

Method for maintenance planning of aircraft engines

The present invention relates to a method for maintenance planning of aircraft engines.

In the technical field of maintenance or servicing of aircraft engines, it is known to maintain them according to fixed maintenance intervals. Furthermore, there may be additional workshop visits, so-called shop visits, which are carried out, for example, depending on an acquired or calculated engine condition or also in the event of a (component) failure. The maintenance intervals are often specified by the engine manufacturer or the airline operating the engine.

The maintenance intervals specified by the engine manufacturers are usually conservative and not optimised in terms of cost and/or maintenance effort. Against this background, approaches have been developed in the state of the art to optimise servicing/maintenance plans for individual engines by means of software. This approach is currently predominant in maintenance planning for aircraft engines. In such an individual optimisation, there may be conflicting external influencing factors that increase the complexity of the optimisation. For example, one may potentially save effort by maximising the maintenance intervals, as one may possibly save a shop visit over the entire lifetime of the engine. However, there is also the effect that later shop visits are usually more expensive (mainly due to rising material prices), so depending on the assumptions made, a different optimum maintenance interval may result.

If a whole engine fleet is considered, an optimum for the maintenance intervals of the individual engines is usually different from the optimum for the individual optimisation of the same engines. This results in a large optimisation potential for engine fleets, which can be increased compared to the individual optimisation of engines. However, due to the high complexity, optimisation across an entire engine fleet and taking into account several external influencing factors also results in an NP-complete problem, which cannot be solved deterministically in a simple way, but requires sophisticated software solutions.

Against this background, it is an object of an embodiment of the present invention to provide an improved method for automated generation and optimisation of a maintenance plan for a fleet of aircraft engines.

This object is solved by a method having the features of claim 1 or claim 5, a computer program according to claim 11 or a device according to claim 12. Advantageous embodiments of the invention are the subject-matter of the dependent claims.

A first aspect of the present invention relates to a method, in particular a computer-implemented method, for automated generation of an optimised maintenance plan for a fleet of aircraft engines, the method comprising at least the following steps:

a) Acquiring input data relating to a plurality of engines representing maintenance-related information for the fleet of aircraft engines individually and/or as a whole and in particular comprising a mean service life ("Mean Time Between Shop Visits (MTBSV)") or data relating to Life limited Parts (LLP) of the engines of the engine fleet (However, this data may also represent, for example, any time or technical constraints to be met for the maintenance of the aircraft engines and/or at least one influencing factor on the effort to be expended for the maintenance of the fleet);

b) Providing an existing initial maintenance plan or generating an initial maintenance plan based on the acquired input data, in particular the MTBSV and/or LLP data, for the engines;

c) Determining a total maintenance effort for the fleet in case of an application of the initial maintenance plan, such as a total cost or a total time or material effort;

d) Sorting the engines into a defined order according to at least one criterion, in particular according to an estimated maintenance effort or estimated maintenance costs (per engine);

e) Applying at least one optimisation strategy or heuristic (exemplary optimisation strategies are described later), which may be stored in particular as an algorithm in a computer programme, to the respective engines of the engine fleet in the defined order; and

f) Outputting of an optimised maintenance plan for the engines after application of step e) (the maintenance plan may in particular comprise maintenance intervals and scopes of

the individual shop visits) and optionally additional output data comprising in particular an estimated total maintenance effort of the optimised maintenance plan, e.g. total costs or total time effort after optimisation. Preferably, the influence of the applied optimisation strategy(strategies) when optimising one of the engines on the other engines of the fleet may be taken into account in the method.

Such an optimisation method according to the first aspect of the invention makes it possible to achieve a greater savings potential by pre-sorting the engines and taking into account the interactions between the engines of the fleet according to the expected effort compared to individual optimisation. The aforementioned optimisation strategies may be pre-programmed or pre-determined optimisation algorithms or heuristics. An example of such a strategy could be an algorithm that reduces a shop visit where LLPs are to be replaced in the maintenance plan to a shop visit without replacing the LLPs, if the condition is fulfilled that less than 2 LLPs in no more than one engine module are affected.

