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THE PROCESS OF STORING AVIATION PARTS IN THE CONTEXT OF FLIGHT SAFETY

Proces magazynowania części lotniczych w kontekście bezpieczeństwa lotów

Abstract: *The article describes the general principles of storing aviation products as well as a classification of individual groups of stock range. Moreover, the general characteristics of storage processes are covered. The main factors that have an influence on the quality of stored products are discussed. The option to use an IT system for warehouse management is also mentioned. The main part of this manuscript analyzes the risk of storage processes. Based on this analysis, the cause-and-result relationships between product storage errors and authorization of a faulty product to use. Hence, the most probable storage errors and their sources are indicated. This enabled to determine the methods to improve flight safety due to reduction of errors in storage management.*
Keywords: storage, storage processes, storing, flight safety

Streszczenie: *W artykule opisano ogólne zasady magazynowania wyrobów lotniczych oraz podział poszczególnych grup asortymentu magazynowego. Ponadto przedstawiono ogólną charakterystykę procesów magazynowych. Omówiono główne czynniki mające wpływ na jakość przechowywanych wyrobów. Wskazano również możliwość wykorzystania systemu informatycznego do zarządzania magazynem. W części głównej artykułu dokonano analizy ryzyka procesów magazynowania. Na tej podstawie wyszukano związki przyczynowo-skutkowe pomiędzy błędami w magazynowaniu wyrobów i faktem dopuszczenia do użytkowania wyrobu wadliwego. W ten sposób wskazano najbardziej prawdopodobne błędy w magazynowaniu oraz ich źródła. Na tej podstawie określono metody poprawy bezpieczeństwa lotów wynikające z redukcji błędów w gospodarce magazynowej.*
Słowa kluczowe: magazynowanie, procesy magazynowe, składowanie, bezpieczeństwo lotów

1. Introduction

Since the very beginning of aviation, broadly understood supplying has been its inevitable part. Storage of aviation products as the element of supplying has also dated since the moment aviation was born. However, its meaning was then marginal. Initially, it was rather storing a small amount of raw materials than ready-to-use assemblies and parts. This was due to the fact that aviation was based on single planes or short series thereof. The basic element of technical servicing was repairing, not exchanging structural elements. At the same time, relatively low complexity of the aeroplanes in that time, and common availability of other materials from the separate industries resulted in a disregard for storing aviation goods in those days.

Currently, this issue has changed significantly. The universality of various aviation kinds, as well as a high degree of its complexity, increased the meaning of previously marginal areas of aviation. This is also true for the issues related to storing aviation goods. The increase in the significance of these problems also results from the increased significance of aviation safety, which can be influenced by issues related to the storage of aviation goods.

Hence, in this work, apart from a general description of issues related to storage of aviation goods, we present possible errors upon the storage of aviation goods, their causes and effects. Moreover, counteractions preventing the most common errors are identified. Such actions certainly increase the level of safety and eliminate potential economic loss.

2. Storing of aviation products

2.1. Generals principles of storing aviation products

General storage conditions for spare parts, assemblies and aviation materials, further referred to as aviation products, are applicable in the case when there is no strict manufacturer guidance within this scope and when they are not in contrast to those recommendations. The storage conditions for products are an important element of maintaining further usability of aircraft and safety.

Storage conditions must be defined within the following basic ranges:

- storage temperature,
- storage humidity,
- storage duration,
- time and scope of maintenance,
- methods of storage verification,
- manner of storage.

The warehouse premises should comply with general construction and fire protection regulations. They should be clean, well-ventilated and maintained at conditions that

minimize water vapor condensation and in agreement with fire protection regulations. The basic element for every warehouse functioning is the available space. Warehousing facilities can be divided into the following three groups of warehousing: open, half-closed and closed.

Storing aviation products in closed warehouses should be performed using racks that allow free flow of air. The racks are usually made of metal, potentially also of painted wood. The racks cannot be located near the sources of heat or light to minimize the influence of both factors on the collected products.

