Foolishness without consequence? From physical to virtual modeling in the history of military aircraft development at Saab

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Abstract
From Jim March we learned that organizational intelligence demands adaptation to the needs of a distant future as well as the efficient use of resources in the present. Commitment to new ideas that deviate from norm is necessary for long-term adaptation, but comes with great uncertainty as to if when or how success will come. This article uses a historical study of military aircraft manufacturer Saab to explore the transition from experimenting with physical models and dangerous test flights in the development of rather simple aircraft systems, to the development of complex integrated aircraft systems using virtual models that can be tested in a simulated world, thereby postponing choice and the need for commitment of resources in the physical world. We show how modeling techniques and tools were developed over five generations of aircraft to help developers represent and evaluate alternative ideas, in an increasingly realistic virtual reality, thereby reducing material and fatal consequences in aircraft development. We distinguish hybrid forms of evaluation and a transition that seems to be moving in the direction of “virtual online evaluation,” where empirically informed simulation models, based on real flight data reduces the fidelity gap between reality and representation. Drawing upon a selection of Jim March’s writings, we speculate what this transition implies for learning from experience and the possibility of foolishness without consequence.

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from norm is necessary for long-term adaptation, but comes with great uncertainty as to if, when, or how success will come. The decision to commit, however, can normally not be postponed until more knowledge has been acquired. Consequences for being wrong can be dire and hence organizations turn to “technology of reason” to better adhere to ideas of rationality, but at the expense of long-term intelligence and the unusual combinations that can result from sensible use of “technology of foolishness.”

Recent developments in tools used to model and test ideas in a digitally simulated environment may be about to change this however. In this article we present a historical study of Swedish military aircraft manufacturer Saab and their journey from experimenting with physical models and dangerous test flights in the development of what we now see as comparably simple aircraft systems, to the development of complex integrated aircraft systems using virtual models that can be tested in a simulated world, thereby postponing the need for commitment of resources in the physical world. We explore how these developments may change the dynamics of how knowledge is gained from experience, especially how options are evaluated and choices are made, and we ask if this may be a technology for “foolishness” without consequence.

2. Making choices for a distant future

A jetfighter is an example of an artifact that can neither be built, nor fully comprehended by one single person. As suggested in Baldwin and Clark (2000) and Prencipe et al. (2003), such artifacts house a high level of complexity, and their accomplishment necessitate embedded development in an efficient coordination system. Although developed in parts by different groups of people, in the end, the parts must work together as one whole. The expected life cycle of a modern military aircraft from concept to retirement is somewhere around 50 years, which means that in the early conceptual stages, a large number of design choices have to be made for an uncertain future. Initially, neither the final parts nor the whole are well-known. To add to that, the product is a complex critical system including a flying machine, a tactical system, and a pilot to handle them both in a hostile environment set on disabling them. As we know, time may change preferences (March, 1978), but so too may unexpected systems effects as development progresses. The challenge was succinctly summed up by Alexander (1964: 26) as “we are searching for some kind of harmony between two intangibles: a form which we have not yet designed, and a context which we cannot properly describe.”

2.1 Learning from ambiguous experience

A classical model of how a choice is made includes a number of options that each has potential outcomes and consequences, and a decision-maker who evaluates those options by matching consequences and preferences in an optimal way. Over the years, the rather simplistic and prescriptive model of decision making was added to in the form of descriptive studies of how decisions actually happen (March, 1991b). As all information pertaining to a problem only very rarely is available at the outset, Jim March in his groundbreaking work in collaboration with Herbert Simon and Richard Cyert directed our attention to how organizations use search as a fundamental principle in making choices (March and Simon, 1958; Cyert and March, 1963). Search for solutions is usually conceptualized as experiential learning involving search for knowledge that is either distant or close to existing solutions (Laursen, 2012).

Over the years, Jim March identified a number of pitfalls related to organizational intelligence and adaptation. First, when making choices for a distant future, we have to make two guesses (March, 1978). What will the future consequences of our options be and what will our preferences for those consequences be in that distant future? We may get what we want, but at that time, will we still want it? Second, learning takes time and often has to be started long before it is possible to see what may be relevant to know, resulting in speculative knowledge inventories, and the risk of organizations either investing in knowledge that turns out not to be needed, or not having invested in knowledge that turns out to be crucial (March, 1995). Third, experience is not only an important, but also ambiguous, source of learning, and therefore a teacher that cannot be trusted to always teach the right lessons (Levitt and March, 1988; Denrell and March, 2001; March, 2010). Listening to feedback based on experience will often not only lead to rejection of bad ideas and further development of good ideas, but also rejection of good original ideas that initially look poor. Fourth, the returns on good original ideas that come to fruition are often separated in time and space from the cost of their pursuit. Although the pursuit of new and distant ideas is necessary for long-term adaptation and survival, it is tempting to choose more local refinement of ideas with more immediate returns. Fifth,
an adaptive organization needs to pursue a steady stream of deviant ideas of unknown potential in order to have variation in options (March, 1995). Only very few of those deviant ideas will turn out to be good ones, most of them will fail. However, incentive systems rarely reward commitment to seemingly foolish causes and the “slow learners” who pursue them (March, 1991a). The “technologies of foolishness” that support the discovery of new goals and encourage action followed by thinking are rare compared to the “technologies of reasoning” that encourage organizations to think before they act and to do things for which they have good reasons (March, 1971/1988, 2006).

As a result, experiential search often does a poor job in producing novel, yet tractable, solutions to problems (March, 2010; Laursen, 2012). Novel solutions find it difficult to survive as adaptive mechanisms are in operation. Ways to resolve the issue have been suggested (March, 2010). One is to protect ideas by dividing the organization into diverse separate entities that each pursue their own agendas and logics (Levinthal and March, 1993). A caveat identified is that at some point, entities may need to be re-integrated, or ideas need to be handed over, which may be difficult to do in an organization created to protect subunits from cross contamination. Another suggestion is to reduce the bet-size by running small-scale experiments to evaluate options and reveal more of their potential before committing to a choice. In this article, we specifically focus on this latter strategy; how physical and virtual models allow for evaluation of alternative options in (relatively) small-scale experimentation.

2.2 Physical and virtual models as representations

Experiential search and the organizational learning associated with it draws upon the human ability to interact with reality (i.e. to generate experiences), and to draw inferences from these real-world encounters. The knowledge gained comes at the price of suffering consequences and hard-earned lessons. In the history of military aircraft development, for example, such consequences have not only involved material losses, as in damaged and crashed aircraft, but also fatalities in the form of pilots who lost their lives trying out new solutions. It is therefore not surprising that throughout history, humans and organizations have sought alternative ways to search for solutions. One prominent avenue for explorations in this direction has been the use of representations and models to first explore alternatives and their consequences in the abstract virtual world.