According to a preferred embodiment, when performing step e), at least one optimisation strategy may first be applied to the first engine, wherein effects of this optimisation on the other engines in the fleet are taken into account (e.g. postponement of the shop visits, availability of spare parts, etc.) and then a total maintenance effort for the entire fleet may be determined after this sub-step. In the event that the total maintenance effort for the entire fleet is reduced by applying the strategy to the first engine, the optimisation may be maintained and it may be advanced to the next engine in the fleet or, if a predetermined termination criterion is met, the optimisation could also be terminated at this point. In the event that the total maintenance effort for the engine fleet is not reduced by applying the strategy to the first engine, either a different strategy could be applied to the first engine, or it may be advanced to the next engine without optimising the first engine, or the optimisation may be terminated. Thus, in a further preferred embodiment, optimisation of the individual engines may be performed in the pre-sorted order, with interactions between the engines being included in the consideration. In an alternative embodiment, when applying the selected optimisation strategy(strategies) sequentially, a strategy could not be applied to an engine if it altered a maintenance plan of an engine that has already been optimised previously. Such a further

refined optimisation method according to the first aspect makes it easier than the conventional one to find an optimum at fleet level, to take synergies into account and thus to achieve a greater overall optimisation or cost saving than could be achieved by optimising the individual engines individually.

According to a preferred embodiment of the invention, after sequentially applying at least one optimisation strategy or heuristic to each of the engines according to step e), the engines may be sorted again according to step d) according to the at least one criterion and, after this step, an optimisation strategy or combination of optimisation strategies may be applied again to the respective engines in the newly determined order.

In a further preferred embodiment of the invention, output data, in particular an estimated total maintenance effort or estimated total costs, may also be output in step f) in addition to the optimised maintenance plan. In this case, steps d) and e) may be iterated until a predetermined termination criterion is met on the basis of the above-mentioned output data, for example a working time reduction or cost reduction by a defined percentage.

Alternatively, a predetermined number of iteration cycles may also be defined as a termination criterion, for example. Preferably, the engines of the fleet may be re-sorted according to the at least one criterion before each new iteration.

In another preferred embodiment, a different optimisation strategy or heuristic may be applied during each iteration. Different planning strategies may also be combined during the iterations. Here, the individual aircraft engines may each be optimised individually or also as a collective, since the planning strategies for each individual aircraft engine may also have an influence on the overall planning strategy of all aircraft engines of a fleet. Accordingly, the applied method or algorithm calculates combinations that lead to low total operating costs step by step in an iterative process. For each maintenance plan, which is determined by the method in the individual iteration steps, different maintenance strategies may be selected and applied independently of each other. In a preferred embodiment, the results generated from the individual iterations may be compared with each other, in particular with the respective previously determined maintenance plan. If an applied optimisation strategy leads to a worse

result/output value than the previously determined maintenance plan, the algorithm may jump back to this previous plan and apply an alternative optimisation strategy to it. Therefore, a user does not have to manually determine and establish the strategies and synergies between the individual maintenance plans of the individual aircraft engines and sub-fleets in advance, but these are iteratively identified by the method in an automated manner. In other words, the method according to the invention may comprise a selection of predefined or pre-programmed optimisation strategies, each of which is then applied sequentially to the individual engines of the fleet and exchanged in multiple iterations until a specific termination criterion is met or a local optimum is reached.

In some embodiments, the iterative optimisation in each iteration may further comprise the step of: setting the optimised fleet maintenance plan associated with that iteration based on an aggregation of the individual aircraft engine maintenance plans resulting from that iteration.

By optimising each aircraft engine's maintenance plan individually, the maintenance plan for the fleet may also be further optimised.

In some embodiments, an interaction of maintenance actions for the individual aircraft engines may be considered for determining the maintenance plan and/or for determining the respective individual maintenance plans. For example, the availability of an aircraft engine as input data may result in an aircraft engine to be replaced being able to be replaced by the available aircraft engine at a certain point in time, whereas another aircraft engine to be replaced may only be replaced at a later point in time, since the required available aircraft engine is already provided for the earlier replacement and another aircraft engine must first be procured.