The products should be packaged, with the transporting package if possible. Alternatively, they can be stored in metal containers or plastic containers (polyethylene, hard polyvinyl chloride, etc.), glass laminates or even paper or cardboard. Product packaging must be performed with the use of tight layer of plastic, plastic bags, oil-covered fabric or paper bags covered with plastic in the inside. A typical aviation warehouse is presented in fig. 1.

Fig. 1. Typical aviation warehouse of small products stored in plastic bags and containers, away from windows and sources of heat. Green warehouse tags confirm that the products are within their expiry date

Manufacturers of aviation products usually indicate humidity for storage of their products. To ensure maintaining temperatures and humidity within the required limits, the temperature and humidity levels must be constantly monitored. At the same time, to protect the products against corrosion, vapor phase corrosion inhibitors and dehumidifiers are used for products made based on iron.

Common storage of certain groups of products (including substances) may result in its mutual adverse influence. Hence, it is necessary to identify such products and to properly

separate them. And, in this way, e.g., acid vapors can damage metallic products. Apart from the interaction, combining such products can pose a fire hazard.

Most manufacturers of aviation products determine the maximum duration of storage. Before the shelf life is reached, the products must be used, disposed of or actions must be taken to allow further storage. After the shelf life has ended, the products must be removed from the warehouse as unusable, and they are subjected to other procedures.

2.2. Storing the main groups of ready aviation products

The ready aviation products are those products, the design and composition of which allows implementation in the aircraft without any further interference with their structure. The main groups of aviation products, with the criteria being both, the functionality of the product and the manner of its storage, are as follows: aggregates and installation assemblies, bearings, aviation instruments, heat exchangers, cables and products made of rubber, tires and inner tubes, elastic and rigid tanks, spark plugs, aviation motors and rotors, aviation batteries, pyrotechnic agents, evacuation and rescue equipment, wooden products, radio-electronic products and electrostatically sensitive devices (ESD).

Such division is, of course, not strict and can involve more groups.

2.3. Principles of storing materials and raw materials

A separate group of products are materials and raw materials for manufacturing of aviation products. Qualifying them to this group results from the fact that without intervention (processing, preparation), they cannot be installed in the aircraft. This property requires a special methodology for storing such products, and the main group of the products includes in particular: forgings, castings and mouldings, metal sheets, rods and metal pipes, acrylic glass, aviation window glass, fabrics, electric cables, paints and lacquers, compressed gases in cylinders, oils and greases.

2.4. General characteristics of storage processes

Warehouses are places where products are gathered; hence the warehouse functions are derivatives of the flow of inventories and their nature. Warehouse facilities have separated functional areas, called the zones. Individual zones are used to perform respective processes. One can distinguish the following zones:

- reception zone,
- storage zone,
- complementation zone,
- dispatch zone.

3. Factors influencing the quality of the supplied products

3.1. Verification of suppliers

Aviation parts are delivered to the area of the warehouse from the suppliers. Supplier qualification is of key importance for the quality of the stored products. To ensure control over the companies that supply products, the companies should be assessed according to the following main criteria:

- EASA Part – 21 or Part 145, ISO 9001 certification, or any other acceptable certification,
- manufacturer authorization, having appropriate accreditations,
- timely deliveries,
- close location, if possible,
- good product quality,
- positive delivery assessment.

and other additional criteria.

Suppliers who were verified positively for the indicated criteria can obtain accreditation that enables delivering aviation products. Such actions allow selecting reliable suppliers. The will allow obtaining parts in time required to perform servicing, performing potential automatic generation of order type and control of parts in stock. Trusted suppliers can also help to ensure the high protection level of parts during transportation, as well as further storage process.

It must be noted at the same time that suppliers must be controlled in set time intervals. This will allow for constant control over the supplier. In the case of errors or inconsistencies in the process of deliveries for the supplier side, it will allow for fast reaction to avoid irregularities. In the case when the results of verification of suppliers and monitored quality were unsatisfactory, an audit should be performed to extend the time of cooperation approval or, in justified cases, to reject the delivery.

