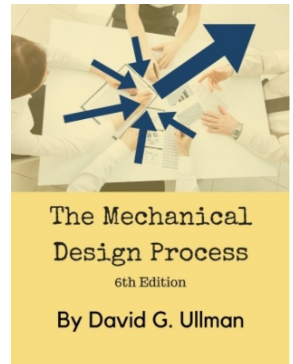
Agile Design of an Agile Fighter at Saab Aerospace



A Case Study for The Mechanical Design Process

Introduction

The Saab JAS 39 Gripen is a light single-engine fighter aircraft designed using Agile methods. The E model, first test flown in 2017, can reach Mach 2.0 with a combat range of 1500 km (932miles).

Figure 1. The JAS 39 Gripen E

Besides the Gripen's impressive flight characteristics, its development costs were about one-tenth that of the Lockheed Martin F-35 to which it is often compared. Saab achieved these cost savings while improving quality using the Scrum design process - an Agile methodology. This case study explores the use of Scrum for the design of the Gripen E's oxygen system and its testing during 2018.

The team featured here consists of 10 members and is known as the "Escape&Oxygen" team. It is responsible for pilot survival and integrating an oxygen concentrator supplied by Honeywell with an ejection seat supplied by Martin-Baker.

> **The Problem**: Develop the oxygen/escape system for the Saab 39-E through the integration and testing of components supplied by other vendors.
> **The Method**: Use Scrum to manage product evolution, testing, and team communication.
> **Advantages**: Saab's focus on autonomous teams using a Scrum design process both reduces bureaucracy and encourages decision making at the lowest possible level in the project organization. There is clear communication between individuals and teams leading to an aircraft delivered for lower cost, faster, and of higher quality.

Background

The Gripen E is the latest Saab fighter. It was designed to be lighter and less expensive than many of its competitors such as the US Lockheed Martin F-35[i], the Russian MiG-35[ii] or the Chinese Chengdu J-10[iii].

Figure 2. The Gripen with its optional ordinance

The Gripen fighter was first introduced in 1997. The E model is the latest in the series where A was the first single-seat version, B was similar to the A with twin seats, C was the second-generation single seat and D the second-generation twin-seat version. The E version has a single seat, and the F, still in development, will be a twin-seat version. The E is basically a new airframe, larger than the C model and with many changes to the oxygen system. As can be seen in Fig.2, the Gripen can carry a wide variety of weapons, and communicating and sensing pods.

A comparison of the Gripen E to the Lockheed-Martin F-35 Lightning, the newest US fighter, is shown in Table 1. Both aircraft have similar operating speed and range and can carry similar weapons. However, while the F35 is a stealth fighter, probably the best ever designed, the Gripen has a very low radar signal compared to earlier aircraft. Off-setting this stealth capability is that the Gripen is much less expensive to buy and to fly. Further, it was designed to be much easier to maintain.

Table 1. Comparison between the F35 Lightning and the Gripen E

Measure	F35 Lightning	JAS 35 Gripen E
Max Velocity	Mach 1.6	Mach 2
Combat Range	1300km	1500km
Stealth	Yes	No
Sensors	State-of-the-art	Good
Initial Cost	$94M -122M	53M
Operating cost	$31,000/hr	$4,700/hr
Maintainability	Needs a hangar and special equipment	Very good, can be repaired in the field

The low cost to purchase and to operate are a direct result of the design process used at Saab. As discussed in Section 2.2 of *The Mechanical Design Process*, 6th edition (*MDP6*) design can have a substantial effect on cost, quality and time to market and that is reflected in the Gripen E.

The Use of Scrum at Saab

Like any modern fighter, the Gripen is highly complex. To manage this complexity, Saab introduced Agile practices such as Scrum, Lean, and Kanban in the early 2000s, during development of the earlier Gripen versions. The use of Scrum began with software design and spread throughout all the other aircraft disciplines. Since Agile methods encourage introspection and change, the methods applied at Saab have evolved over the years. By the time of the design of the Gripen E, Scrum had been implemented in every discipline and at every level in the organization.