According to a second aspect of the invention, there is provided a method, in particular a computer-implemented method, for automated generation of an optimised maintenance plan for a fleet of aircraft engines, the method comprising at least the following steps:

- a) Acquiring input data relating to a plurality of engines representing information specific to the individual aircraft engines and/or related to the entire fleet and including, in

particular, a Mean Time Between Shop Visits (MTBSV) or data relating to Life limited Parts (LLP) of the engines;

b) Providing an existing initial maintenance plan or generating an initial maintenance plan based on the acquired input data, in particular the MTBSV and/or LLP data, for the engines (E1, E2, E3, E4);

c) Calculating a total maintenance effort for the fleet in case of an application of the initial maintenance plan;

d') Optimising the initial maintenance plan by means of a self-learning algorithm trained for this purpose; and

f') Outputting an optimised maintenance plan for the engines after application of step d') and/or output data comprising in particular an estimated total maintenance effort of the optimised maintenance plan. The trained algorithm may be based on machine learning and may comprise a neural network. The trained algorithm may, for example, be trained on manually optimised data sets or based on results of the automated iterative optimisation method for engine fleet maintenance plans described above.

According to a third aspect of the invention, the automated iterative approach may be combined with the machine learning based approach. For example, an automated iterative maintenance plan generated according to the first aspect of the invention may be used as the initial maintenance plan for a machine learning based optimisation method or vice versa. The automated iterative approach in this case provides one with a good starting point from which the machine learning based algorithm may quickly converge to a further optimised solution.

In any of the embodiments described above, the input data may preferably represent at least one data set from the group: mean service life/Mean Time Between Shop Visits (MTBSV); the time effort and/or the costs (Workscope) of respective types of shop visits; data relating to Life limited Parts (LLP) of the engines (E1, E2, E3, E4), in particular remaining cycles of the LLPs; engine type; replaceable small parts; availability of used and/or new spare parts; costs of used and/or new spare parts; technical specifications of the aircraft engines; the time interval for each aircraft engine since the initial registration or since the last shop visit; the availability of the same type of the respective aircraft engines planned for maintenance.

One or more of these input data may be used to generate the maintenance plan. Other input data/variables may result in completely different maintenance plans for the respective individual aircraft engine or for the fleet.

In any of the embodiments described above, the output data output in step f) or f'), respectively, may comprise one or more data sets selected from the group consisting of: next maintenance date of the aircraft engines; spare and short-term lease engine requirements for the next maintenance; material requirements for the next maintenance; working time requirements for the total maintenance plan; total cost of ownership for the engine fleet; costs per flight hour for the engine fleet; and/or cash flow.

The provision of at least one of these data enables the concrete assignment of the aircraft engines to a measure concerning maintenance.

In any of the embodiments described above, the total maintenance effort used when comparing the initial maintenance plan with the optimised maintenance plan may represent the labour effort or the material effort or the total cost of the fleet. In some embodiments, the total maintenance effort represents the labour effort or the material effort. In this regard, the labour effort may comprise the total labour hours required to perform the maintenance, the personnel required to perform the maintenance, or the costs incurred by the labour hours and/or the material required. The material effort may comprise the required spare parts and their logistical provision at the maintenance site. Methods for deriving these values from a maintenance plan are known, for example, from US 8,744,864 B2.

According to a further preferred aspect of the invention, the input data may comprise qualified estimates of market development, such as the availability of material/spare parts on the market; the material costs as well as material cost development or the availability and costs of external spare engines or green time or leasing engines. In this case, the method may be set up to output optimised maintenance plans for different scenarios in an automated way. For example, for good, neutral and bad price development on the material market.

Another aspect of the invention relates to a method for optimised maintenance of an engine fleet, wherein an optimised maintenance plan is first generated or obtained in accordance with any of the aforementioned aspects, and subsequently the engine fleet is maintained, repaired and/or overhauled in accordance with the optimised maintenance plan.

A further aspect of the invention relates to the automated execution of the above-described methods for optimising maintenance plans for engine fleets by computers or other means for data processing. Such a means in the sense of the present invention may be configured in terms of hardware and/or software, in particular comprising an, in particular digital, processing unit, in particular a microprocessor unit (CPU), which is data- or signal-connected, preferably to a memory and/or bus system, and/or one or more programs or program modules. The CPU may be configured to process commands implemented as a program stored in a memory system, to acquire input signals from a data bus and/or to output signals to a data bus. A memory system may comprise one or more, in particular different, storage media, in particular optical, magnetic, solid state and/or other non-volatile media. The program may be such that it embodies or is capable of executing the methods described herein so that the CPU may execute the steps of such methods.

