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Measuring Compliance During Aircraft (Component) Redeliveries at KLM Engineering & Maintenance

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Abstract. Aircraft and aircraft components are redelivered to the next operator or owner during the phase-out process. During this process the operator is required by law and contract requirements to show compliance with maintenance procedures. At KLM E&M the phase-out documentation process is under increasing scrutiny as the number of aircraft phase-outs is assumed to rise in the coming years. The compliance process is investigated in order to measure, analyze and improve compliance with regard to maintenance data and record keeping during aircraft (component) redeliveries. For this purpose a benchmarking study is conducted to identify process bottlenecks. This study proved that in the case of KLM E&M phase-out, Landing Gears Life Limited Parts (LG LLPs) form the major bottleneck. Subsequently, an aircraft compliance model is developed to support the compliance cycle. As a case study, the documentation of LG LLPs of KLM's Boeing B737 aircraft fleet is investigated in this research. LG LLPs which are most frequently interchanged and installed on the nose gear miss the highest percentage of documentation necessary to prove back-to-birth traceability (a traceable history of a component over its life), which is a necessary feature from a phase-out perspective. On the basis of the compliance model and the observed data, several improvements to the phase-out process are proposed.

Keywords. Aircraft maintenance, phase-out, traceability

Introduction

Aircraft record keeping is a complicated process, involving thousands of parts, subsystems and systems as well as multiple interactions with these parts over aircraft life – typically ranging from 30 to 40 years. Furthermore, record keeping and storage involves a variety of physical and digital locations (e.g. hangars, line maintenance stations, workstations, tablets, paper-based print-outs, etc.), and involves many stakeholders. Each stakeholder may have a different perception and priority concerning the documentation process. Managing the diversification of data and records, where thousands of paper files, output from a variety of IT systems and even microfilms are involved, can prove to be costly and time demanding.

During aircraft phase-out, defined as the handover of an aircraft (component) to a subsequent owner, it is necessary to prove to the authorities and the next owner that all necessary operational and maintenance activities have been performed correctly, or have been duly rectified if not performed correctly. In other words, *compliance* with regulatory provisions and business standards is a must. During the phase-out process many sections, departments and divisions are involved, because during the service life of an aircraft it receives maintenance in different places [1], as recorded by various paper-based or software systems under the banner of Product Lifecycle Management, or PLM [2,3,4]. The operator is required by the competent authorities to redeliver the aircraft (components) in an airworthy state, as regulated by national aviation authorities (e.g., the European Aviation Safety Agency (EASA) for large parts of Europe). Furthermore, any contractual (lease) requirements associated with an aircraft should be complied with during hand-over. To prove compliance, it is necessary to keep records of all performed activities, and to retrieve and show these documents upon phase-out to the next owner. However, retrieving all the necessary documents is considered to be a very difficult, inefficient and time consuming task.

The goal of this paper is to analyze the current process of aircraft record collection during phase-out and to propose a documentation compliance model to assist in the phase-out process. This requires definition and identification of waste in the current compliance process, modelling of this process as well as validation of this model via analysis of a specific phase-out example, which also highlights specific improvement opportunities. The remainder of this paper follows this basic structure.

1. State of the art in phase-out compliance

Aircraft phase-out processes are, to the best of the authors' knowledge, not covered by existing scientific literature. No specific methods are available to model, analyze and improve the phase-out process of an operator. As such, for the purpose of thoroughly investigating phase-out compliance, the Define-Measure-Analyze-Improve-Control (DMAIC) method from the Six Sigma process improvement methodology is adopted [5]. In applying DMAIC to the phase-out problem, specification of the involved data and records, representation of the current process and benchmarking of its performance are involved, as discussed in the next sections.

