The lean thinking application in aircraft maintenance

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Abstract:

The Portuguese Air Force has been applying lean thinking in aircraft maintenance since the implementation of the F-16 MLU (Mid-Life-Upgrade) modernization program. The aim of this article is to present the work carried out with the purpose of reducing the immobilisation time due to the aircraft maintenance and the cost reduction associated with the support of weapon systems.

The achieved results prompted the development of the application of lean management to programmed maintenance activities for the F-16, Epsilon TB-30, C-130 and Alouette III fleets. The benefits achieved have been evident, not only at the decreasing of the process times and in the economy achieved in financial, material and human resources, but also in the management of stocks and in the organizational culture change which has taken place since its implementation.

The use of the seven-week rapid improvement event method based on the A3 methodology has been instrumental. Leadership actions, strategic alignment and communication throughout the chain of command, along with the involvement of those who have an active part, are crucial in producing the desired end result.

The interventions confirmed a reduction, between 30% and 60%, in the aircraft immobilization time, leading to an increase in the availability of aircraft and a reduction in the operating costs.
Keywords: Aeronautics, Kaizen, Lean Management, Maintenance.

1. Introduction

In order to accomplish its assigned mission in Portugal, as well as to answer the increasing demands and requirements of NATO missions, the Portuguese Air Force (PoAF) has implemented a project aimed at increasing the maintainability of its weapons systems, as well as maximizing monetization processes work and reducing support costs. Many of these studies have led to academic studies (Botas, 2008; Ferreira, 2009; Cruz, 2010; Ribeiro, 2011) in addition to the ones referenced throughout this article.

Accordingly, in October 2007, innovative work was first implemented for the methodologies of the last phase of the F-16 / MLU modification program, called Dock 4 (Air Base no. 5, Monte Real), of which we highlight the "Lean Technics".

The achieved results boosted the expansion of the methodology into other areas of aircraft maintenance in the F-16 fleet, as well as, in the C-130, Alouette III and Epsilon TB-30 fleets. This resulted in reductions of around 50% in aircraft downtime and the consequent reduction in the weapon system support cost.

This recognition was clear as mentioned in the speech of General Chief of Staff for the Air Force, during the celebration of the 60th anniversary of the Air Force:

"... The success of this process, flows naturally from the quality of people, their adaptability and voluntary membership, which resulted in impressive results, deserving of the recognition for their effort."

During this lean journey, it was noticed that the application of this management philosophy, known among us as "Lean Technics", included more than just techniques and tools. It also included values, beliefs and habits needed to promote a cultural change. Thus, the name is not significant, what matters is the contribution to the operational excellence and ongoing commitment to continuous improvement.

2. Getting Started with the "Lean Technics" in the Air Force

Due to the initial difficulties, the F-16 modernization program which should have an output of one aircraft every two months, did not reach its desired pace in the first four years of production.
Economically more valuable, compared with the acquisition of a new weapon system, this program consisted on the introduction in the aircraft of the structural and technological improvements implemented by the USAF (United States Air Force) and the other European Air Forces (EPAF - European Participating Air Forces). This would allow for the increase in the operational capabilities and the extension of the period of operation of the F-16 weapons system, as well as, to provide cutting edge equipment capable of responding effectively to the new challenges.

After several attempts to catch up, the implementation of the "Lean Technics" was instrumental for improving the work processes, which involved many entities, namely the maintenance team, engineering, middle management, program management and, also, the participation of experts from the USAF for the continuous improvement of the program. This initiative was made possible through the implementation of rapid improvement events or kaizen\(^1\) events, identifying a number of areas and tasks that could be optimized in order to reduce the takt time\(^2\) of the process, to achieve a production of at least six aircraft per year (in the first five years of production, delivery never exceeded two aircraft).

As a major improvement, the fixed dock type of maintenance moved to flow maintenance, and there was the implementation of four work cells, takt time of 50 days, levelling the workload in each cell, reviewing the entire planning with dismemberment of the work cards\(^3\), reviewing the sequence of the modification process, standardizing working instructions, normal workspace tool (6S), daily preparation and delivering the material on the dock and introducing visual management boards (Leite, 2010). All these factors have lead to a strategic alignment between the top management and the production teams. This alignment combined with leadership, communication and utilization of human potential enabled for an increase in productivity of over 60% in a year, which consistently remained in the last five years of the program and efficiently allowed, with the same human resources, for the accomplishment of the goals (see Figure 1).