3.2. Control of aviation products

Packages delivered to the warehouse of the servicing organization must be controlled by an authorized and qualified person. Upon verifying the delivery of aviation products before its acceptance into stock, its quality must be checked by means of:

- verification of conformance of the number/amount of the delivered products with the order and delivery documents,
- condition of the packaging on the assemblies themselves for damage that can influence integrity of the assemblies,
- control of conformance of manner of packing with the type of assembly specified according to ATA 300 – Specification for packing aviation materials,
- checking completeness of plugs and hoods mounted on the product and the correctness of mounting,

– having certifications and other documents that confirm their status of usable in the aircraft.

Products that have successfully completed the control procedure may be accepted into stock. Accuracy of the control process helps avoid errors in the process of product receipt. Each part should be received individually, with due care and without simplifications.

All detected faults in the product that disqualify the product from being used should be identified at the initial stage of reception.

3.3. Cases of incompatibility of the product

In case when during delivery, inconsistency is found, e.g. damage, lacking quantity, lack of required documentation, a protocol of delivery inconsistency should be issued. The delivery should have the status of quarantine and appropriate yellow storage tag with numbers of Part Number and Serial Number, number and date of delivery, name of the part, identification of location in the quarantine storage and information about the person who transferred the goods to the quarantine.

Fig. 2. Packed aviation product in the quarantine storage with a visible tag

Aviation parts marked with such tag should be stored in a separate warehouse or in its separated part labelled as quarantine. The goods stored therein should remain there until the discovered inconsistencies are solved. The product is moved to the stock when all inconsistencies are solved. Otherwise, the product should be returned to the supplier. Such a protocol will help avoid unwanted use of the product in the aircraft. Separating the product that did not pass the verification process successfully allowing to place it in the warehouse,

and placing it in a separate storage location helps to avoid the case when it is mistakenly taken as an operative product.

3.4. Inoperative (faulty) parts

Inoperative parts are stored in a separate part of the warehouse, designated for the faulty parts. Faulty assemblies, disassembled from the aircraft, may be divided into two basic groups:

- repairable assemblies,
- unrepairable assemblies.

Qualification of the disassembled part into one of these groups is performed by authorized certifying staff. An assembly that is qualified as inoperative but repairable must be labelled with a yellow tag indicating temporary inoperativeness (fig. 2). In the proper time, the product is sent for repair (regeneration, repair).

Products qualified as inoperative and unrepairable are separated from the other products and are labelled with a red tag. Moreover, to avoid introduction into the secondary cycle, the following actions should be taken: removal of the nominal plate, permanent labelling of the assembly as a faulty one by, e.g. placing a red stripe, permanent removal of usable features of the product, e.g. drilling through it.

Such actions prevent introducing a faulty assembly into an aircraft. Separation of parts qualified as inoperative prevents incorrect collecting them from the aviation warehouse and using onboard the aircraft.

3.5. Information technology software that supports the activity of aviation warehouse

In the still growing number of service companies, management of storage is supported significantly by IT systems. This allows performing the following storage operations using computer technologies:

- receipt in the storage registry,
- monitoring of inventory,
- gathering and providing any information about the product,
- indicating products that need servicing or maintenance,
- indication products that end their service life,
- indication products that end their shelf life,
- accurate localization of the product in the warehouse,
- recreating full history of the product,
- printing tags and storage labels, etc.

It must be highlighted that the use of IT system shortens the time needed to perform the individual operations, minimizes the number of people engaged in the storage process, decreases the probability of an error due to human factor, facilitates rotation of products between the warehouses, facilitates restocking and allows indicating a person responsible

for performing any operation and determining the failure rate if individual products. At the same time, storage IT systems minimize most common errors within the scope of storage management, discussed in the following section.