In a stream of research, general features of experiential and cognitive search have been outlined (Gavetti and Menon, 2017). Language, signs, symbols, theories, equations, etc. can be useful tools not only in arranging representations of reality, but also allows for the construction of potential future realities. In the language of cognitive science, a representation can be taken to mean a hypothetical internal symbol that represents some external reality (see e.g. Shea, 2018). Adopting a very stylized and simplistic version of this representation versus reality approach, the purpose of the representation is to depict what is real, or that which could be realized.

A particular type of representation is the model. “A model is a simplified picture of a part of the real world. It has some of the characteristics of the real word, but not all of them. It is a set of interrelated guesses about the world. Like all pictures, a model is simpler than the phenomena it is supposed to represent or explain” (Lave and March, 1975: 3). Scientific modeling is one important activity which results in theories that can aid the search for new solutions “...as it provides inventors with the equivalent of a map—a stylized representation of the area being searched” (Fleming and Sorenson, 2004: 911). Not only scientific theories and models affect search in engineering, much activities of engineers themselves consist in modeling using different means of representation, ranging from paper drawings and sketches to full-scale physical replicas of the modeled object (Henderson, 1999; Leonard, 2012). Not least in aerospace engineering, modeling has been an important tool when developing new aircraft subsystem technologies and new generations of aircraft (see e.g. Constant, 1980; Vincenti, 1990; McCullough, 2015). Models can be physical (made e.g. in clay, wood, or plastic) or virtual (foremost digital, produced using software and simulation tools) and constitute a crucial means in the engineering of a new product (D’Adderio, 2001).

Recent research has tied the making e.g. in clay, wood, or plastic) or virtual (foremost digital, produced using software and simulation tools) to cognitive dimensions of solution search and offline modes of evaluating alternatives (Thomke, 1998; D’Adderio, 2001; Becker et al., 2005; Yakob and Tell, 2007; Lopez-Vega et al., 2016).

In this article, we use a three-pronged approach to models. First, we acknowledge their role as representations. As representations of real world and imagined features of the world, models facilitate communication and coordination among organizational members (D’Adderio, 2001; Becker et al., 2005). Second, models provide means for evaluation. Models enable organizational members to assess offline the implications and consequences of choices (Gavetti and Levinthal, 2000). Third, models articulate, codify and document knowledge. This means that models can function as organizational memory and storage of routines (D’Adderio, 2003).
The evaluation of options has been conceptualized in two main forms (Gavetti and Levinthal, 2000). Online evaluation, which indicates direct, hands-on testing that generates actual experience, and offline evaluation where evaluation is done without direct involvement using the actors’ cognitive maps. Gavetti and Levinthal (2000: 114) emphasize the crucial role of evaluation of alternatives in analyzing choice: “Three basic properties distinguish cognitive from experiential based choice: the mode of evaluation of alternatives, the extensiveness of alternatives considered, and the location of these alternatives relative to current behavior. Perhaps the most central element of these three dimensions is the process by which possible alternatives are evaluated. Cognition permits the assessment of alternatives ‘off-line’ (Lippman and McCall, 1976), that is, actors need not engage in an activity in order to evaluate it.” To reduce uncertainty and save on cost, engineers evaluate options through scaled down models that are faster and easier to build, or models made out of cheaper material. Evaluation of alternative options in the early days of flight required physical rigs, or even whole aircraft to be built. Those prototype aircraft also required test pilots, sometimes with fatal consequences. As knowledge of aircraft development became increasingly objective (separated from the “intuition” of the engineer or test pilot) through, for example, theories of aerodynamics and solid mechanics and beyond, early expert evaluation turned into more of an academic exercise. The scaling of physical prototypes and environments, such as wings in wind tunnels, has been known to introduce inaccuracies though when faced with the full size and complexities of the real world (Lissaman, 1983). Virtual modeling, however, has opened up other possibilities. Increasing sophistication and precision in representational languages (mathematical, as well as linguistic and visual) together with enhanced measuring devices and improved computational processing capacity has made it possible to model and simulate with great fidelity. The decision to commit physical resources and risk suffering real consequences can now be postponed to a time where much has already been learned.

Using the framework introduced by Gavetti and Levinthal (2000), we suggest that evaluation increasingly is done offline, that is, not only without direct involvement and severe consequences, but also without generating direct experience. Online evaluation required direct involvement and could not only generate potentially severe consequences, but also direct experience. The wind tunnels once represented a physical hybrid between the two. Today, we see a virtual hybrid form of evaluation developing and moving in the direction of a form of “virtual online evaluation,” where empirically informed simulation models based on real-flight data are used to represent both the “form” that is developed and the “context” in which the form must find a “fit” (Alexander, 1964), providing a virtual world for experimentation, and also for training of pilots. In theory, virtual prototypes and environments seem to have great potential as a goal generating “technology of foolishness” that explore without requirements of immediate relevance to offset cost.

In this article, we hence return to Jim March’s original pitfalls of organizational intelligence and the problem of distinguishing good ideas from bad ones beforehand when uncertainty is prevailing and there is ambiguity regarding experience involved. We explore how an increasing use of virtual models affected processes of search for solutions to technical problems in military aircraft development at Saab. We describe how the reduced fidelity gap between representation and reality has made it possible to gain experiential knowledge with increasingly limited real-world consequences, and we ask how this may change how experience interacts with the process of learning.

3. On methods employed and empirical data used

This article is based on a historical, longitudinal, and single-case study of aircraft development at Saab AB (hereafter: Saab). Arguably, the aircraft industry is a setting where different types of models and testing has played an important role throughout the industry’s evolution during the last century (Gavetti and Levinthal, 2000). This study started in 2015 with interviews aimed at understanding jetfighter development in general at Saab, and more particularly how the new Model Based Systems Engineering (MBSE) method that had been chosen for implementation in 2006 had influenced the work of engineers. We started with a focus on the fuel system and wings, but quickly transitioned to engineers working with modeling and modeling support. Life cycles of jetfighters are typically rather long and at the outset of our study, Saab had recently started development of the first new aircraft in 30 years that was designed from scratch. In order to create a backdrop contrast to understand how development work had changed, we started a longitudinal, historical process study (Langley, 1999; Langley et al., 2013) of tools and methods used in aircraft development at Saab. In addition to current employees for interviews, we had access to two archives. One run by Saab and one run by Saab’s Veterans Club. The Veterans Club is an association of retired Saab employees who meet every Thursday to discuss Saab memories, work on their archive, and produce the annual “Saab Memories” magazine.
They often receive so-called “widow boxes” with work material that the wives of deceased employees do not know what to do with, and they archive that material. The house where they reside, Flyget’s Hus (The Aviation House), is owned by the regional Östergötlands flyghistoriska sällskap (the Aviation History Society of East Gothea) and is a meeting point for people interested in aircraft in general. The first “Saab Memories” was produced in the 1980s and contain interviews with some of the legendary great engineers of the early days. We have had access to every edition produced, but could also come to the Thursday meetings for coffee and conversations. The oldest member we have met was aged 94 and the youngest in his 60s, and former occupations ranged from design engineers and factory workers, to test pilots and one CEO. We also had access to the many books produced by Östergötlands Flyghistoriska Sällskap and written by Saab veterans. They range from biographies of individual pilots to Gripenkrönikan (the Gripen Chronicle), where some 60 Saab engineers who were part of the Gripen project decided to write down their story in 2007. Another important source was the online book A Journey of Change in the Aircraft Industry that long-serving Saab employee Martin Hjelm wrote before he retired in 2016. During the project, we also made two 1-hour visits to the Simulation Center that houses the Gripen simulator dome, and had the opportunity to test fly it ourselves.