In an embodiment, a computer program product may comprise, in particular be, a storage medium, in particular a non-volatile storage medium, for storing a program or having a program stored thereon, wherein execution of said program causes a system or controller, in particular a computer, to execute a method described herein or one or more of its steps.

In an embodiment, one or more, in particular all, steps of the method are carried out completely or partially automated, in particular by a computer or other data processing system.

Another aspect of the present invention relates to a computer program configured to perform the method according to the first aspect.

Another aspect of the invention relates to a device for automated generation and optimisation of a maintenance plan for aircraft engines, wherein the device is configured to perform the method according to the first aspect.

Further advantages, features and possible applications of the present invention will be apparent from the following detailed description in connection with the figures.

For this purpose, partially in a schematised way:

Fig. 1A shows a first embodiment of the present invention; and

Fig. 1B shows a second embodiment of the present invention

Fig. 1C shows a third embodiment of the present invention;

Fig. 2A shows an illustration of an initial maintenance plan;

Fig. 2B shows an illustration of an improved maintenance plan.

In the figures, the same reference signs are used throughout for the same or corresponding elements of the invention.

Fig. 1A shows a first embodiment of a method 100 for automated generation of an optimised maintenance plan for an engine fleet according to the present invention. In the present example, the method 100 is computer-implemented. For the sake of clarity, the engine fleet in the present example comprises only aircraft engines E1, E2, E3, E4.

In a first step of the method, input data 110 are acquired in a database, each relating to one or more aircraft engines E1, E2, E3, E4. The input data 110 may represent aircraft engine fleet data, customer data, manufacturer specifications, maintenance, repair and overhaul data, cost and price development data, technical specifications of the respective aircraft engines, or

market forecast data. In particular, manufacturer specifications such as service life or airline maintenance strategies are taken into account. In addition, technical and commercial information concerning repair, maintenance and overhaul is taken into account.

For example, the general engine data or engine fleet data may include one or more items from the following list: Engine type, Time since New (TSN), cycles since new (CSN), time since last shop visit (TSLSV), cycles since last shop visit (CSLSV), Entry into service date, phase out date/End of Life, status of the "Life Limited Parts" (LLPs), in particular remaining cycles for the individual parts, remaining engine performance or the configuration of the engine.

The manufacturer's specifications may comprise, for example, mandatory life limits on various parts, mandatory inspections, part numbers and configuration data of the engine.

Customer data (usually an airline) may be, for example: availability of spare engines or parts; data on the routes operated.

Maintenance, repair and overhaul data may be based in particular on the technical experience and the input of the optimisation programme operator. These may comprise, for example: Workscope of certain types of shop visits; cost development of shop visits; time availability of capacity for shop visits or the mean service life "Mean Time Between Shop Visits"/On Wing Time.

Qualified market development estimates may comprise: Availability of material/spare parts on the market; material costs as well as material cost development; availability and costs of external spare engines or greentime or lease engines.

After the input data 110 is acquired, an initial maintenance plan 140 is generated with predetermined maintenance intervals between shop visits or from entry into service for the aircraft engines E1, E2, E3, E4 as part of a chronological forward plan. The predetermined maintenance intervals may, for example, be specified by the customer or based on a maximum maintenance interval specified by the manufacturer or by law. Alternatively, a

customer-specified initial maintenance plan 140 could be entered into the method as an input data set, or the initial maintenance plan 140 could be generated based on other input data, such as the remaining cycles of the Life Limited Parts or the Mean Time Between Shop Visits.

To further optimise this initial maintenance plan 140, an automated iterative algorithm 120 is run in the embodiment example of Figure 1A. In a first step 150 of the iterative algorithm 120, a maintenance effort is estimated according to a predetermined criterion for each of the aircraft engines E1, E2, E3, E4 and the aircraft engines are then sorted according to the expected effort (in descending order). This allows the engine with the highest expected effort and thus the highest presumed savings potential to be considered first in the next step. The expected effort may be a value generated from the initial maintenance plan for the individual engines. For example, a maintenance duration, estimated maintenance costs, material efforts or a combination of these may be stored for individual operations, which are then cumulated or converted into a parameter in another way.