The Gripen E was designed by more than 1000 engineers grouped into more than 100 Scrum teams[iv]. All teams have the same three-week sprint cycle, starting and ending at the same time. This gives Saab a common rhythm and a stable pulse. Saab has realized that Scrum methods provide:

- Clarity: Each team knows what is expected of them.
- Creativity: The teams know what is desired, not required as that would stifle creativity.
- Good decisions: Saab has driven decision making to the lowest possible level enfranchising teams.
- Clear communication of needs: While the ideal Scrum team interacts with the customer, this is not possible in a large project like the Gripen. To counter this, the Product Owners (POs) establish the value of features, set priorities and coordinate with other teams.

The project master plan for the Gripen E began in 2013 with the first customer contracts. As is common in Saab, this plan was broken into development steps with well-defined functional targets for each specific prototype aircraft. Each one has a test program with minimal functions for the first months, and additional functions added as the tests progress.

Development steps at Saab are broken down into "Increments." An increment is timeboxed at one calendar quarter, and this gives a well-defined delivery schedule. Increments are further divided into sprints with four three-week sprints in an increment. Functional increment targets are established each quarter and drive sprint planning. While orthodox Scrum requires delivery of product at the end of each sprint, Saab tries to have well-defined sprint targets, but these are not always deliverable.

This top-down organization of master plan, development steps, increments, and sprints are necessary on a project as complex as the Gripen. To manage this complexity, there are structured meetings to identify the system dependencies and make them visible across the project. These meetings are revisited at the beginning of each three-week sprint. System integration occurs not only at the end of each sprint but during them also as needed, ensuring that issues are visible and corrective action can be taken as soon as possible.

Focus of the case study

This case study focuses on the design of the Gripen E oxygen delivery system. The E model has a single pilot who must be supplied oxygen throughout the flight envelop, up to a ceiling of 16,000m (52,000 ft). Further, the system must also supply oxygen in the event that the pilot ejects from the airplane.

Historically, early oxygen systems used Gaseous OXygen (GOX) with oxygen stored in metal cylinders at 1800psi (12.4 MPa). The weight and size of GOX systems increase proportionally with desired flight duration limiting their use in long-range flights.

More advanced systems used Liquid OXygen (LOX). These systems allowed greater storage since the oxygen was in liquid form which expands 900 to 1 in use. The liquid oxygen is not only pressurized but must be kept cold (-197F or -127C) and then warmed for delivery complicating the system and adding weight. Even with high expansion ratio, there is still a fixed amount of oxygen that can be carried, limiting the range.

Recently GOX and LOX have been replaced by On-Board Oxygen Generation Systems (OBOGS)[v]. With an OBOGS, the aircraft generates its own oxygen. Honeywell, at its British facility, makes the one used in the Gripen.