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1. **Kaizen** – Japanese word meaning "change for the better".
2. **Takt Time** – German word meaning "pace" or "step" defined by the client that results from dividing the available production time by the customer needs.
3. **Work card** - Document where maintenance actions are recommended divided into Basic Cards (eg.: scheduled inspections), Additional Cards (eg.: fulfillment of a technical nature) Deriving Cards (eg.: repairs or replacements not scheduled).
The achieved results of this modification program, contrasting with difficulties in other maintenance areas (due to the high variability of downtime and the difficult management in allocating resources for the execution of tasks) resulted in the use of the lean philosophy to the F-16 scheduled maintenance, particularly the Phase Inspections, which occur every 300 Flight Hours (FH).

The average downtime in these inspections was 72 days, the works were carried out in a fixed dock, the work-in-progress (WIP) ranged between four and five aircrafts and the shortage of human and material resources made it impossible to run all this simultaneously. The change resulted in having a maximum of two aircraft in WIP and decreasing the downtime for 35 days, resulting in an over 50% reduction (2010).

A second operation of the same type happened in late 2011, which allowed for the consolidation and improvement of the results, stabilizing the average inspection times on 35 days (see Figure 2).

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4 DMSA – Weapons Systems Maintenance Direction.
The success of these interventions can be credited to the careful mapping of the value chain; the creation of a future state aligned with the takt time, the creation of balancing standard workloads and the correct assignment of priorities. The resulting alignment of all sub-processes and the implementation of visual management tools allowed us to identify process problems and quickly act to solve them. Due to the encouraging results in the F-16 fleet, this experience was tried in other fleets. Among other lean thinking applications in the Air Force aircraft maintenance, the following results are highlighted:

— Helicopter Alouette III Intermediate Maintenance, 40% reduction in downtime (2008-2009);
— C-130 Intermediate Maintenance, a decrease of 40%, with limited support (2009);
— Epsilon TB-30 Intermediate Maintenance, an average 29% reduction in 250HV and 500HV inspections; Overhaul Maintenance (IRAN^5), average reduction of 33% (PoAF) and 56% (outsourcing) in downtime and about 60% cost reduction of (in detail in section 4.2 of this article).

^5 IRAN - Inspect and Repair As Necessary.
3. “Lean Technics”

3.1. Origins and Evolution

The lean management philosophy is based on the TPS (Toyota Production System) and seeks to create a culture based on respect for people and continuous improvement, by adding value through the relentless pursuit of waste. For scientific problem solving with the PDSA - Plan, Do, Study, Act; methodology was a fundamental tool for organization learning.

The lean thinking goes beyond a "roadmap" to implement changes, being considered as a strategy for operations restructuring at the processes level (Silva, 2014), which contributes to the transformation of attitude and corporate culture / organizational. It is an operating process to simplify the way that material and information are managed, being a way of thinking and thus acting.

It was based on the study presented by Womack et al. (1990), in the book "The Machine That Changed the World" that the USAF joint efforts, in 1993, with the Massachusetts Institute of Technology (MIT), in a partnership that aimed to study the TPS model and its implementation to the military aeronautics.

The lean management transformation and implementation process is fundamentally based on respect for people, the leadership and “buy-in6” skills, process flow optimization and it is focused on continuous improvement, with the goal of creating value through the elimination waste.

The eight typified wastes in the aircraft maintenance industry have been consistent over the improvement processes developed in the different weapons systems: over processing (inherently bureaucratic); inventory; transportation (aircraft / equipment); standby time; movement (people); defects (error correction); overproduction (over maintenance); non-use of human potential.

In order to eliminate these wastes, some main lean tools have been used: value stream mapping, rapid improvement events or kaizen, A3-PDSA, 6S (5S + 1), visual management, kanban, standard work.

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6 Buy-in - Ability to promote the people's acceptance and commitment to a particular goal.
3.2. Value Stream Mapping
One of the most important tools in the implementation of lean process methodology consists of mapping the value chain (see Figure 3), used to map the flow of processes. There are three phases: current situation identification, drawing the ideal situation and mapping the future situation (generated from the analysis of the first and from a set of inputs from vision created with the second). This leads to the creation of a planning action plan that leads to the implementation of the future situation and consequent process improvement.