1.1 Specification Maintenance Data & Records

In general, a maintenance provider is responsible for generating and storing the vast majority of documentation related to proof of compliance with respect to continued airworthiness of an aircraft. As such, a maintenance provider needs to comply with regulations from the relevant aviation authority (e.g., the European Aviation Safety Agency (EASA)). Furthermore, requirements from the operator (current owner or lessor of the aircraft) as well as any requirements of a lease company (potentially the current owner, in case of lease constructions) must be respected. Therefore the variety of documents at aircraft (component) redelivery is considerable high (see Figure 1). This figure clearly shows the variety and size of document gathering and controlling during the phase-out process. At KLM Engineering & Maintenance, the standardized list of document categories (note: not individual documents!) approaches 100 in number.

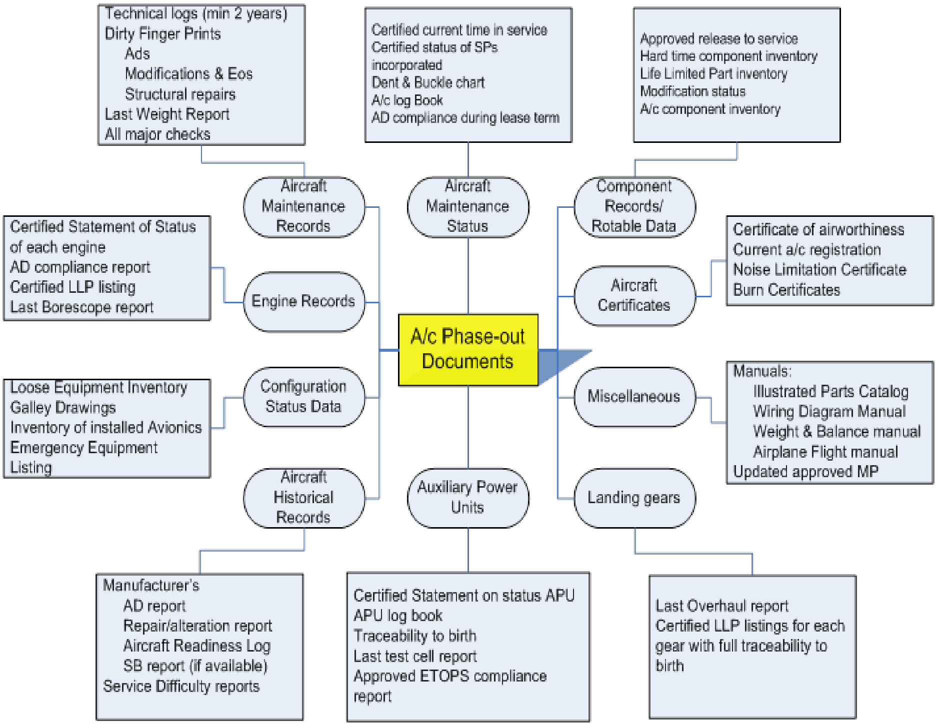

Figure 1. Aircraft phase-out documentation and records.

1.2 Consolidation Phase-out process

The current phase-out process has been reconstructed from existing procedures. Furthermore, estimates of phase-out process duration have been derived from in-house project reports. Table 1 clearly shows that the entire process takes about 33 weeks and is divided into 8 different steps [6]; data for this table has been compiled by considering the average time traces of 18 individual phase-out projects. Each of the 8 phase-out process steps are analyzed. Step 1, 2 and 3 are routine steps: These are performed at the start of each AC redelivery project and take up to 12 weeks. This long period of time can be explained somewhat by an illustrative example. Consider that for the phase-out of a 20-year old Boeing 737, the following is required:

- Approximately 200 boxes of paper (80,000 pages of hard copy documents) of data and records are received by the Phase-out Team. Eventually only about 36 boxes will be handed over to the next operator or owner after documents filtering and controlling.

- Most of the boxes are in Iron Mountain (Static Archive E&M). At this moment there are about 20,000 boxes of E&M data in the static archive present.

- Also documentation should be gathered from different local archives, such as from the Landing Gears Department, Engine Services, Aircraft Structures Department and other.

Table 1. Phase-out process steps and duration.