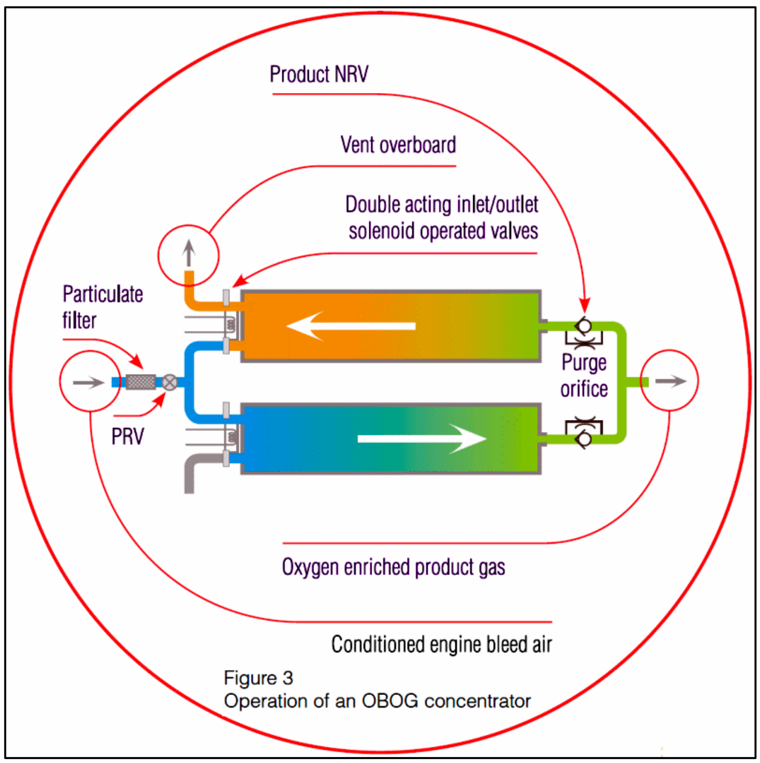


Figure 3. OBOGS' Operation

To explain how the oxygen is "made" Fig. 3 shows a schematic of the OBOGS. It uses what is called a "swing system" with two Zeolite beds (the center rectangles). Zeolite is a molecular sieve that lets oxygen molecules through and captures nitrogen molecules. There are two of these beds, one in use (the lower one in the figure) while the other is back-flushed to remove the nitrogen. When the lower one becomes nitrogen saturated the process is "swung" so the top one now is active and the bottom one is flushed. Conditioned (i.e., cooled) engine bleed air is brought into the beds (at the bottom of the figure) and oxygen enriched air (up to 95% oxygen) is produced (on the right). The remaining 5% is argon which does not affect human respiration. The oxygen-rich product of the OBOGS is later diluted down to a breathable level by the regulator/controller.

The OBOGS is integrated into the system as shown in Fig. 4. Oxygen flows from the OBOGS to a regulator/controller and then to the pilot. There is also a GOX Backup Oxygen Supply (BOS) integral with the ejection seat. In the case of ejection, the OBOGS in the airframe is disconnected, and the BOS takes over. The regulator/controller manages the source, pressure, and flow, and compensates for altitude.

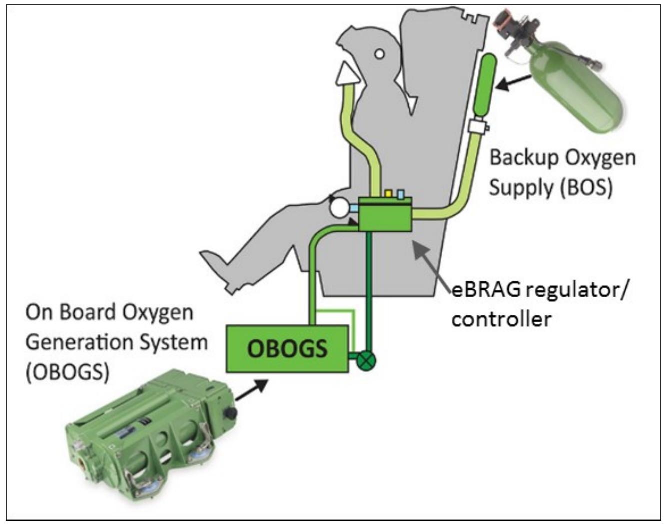


Figure 4. The OBOGS in the Gripen system

The regulator/controller, called the eBRAG manages the source of oxygen and the oxygen concentration. "eBRAG" means Breathing Regulator and Anti-G valve. The logic in this system combines pilot control with automatic sensing of flight conditions to provide a breathable oxygen mix.

Part of the challenge for the Gripen E Escape&Oxygen team is the need to integrate the OBOGS with the ejection seat. The seat is a Martin-Baker Mark S10L zero-zero (zero altitude, zero speed) rocket-propelled ejection seat[vi], Fig. 5. This is a well-tested seat with over 5,500 in service and over 800 lives saved.


Figure 5. The Martin-Baker ejection seat

The seat begins the ejection sequence when the pilot pulls the firing handle located between their legs. This initiates firing of a detonating cord which blows off the canopy. Then, the main gun located at the rear of the seat fires. This consists of a telescopic tube with two pairs of explosive charges that fire in sequence thrusting the seat clear of the airplane. As the seat moves up its guide rails, the OBOGS is disconnected, and the BOS is activated. At the same time, communication leads are automatically disconnected, and leg and arm restraints lock the pilot's limbs to the seat preventing injury.