We went through all Saab Memories and Gripenkrönikan and sorted these with the aim of mapping the introduction of new tools (e.g. finite elements), breakthroughs (e.g. unstable jetfighters), as well as conspicuous failures (e.g. a wing that broke off) as critical events. We then connected these critical events to ways of working in order to understand how design processes had changed. We used NVivo to stay organized and code the data. What is considered by Saab to be the five main combat jet aircraft vintages (Tunnan, Lansen, Draken, Viggen, and Gripen) were chosen as demarcations of time periods, although development of the early ones overlapped time-wise. We employed visual mapping to understand changes in models and tools used to facilitate (i) the communication and articulation of ideas (sketches, CAD/CAM models, etc.), (ii) the evaluation of ideas (test-rigs, fuel system simulations, test flights, etc.), and (iii) the documentation of progress made (small-scale models, paper documents, etc.).

Subsequently, we wrote case narratives for each aircraft vintage to organize quotes into a storyline. When analyzing, we categorized models and tools based on Gavetti and Levinthal’s (2000) “online” and “offline” evaluation as one way of understanding what had changed. When writing the case narratives, we needed technical details and overviews that were not to be had from the Saab memories and books in a consistent manner. Luckily there are many aviation enthusiasts who keep Wikipedia well-updated so for technical information it has been a source of initial information that we have then cross-checked with other sources, primarily Flygvapenmuseum (Linköping Air Force Museum) and flight history journals. During spring 2019, while writing this article, one of the authors was part of a government funded mobility initiative and spent 3 months at a desk in the Methods Support Group at Saab. This meant that findings and analytical patterns could be continuously discussed and developed in interaction with Saab engineers and managers working with modeling and simulation.

4. Military aircraft development at Saab 1945–2009: five aircraft vintages

The Swedish military aircraft manufacturer Saab, situated in Linköping, Sweden, was founded in 1937. The company produced its first aircraft right before and during World War II (WWII), but these did not measure up to the standards of those produced by German, Russian, and American manufacturers. Saab quickly caught up, however, and when their first purpose-built jet fighter, Tunnan, was introduced in 1950, it represented the frontier of military aircraft development. Tunnan was quickly followed by Lansen (1956) and Draken (1960) and, later on, by Viggen (1971) and Gripen (1997). Below, we sketch the history of military aircraft development at Saab from WWII until 2009. Characteristics of each aircraft model, the methods used for its development and testing, and statistics related to casualties are presented in Table 1.

The key themes in the short narrative that aims to capture central elements of development work associated with each aircraft are as follows. Each presentation is introduced with some novel features of the aircraft and a sketch of design choice in terms of preferences (such as requirements), alternatives (e.g. major design options explored), and consequences in terms of, for instance, performance, cost, and crashes. This is followed by an integrated discussion on models used (e.g. with respect how they represent form and/or context), evaluation (online real tests and/or offline simulations), and knowledge developed (from physical to virtual experience embedded in individuals vs. general theories and systems).
<table>
<thead>
<tr>
<th>Characteristics of the aircraft</th>
<th>Tunnan</th>
<th>Lansen</th>
<th>Draken</th>
<th>Viggen</th>
<th>Gripen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of development</td>
<td>1945</td>
<td>1948</td>
<td>1949</td>
<td>1952</td>
<td>1979</td>
</tr>
<tr>
<td>Type of aircraft</td>
<td>Jet-powered fighter (second in the world)</td>
<td>Turbojet-powered attack aircraft (later also fighter and reconnaissance versions)</td>
<td>Fighter aircraft</td>
<td>Attack aircraft (later also fighter, reconnaissance, and trainer versions)</td>
<td>Multirole fighter aircraft (A/B upgraded to C/D where B and D were the double seated versions of A and C)</td>
</tr>
<tr>
<td>Unique characteristics</td>
<td>Swept wings (new to the world)</td>
<td>Transonic speed Low-mounted swept wings Built-in search radar (new to the world) Fully automated fuel system</td>
<td>Supersonic speed Slender with sharp front Double delta wing (new to the world)</td>
<td>Supersonic speed Mounted double delta wing Canard configuration Short take-off and landing (STOL) Digital computer for pilot support (new to the world)</td>
<td>Supersonic speed Delta wing Canard configuration Relaxed stability Fly-by-wires control Integrated computer system</td>
</tr>
<tr>
<td>Methods for development and testing</td>
<td>Wind tunnel tests of models of entire aircraft and specific parts.</td>
<td>Wind tunnel tests of models of entire aircraft and specific parts. Mathematical shape definition</td>
<td>Wind tunnel tests of swingline model of entire aircraft (scale 1:7) and tests of specific parts. New wind tunnel for testing of supersonic aircraft.</td>
<td>As on previous aircraft.</td>
<td>“Supercomputer” (Cray 1, took 1 h to calculate what had previously taken 45 h) Simulated wind tunnel by CFD – Computational Fluid Dynamics Extensive wind tunnel testing, abroad and in Sweden</td>
</tr>
<tr>
<td>Aerodynamics</td>
<td></td>
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<tr>
<td>Mechanical integrity</td>
<td>Finite element methods for stress and strength calculations—manual. Criteria for static mechanical integrity</td>
<td>Stress and strength calculations on specific parts of the aircraft body conducted on punch card machines Criteria for static mechanical integrity Matrix methods Increasingly large equation systems</td>
<td>Finite element methods with an increasing number of unknown variables made possible due to use of computational machines (SARA, BESK). Carpet plotting Already existing calculations. Criteria for static mechanical integrity Fatigue calculations based on partial damage theory</td>
<td>As on previous aircraft Fracture mechanics Computer-based testing of details and for fatigue testing of entire aircraft</td>
<td>As on previous aircraft</td>
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(continued)
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<th>Table 1. Continued</th>
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<tr>
<td><strong>Ground testing</strong></td>
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<tr>
<td>Rotatable rigs for testing of fuel system.</td>
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<tr>
<td>Rigs for testing of steering system</td>
</tr>
<tr>
<td>Flight tests</td>
</tr>
<tr>
<td>Strain gauges to verify stress and strength calculations.</td>
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<tr>
<th><strong>Data processing</strong></th>
<th><strong>Tunnan</strong></th>
<th><strong>Lansen</strong></th>
<th><strong>Draken</strong></th>
<th><strong>Viggen</strong></th>
<th><strong>Gripen</strong></th>
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<tbody>
<tr>
<td>Experienced-based and gut feelings</td>
<td>Experienced-based and gut feelings</td>
<td>Analog computers</td>
<td>Digital computers</td>
<td>Digital computers and supercomputers</td>
<td></td>
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<tr>
<td>Punch card machines</td>
<td>Experience-based and gut feelings</td>
<td>IBM computers combined with punch card machines Automated computers (SARA, BESK)</td>
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<tr>
<th><strong>Incidents and fatalities</strong></th>
<th><strong>Tunnan</strong></th>
<th><strong>Lansen</strong></th>
<th><strong>Draken</strong></th>
<th><strong>Viggen</strong></th>
<th><strong>Gripen</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of aircraft produced</td>
<td>661</td>
<td>450</td>
<td>606</td>
<td>329</td>
<td>Around 250 (still in production)</td>
</tr>
<tr>
<td>Number of accidents</td>
<td>242</td>
<td>150</td>
<td>125</td>
<td>54</td>
<td>12</td>
</tr>
<tr>
<td>Number of pilots dead in accidents</td>
<td>99</td>
<td>100</td>
<td>34</td>
<td>17</td>
<td>1</td>
</tr>
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</table>
4.1 Saab 29 Tunnan