Phase-out process step	Avoidable	Routine	Duration	% of total time
1 Requesting phase-out data		**X**	**4 weeks**	12%
2 Collecting phase-out data		**X**	**4 weeks**	12%
3 Controlling received data		**X**	**4 weeks**	12%
4 Sorting out received data	**X**		**8 weeks**	24%
5 Searching missing documents	**X**		**5 weeks**	15%
6 Final preliminary data set		**X**	**1 weeks**	3%
7 Handing over data and solving open issues	**X**		**6 weeks**	18%
8 Final updates phase-out data		X	1 weeks	3%
Total	**3**	**5**	**33 weeks**	**100%**

Given the large amount of data, the number of departments involved as well as revenue-generating functions and parallel phase-out activities performed during the first three steps, the 12 week time set for requesting, collecting and receiving cannot be significantly shortened. Steps 1, 2 and 3 are considered routine steps and the time used in these steps cannot be considered avoidable.

Following step 3, the aircraft will be grounded and is not allowed to make more flights. This implies that from step 4 onwards, all the steps of the process should be performed as quickly as possible, but the reality is that step 4 is the longest step (see Table 1). One can furthermore observe in Table 1 that steps 4 and 5 are about sorting out the received data and searching for the missing documents. If the received data is correct and no documents are missing, these steps would not have to be taken; therefore these steps are considered as Avoidable. Similarly, step 7 can be avoided if the data which is handed over contains no mistakes and incomplete documents. The daily reality is that the steps 3, 4 and 7 take the most time and are the most labor intensive ones. Table 1 also shows that about 57% of the time spent by the Phase-out Team is Avoidable.

2. Aircraft Phase-out Compliance Model

Given the previous findings, there is a necessity to construct a model of the current phase-out process, as well as its to-be counterpart, to achieve savings with respect to the avoidable (wasteful) process steps. In this section, construction of an Aircraft Phase-out Compliance Model is discussed. The building blocks of the model are given in Figure 2, where the model depicts the compliance cycle.