4. Identification of hazards related to incorrect storage of aviation parts

4.1. Determination of structure and processes in the aviation warehouse and analysis

The figure below shows (fig. 3) a scheme of activities that are performed during the receipt of a product to an aviation warehouse. As shown, it contains a number of different activities and actions. The complexity indicates a big potential to make a mistake.

To perform a risk analysis of making an error during a broadly understood process of storage, we searched for cause and effect relationships between the storage errors and the fact that a faulty product was accepted for use.

The next step is to eliminate the risk-related factor. Failure Mode and Criticality Analysis – further referred to as FMECA, is based on the estimation of risk factors. This method includes an analytical presentation of the cause and effect relationships that occur during the process and influence potential faults. This analysis assesses each studied fault with a number from 1 to 10 based on the following criteria:

- rate of occurrence (R),
- meaning of the fault (Z),
- detectability level (W).

Table 1

FMECA analysis sheet

Item	Possible errors	Effects		Z	Reasons		R	Detection	W	RPN
		local	global		local	global				
Storage procedures	Wrong storage conditions for aviation products,	Damage of aviation components	Lac of possibility to assemble on the aircraft	8	Use of wrong packaging	Human error	2	Sight	2	32
		Loss of chemical and physical properties	Damage of the component	5	Incorrect humidity and temperature in the warehouse Incorrect storage conditions	Work conscious-ness	3	Audittemperature and humidity sensors	6	90
		Shortening of product life	Not accepting the manufacturer's guarantee	3	Wrong storage	Decrease of organization costs	2	Sight, sensors	7	42
Control of suppliers	Untimely deliveries	Lack of components on stock	Grounding of the aircraft	3	Human error	Human error	2	Audit	1	6
	Delivery errors	Lack of components on stock	Grounding of the aircraft	3	Human error	Human error	3	Audit	1	6
Verification of assemblies	Erroneous verification of an assembly	Incorrect receipt to stock	Grounding of the aircraft	7	Human error	Human error	5	Control at each step	4	140
Verification of the certificate with the part	Erroneous verification of the certificate with the part	Incorrect receipt to stock	Grounding of the aircraft	7	Human error	Human error	5	Control of the parts at each step	4	140
Packaging according to ATA 300 regulations	Incorrect packaging	Damage of the component	Grounding of the aircraft	6	Warehouse worker error	Supplier error	2	Control during the receipt	1	12
Electrostatic-ally sensitive parts	Verification of the parts outside the ESD area	Part damage	Grounding of the aircraft	8	Human error	Human error	7	Control of the receipt	7	392
Parts in the warehouse– quarantine	Use of the part as operative	Installation of a faulty part in an aircraft	Grounding of the aircraft	9	Human error	Human error	2	Control of the parts	1	18
Parts in the warehouse – inoperative	Use of the part as operative	Installation of a faulty part in an aircraft	Grounding of the aircraft	9	Human error	Human error	2	Control of the parts	1	18
IT systems	Incorrect receipt of the aviation part to stock	A part is lost	Component costs	4	Setting incorrect location	Human error	2	Inventari-sation	2	16
		The part is not installable after its shelf life has passed	Lack of possibility to assemble on the aircraft	5	Lack of part control	Lack of part control	2	Inventari-sation	2	20
Control of motors/APU	Negligence in the storage process	Removal of the motor/APU from stock due to failure	Failure of motor/APU, no possibility to install it	9	Negligence in the way of storage	Failure to comply with the procedures regarding the way of storage	2	Control	2	36

Based on the estimated results, the risk priority number is determined – which is an index of the risk level – based on the following equation:

$$RPN=R \times W \times Z$$

The result is a number between 1 and 1000 (tab. 1). The higher is the score, the greatest is the risk of the fault. One must determine a critical value, above which the analyzed faults would not be accepted.