Saab 29 got its name Tunnan (“the Barrel”) from its characteristic rotund appearance and it was the first European fighter with a swept wing and the second jet-powered fighter developed by Saab. While jet-powered fighters were used by the German air force during WWII, swept wings were new to the world. Together, these two design features later made it possible to approach the sound barrier—something that had been considered impossible only a few years before. The design of Tunnan, and particularly the effects from swept wings and jet-power, pushed the engineers at Saab into unknown terrains in which their previous knowledge and experience of military aircraft development might have been necessary, but not sufficient.

The aircraft was not without problems, however, and there were no less than 242 accidents, resulting in 190 crashed aircraft and 99 dead pilots, something that was partly due to the lack of knowledge about swept wings, but also limited training possibilities for pilots. For instance, there was no dual control trainer version of the aircraft. The high number of incidents indicates an iterative process of trial-and-error learning long after the first Tunnan had been delivered to the Swedish Air Force.

Physical models of components, subsystems and, finally, the entire aircraft were important for testing and evaluation of alternative designs. For the first time strain gauges were installed in the aircraft, primarily to verify calculations by measuring the different loads on e.g. wings and hatches. Much wind tunnel testing was performed to learn more about aerodynamics and swept wings, but there was also full-scale testing with a flying testbed demonstrator.

As described in Saab’s internal corporate magazine “VIPS”: “In addition to different tests with aircraft models, there were also a huge number of tests of different parts, particularly parts which were important from an aerodynamic perspective. First to be mentioned among these are some particularly extensive tests with the air intake of the aircraft, not only in wind tunnels but also full-scale tests with the air intakes connected to different types of jet engines.” New test methods were continuously introduced and testing was also planned and prepared more meticulously than for previous aircraft. For example, Lars-Axel Strömberg remembers the testing of the fuel system of Tunnan: “For Tunnan, full-scale, 360 degrees vertically rotatable rigs [of the fuel system], were made to test high capacity pressure refueling as well as the fuel supply of the engine at different flight positions.” Power steering, which just had been introduced, called for extensive testing to remedy problems of instability which had been discovered during ground tests of the aircraft. Therefore, rigs for the hydraulic- and steering systems were built.

There was an increased formalization of test programs during flight tests and in the development of measurement devices. The pilot was no longer to make subjective assessments or to note his impressions of the aircraft’s performance, but rather to execute preplanned tests. Saab employee KG Häggström recounts: “The introduction of measurement devices was not popular among the test pilots who were no longer granted the freedom to decide on the test program. The pilot’s main task instead became that of pushing the aircraft into the conditions described in the test program and execute required expositions by pushing a button.” For each exposition, 494 test values could be recorded and for each test flight almost 50,000 values. However, all possibilities could not be fully used due to the limited capacity of the test department which would risk, as Olle Klinker puts it, “...drowning in measurement data. At this point in time, automatic data processing did not exist, but manual data processing was the only kind of data processing we knew of.”

Early publications presenting the Finite Element Method (FEM) used for stress and strength calculations were circulated and FEM was now used by Saab for the first time to explore the swept wings design. Börje Häkansson, at the time employed to work with stress and strength calculations, describes: “I did not understand much of what I was doing but later on, it made more sense to me. We used the Finite Element Method. The results were strongly misleading however – something that was due to the fact that we had no computers [...] however, the Finite Element Method was here to stay.” Standards and procedures for estimating stress and strength had existed previously. However, the jet-powered feature of Tunnan with its high-speed performance, made those standards less reliable and relevant. Hence, Saab’s application of FEM emanated in a report which was used in further development work where the method was applied, experience gained, and refinements made and documented.

Despite increasing formalization of different bodies of knowledge and use of abstract methods for calculations, single individuals were key to gaining experience from physical testing. There was one experienced chief engineer, Lars Brising, who took on a leading role in the development and who sometimes is attributed to have invented Tunnan. Moreover, single individuals who were responsible for different research tasks were still important repositories of
knowledge of specific aspects of the aircraft as a result of their responsibilities. Over time, the problems were remedied and no less than 661 aircraft, in five different versions, were produced for the Swedish and Austrian air forces.

4.2 Saab 32 Lansen

Lansen (the Lance) was the first Swedish aircraft to break the sound barrier in 1953. During autumn 1946, Saab started internal studies on a new military aircraft to replace the Saab 18 attack aircraft. These studies resulted in the starting up of the development phase of the Saab 32 Lansen, in December 1948. Lansen was to become a two-seated, transonic, turbojet-powered, aircraft with low-mounted swept wings. It was developed in attack, fighter, and reconnaissance versions. The aircraft included advanced electronics and was the first military aircraft to carry a built-in search radar, also equipped with a fully automated fuel system. It was the first aircraft where early application of computer technology enabled every mould line to be a result of mathematical calculations.

Breaking the sound barrier had only a few years earlier had been considered impossible. Frid Wänström remembers: “With hindsight, it could appear a bit strange that we, at the end of the 1940s, had such a respect for the sound barrier that I, in a speech in 1946, expressed my doubts that we would build a supersonic aircraft during my lifetime. The reason was a technical misunderstanding. All known wind tunnel tests at the time had shown that the resistance raised towards infinity and that the stability and steering ability were indefinite—to say the least—when you approached the sound barrier. That these results were due to characteristics of the wind tunnel and the fact that the model tested blocked part of the cross-section area in the tunnel was something that we understood later.”