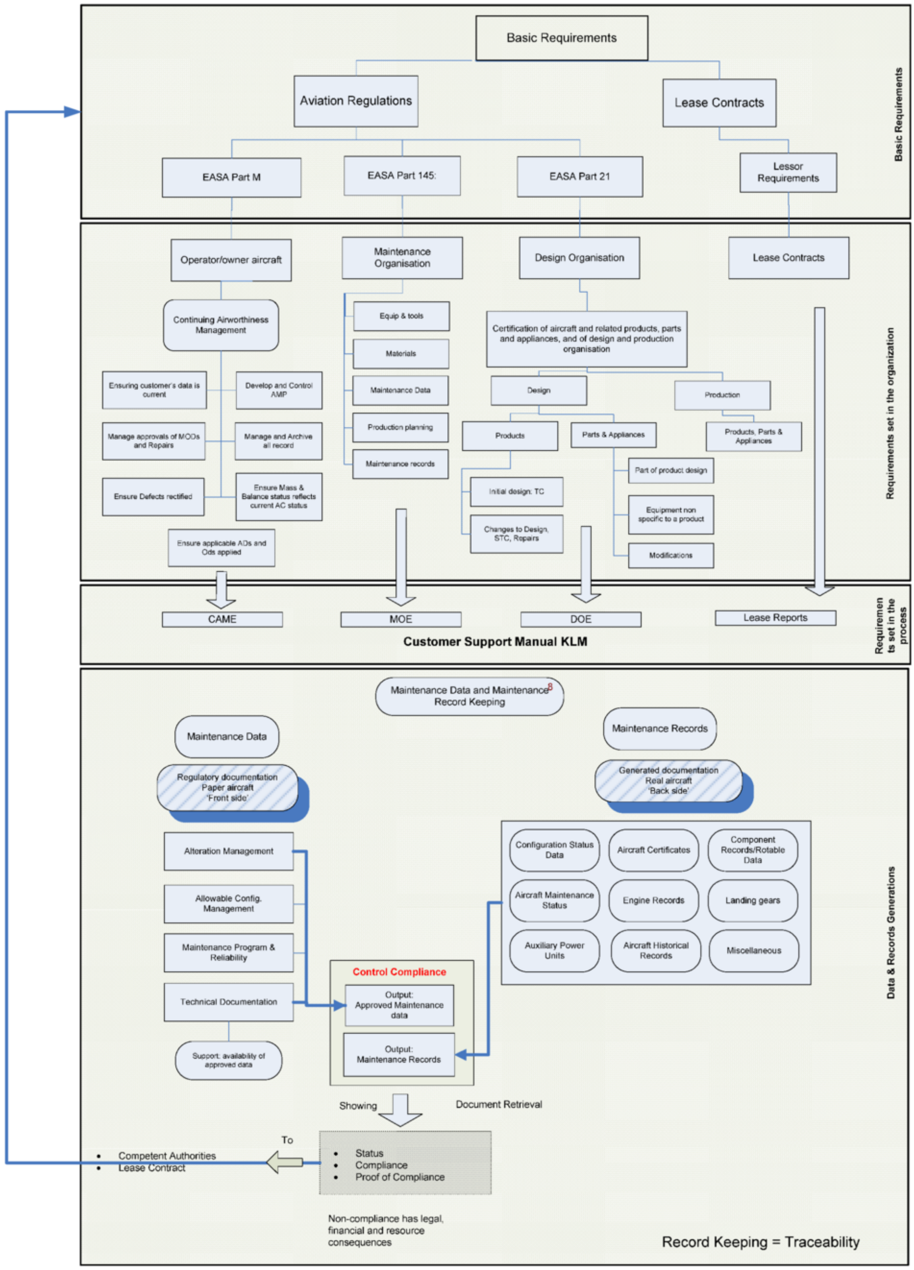

Figure 2. Aircraft Phase-out Compliance Model.

Four main building blocks can be distinguished: 1) basic requirements coming from regulators and/or lease companies, as stipulated contractually in the latter case; 2) organizational requirements derived from the different organizational roles involved in operating and maintaining the aircraft (as represented by the operator, maintainer and design organizations); 3) process requirements – which are specific to the process implemented by the organization running the phase-out process; 4) data and record generation, which deals with the actual data and records being generated over the aircraft life on the one hand, compared to the legislative and design-required documentation on the other hand. A full match of approved maintenance data (the output of the regulatory side of documentation) with maintenance records (the output of the generated operational aircraft documentation) is sufficient for showing formal proof of compliance, which is the necessary end state of the phase-out process from a documentation perspective.

The Aircraft Compliance Model can be used in any maintenance organization; however it should be modified in order to depict the organization's compliance cycles. In the next section, a case study concerning documentation of landing gear Life Limited Parts (LLPs) is considered, where the object of study is a representative aircraft subsystem necessitating phase-out proof of compliance at times of hand-over.

3. Landing gear phase-out case study

During redelivery of landing gear LLPs, compliance with law [7] and lease contracts should be performed. First of all it is essential to find out about the means and records which the Landing Gears Department has available to comply with the requirements. The right part of Figure 3 shows these documents and records. On the left side the documents and records which are required according to the law and market. During the extensive analysis of the Landing Gears data measurements the quality of the available documentation is investigated.

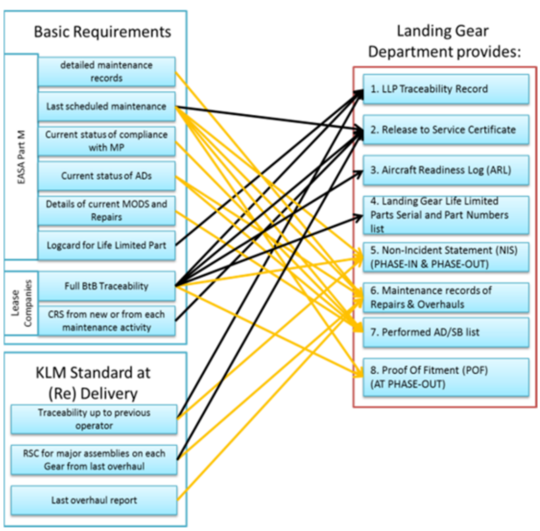

Figure 3. Landing Gear compliance – requirements and records.

