

The ability and efficiency of a project seems to be dependent on the driving forces during project start-up. Customer driven transition had the MBD requirements in a package from the customer. Internal driven transitions had more internal cost focus and the implementation requirement had to be set internal, the internal knowledge were not mature enough for that challenge. The conditions in the start-up phase of a development project provide prerequisites regarding way of working and the MBD methodology for the continuation of the project.

Table 1. Description of the transitions within the change process.

Transition	Development of MBD	Motivation	Target Project	Members	Project size	Change Type
1	2D to 3D definition	Customer Driven	Commercial	Chosen experts	Medium	-Planned -Radical
2	Commercial to military	Customer/ Internal	Neuron	Chosen experts	Medium	-Planned -Incremental
3	-Serial production -Maintenance added -More user-friendly software	Internal	Gripen E	All	Large	-Planned -Incremental
4	2D to 3D definition	Internal	Gripen C/D	All	Large	-Planned -Radical
5	-Utilize the benefits from MBD -Internationalisation	Customer/ Internal	TX	Chosen experts	Small	-Planned -Incremental

5.2. Analyse the organizational learning enhancement through the implementation of MBD

Figure 1 that illustrated the development of MBD through four projects into the fifth can also illustrate how knowledge has been exchanged between, and increased through the projects. The exchange of knowledge is mainly performed by the project members, moving between projects. As earlier mentioned the projects (product development and production included) are strong compared to the line organization. Projects usually span several years due to low batch volume and process complexity. The knowledge mainly enhances within these project organizations through the project members. The training became more and more complex to administrate, in transition 3 and 4, the knowledge is spread in level and in novelty. The MBD method has developed further, this result in a need to update the organization “best practice” connected to the project members, since much of such knowledge is tacit, this is a challenge.

5.3. Identify where and how the largest challenges occurred

In transition 1, the largest challenges were that the change consisted of a new technique/method and new ways of working for all project members. The largest challenges in transition 2, was that almost all communication and production documentation within the project was in English, this was a difficult barrier. Most of the employees use Swedish both in their everyday life and at work. Another challenge was that the software Delmia was used in production, which set high requirements on the computer hardware. In transition 4 (Gripen E), an integrated application of Delmia was used to create and store data in a light weight format. Applying a light weight format instead of Delmia gives the advantage that the interface for the operators is more user-friendly and requires less from the hardware. The largest challenge in transition 3 was all development of the method to reach the standard of serial production instead of manufacturing a single Neuron demonstrator.

Transition 4 is a methodology change going from 2D to 3D. It has similarities with transition 1. However, one large difference is that in transition 1, MBD was new to everyone. In transition 4, the method was new for those from the Gripen C/D project. Both transitions involved the same product (Gripen) in different product versions. This makes the people novice and experts at the same time but in different areas. In transition 3, the Gripen E project members consisted of a mix of experience, from all levels in Dreyfus model. The project member from transition 4 (Gripen C/D) has mainly the levels Novice and Advanced beginner. The project members that came from Neuron are either experts or competent to proficient. According to figure 1, also competence from Universities is captured; they are often on a level from proficient to expert. However, the issue is not the distribution of the project members in the Dreyfus model, the challenge is timing at which people with different levels of skills entered the Gripen E project. The competent to expert attended first, then a supporting structure (based on the PM&T organization) was built for the Gripen E project. Then more novice and advanced beginner (former Gripen C/D members) were relocated to the Gripen E project. The balance in the project was not optimal. The introduction and method/tool training of MBD had already started when the relocated members arrived. This set the education and introduction of MBD in different phases for various groups.

In transition 4, all resources were moved, no selection was performed. This can be related to figure 2, the experts are often the first to attend to new projects. As seen in figure 2, the experts are a small part of the entity. As a result most of the resources from Gripen C/D were not familiar with MBD. One problem that occurred was that the competence and knowledge (especially concerning MBD) within the project became spread and low. This makes the need for different types of education complex, the PM&T organization responsible for the education programme needs to have access to those experienced users with teaching and/or mentoring skills.
The inertia was largest in Transition 4, the experts had already left the Gripen C/D project, and when the rest of the members were relocated to the Gripen E project all existing members in Gripen E had already gone through the project introduction programme.

6. CONCLUSIONS AND FUTURE WORK

As illustrated in figure 1, the implementation of MBD at Aeronautics could be divided into five transitions.

Important factors at Aeronautics during the implementation of MBD were:

- The ability and efficiency of a project is shown to depend on driving forces during the project. Even though the projects in this study work with MBD, the identified motivation factors vary, for example, the motivation factors can be internal driven or customer driven.
- A major factor for how the MBD methodology is applied and developed is the staff available and its experience level, during the initial phase.
- The possibilities to choose project members based on their experience and skill enables thorough planning for education, method support, and further methodology development.
- Different type of change are observed for the transitions into the MBD methodology, incremental or radical.
- The complexity in developing the method increases when the organization structure get complex and the project grow. Both the line- and project organizations are responsibility for education, end-user support, and further development of the MBD method.

Future work may include investigation of the introduction of model based methods within software development to compare the driving factors and level of success. It would also be interesting to investigate how knowledge can be captured and remained in an organization driven by few large customer projects (with low batch volume). The risk is that the knowledge follows the projects and not the line organization. This aspect could also be viewed and compared from an organization driven by mass production (with large batch volume).

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