Tools for calculations improved, but despite the increased capacity to calculate and simulate, tests were still to a large extent conducted in the same way as for previous aircraft, using physical models and mock-ups. For instance to study how the dynamic loads diffused through the aircraft’s structure, a drop-weight test was conducted in 1953 using an entire aircraft, the wheels of which rotated at landing speed. Strain and deformations’ measurement, complemented with high-speed filming were conducted. Building on experience gained during the development of Tunnan, hydraulic and steering systems rigs were also used in testing those specific subsystems of the aircraft. Flight tests were essential as several test aircraft were produced and intensively used in testing. One third of all Lansen aircraft (of 450 in total) were destroyed in accidents during its 25 years of service and a total of 100 crew members died in those accidents, which were due to technical problems, aircraft being taken into service before they were ready, as well as deficiencies in pilot training.

While theories applied to problems of mechanical integrity and aerodynamics essentially did not change, their potential when applied to the development of a new aircraft could be better captured due to those increasing capacities for conducting calculations. Börje Langefors describes how Saab’s computational department acquired “modern, electronic, punch card machines [for] stress and strength calculations of wings and aircraft body parts” which allowed a workforce of ten people to conduct the work in a month’s time instead of a year “at the same time as other calculations were running”. Among the calculations conducted on the punch card machines were air forces on the aircraft based on pressure measured in wind tunnels. Saab also developed analog computers which operated as early forms of simulators when used in the study of mechanical problems. The analog computer produced a diagram on an oscillograph that showed how an aircraft with given design data behaves during defined maneuvers. The range of calculations possible increased, which contributed to development work in several ways. First, efficiency increased when calculations could be undertaken in a fraction of the time previously used for the same operations. Gains in efficiency allowed the engineers to conduct more calculations and explore more alternatives. Second, the precision of calculations increased because new methods enabled engineers to solve more extensive systems of equations, involving more unknown variables than before. This development contributed to pushing the sophistication of theories and models which had started to accelerate during the development of Tunnan.

Lansen incorporated a high level of novelty and it enabled the engineers and pilots to fulfill a dream—that of breaking the sound barrier. This required them to test the limits and work at the edge of what was considered possible at the time. In doing this, they relied on both previous experience from the development of Tunnan (e.g. swept wings) and frequent testing with physical artifacts (e.g. fuel system rigs). However, before testing the new profile of the swept wing, they had made calculations to evaluate its viability. The experienced gained was such that it combined previously established principles, physical model testing with abstract calculations in the quest to find viable design solutions.
4.3 Saab 35 Draken

The history of Draken (the Dragon) starts in 1949 when the Swedish Defense Material Administration put forward a number of requirements for a new military aircraft. The administration envisioned that the new aircraft should be a “cutting-edge inceptor aircraft” with a top speed of Mach 1.4–1.5, i.e. supersonic speed. Draken represented a major technological leap forward. Saab engineer Krister Karling summarizes: “Supersonic performance required radical changes of the aircraft body. It had to be slender and with a sharp front. The wings had to be extremely thin [. . .] The problem was to get good lift- and longitudinal stability characteristics, also at low speed”

It was decided early on that Draken should be designed with a delta wing. When discussing alternative designs to remedy the problems with delta wing designs, the idea of a double delta wing was put forward. The double delta wing was a revolutionary idea—such a solution had never been explored before. Therefore, a proof-of-concept aircraft referred to as Saab 210 or “Lilldraken” (the little Dragon) came to be to assess low speed characteristics. It made its first flight in January 1952 and undertook almost 900 flights during a period of 4 years. After a few months testing, work with the full-scale aircraft begun. The primary drawback of the double delta wing was a phenomenon called superstall. Gunnar Löw, who worked with aerodynamics, mechanical integrity, and testing of various kinds during these years, describes: “Lilldraken accidentally went into a condition which resulted in loss of altitude during oscillation in vertical position. The first spin (later to be referred to as superstall) in the world with a delta wing aircraft had probably been experienced. Any knowledge about how a spin with a delta wing aircraft should be managed – obviously – did not exist at the time. However, the pilot, thanks to his judgement and skills, could quickly analyze the situation and after considerable loss of altitude, cancelled the spin and returned to a more normal flight and landed the aircraft.”

Draken was developed during a time of transition, from pen and paper to computer, from calculations to computations, from personal knowledge and gut feelings to codified knowledge to be reused. Saab built a wind tunnel for testing of supersonic aircraft. Flight tests were more important than ever before. In aerodynamics, where strain gauges had been introduced during the development of previous aircraft, the full potential had not yet been utilized due to the lack of recording equipment during flight. The proof-of-concept aircraft Lilldraken was now equipped with a number of measurement devices. Airflows around the inner and outer wing of the aircraft were explored by photographing yarns attached to the wings, while the airflow between the body and the wings was assessed by emitting colored liquids.

Continuously increasing computational capacity made it possible to more fully utilize the potential of already existing methods. Saab was one of the pioneers in developing and using FEM to solve large equation systems. Börje Håkansson, employed as a mechanical integrity engineer describes: “Unfortunately, we did not have sufficient electrical energy to solve equation systems with more than 9-12 unknowns using electric FACIT calculating machines. When Börje Langefors realized that you could use machines like IBM-604 with ordinary punch cards to perform some types of calculations and therefore started to systemize input data for hyperstatic calculations in matrices, FEM-calculations could be increasingly applied.” The need for performing advanced calculations continuously increased, and automated computers were developed and applied internally at Saab, and equation systems with up to 60 unknown parameters could be solved.

The improvement of measurement devices and calculation methods enabled exploration of unchartered terrain that led to refined knowledge about how these knowledge domains could be applied within the particular context of aircraft development. Gösta Niss, working at the test department, elaborates: “As the laws of physics are the same now as they were then, the difference lays mainly in the amount of data that you can record and analyze, using computers, and the more complex analyses that you can perform [. . .] today’s engineers are often computer freaks [. . .] and have much higher theoretical qualifications than we had. But to many of them, flying is just a means of transportation. To us, flying was religion.” Despite the improved methods for computing and the increased sophistication of knowledge, the experience of old-timers was still essential and what the engineers referred to as “guesstimations” i.e. an informed, experience-based trial-and-error process, were considered immensely valuable.

Such “guesstimations” played a major role in deciding on what alternatives to check out further by using advanced calculations or computations. Measurement values were not perfectly reliable. Approximations and gut feelings were therefore used for evaluating flight test data. Saab test engineer John Johansson reflects: “I worked with test data evaluations and as soon as the aircraft had landed, I had to get hold of the oscillogram. An expert on flutter was also called in. A ruler was used to measure the amplitudes of the registered values and the damping ratio was...
calculated. The flutter expert scrutinized the protocol, knot his brows and said, in the best of scenarios; OK, let’s increase a bit. Considering the risks for the pilots this felt to be a rather primitive way and the difference as compared to the computerized analyses made today is huge.”

4.4 Saab 37 Viggen

In 1952, Saab introduced a series of studies to investigate different design concepts in an effort to meet the challenging requirements posed on future generations of military aircraft. For instance, these aircraft should be able to operate at supersonic speeds at different altitudes and perform short landings. Among the concepts investigated were those of single- and twin-engine configurations; traditional-, double delta and canard wings, and those with separate lift engines, adapted for vertical take-off and landing. Already at the inception of these studies a long development time was anticipated, and Saab 37 Viggen (the Thunderbolt) did not make its maiden flight until February 1967, i.e. its development time corresponded to the total development time of all the previous aircraft.