As the seat moves further up and out of the aircraft, a rocket pack is fired. These rockets push the pilot and seat further from the aircraft. A small drogue parachute is deployed to stabilize the seat's descent path. A system prevents the main chute from opening above16,000 ft (5,000 m). Once below this altitude, a time delay mechanism opens the main parachute. The seat then separates from the pilot for a normal parachute descent. A manual separation handle is provided should the automatic system fail.

With all this complexity, the Escape&Oxygen team is faced with a myriad of design tasks:

- Specify requirements
- Find suppliers and get quotations
- Evaluate standard products and specify changes
- Develop logic (data, alarms, etc.)
- Work with suppliers on the design
- Find optimal solutions
- Review/approve suppliers' test program
- Run Saab tests and reduce test data
- Develop mechanical and electrical connections between the supplied components and the aircraft

Teams

The one hundred plus Scrum teams at Saab who work on the Gripen E range in size from 5 to 10 members. Most of these teams have been together for a long time, some more than ten years. While each team generally has a consistent set of team members, they lose members due to normal transfers and retirements, and they gain members as new employees are hired. If a team gets too large, it may be divided into two teams, at the discretion of the team members themselves.

Within Saab, team practices are not prescriptive. Individual teams have the autonomy to develop the best implementation for their situation. Decisions are driven down to the team level whenever possible. Saab has learned that commitment and clarity drive performance and efficiency.

The Escape&Oxygen team has ten members: Peter is an expert on the eBRAG logic, Ingrid on testing, Gustav on the seat, Mattias on the software integration to the aircraft computer system, David on system safety, and others.

Like most teams at Saab, they all sit and work together to facilitate communication. Fig. 6 shows the Escape&Oxygen team and its Scrum Board. This photograph was taken at one of their daily standup meetings.

Figure 6. Escape&Oxygen Team and their Scrum Board

The Gripen E program uses the Product Owner (PO) as a proxy for the customer. The PO is responsible for establishing the value of features and works with all stakeholders on different management levels re-prioritizing them on the increment and sprint cadence. Each PO covers 1-8 development teams contrary to Scrum orthodoxy of one PO for each team. This is possible because there are relatively few Gripen customers and their voices are reflected through the high-level fighter aircraft requirements (See Requirements and Stories below). Also, this is necessary because the systems are so complex that one of the PO's primary role is coordination between teams due to systems' dependencies.

Each team has a team leader who acts as a Scrum Master holding the daily stand-ups helping the team decide who is doing what, resolving any disturbances to the sprint, ensuring all the needed input is at hand and so on.

A primary goal of the Escape&Oxygen team is the integration of components supplied by vendors such as Honeywell and Martin-Baker. These companies have their engineers in Great Britain. It is not economically realistic for them to have an engineer co-located in Sweden to be on the team. So, while representatives of these companies are not full-time members of Saab's Escape&Oxygen team, there is a weekly Skype meeting with each vendor to resolve issues, and communication more often by email and phone is standard.

Since the ejection seat and oxygen system need to work with a pilot, Saab also has a pool of test pilots who are available for team integration on an as-needed basis. Many of these test pilots have engineering backgrounds and can integrate easily within the team.

Requirements and Stories in the Product Backlog

For a fighter aircraft, the requirements develop over several years. They begin with the specification of the earlier version of the Gripen (the C model) and the changes needed for the desired operation of the E model. The requirements drive the product backlog for each team. The backlog contains the "stories" in bigger chunks, and sprint planning breaks them down to smaller pieces as tasks. While there are no "Stories" in the traditional Scrum sense, the goals that drive and focus team activities take many primary forms:

1. Requirements Development: Understanding airplane requirements and breaking them down to how they affect the new system.
2. Vendor selection: Solicit proposals, review proposals and choose suppliers.
3. Vendor specifications: Some stories require developing specifications for the vendors. These include determining design limits and other details that drive Honeywell's and Martin-Baker's design teams.
4. Detail design: Detail design in-house parts and assemblies and work together with suppliers developing their details.