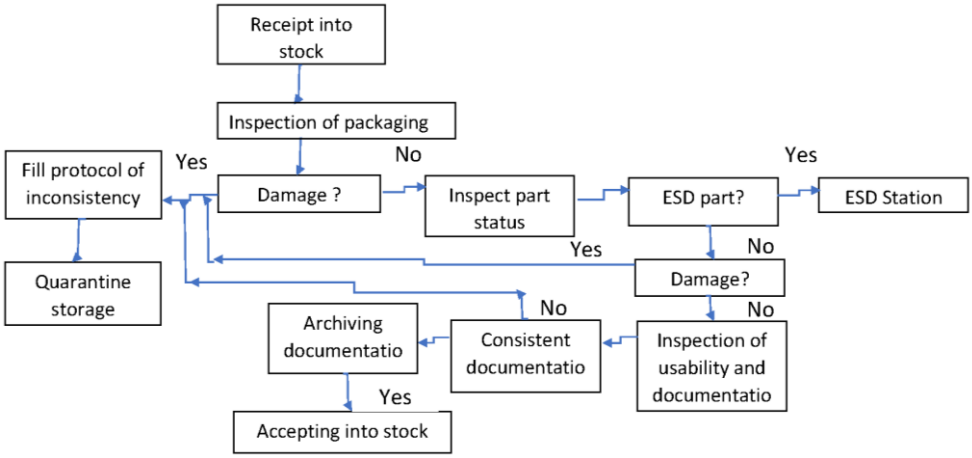

Fig. 3. Block scheme of the process of receipt of aviation parts into stock

4.2. FMECA results

From the above analysis, the three highest RPN indexes were separated, as shown in tab. 2.

As the analysis shows, the most probable errors in the storage process may occur due to the receipt of the electrostatically sensitive devices (ESD). They may be due to an error on the side of the person verifying the parts at each of the storage steps. Other possible irregularities are erroneous part verification and wrong verification of parts with a certificate. The indicated errors are due to the following reasons:

- human factor,
- the inaccuracy of the performed duties,
- being in a hurry.

The source of these inaccuracies may be lack of personnel, large duty burden, extensive rotation of the personnel, lack of training, lack or poor quality of instructions, lack of computer-based assistance in the warehouse.

Table 2

The highest RPN values

No.	Item	Possible errors	RPN
1	Verification of the parts outside the ESD area	Damaging the part by not using the ESD station	392
2	Erroneous verification of an assembly	Incorrect acceptance into stock	140
3	Erroneous verification of the certificate with the part	Incorrect receipt to stock	140

4.3. Methods to increase reliable storage

Considering the structure of the storage processes and the indicated errors along with their sources, numerous corrective actions can be pointed to facilitate effective storage process. The main actions include:

- audits of aviation warehouse function,
- personnel training on the human factor,
- specialist training for the employees on the warehouse operations (especially handling electrostatically sensitive parts,
- continuous control of receipts to stock,
- providing ESD stations,
- repeated control of products upon dispatching them for servicing on the aircraft,
- doubling the control activities at each step during storage (the last process is shown in fig. 4.

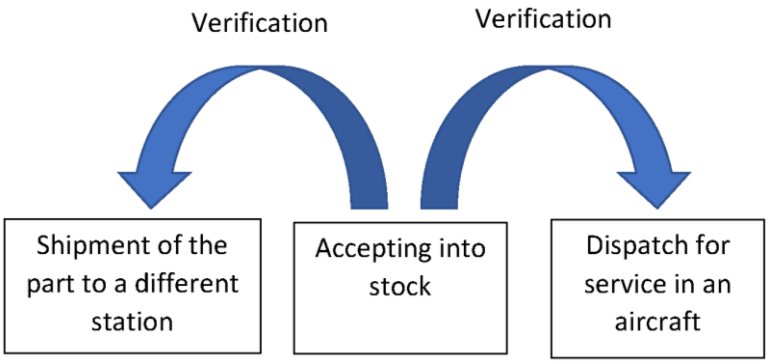

Fig. 4. Scheme of the control process at each step of storage cycle

The constant process of hazard identification and risk management allows determination of an acceptable level of risk. Processes that maintain or improve the risk level may also be implemented. The structure of the SMS system may be divided into two

parts: proactive and reactive. The process is perceived as reactive if it attempts to define the risk and hazards before incorrect events occur. Hence, reporting critical incidents is a proactive method. The risk of human error is also a proactive method. However, it is rather an analytical method.