The Landing Gear Department has eight documents available to prove the airworthiness of a Life Limited Part specific to a Landing Gear. These are briefly explained below:

1. **Life Limited Parts Traceability Record:** This is one of the most extensive and elaborated document. Various information and details about the specific LLP are stated in this document
2. **Release to Service Certificate:** This document is explicitly required by Aviation Regulations. EASA Part M.A. 803 (a) states: "A Certificate of Release to Service shall be issued at the completion of any maintenance carried out on an AC component." As stated earlier, major Landing Gear Maintenance at E&M is performed by vendors. Therefore every time a component or a complete Landing Gear receives maintenance and is considered airworthy again, a Release to Service Certificate (RSC) must be provided.
3. **AC Readiness Log:** This is an official hard copy document which the operator has to have in its archive. It is one of the Original Delivery Records which is provided by the OEM to the operator.
4. **Landing Gear Life Limited Parts Serial and Part Numbers list:** This is an official hard copy document which the operator has to have in its archive. It is one of the Original Delivery Records which is provided by the OEM to the operator.
5. **Non-Incident Statement:** This statement which is signed and stamped by KLM states that during the operational life time of the component within KLM no major incidents have occurred where the specific component was involved. However, this document is not regulatory required, but it is only provided upon request by KLM to the Lease Company or next operator.
6. **Maintenance records of Repairs & Modifications of the most recent work performed:** Examples are Dirty Finger Prints of the maintenance provided to a LLP.
7. **Performed AD/SB list:** This is a list of performed Airworthiness Directives or Service Bulletins, the ADs and SBs are performed as Central Engineering Orders (CEOs))
8. **Proof Of Fitment:** If a component of a Gear has been changed separately, in other words not at the standard Time Between Overhaul (TBO), then at redelivery of the Gear the next operator or Lease Company demands a Dirty Finger Print(DFP) of the maintenance task which the component received during the maintenance job. If the operator cannot provide that specific DFP, then the AC will be inspected and a statement will be signed by the inspector in order to prove the specific components' fitment was according to the standards. This statement is called Proof Of Fitment and is provided by the operator to the customer at the time of Gear redelivery.

The arrows in Figure 3 show the connection between the basic requirements and the available documents of the department. These arrows show the available resources of the department to comply with the rules and requirements. There is however a distinction between the eight documents of the department: the number 5 up 8 can only be required at Gear redelivery. The first 4 documents are needed to show that the current status of the component is according to rules. This difference is illustrated with the black and orange colors of the arrows. Therefore, by controlling the first four documents of a LLP one can find out about its traceability.

In the following sections, quantitative analysis is carried out with respect to specific landing gear LLPs. There are in total 97 different LLPs [8] which account for 8481 individual parts. Analyzing the documents of in total 8481 components is not feasible, therefore the available information about the components is used to choose such samples that they would give a good indication of the complete documentation quality of the all the components.

In Figure 4 some indicative results are presented based on the installation position and price of the measured LLPs. One can see that LLPs which are installed on the Nose Gear of B737-300/400 have the poorest documentation. The Main Gears of the 300 and 400 types come on the second place.

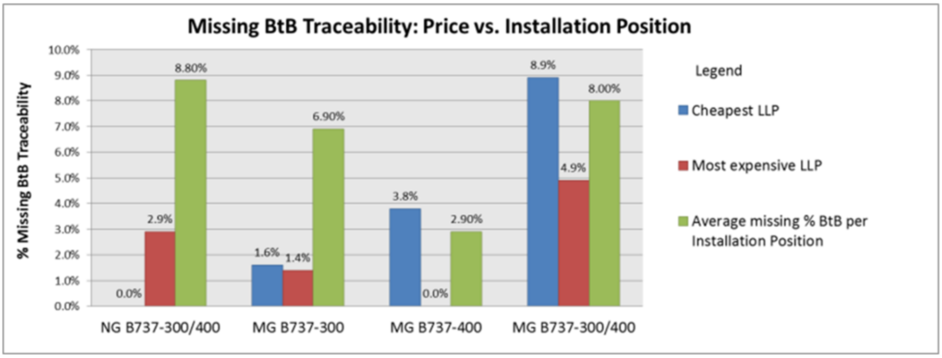

Figure 4. LLP installation position versus missing documentation for nose and main landing gears (NG; MG).