Military aircraft development took huge leaps both with respect to the aircraft’s technical advancements and with respect to the technology used in its development. Much was learnt about both aerodynamics and mechanical integrity during the development of Viggen. Aerodynamics, to a large extent, were explored using the same means as for previous aircraft, primarily wind tunnel tests with many and fast iterations. Initial exploration of canard configuration with suitable location of canard wing relative to main wing to optimize synergy was performed in water tunnel testing in which the flow was easily visualized. In the design of the new aircraft, engineers relied on proven methods for testing although computerization also offered new opportunities. Saab also set up a new cross-functional test facility to facilitate collaboration around testing. One important study was aimed at finding ways to aerodynamically improve the ascent characteristics of the aircraft. Wind tunnel investigations of different concepts constituted an important part of this work and were instrumental in developing the final configuration of Viggen. The results formed the basis for the further development of the aircraft and intensive work to optimize the configuration commenced. Revolutionary aerodynamic results enabled the writing of a project specification in October 1962, where extensive geometric data were included to form the basis for a prototype. Efforts were also made to make the aircraft smaller and reduce its weight. Access to digital computers was essential in enabling explorations in aerodynamic optimization with unknown results. Digital computers were key not only in pushing the frontiers of mechanical integrity where electronics contributed to better computational capacity and thereby to employ new and more sophisticated theories, but also for advanced testing of materials.

Viggen was delivered and taken into service by the Swedish Air Force in 1971. A few years later, in July 1974 and October 1975, two serious accidents, in which the pilots were saved by the ejection seat, happened as the wings broke off from the aircraft body fuselage during tight maneuvering at high loads. These accidents had far-ranging consequences with respect to how issues of mechanical integrity were approached. Erik Bergstedt, working at Saab, elaborates: “The loss of the wings ignited a revolution with respect to the methods used for evaluating the aircraft’s lifespan. Previously we had used data based on testing of the material’s static properties, simple partial damage theory and empirically derived principles, to establish the lifespan of a perfect structure. Now, we started to apply principles of fracture dynamics, i.e. we assumed that defects existed, e.g. cracks, and tried to evaluate how much life was left before the cracks became critical.” While before the accident, loads were manually added to the structure to test its mechanical integrity, after the accidents Saab acquired computer-based systems for testing of details and fatigue testing of the entire aircraft. These computer-based systems not only made fatigue testing of the entire aircraft possible but also contributed to efficiency in such testing and resulted in major changes in design, manufacturing, and control of aircraft. Furthermore, Saab gained valuable understanding of actual operational usage of a combat jet in terms of cycles and load factors which made Saab world leaders in operational loads spectra analysis.

The digital tools expanded the range of what was considered possible in terms of improved capacity for calculations and testing. There was a shift from experience-based, “real-life” testing, to computer-based testing based on theories and hypotheses. These calculations and tests in turn contributed to the design engineers being able to test new ideas, based on new theories. Not all ideas were implemented in the final aircraft configuration, but that these ideas were possible to explore in a safe way, within a reasonable time and to a reasonable cost contributed to lessons learned. Computers enabled extensive calculations to many of the studies that constituted part of the development of Viggen.
4.5 JAS 39 Gripen

After a number of studies aimed at a concept for a new military aircraft during the 1970s, Saab started development of 39 Gripen (the Griffin) in 1982. The challenge was set to performance equal to or better than Viggen, half Viggen’s weight, at maximum of 60% of its cost. Production volume would be important for economies of scale, something that could be achieved by developing an aircraft that could perform multiple roles (fighter, attack, and reconnaissance missions). Weight and cost are also related, so it would have to be a small aircraft with a single engine.

The small size of the aircraft turned out to be a challenge and multiple alternatives were explored before the developers settled for a configuration unstable in pitch with a delta wing and an all-moving canard. In A Journey of Change, Martin Hjelm explains why: “The stability requirement (safety, precision, comfort) is a trade-off against requirements for gains in maneuverability, take-off and landing performance, weight, cost, etc. Up until now, this had been managed through compromises, but now the requirements had grown to a point where something radical was needed in order to advance further. The solution is normally referred to as “the unstable plane.”” Gripen turned out more of a systems engineering challenge than previous aircraft—where increasingly powerful computers facilitated close collaboration between various disciplines. At this time, Saab invested heavily in CAD/CAM, which resulted in the exploration of more alternatives and quicker iterations between different disciplines. Lars Furingsten, who partook in the development, explains: “Thanks to the CAD/CAM system we could build dummies really quickly. The use of CAD/CAM systems meant that we could iterate the look of the aircraft several times and control the continuity of the second derivate in the streamlines.”

Software was an increasingly important part of the aircraft and as performance of simulators improved, these were more extensively used in development work. The initial definition of the control system was based not only on experience from the development of Viggen but also from studies made for an envisioned aircraft design that never materialized. Before the first Gripen test aircraft had been developed, the control system was integrated into a Viggen for experimentation. To be able to ground test the entire system, development called for simulation models which integrated the work of the different disciplines and Maneuver and Hydraulic Simulator (MAHS) was introduced. In A Journey of Change, Martin Hjelm explains: “To do this [ground testing], a MAHS was built. This is a rig for comprehensive simulation where current hardware as well as the flight control system and different other systems were included. […] The simulator consisted of hardware such as the control stick, sensor inputs, computers and servos. […] The aircraft’s aerodynamics and flight mechanics were simulated in computers in the simulation department […] Gyro and load factor signals from the simulation computers were entered into the MAHS rig and then into the flight control system. […] The disadvantage of this type of visual simulation was that the aircraft response when rolling was perceived as being slow so it tended to be increased.” This disadvantage turned out to be significant as a test aircraft crashed in 1989. One conclusion drawn from the crash was that the MAHS was too simple and hence “in-flight-simulations” were adopted. Therefore, Gripen’s flight control system was programmed into an American flight simulator (Calspan).

The boundaries and processing capacity of simulators were continuously pushed—and, importantly, simulators became completely digital. The integrated structure of Gripen influenced the new system simulators as the earlier division of the aircraft into base aircraft, avionic system and control systems became less immanent as systems were computerized. A relatively large portion of development and testing was also performed in simulators. Improved model verification, measurement data telemetry, and increased computing capacity all played their part. In Gripenkrönikan it is emphasized: “The most important tools to be able to carry through the flight envelope opening have been the simulators and the advanced telemetry system that also could be used for training together with the simulator. […] While flying the simulator we could introduce failures that neither the pilot, nor the test engineers […] knew about and in that way, train the crew in analyzing and correcting problems that could occur during real flights.” Simulation resources were further refined as simulation capacity continuously hit new limits in terms of hours per week and the resulting bottlenecks were managed by developing various functional simulators.