In the next step 160, a predetermined or in the program pre-programmed optimisation strategy or heuristic H1, H2, H3, H4 is executed on the engine (e.g. E1) with the highest expected maintenance effort. Exemplary optimisation strategies H1, H2, H3, H4 will be described in more detail later. Interactions with the maintenance planning of the other engines in the fleet are taken into account (e.g. available spare parts or time windows in the assembly hall). After applying one or more of these optimisation strategies to the first engine E1, the programme checks whether the total maintenance effort for the engine fleet has been reduced compared to the initial maintenance plan and takes into account the respective individual maintenance plans of the engines E1, E2, E3, E4 (cf. Fig. 2). If the total maintenance effort has decreased, the changes to the maintenance plans are maintained by the optimisation strategy and the algorithm continues with the optimisation of the next engine. If the total maintenance effort has not decreased or has worsened, changes to the maintenance plans are discarded by the optimisation strategy and the algorithm either selects another optimisation strategy H1,...,H4 or continues with the next engine if no more stored optimisation strategies are available.

In the following step 170, one of the predetermined or pre-programmed optimisation strategies H1,...,H4 is calculated on the engine (e.g. E2) with the second highest expected maintenance effort, and if there is a further improvement in the total maintenance effort of the fleet, it is also applied, as already described with respect to step 160. This procedure is repeated sequentially for each engine until the last engine in the fleet has been considered (step 180). In other words, the programme iterates optimisation strategies for each engine E1, E2, E3, E4 sequentially until an improvement is obtained for the entire engine fleet.

Following this iteration run in steps 160-180, a decision is made in step 190, based on a comparison of the achieved optimisation with a predefined constraint (e.g. a predefined number of iteration cycles or a predetermined desired percentage effort reduction), whether to perform another iteration. If another iteration is to be performed, an updated sorting 150 of the aircraft engines is performed based on the expected effort per engine E1, E2, E3, E4, i.e. the engines are again sorted in descending order of effort/cost. Subsequently, the engines are iteratively optimised again sequentially as described above.

In case the comparison 190 shows that no further iteration should take place, the output data 130 is output. Termination criteria could be, for example, that a target optimisation was achieved or that no further improvement was achieved in the last x iteration cycles.

The output data may represent predictions about planned maintenance dates, predictions about required material, as well as predictions about the total cost of ownership. Methods for generating such characteristic data or output data from a maintenance plan are known to the skilled person, for example, from US 8,744,864 A.

In summary, in iterative optimisation, an initial maintenance plan is optimised iteratively. First, a maintenance plan assigned to the respective iteration is defined. In each iteration, the engines are sorted into a specific sequence and processed one after the other according to a predetermined optimisation strategy. From this, a modification may be made with respect to the type or timing of maintenance actions to be taken with respect to the individual aircraft engines if an improvement is identified by applying the optimisation strategy. The

modification of the type of maintenance action may mean, for example, a change from repairing a part of an aircraft engine that was planned in the previous iteration to replacing the part with a spare part for the current iteration.

For further improvements of the optimisation method, a choice may be made between automated iterative processing as described above and an algorithm based on artificial intelligence, see Fig. 1B.

Fig. 1B shows a second embodiment of the present invention. During the automatic iterative processing according to Fig. 1A, the number of possible planning strategies increases very quickly and very strongly with the number of engines in the fleet, so that not all options can be explicitly calculated. Therefore, as an alternative or supplement to the automated iterative processing, a method based on artificial intelligence (AI) is provided. In this case, the input data 110 described above is processed using a trained self-learning algorithm, for example a tree-based algorithm, to generate output data 220 based on AI. For example, the algorithm may be manually trained by feeding it the input data and the respective optimised maintenance plans and output data sets generated by an experienced maintenance planner. Alternatively, it may be trained using existing data sets from the iterative automatic optimisation method described above according to the first embodiment. In doing so, the algorithm learns in which situations which decisions (which optimisation strategies H1, H2, etc.) are more promising than others, and uses them preferentially. The processing by AI may be activated or deactivated by a user.