3.3. Rapid Improvement Events
The rapid improvement event methodology (see Figure 4) is one of the most powerful lean solutions that allow us to create, in a short time, an enhancer mechanism for radical changes in the organization’s current processes and activities; being generators of quick and significant results, creating an environment of optimism, confidence, enthusiasm and satisfaction among participants (see Figure 5). It also allows us to create the new desired situation by successive advances.
3.4. A3-PDSA

The A3PDSA (Plan Do, Study, Act) methodology is based on the Deming cycle (Plan, Do, Check, Act), the main action of the continuous improvement philosophy. It is, almost worldwide, oriented to problem solving, with application directed at identifying the causes, while pursuing the best solution (see Figure 6).

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Figure 5 – Rapid improvement event in Air Base no. 5

A3 – Its name arises from the use of an A3 sheet for placement information.
The implementation of the lean management methodology, and its steps, follows the practice applied in the Portuguese Air Force described in "Manual Tático de Implementação de Lean Management" (Ribeiro, 2012), represented by the flow diagram process (Figure 7):
3.5. **6S (5S+1)**

The 6S is a workplace management and organization method widely accepted and easy to perform, which features quick and visible results, perceptible by all. It immediately translates the visible face of ongoing organizational transformation. In addition to reassuring stakeholders, it motivates even the most sceptical ones, making everybody believe that the adoption of a more active role in the process may lead to increased discipline, greater accuracy and more efficient working methods.

3.6. **Visual Management**

The visual management tools are considered as communication tools that allow, in real time, for a quick decision by analysing and monitoring the performance metrics, amplifying the transparency of the process. This, inherently, increases the trust between
the various levels of management, serving as a mitigating element to the resistance to change and an aggregator of all the team to achieve the desired objectives (see Figure 8).

Figure 8 – Epsilon fleet, overhaul visual management tool

Source: MNT101® (adapted)

While referring to active or passive information, this tool controls the active, exposed in the frames of visual management, making it possible to know the status of each process in five seconds and, in this way, to have a rapid decision making process. The information, recorded in the information systems, while considered passive, requires effort and time to be accessed.

3.7. Kanbans

Kanban is a Japanese word, meaning card or signal, which represents the beginning of a need for replacement material. Ensuring the pull operation system components through visual management have very successfully been used as a facilitator and a communicator element, between maintenance and the logistics areas.

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8 MNT101 – Squadron 101 Maintenance.
3.8. **Standard Working Instructions**

Process standardization is one of the most relevant lean thinking characteristics, aimed at performing tasks in the same way, in the same working sequence, by all stakeholders; using the same tools and knowledge to intervene in unpredictable situations, increasing efficiency of the process, with repetition benefits.

4. **Challenges and Results**

Maintenance and logistics play a key role in resource and service distribution. They aim to keep the aircraft in top condition, to ensure airworthiness and capability for immediate response at the lowest cost. Maintenance should be organized in order to allow the aircraft to be in non-operating conditions for the shortest possible time. This is incidentally, one of the main challenges of any weapons system logistic chain.

4.1. **F-16 Implementation**

The success and improvement achieved through the implementation of tools and concepts of lean management philosophy, in the F-16 aircraft modification and in the Phase Inspections, led to its application to other areas of maintenance, particularly in procedures of: regeneration of Augmentor engine module potential (Gouveia, 2010) (see Figure 9); Inlet Fan Module mounting (Correia, 2012); Mechanical, Hydraulic and Motor Systems (Bajouco, 2011) and Avionics (Carvalho, 2011) Supply Chains Optimization.

*Figure 9 – Examples of improvements in the Augmentor engine module potential regeneration*

Source: (Gouveia, 2010)
Other studies were made with the objective of improving the supply chain and repair material fluidity, and to optimize the sorties generation of this weapon system, including training, operational planning and front line maintenance.

4.1.1. Lean Logistics

A lean management methodology implementation project was developed to: improve the supply chain and repair material efficiency and effectiveness, ensuring its delivery at the right time; seek a financial benefit of €1.5 million a year; halve the time between requesting the material and its satisfaction.

Initially, there was an excessive inventory with a low stock rotation, an acquisition material process based on historical and inaccurate forecasts, information gaps and long transportation times were found.

The big challenge was to change from a traditional logistics concept to a lean logistics one, shifting the paradigm. The main differences between these two systems are summarized in Figure 10.