With the development of Gripen, the articulated theoretical knowledge of aircraft and their environments, measurements, measurement devices, calculations, and computation methods of the previous generations were modeled in the computer and by time, the flight experience gained from simulators became increasingly realistic. Paired with more advanced visual representation methods (from 2D CAD to 3D), digital training simulators could be developed that were easier to update as progress was made in development. Simulation models could easily process large batches of alternative options. Models would feed reality results, but reality also started feeding the model in a more
direct way. Flight tests became a verification of the model, which in turn could be used to verify new functions of the aircraft. The Gripen design introduced increased complexity of the product; a growing number of people involved in a jungle of tools and systems, combined with various versions of documents and excel sheets.

5. Consequences of looking down (almost) all roads before committing

Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveler, long I stood
And looked down one as far as I could
To where it bent in the undergrowth;
Then took the other, as just as fair,
And having perhaps the better claim,
Because it was grassy and wanted wear;
Though as for that the passing there
Had worn them really about the same,
Robert Frost (1916), *The Road Not Taken*

The transition from using physical to virtual modeling in the evaluation of options has made it possible to travel a significant distance down several roads before physically committing the traveler to one of them. As opposed to Frost’s traveler, today’s aircraft engineer can in a way travel down billions of roads and remain one traveler. Being able to see further down the road has not only meant great savings on development cost, it has also gradually made it possible to avoid fatalities and material consequences, both when evaluating design options and when later using the product. There was a significant reduction in the number of fatalities and lost Saab aircraft per flight hours in the Swedish Air Force. More sophisticated models were of course not the sole driver of this change. In the mid-60s for example, a new anomaly report system was introduced in the Swedish Air Force where pilots could report mistakes without risking prosecution, which made pilots more prone to report problems that could then be fixed. The general air force culture and acceptance of loss of lives has also changed since the days of the Cold War when realistic combat training was held high. The intake and training of pilots has changed. In the Cold War era, large groups were admitted and then candidates were eliminated as the training progressed. Today, only a small group is selected for training, but then nurtured with the intent that all should become air force pilots. Pilot training has, however, also improved through the use of simulators, which can replace many hours of flight training in an airborne aircraft.

5.1 A changing nature of experience

Ever since the Wright brothers, representations in the form of scaled down models, or prototypes, have been an important way to mitigate consequences of developing and testing new ideas in aircraft development (McCullough, 2015). Today, simulators have replaced many physical models, and even wind tunnels can be simulated. This is not unique to the military aircraft development. In a study in the automotive industry, Thomke (1998) shows how computer simulation used in the modeling of crashworthiness of cars increasingly came to replace physical tests, as it both increased number of iterations at the same time as it reduced cost in the design process. Drawing upon an extensive study of digital modeling in prototyping, D’Adderio (2001) challenges the notion that virtual prototyping is a substitute for physical prototypes. Instead, she argues, virtual and physical prototypes are complements as they draw upon different forms of knowledge (explicit and tacit). In the evolution toward increased digitalization and widespread use of virtual prototyping, she suggest that hybrid modes of prototyping are emerging, as “hybrid prototyping techniques provide the richest standpoint to support the early integration of heterogeneous knowledge types and sources into the product definition” (D’Adderio, 2001: 1412). However, in D’Adderio’s conceptualization of hybrid prototyping, hybridity takes place between two quite rough instantiations of experimentation using both physical and virtual prototypes. Drawing upon our historical case study, we propose that virtual simulation is indeed replacing (thus being a substitute for) physical prototyping in the development of aircraft design. At the same time, drawing upon Gavetti and Levinthal (2000), we suggest that these proceedings do not imply a straightforward switch from online to offline evaluation in the search processes involved.
5.2 Limitations of representations in transition

Key to understand the performance of offline evaluation is model fidelity (Gavetti and Levinthal, 2000; March, 2010; Marengo, 2015). In the evolution of models at Saab, the transition from physical testing to virtual simulation hinges on new forms of knowledge being developed as well as the visual, mathematical, and verbal, “languages” of representation. Some visual forms of representation would aim to “map” (Gombrich, 1999) the aircraft as in electrical wiring diagrams “portraying” (Black, 1973) an existing physical form. Others would aim to “mirror” (Gombrich, 1999) the form as in sketches that would “display” (Black, 1973) the engineer’s imagined aircraft concept. The 2D paper models and physical 3D models developed into CAD-based 2D models and 3D models. The mathematical representation language went through a similar journey of increasing capacity. As engineers learned more about problems at hand, they generated increasingly sophisticated and fine-grained knowledge of the aircraft and interacting subsystems as well as the environment in which the aircraft was operating (Alexander, 1964). Not only did this knowledge reside in the heads and hands of the engineers, but it could be codified into formal propositions regarding action-outcome linkages. Such theoretical knowledge could be used as input in simulations enabling the representations generated in simulations to more correctly represent reality. Realistic models \textit{in abstracto} meant that sensible evaluations could increasingly be made offline without suffering from severe consequences. Today, flight testing still needs to be done, however, engineers obtain empirical flight data primarily to use as input for model development and verification, rather than for online testing of the design.

5.3 Evaluation of options in transition

As indicated by Gavetti and Levinthal (2000), the real-world distinction between online and offline evaluation is often blurred. In Saab’s journey we can, however, distinguish transitional steps that come with new modeling possibilities (see Figure 1). In the early days of development, we see the use of online evaluation in the form of building and test flying the aircraft, offline evaluation in terms of calculations of forces and aerodynamics, as well as a “physical hybrid” version between the two in the form of wind tunnels. Early use of wind tunnels was explorative and contributed to building theory. As theory formed and calculation methods as well as measuring devices were developed, the physical hybrid forms of evaluation could also be used for verification. The physical hybrid form of verification induced more limited undesired material and human consequences compared with online evaluation and full-scale building, but results were not as trustworthy as results obtained through online evaluation. When measuring devices could use telemetry to harvest data, and computations could be done by machines, a “virtual hybrid” form of evaluation developed in the form of abstract models where failure during evaluation had no material or human consequences, but accuracy of results was still a limitation. Models would tend to be developed within disciplines, which meant that systemic effects emanating from the integration of developed parts were still difficult to predict. With dynamic system simulations and flight simulators that are fed real-flight data, we see a step toward a point where a form of “virtual online” evaluation becomes possible where the fidelity between model and reality allows model failure to produce realistic outcomes, but simulated and with no material consequence.

