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THE STUDY OF THE TECHNICAL SERVICE IMPACT ON THE AIRCRAFT TECHNICAL READINESS

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Abstract

The efficiency of the aircraft exploitation process is a problem, to which more and more attention is paid not only in the commercial aviation, but also in the military one. One of the factors, which have a direct impact on its level, is the operated aircraft or helicopter technical readiness that is the ability of airworthiness when there is a need to use them in order to perform specific aviation tasks. In turn, the aircraft technical readiness level is affected by a number of factors, the most important of which include its characteristics, technical service system and logistical security system.

This paper is devoted to the issue connected with the aircraft technical readiness assessment as well as identification of factors, which have an impact on its level, and also their impact level analysis. Furthermore, the particular attention was paid to technical services. The research results of a few types of aircraft in terms of the technical service malfunction and damage impact on their technical readiness level were also presented. At the end, the importance of such an approach and the possible use in practice were emphasised.

Keywords: *exploitation system efficiency, aircraft technical readiness, technical services*

1. Introduction

One of the problems, to which more and more attention is paid both in civil and military aviation, includes the aircraft exploitation process efficiency that is the implementation level of their exploitation potential. It takes on particular significance if the operated object is important for the specific task implementation and if their acquisition and use costs are considerable. Furthermore, it is important to remember that the flight performance safety is a function of reliability, readiness and exploitation efficiency [3].

In order to make it possible to use the exploitation potential of a technical object or system throughout its life and to provide its safe and economic use, it must be maintained in the state of airworthiness. The achievement of this objective enables properly to organise the maintainability process. It mostly includes the current, periodic and special maintenance.

One of the most important factors directly affecting the exploitation process efficiency level of any technical object includes its technical readiness. It is generally accepted that the technical object readiness (or availability) is a property related to the ability of being airworthy, if there is a need for its use in order to fulfil specific tasks, while providing the object supply. It is expressed using a statistical index of the technical object airworthiness time share during its exploitation, or the share of the number of successful airworthiness tests (e.g. start-ups), in the number of attempts [1].

Technical readiness of the aircraft exploitation system contains a set of such exploitation states, in which they are suitable in a given moment in terms of their reliability, have the material, energy and information resources necessary for exploitation, and are located in a specified area. Technical readiness includes the exploitation states, in which the utility potential did not exceed the limit values that allow for the proper exploitation [5].

Within the reliability theory, the exploitation system efficiency is assessed most often based on the $K_g(t)$ technical readiness index, which determines the system's readiness for implementation of the entrusted tasks within a given period. This index is defined according to the following dependency [8]:

$$K_g(t) = \frac{E(T)}{E(t) + E(\theta)}, \tag{1}$$

where:
$E(T)$ – the expected value of the object airworthiness time random variable,
$E(\theta)$ – the expected value of the object non-airworthiness time random variable.

In case of practical calculation, a simplified form of the above formula is used [7]:

$$K_g = \frac{T_z}{T_z + T_{nz}}, \tag{2}$$

where:
T_z – the average time of the object's (system) staying in the state of airworthiness,
T_{nz} – the average time of the object's (system) staying in the state of non-airworthiness.

The exploitation system technical readiness level of the particular aircraft type is affected by a number of factors, the most important of which include its characteristics, technical service system and logistical security system. Among the features constituting the aircraft characteristics, durability and reliability, as well as exploitation susceptibility, maintainability, the ability of diagnosis, repairability, renewability and ability of renovation have the most significant influence on its technical readiness.

The $K_{g(SP)}$ aircraft technical readiness index defines its overall airworthiness level, but it does not inform about the non-airworthiness state causes. Due to these reasons, it is insufficient to analyse the exploitation states and take the actions aimed at maintaining a high level of technical readiness. In order to conduct this type of analyses, it is necessary to have information on the cause of every aircraft exclusion from technical readiness, the time of staying in the non-airworthiness state and the organisational units (or unit) responsible for restoration of the aircraft airworthiness state.

2. Basic factors affecting the aircraft technical readiness

In the aircraft exploitation process, the most common reasons for excluding it from the state of technical readiness include:

- technical services,
- malfunctions and damage,
- change of units, components, parts and on-board devices due to their resource exhaustion,
- work related to the technical bulletin performance,
- repairs,
- modernisation and modifications,
- temporary suspension of using due to other reasons (e.g. by the civil aviation authority).