<table>
<thead>
<tr>
<th>TRADITIONAL LOGISTICS</th>
<th>LEAN LOGISTICS</th>
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</thead>
<tbody>
<tr>
<td><strong>Characteristics</strong></td>
<td></td>
</tr>
<tr>
<td>High inventory</td>
<td>Minor inventory</td>
</tr>
<tr>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Uncertainty in transportation</td>
<td>Reliable delivery</td>
</tr>
<tr>
<td>Repair in batches</td>
<td>Optimum repair flow</td>
</tr>
<tr>
<td>Static process</td>
<td>Continuous improvement</td>
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<tr>
<td>High cost</td>
<td>Minor investment</td>
</tr>
<tr>
<td><strong>Main Process</strong></td>
<td></td>
</tr>
<tr>
<td>High capital investment</td>
<td>Lean maintenance in 2 levels</td>
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<tr>
<td>High stock in peacetime</td>
<td>Minor dedicated stocks</td>
</tr>
<tr>
<td>High availability of parts</td>
<td>Oriented mission support</td>
</tr>
<tr>
<td><strong>Principals</strong></td>
<td></td>
</tr>
<tr>
<td>High inventory determines the infrastructure</td>
<td>Innovation simplifies the infrastructure</td>
</tr>
</tbody>
</table>

The change or transition from the current to the desired future state was achieved through various rapid improvement events which implied a direct relationship "supplier - Air Base" with intermediate passage elimination, namely: the central warehouse of the Portuguese Air Force, via delegation and decentralization of tasks; intermediate bench redundancies and stock elimination; main warehouse reorganization by needs frequency; creation of kanbans with material for the "Top 20" of the unannounced failures in the
dedicated maintenance docks. During this process, outside support was crucial ("Lean Sensei - based on SBS - Simpler Business System").

The main results, as shown in Figure 11, represent the resulting significant improvements. As a result, the material is acquired according to the actual demands, resulting in simpler processes, inventory cost reduction and faster material delivery.

![Figure 11 – F-16 lean logistics implementation results](image)

<table>
<thead>
<tr>
<th>F-16 Logistics Chain Improvement</th>
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<tbody>
<tr>
<td>- May 2010 – Vision and value stream mapping</td>
</tr>
<tr>
<td>- June to December 2010 – One kaizen event per month</td>
</tr>
</tbody>
</table>

**Results**

- 10 kanbans implemented (80% procurement)
- Staff involved - 44% reduction
- Inventory reduction - € 14.7 million
- Acquisitions satisfaction time - 79% reduction
- Consumables purchase - 56% reduction per year

### 4.1.2. F-16 Sorties Generation

To achieve the defined optimization objectives regarding the sorties generation, based on the value stream mapping chain, opportunities for improvement were identified in aspects related to: high dispersion of the aircraft; seasonal sorties; changes to the planning; aircraft preparation time.

The new implementation and execution procedures confirmed the objectives of: 15% reduction in the effective aircraft preparation time; 50% reduction in the pilots and mechanics qualification time, as well as, the number of instructors; elimination of sorties cancellation.

To achieve these results, one of the intervention areas was the support equipment maintenance, in order to increase its availability, because many F-16 maintenance sectors depend on its operation to perform maintenance actions. The implementation and validation of the improvement opportunities identified, enabled us to achieve, in two months, an increase of 20% in the availability of these equipment (Meneses, 2012).

This F-16 sortie generation improvement project, together with the intervention in the logistics and material repair chains, allow us to make the flight operations, maintenance
and material supply more effective and efficient, by focusing on value creation, waste eliminating, cost reduction and continuous improvement.

### 4.2. Epsilon Implementation

Squadron 101 Maintenance (MNT101), located at Air Base no.1 in Sintra, is responsible for the maintenance of the Epsilon TB-30, Chipmunk Mk-20, Dornier DO-27 and ASK-21 glider fleets. Firm in its motto "Nothing is Permanent Except Change", it has, successively, wagered continuous improvement bearing in mind its human and material resources optimization.

A clear example of this change is the choice to carry out the maintenance actions that occur in the Epsilon fleet every 2000HV or eight years (whichever comes first), outsourcing only structural repairs and painting. This type of maintenance was, until 2007, done entirely by external contracting.

Verifying that this regeneration potential cadence did not follow the aircraft pace to achieve the Potential Limit Time (PLT), in 2010, the lean maintenance implementation process began in MNT101. This decision, based on the excellent results obtained with the F-16 modification program has made it possible, extremely swiftly and efficiently, to carry out the number of IRANs needed to support the 101 Squadron mission.

With this implementation, the overhaul maintenance capability significantly increased. There was an increase in cell potential, driven by a significant reduction in downtime of the aircraft, as a result of a better work flow.

In the first stage, the optimization of maintenance actions and 3rd tier called “Small” cell and engine inspections – 50FH and 100FH were analysed. “Small Inspections” represent, on average, about 80% of the total number of annual inspections. The “Major Inspections” of the engine – 400FH (2011) and cell – 250FH and 500FH (2012) were not analysed.