5.4 Experience and the process of learning

Although the distance between reality and representation grows smaller in modeling, for engineers working with modeling, the gap to reality may be growing bigger. Many Saab engineers have little reason to interact with the physical product in their daily work nowadays. Older engineers worry that the younger ones, who are used to working only in a model, have lost concretion and cannot connect to the physical product and the characteristics that their model portray. The young engineer expressing a desire to “get the red pressure more green” without realizing that red in the model indicated high pressure and what that meant for the physical product was used as a cautionary tale in our interviews. When developing options, trying them out and failing in the real world, experience is messy, complex and noisy (March, 2010). The sound of vibrations, the smell of smoke, and the touch of a smooth surface convey additional information in the physical world that may or may not be relevant. In the physical world, samples are often restricted (March et al., 1991; March, 2010). In the simulated world, experience is more clean and calculated, and myriads of options can be tried out. There is also an emotional dimension attached to it that influences how and what we take away and remember from an incident (Kensinger and Schacter, 2010). Feelings of regret for example, serve the purpose of making us less likely to repeat actions that we experienced as mistakes (Landman, 1987). When
Figure 1. A transition in modes of evaluation.
experimenting mainly in a virtual environment where very little is at stake, the emotional component is likely to be different. The process of drawing lessons out of our experience is ordinarily not straightforward, and what we learn is often somewhat ambiguous (March, 2010). What happens to the intuitive and tacit understanding of the product system when the physical experience of consequences can be avoided? When modeling engineers become increasingly specialized and separated from the physical realization of their work, keeping up the ability to transition between the two may become increasingly challenging. On an individual level, learning becomes layered rather than direct. This raises questions regarding the nature of experience gained by these engineers and how it may change the process of learning.

Small scale experimenting and the choice of what paths to pursue would normally come with a consequences landscape that ranges from desirable to undesirable as well as imminent to distant. As for the undesirable consequences, some will be reversible, as in a lost reputation that is regained, but some will be irreversible, as in the death of a pilot. Just as our preferences for desirable consequences may change over time (March, 1978), so may our aversion for and acceptance of undesirable consequences. In military aircraft development we can see a transition in how the deaths of test pilots is made sense of over time. Although never desirable, in the early days it was expected that it would happen because flying was dangerous. In war time and during the Cold War, urgency took precedence over safety, and so did realistic combat training and preparedness, and hence casualties were considered undesirable, but acceptable, and had a role to fulfill. As summarized by one of the engineers who participated: “Methods for analysis always seem to take a leap forward after a serious accident. In the investigations, money is spent almost without restrictions and the engineers are allowed to use their creative abilities. […] A crash often leads to a better end product. […] A crash or mishap is not the end of the world, it’s the beginning of more hard work to build a better product. This has been the truth for every aircraft built worldwide.”

This can then be contrasted with the more recent development of Gripen, which suffered only two crashes, but very public ones, where luckily no one died (the only fatality occurring in 2017 in Thailand’s Air Force). However, those two crashes resulted in public calls for cancellation of the entire project.

5.5 Foolishness without consequence?

And both that morning equally lay
In leaves no step had trodden black.
Oh, I kept the first for another day!
Yet knowing how way leads on to way,
I doubted if I should ever come back.
I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I—
I took the one less traveled by,
And that has made all the difference.
Robert Frost (1916), The Road Not Taken

If the “virtual online” evaluation mode is where we are headed, what might that indicate for organizational intelligence and our possibilities to beforehand distinguish the good deviant ideas from those that are merely deviant? One interpretation of this transition is that it will be possible to better know beforehand what is a good deviation, and that our traveler no longer needs to have doubts about the road taken, or have regrets over the one not taken. The point of choice can now be delayed until more has been learned without having to face the consequences of trying out a road, and hence our traveler will not make a foolish choice. That interpretation, however, assumes a logic of consequences where thinking comes before action in the pursuit of a goal (March, 1991b). Another interpretation is that we have only moved the frontiers of foolishness. Foolishness without consequence is also foolishness that risks very little, and if there is little risk of consequences, then whatever is tried out cannot be very foolish and we need to try harder. If the rationale and value of the same deviant idea is obvious to most, it can no longer qualify as deviant.

Foolishness and imagination are two important concepts in Jim March’s theory of organizational intelligence and adaptation. Part of the problem of using experimentation to distinguish good ideas from bad ones beforehand, is that persistence in the development of good deviating ideas normally requires the fool’s ability to disregard feedback received from reality rather than accepting it (March and Weil, 2005), and to continue despite the fact that common
sense says there is no point. In most instances, such behavior will not generate success. Imagination that conjures a strong vision of what might come to be therefore plays an important role for the commitment to and protection of deviant ideas, thereby sustaining the intelligence of a larger system by providing the variation that allows it “to choose among alternative insanities” (March, 1995: 437). March often returned to the story of Don Quixote to explain what the pursuit of deviant ideas may look like to the outsider and mean for the person pursuing it. He used it as a contrast to the success stories of deviating innovators that we normally tell, who disregarded feedback from reality and in the end turned out to be right (March and Schechter, 2003). Quixote’s pursuits within his knight errant identity more often than not had disastrous effects, yet he persisted in his vision. His vision was, however, not based on justification and the hopes and fears of consequences.

“When Quixote meets the traders from Toledo, he insists that they recognize the unique beauty of Dulcinea. When they protest that they have never seen the lady, he says there would be no virtue in their admitting her beauty if they had seen her. You must swear to it ‘without seeing her’, he says. When Sancho challenges him to provide consequential reasons for his crazy behavior, Quixote says that providing such reasons merits ‘neither credit nor thanks’, that one should act foolishly without justification.” (March and Weil, 2005: 95–96)

Virtual modeling on the one hand means that more options can be tried out with little extra cost, and hence in theory the more far-fetched ideas should have a better chance to be selected to be pursued and evaluated. On the other hand, once more far-fetched ideas can be justified without real-world commitment, they will no longer look far-fetched and foolish. It would seem that a version of the “Logic of Vanity Fair” (Gombrich, 1974) could apply, where a deviant fashion style will attract attention, something that is desirable to some and undesirable to others. As more of those who seek attention adopt the deviant style, also the more moderate attention seekers will adopt the style and it will gradually become a new norm. This means that the ones who find attention undesirable must adopt the once deviant but now normal style too to avoid deviating from norm. Attention-seekers must then find a new deviation from norm. The difficult part is to tell beforehand which deviation from norm that will attract positive attention. In our case, the deviant idea will only be risky enough to look foolish as long as it bears real-world consequence. Once it can be justified it becomes common sense, and hence maybe there is no foolishness without consequence.

In the early, more physical, days of aircraft development, many Saab engineers were driven by a passion for aircraft that went beyond consequences. It was part of who they were. They imagined new frontiers to cross, such as the sound barrier, sometimes for good reason, but with great uncertainty if they would ever get there and if so at what price. The “Saab spirit” was to commit and pull together and do what was necessary to live up to the identity of being a Saab aircraft engineer and build the plane. They had far more respect for reality than Quixote had, but they shared his passion and discipline, and joy in what they were doing. Many of those engineers are today retired, but still busy writing the stories of a Saab that once were, in the form of Saab Memories. Today’s Saab engineers may be equally passionate about their jobs, but are not necessarily driven by a passion for aircraft. They have spent most of their careers updating the Gripen, using models that have been honed over many years and, therefore, provide a sense of clarity and certainty. The time has, however, come to start over from scratch again. Will there be someone willing to commit to the deviant ideas that the model says cannot be done?

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References