5. Test specifications: The team often analyzes the airplane level requirements (derived from customer contracts and flight worthiness standards) to understand how they affect the oxygen system. For example, the aircraft level requirement requires that it can operate at -40 C. The team then analyzes test reports from the supplier and decides how to conduct their own “top-level” testing. This includes setting targets for passing or failing the vendor’s equipment.
6. Test evaluations: The results of the tests are compared to the specifications and working with the vendors to overcome any issues,
7. Conceptual design: Make a conceptual design of hardware and software for both internal Saab systems and those supplied by vendors.
8. Quality control: Evaluate parts and assemblies and ensure they meet the specifications.

While formal Scrum practice suggests writing stories in the form "As a < (customer role or system)> I want to <perform an action> so that I can <gain this benefit>," Saab uses just simple headings. An unedited sample of Escape&Oxygen team stories from early in an increment are:

1. Define the mechanical interfaces between the Martin-Baker seat and the airplane.
2. Define the electrical interfaces between the seat and the airplane.
3. Define the testing program for the seat due to changes in the Gripen E (compared to Gripen C).
4. Define technical specification/performance of the Honeywell eBRAG/OBOG system with regard to oxygen concentration (up to 90% O2 at high altitude).
5. Define test program for O2 generation system.

The Product Owner prioritizes the product backlog with an interface to upper management and coordination with other teams’ POs. This includes making sure the time plan for the upcoming sprints is correlated. For example; planning when the software integration is taking place, or what tests need to be performed together with other teams. Also, the PO must make sure that the product interfaces that are owned by other teams are coordinated. For example, the engine bleed air that provides the raw flow for the OBOGS (see fig. 3) is provided by another team.

Tasks

Tasks define the work done during a sprint. Ideally, a "task" includes the activity that needs to be done complete with measures for it and targets so that "done" is fully defined. Saab is very good at defining the activities to be accomplished, and during the sprint planning meeting, they discuss what needs to be accomplished. Then, during the daily standup meetings, they further discuss if the task is completed or if more work needs to be done.

The entire oxygen system is modeled in Simulink for testing functionality and as a solid model in CAD. Saab has developed models of most of the systems in their aircraft[vii].

The teams manage the tasks on Scrum boards as in Fig. 6. In orthodox Scrum, both stories and tasks are posted, but at Saab only tasks. The colors of the sticky notes in Fig. 5 indicate who on the team is responsible for the task.

For example, the tasks addressed during the May 2018 sprint are shown in Fig. 7. These are from the “Doing” section of the Escape &Oxygen team’s Scrum Board. Here the first number refers to the equivalent story in the story list, and the letters are just sequential numbering. Note that many of the targets are inferred.

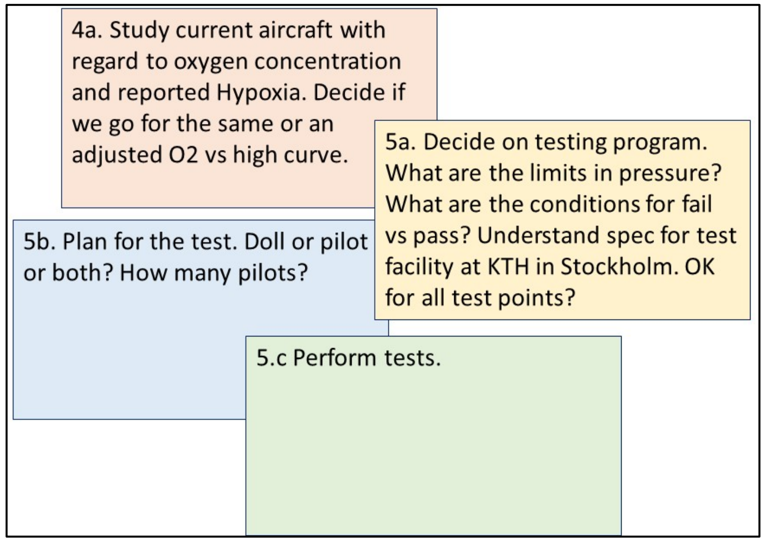


Figure 7: May 2018 Escape&Oxygen tasks on the Scrum board.