Fig. 1C shows a third embodiment of the present invention. Here, a method with automated iterative processing and AI for generating a maintenance plan is shown schematically. In this case, the input data 110 is successively processed by the automated iterative algorithm 120 and the AI-based algorithm 210. It is also conceivable that processing is first performed by the AI-based algorithm 210, followed by processing by the automated iterative algorithm 120. Output data 220, 310 are generated from this. It is also conceivable to set the intensity with which the AI-based algorithm pursues strategies H1, H2, etc., or to preset strategies to be pursued, for example by a user. The use of both algorithms, i.e. automated iterative and AI-

based, is advantageous for particularly demanding models that require a lot of computing power.

The methods described in Figures 1A, 1B and 1C also enable the selection of the appropriate planning strategy for generating a maintenance plan of an aircraft engine fleet from a variety of applicable planning strategies. These include adjusting the average time between maintenance dates, allocating life limited spare parts (LLPs), and using new or previously used aircraft engines from within the organisation or from an external company. In addition, different conditions and/or restrictions specific to a particular aircraft engine fleet may be defined. Similarly, phase-out scenarios and conditions for optimisation may be defined and adapted.

Taking into account all input data and boundary conditions, a prediction for a maintenance date can be determined, minimising the total cost of ownership for each individual aircraft engine and the aircraft engine fleet.

Fig. 2A shows an exemplary illustration of an initial maintenance plan 400. Here, the required shop visits for four aircraft engines E1, E2, E3, E4 are each shown on a time axis between a start time t1 and an end time t2 or t3, which may be the end of the life cycle (EOL) of the respective aircraft engine. In the example shown, the engines E1 and E2 have the time t2 as the end of their life cycle and the engines E3 and E4 have the later time t3.

The respective status of the engines for a planned shop visit is indicated in the format Ex-Sy, where "x" represents the number of the aircraft engine and "y" represents a sequential number for the respective shop visit. Thus, E1-S2 represents the status of the aircraft engine 1 at the second shop visit in the initial maintenance plan 140.

Furthermore, the shop visits are marked with an engine symbol, which symbolises the scope of work (workscape) of the respective shop visits. Without further marking, the symbol stands for a Performance Restoration as shown for example in E1-S1, Fig. 2A. This may be a less costly maintenance operation where no parts need to be replaced, but only minor activities are

involved, such as restoring blade edges. If the symbol is enclosed in a square, it is a shop visit where life limited parts (LLPs) need to be replaced (or will soon need to be replaced) with new parts, see for example E1-S2, Fig. 2A, this is a more costly operation than Performance Restoration due to material costs and labour. If the symbol is enclosed in a dotted circle, this means a shop visit where life limited parts (LLPs) are replaced with used parts, see for example E1-S2, Fig. 2B.

The intervals between the individual shop visits of an aircraft engine symbolise the time interval to the next maintenance appointment. In this way, the time intervals of different aircraft engines can be compared, as well as the sequence in which they have to be brought into the shop for maintenance.

Fig. 2B shows an exemplary illustration of a maintenance plan 500 improved by means of a method according to an embodiment of the present invention. Exemplary optimisation strategies that may be used in the context of one of the above-mentioned methods will be explained in the following using this example.

The aim is to illustrate how different planning strategies may be combined to optimise an engine fleet in terms of expected maintenance effort or total cost of ownership.

The engines of the fleet were sorted in descending order (E1-E4) according to the estimated maintenance effort or maintenance cost as described in step 150 above. The automated iterative algorithm begins by searching for a suitable optimisation strategy for engine E1.

A first planning strategy or heuristic H1 that is applied checks for the more costly category of shop visits, where, according to the manufacturer's specifications, life limited parts (LLPs) are to be replaced by new parts, whether the matching LLPs with sufficient remaining life can be found in one of the other engines of the fleet. In the present example, the initial maintenance plan 400 for the shop visits E1-S2, E2-S2, E3-S3, E3-S3 and E4-S1 provides for such replacement of LLPs with new parts. The algorithm finds that LLPs with sufficient remaining cycles are available in the engine E2 at a suitable time, which can be used in the engine E1 for

the shop visit E1-S2, since only a few remaining cycles are left on the corresponding components of the engine E1. By transferring these used LLPs present in the engine fleet from engine E2 to engine E1 (dashed diagonal line in the maintenance plan 500), the engine E1 can continue to operate without the use of additional new parts until its planned End of Life (EOL) at time t2. After applying this strategy, the programme checks whether the measure has reduced the total maintenance effort. Since this check is positive, the programme continues with the second engine E2.