To overcome resistance to change, it is crucial to have training and practice (see Figure 12 and Figure 13), because lean thinking is internalized only in the process of experimentation. In fact, “leaners” learns only by doing. The best solutions are those that result from the involvement and contribution of stakeholders in the processes themselves.
In addition to the value stream mapping and developing the action plan, there was the implementation of the 6S tool and visual management elements on the work docks, the maintenance of cells organization according to inspection type, the work sequences optimization and the takt time definition for each type of inspection. All work cards have been revised so as to be daily discriminated, allowing people, in advance, to know what tasks need to be performed and the required material.

The implemented optimization and process improvements and the acquired knowledge make it possible, through the absence of constraints, to execute and to implement the four steps that comprise the 3rd echelon maintenance (disassembly, structural repair, paint, assembly) in just six months. This is, when compared to the previous situation, an average reduction in aircraft downtimes of 33% (∼ 9 months, PoAF) and 56% (∼ 13.5 months, outsourcing) and a cost reduction of 60%.

The lean thinking implementation in the Epsilon fleet caused, based on the comparison with the previous experience and selection of best practices (benchmarking), benefits in all fleets under the responsibility of MNT101. This was particularly noticed on the identification, establishment and implementation of kits of material. These kits, intended for scheduled inspections, overhauls of the various components and aircraft (e.g.: landings gears, actuators, wheels, ...) systems, as well as kanbans for the "Top 10" of breakdown, avoid the intervention of the maintenance teams in the preparation of material requisitions for scheduled maintenance actions, focusing them on value-added tasks.
In terms of the logistics flow management, the joint work with the Fleet Management and Logistics Area, the consumption and acquisition of rotatable material, based on detailed forecasts and depending on the date of the need, provided an annual reduction in costs of acquisition of approximately 30% (2010/2012). These processes continue to be subject to constant review in order to eliminate constraints, to achieve the desired fluidity in the logistics chain.

The supporting status and the achievements in the 3rd echelon and “Small Inspections” maintenance processes boosted the lean implementation on the 250HV and 500HV airframe “Major Inspections”, spreading this methodology of management to all maintenance programs for the Epsilon TB-30 fleet.

The followed method in this implementation was the A3-PDSA, as a way of aligning the strategic vision from top management to the maintenance teams, in conjunction with rapid improvement events and value stream mapping.

The benefits of this intervention resulted in the implementation of visual management tools, work sequence optimization, manpower utilization and an average decrease in downtime of the aircraft of 29% (Figure 14).
During this intervention, the development and application of a questionnaire made it possible to assess the motivation/satisfaction degree of the Epsilon fleet maintenance teams elements. Regarding this lean philosophy implementation, in scheduled inspections of 250FH and 500FH, the degree of motivation/satisfaction of the people involved was 84%.

On the continuous improvement paradigms point of view, resources optimization, value addition, leadership work, communication, human potential involvement and employment, each MNT101 member team has had the notion that each improvement opportunity identified and implemented may have contributed to the decrease in operating costs/maintenance. Also, increasing the quality of the work done by eliminating waste. These factors are at the root of the consecutive achieved results.
5. Conclusions

Lean thinking in the Portuguese Air Force has been consolidated, based on the knowledge that has been created in the organization. This is reflected by the increased ability to have a maintenance proficiency able to handle the mission requirements.

This organizational culture has been achieved through a set of implementations, over several years. The process as resulted in the following conclusions: confirmation of the expected results regarding the implementation of lean methodology in aircraft maintenance; downtime reducing; logistics chain improvements; decreasing support costs; increasing effective maintainability.

It is considered that the results were made possible by the methodological rigor put into the: analysis of the value chain processes; construction of objectives based on the A3-PDSA; practical changes based on rapid improvement events (kaizen).

The necessary organizational support has been manifested in the strategic alignment and commitment of everyone involved in the process, from top management to the maintenance teams. The implementation of lean tools and techniques must be supported by culture organizational, otherwise it will not work.

The effectiveness and efficiency of "Lean Technics" are based on two pillars, namely, the people and the culture. They must be connected by the leadership, symbolically represented in Figure 15.

![Figure 15 – Pillars of “Lean Technics”](image)

The quality aircraft maintenance improvement is achieved with the contribution and daily commitment of everyone involved, which is consequently reflected in the strengthening of security and cost reduction.
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