Results are also categorized based on the frequency of interchangeability. As Figure 5 shows, the LLPs with the highest frequency of interchangeability (18 months) have the poorest documentation; hence, miss the highest percentage of documentation which can prove traceability of the Lease Contract Requirements.

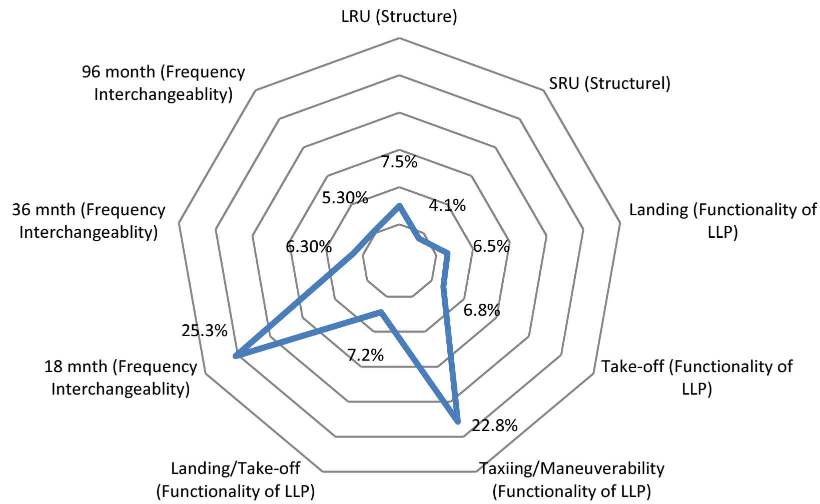

Figure 5. Frequency of interchangeability versus missing documentation.

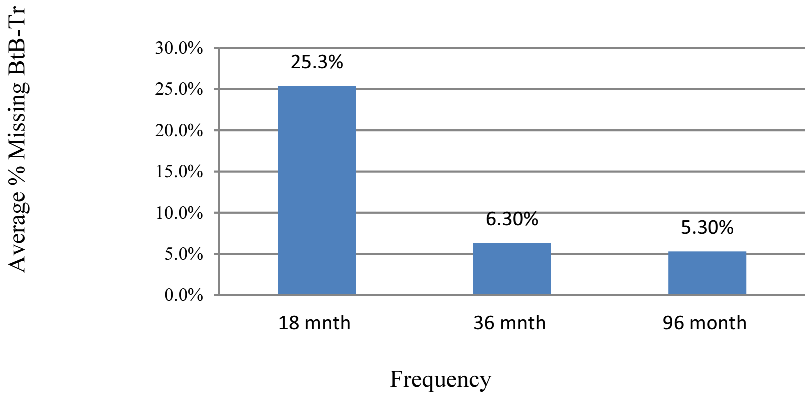

Figure 6. interchange frequency against average missing documentation.

Figure 6 shows a summarized overview of interchange frequency versus missing documentation. Notably, components which are interchanged more often (18 months) miss most documentation compared to the ones which are interchanged less often (36 or 96 months).

4. Conclusions

A generic model to identify aircraft phase-out requirements, associated record keeping and resulting compliance (or lack there-of) has been introduced in this paper. Though some steps have been abbreviated or omitted because of confidentiality, application to a landing gear case study shows the ability to identify documentation requirements and quantify shortcomings in documentation at phase-out.
Recommendations for future research include further testing and validation of the proposed model for more aircraft (sub)systems, as well as providing more detailed guidelines for translation of regulatory and operational requirements to documentation generation. Finally, the capability of the model to suggest areas for improvement in current phase-out process must be highlighted in further research. Though the model has been used within this research for this purpose, aspects of confidentiality prevent wider dissemination of these recommendations. Future research should alleviate this.

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