The programme does not see any applicability for optimisation strategy H1 on engine E2 and therefore checks the second planning strategy H2. This optimisation strategy checks sequentially for all engines E1, E2, E3, E4 for each shop visit where, according to the manufacturer's specifications, life limited parts (LLPs) are to be replaced by new parts, whether suitable LLPs with sufficient remaining service life can be obtained second-hand on the free market and at what price this is possible. In the present example, this strategy determines that new parts may be dispensed with in shop visit E2-S2 by sourcing used LLPs from the market. As this results in an overall improvement in cost, this optimisation is adopted. Similarly, the strategy recognises that for shop visit E3-S1, new parts may be dispensed with by sourcing used LLPs from the market.

At engine E3, the programme determines that a third planning strategy H3 could be applied. Strategy H3 checks sequentially to see if a shop visit to replace life limited parts (LLPs) with new parts may be dispensed with by increasing the scope of maintenance (workscape) of the previous shop visit. For the engine E3, the algorithm determines by this strategy that by early replacement of some LLPs with used parts in better condition in the preceding shop visit E3-S2, a less costly "performance restoration" in the last planned shop visit E3-S3 is sufficient to get through to the End of Life of E3 at time t3. This avoids having to purchase new parts shortly before the End of Life EOL of the E3 engine and thus "wasting" their life cycles. There is also an improvement in the overall view of the fleet and this change is therefore applied.

For engine E4, the programme cannot find an individual optimisation that reduces the effort even further when considered for the entire fleet. An iteration loop is thus completed.

After this iteration loop, the programme applies a fourth planning strategy H4 in a second iteration loop. This checks sequentially for all engines E1, E2, E3, E4 whether shop visits, which are due shortly before the End of Life of an engine, may be dispensed with. This strategy determines that the total costs can be reduced by taking engine E2 out of service more quickly instead of the shop visit E2-S3 and using a replacement engine (engine symbol with closed circle in Fig. 2B) for the short remaining time at this point (for this purpose, it is possible, for example, to query from the input data if a replacement engine is available in the engine fleet; alternatively, it may be compared whether leasing costs for an external engine which are stored in the input database are lower than estimated costs for a Performance Restoration).

Although exemplary embodiments have been explained in the preceding description, it should be noted that a multitude of variations are possible. It should also be noted that the exemplary embodiments are merely examples that are not intended to limit the scope of protection, the applications and the setup in any way. Rather, the preceding description provides the skilled person with a guideline for the implementation of at least one exemplary embodiment, whereby various modifications, in particular with regard to the function and arrangement of the described components, can be made without leaving the scope of protection as it results from the claims and these equivalent feature combinations.

List of reference signs

- 100 Method with an automated iterative algorithm
- 110 Input data
- 120 Automated iterative algorithm
- 130 Output data
- 140 Forward planning
- 150 Aircraft engine sorting
- 160 Optimisation of a first aircraft engine
- 170 Optimisation of a second aircraft engine
- 180 Optimisation of another aircraft engine

- 200 Method based on artificial intelligence
- 210 Algorithm based on artificial intelligence
- 220 Output data based on artificial intelligence

- 300 Method with an automated iterative algorithm and with artificial intelligence
- 310 Output data based on combined algorithms

- 400 Initial maintenance plan

- 500 Optimised maintenance plan

- E1-E4 Respective aircraft engines
- t1, t2, t3 Times concerning the status of the respective aircraft engines
- E1-S1 to E4-S3 Respective status of the respective aircraft engine
- H1-H4 Optimisation strategies/heuristics

Claims

1. A method, in particular a computer-implemented method, for automated generation of an optimised maintenance plan for a fleet of aircraft engines, the method comprising at least the following steps:

- a) Acquiring input data (110) relating to a plurality of engines (E1, E2, E3, E4) comprising, in particular, a Mean Time Between Shop Visits (MTBSV) or data relating to Life limited Parts (LLP) of the engines (E1, E2, E3, E4);
- b) Providing an existing initial maintenance plan (140) or generating an initial maintenance plan (140) based on the acquired input data (110), in particular the MTBSV and/or LLP data, for the engines (E1, E2, E3, E4);
- c) Determining a total maintenance effort for the fleet in case of an application of the initial maintenance plan;
- d) Sorting the engines into a defined order according to at least one criterion, in particular according to an estimated maintenance effort or estimated maintenance costs;
- e) Applying at least one optimisation strategy or heuristic (H1, H2, H3, H4), which is stored in particular as an algorithm in a computer program, to the engines (E1, E2, E3, E4) in the defined order; and
- f) Outputting an optimised maintenance plan for the engines (E1, E2, E3, E4) after application of step e) and/or output data (130) comprising in particular an estimated total maintenance effort of the optimised maintenance plan.

2. The method according to claim 1, wherein in step e), each time an optimisation strategy (H1, H2, H3, H4) is applied to an individual maintenance plan of an engine (E1, E2, E3, E4), the influences on the other maintenance plans are determined and the changes made by the optimisation strategy are adopted only if this reduces the total maintenance effort for the engine fleet.

3. The method according to claim 1 or 2, wherein in step f), in addition to the optimised maintenance plan, output data, in particular an estimated total maintenance effort for the

engine fleet, are also output and the steps e) and f) are iterated until a predetermined termination criterion is fulfilled on the basis of the output data.

4. The method according to any one of claims 3, before each iteration of the steps e) and f) the engines (E1, E2, E3, E4) are re-sorted again according to step d) according to the at least one criterion.

5. The method according to claim 3 or 4, wherein a different optimisation strategy or heuristic (H1, H2, H3, H4) is applied at each iteration.

6. A method, in particular a computer-implemented method, for automated generation of an optimised maintenance plan for a fleet of aircraft engines, the method comprising at least the following steps:

a) Acquiring input data (110) relating to a plurality of engines E1, E2, E3, E4, comprising, in particular, a Mean Time Between Shop Visits (MTBSV) or data relating to Life limited Parts (LLP) of the engines (E1, E2, E3, E4);

b) Providing an existing initial maintenance plan (140) or generating an initial maintenance plan (140) based on the acquired input data (110), in particular the MTBSV and/or LLP data, for the engines (E1, E2, E3, E4);

c) Determining a total maintenance effort for the fleet in case of an application of the initial maintenance plan;

d') Optimising the initial maintenance plan (140) by means of a self-learning algorithm trained for this purpose; and

f') Outputting an optimised maintenance plan for the engines (E1, E2, E3, E4) after application of step d') and/or output data (130) comprising in particular an estimated total maintenance effort of the optimised maintenance plan.

7. The method according to claim 6, wherein the initial maintenance plan (110) has been generated according to a method according to any one of claims 1 to 5.

8. The method according to any one of the preceding claims, wherein the input data (110) represents at least one data set selected from the group:

Mean Time Between Shop Visits (MTBSV);

the time effort and/or the costs (Workscope) of respective types of shop visits;

data regarding Life limited Parts (LLP) of the engines (E1, E2, E3, E4), in particular remaining cycles of the LLPs;

engine type;

availability of used and/or new spare parts;

costs of used and/or new spare parts;

technical specifications of the aircraft engines;

the time interval for each aircraft engine since the initial registration or since the last shop visit;

the availability of the same type of the respective aircraft engines planned for maintenance.

9. The method according to any one of the preceding claims, wherein the output data (130) output in step f) or f'), respectively, comprise one or more data sets selected from the group:

next maintenance date of the aircraft engines;

spare and short-term lease engines requirements for the next maintenance;

material requirements for the next maintenance;

working time requirements for the total maintenance plan;

total cost of ownership for the engine fleet;

costs per flight hour for the engine fleet;

cash flow.

10. The method according to any one of the preceding claims, wherein the total maintenance effort represents the labour effort or the material effort or total cost of the fleet.

11. A method for optimised maintenance of an engine fleet, wherein an optimised maintenance plan is first generated or obtained in accordance with any one of claims 1 to 10,

and subsequently the engine fleet is maintained, repaired and/or overhauled in accordance with the maintenance plan.

12. A computer program configured to perform the method according to any one of claims 1 to 9.

13. A device for automated generation and optimisation of a maintenance plan for aircraft engines, wherein the device is configured to perform the method according to any one of claims 1 to 9.