Table 3

Prevention of errors that can occur during the storage process

Fault in the storage process	Prevention
ESD part damage	• Using ESD stations for the storage processes • Providing training for the personnel on the ESD part protection • Following procedures during verification of a part labelled as ESD • Systematic verification of station efficiency • IT support
Incorrect receipt to stock	• Multi-step and repeated verification of assemblies • Introducing limitations in the computer warehouse software
Mechanical damage of parts	• Use of packaging according to ATA 300 • Use of appropriate storage racks • Strictly following the manufacturer's recommendations • Using appropriate forms in intra-warehouse transportation
Failure to follow the manufacturer's recommendations about the manner of storing	• Increase the intensity of internal controls • Audits to verify the manner of storing products • IT support
Storing of product that are incompatible	• Using separate storage premises • Strictly following the manufacturer's recommendations • IT support

Table 3 lists the most common errors that may occur during the storage process. At the same time, based on the commonly accepted practice, possible preventive actions were proposed. Implementing them should allow limiting the risk of making the indicated errors.

5. Summary

Over the last few years, we observe continuous development of aviation movement and hence, the requirement for services related to providing constant flight-availability of aircraft involved in air freight. There is also a growing need for all types of aviation services performed by small aircrafts. Hence, the functioning aviation warehouses should be adapted to fulfil procedures and requirements set by the manufacturers of aviation parts, as well as by aviation companies and regulations. The procedures in each organization should include detailed rules to limit the risk of errors in the process of storing products.

The article indicates and analyses the procedures that can be applied to the functioning of an aviation warehouse. The importance of the manner of storing aviation products was stressed. At the same time, storage procedures of high complexity were presented. This leads to an increased risk of making an error.

The performed FMECA analysis showed the following, main errors that are likely to be made:

- wrong storage conditions for aviation products – damage of aviation components,
- wrong storage conditions for aviation products – loss of chemical and physical properties,
- wrong storage conditions for aviation products – shortening of products' life,
- untimely deliveries – lack of parts on stock,
- delivery errors – lack of parts on stock,
- erroneous verification of an assembly – incorrect receipt of a part to stock,
- erroneous verification of a certificate with the part – incorrect receipt to stock,
- wrong packaging – product damage,
- incorrect verification of a part as being outside the ESD area – part damage,
- use of an inoperative part as an operative one – installation of a faulty part in an aircraft,
- erroneous verification of a certificate with the part – incorrect receipt to stock,
- incorrect receipt of the aviation part to stock – the part is not installable after its shelf life has passed.

Typical effects of these errors can vary. The most common ones include:

- loss of the product or its service life and hence, financial loss,
- lack of the possibility to dispatch the product leading to the lack of the possibility to exchange it,
- installing and inoperative product onboard an aircraft leading to inoperativeness of the aircraft.

The eventual effect of such errors can be inoperativeness of the aircraft, financial loss or even an accident. Such effects are hard to be neglected. Their potential risks result in the need to prevent them.

Based on the analysis, it is evident that broadly understood human factor is of key importance, as it is in other cases. Hence, to minimize this factor, it is reasonable to take various actions. This can be accomplished by, e.g.:

- determining equivocal storage procedures in the instructions,
- determining procedures for receiving products from external suppliers,
- visible marking of ESD products,
- periodical personnel training,
- allowing work only for employees who undergo training,
- informing and training aviation mechanics within the scope of procedures valid during storage, including dispatching and receiving products from the warehouse,
- auditing the warehouse and the procedures,
- improving the organization of work resulting in the lack of rush,
- using IT technologies.

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