Connected by Stable Fixed Interfaces

Modularity of design allows modularity of organization. In the design of hardware systems, modularity allows teams to work on their tasks relatively independent of other teams.

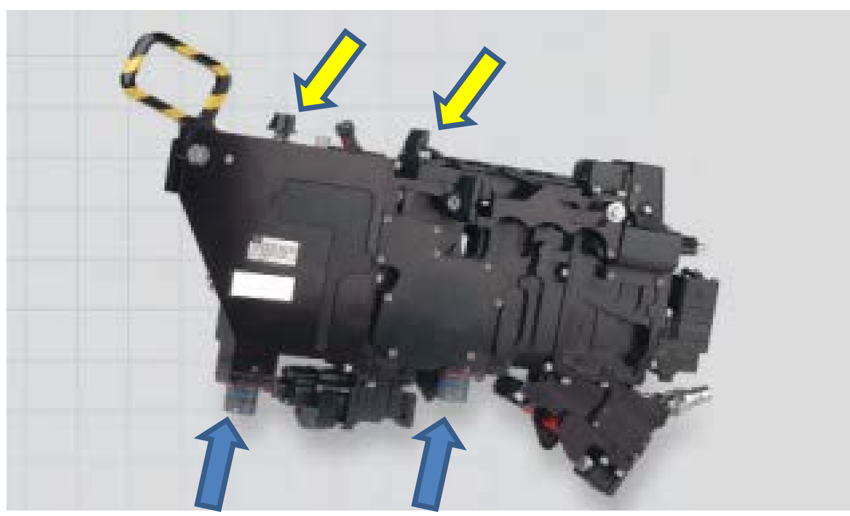


Figure 8. The OBOGS with interfaces indicated.

Fig. 8 shows the OBOGS with its major interfaces indicated by arrows. The yellow arrows point to pilot controls for the oxygen concentration and flow. These must be standard from aircraft to aircraft to ensure that a pilot has a stable environment in which to work.

The blue arrows are OBOGS interfaces with other systems on the aircraft. These are where the oxygen-rich flow from the eBRAG is brought into the OBOGS along with other, low-oxygen air to dilute it. These are where signals from other aircraft systems are input so the OBOGS' logic can help keep the right mixture for the pilot. These interfaces are made standard early in the development of the aircraft along with the physical connecting points for mounting the OBOGS to the aircraft.

Retrospective

Retrospective meetings are held at the end of each sprint. Both the Sprint Review and Sprint Retrospective are considered very important at Saab. The Sprint Review focuses on the product; what stories and tasks were completed, what needs work in a future sprint and when, and what new stories and tasks are needed.

The Sprint Retrospectives focus on the team process (how rather than what). Saab not only has team retrospectives, what could be improved in how the teams did their work, but also a retrospective of retrospectives across teams. This covers not only common problems across teams but also leadership and management issues.

Saab puts special emphasis on the Sprint Retrospectives with frank discussions of how the team worked during the sprint and generating more efficient ways to work in the future. During 2018 retrospectives, some of the ideas that the team developed were:

- A new CAD function was needed. It was defined and submitted it to a support team to implement.
- A weekly meeting coordinating with the test people was lacking so it was instituted.
- A larger Scrum Board was needed as the current board covered only one sprint and the team want a larger board to add in the rough contents of the two following sprints.
- An issue board (in Excel) was desired to support the meetings with Honeywell engineers complete with “status” updates.
- They found they needed a weekly software coordination meeting with stakeholders that are not part of the daily stand up.

All of these ideas developed during the Sprint Retrospectives were implemented.

Conclusion

Saab’s focus on autonomous teams both reduces bureaucracy and encourages decision making at the lowest possible level in the project organization. On the product level, the result is an aircraft delivered for lower cost, with more advanced functions, and higher quality.

On a personal level: each team and each team member knows what is expected of them; they know what is desired, not required as that would stifle creativity; they make decisions and feel enfranchised, and there is clear communication between individuals and teams leading to product quality.

Acknowledgments

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