In order to make it possible to conduct the aircraft technical readiness detailed analyses, it is important to define the various exploitation states. They are usually adapted to the existing exploitation system and the user's individual requirements. For example, it is possible to quote the following categories of the aircraft exploitation states:

- airworthy (including airworthiness with restrictions),
- non-airworthy due to technical services or other work performed by the user's personnel,
- non-airworthy due to technical services or other work performed outside the user's unit,
- non-airworthy due to malfunctions or damage,
- non-airworthy due to repair or modernisation,
- non-airworthy due to other reasons.

The technical services include the current, periodic and special maintenance as well as work performed within the framework of technical days. This maintenance is usually carried out in a planned manner, according to the schedule and scope defined in the exploitation documentation. They also include inspections and additional maintenance conducted on the basis of the immediate decisions of the aviation and engineering service. This category also includes the work performed under the current exploitation bulletins, as well as the work related to the change of units, components, parts and on-board devices due to the technical resource or calendar service life resource exhaustion. The basic technical services are usually performed directly by the user's aviation and engineering service personnel; however, the work and higher-level periodic maintenance are performed by other organisational units, which are specialised in this field. Actually, the performed service type is not so crucial for the overall assessment of the aircraft technical readiness. However, their frequency and execution time are relevant. In turn, the separation of the contractors' individual levels allows analysing and assessing their exploitation efficiency.

Apart from the technical services, the malfunctions and damage of the aircraft, as well as its units, components, parts, systems and on-board devices have a great impact on technical readiness. The frequency and scope of their occurrence is largely dependent on the reliability level of a given type of aircraft or helicopter. This category also includes the damage caused by improper use by the flying personnel, improper technical service, and inappropriate exploitation of the airport security services, or the ones resulting from unfortunate accidents. In the process of removing technical malfunctions, the user's aviation and engineering service personnel is ordinarily involved. However, the aircraft damage repair is performed by the organisation, which has the required authorisations as well as the potential to perform a given scope of work. Frequently, different types of malfunctions and damage are detected only during the execution of technical services and repair. Then, they are removed or repaired by the organisational unit that performs the repair or a given level of the technical services. In practice, therefore, repairs are performed at all levels of the technical service system. The malfunctions and damage occur randomly, and due to this fact, it is difficult to predict them, and at the same time, to plan the related work.

The repairs constitute a separate category of the non-airworthiness state causes. They include both the repairs due to exhaustion of the current resource as well as the ones due to the aircraft damage. The first group also consists of the works, which relate to different types of modernisation and modification, performed by the repair plant. The modernisation and repairs connected with the resource exhaustion are performed in a planned manner. Both the indicative scope of work and the time required for their execution are known and relatively easy to be planned. However, the repair due to the aircraft damage is incidental and usually unique. Therefore, a scope of the carried out work is different in each case.

In exploitation practice, there are some cases that the aircraft converts to the non-airworthiness state due to the simultaneous occurrence of causes classified as different categories. The typical example of it is a situation, in which the malfunctions or damage will be detected during the periodic maintenance performance.

The above-mentioned categories of the aircraft airworthiness causes relate to the widely understood maintenance actions aimed at its keeping within the state of airworthiness. The performed division into technical services, malfunctions, damage and repairs does not fully meet the adopted criteria related to e.g. exploitation susceptibility, durability or reliability. However, it allows analysing the impact of the mentioned categories of the non-airworthiness causes on the technical readiness state.

In the exploitation process, also other factors result in the aircraft transition to the non-airworthiness state. Their impact on technical readiness is much smaller, but in order to reliably present the exploitation states, they should not be omitted.

During the analysis of the issues concerning the aircraft technical readiness, not only the causes of the non-airworthiness state are essential, but also the period of staying in this state. Within the conducted record, the dates of the aircraft transition to the non-airworthiness state as well as its return to the airworthiness state are usually entered. It provides the general information about its exclusion from technical readiness, but it does not always reflect the actual causes of this state. The illustration of the discussed problem is a case of the aircraft, in which the damage that requires the change and repair of a specific part or component during the periodic maintenance performance. Then, it is frequent that due to this situation, the non-airworthiness period significantly extends.

3. Indices characterising the aircraft technical readiness state

In accordance with the above-mentioned dependency (2), the $K_{g(SP)}$ technical readiness index of a single aircraft in a given time period can be specified as:

$$K_{g(SP)} = \frac{T_{z(SP)}}{T_{z(SP)} + T_{nz(SP)}}, \tag{3}$$

where:
$T_{z(SP)}$ – time of the aircraft's staying in the airworthiness state in a given time period,
$Tn_{z(SP)}$ – time of the aircraft's staying in the non-airworthiness state in a given time period.

In case, if a given aircraft is operated throughout the entire considered period, the above formula can take the simplified form:

$$K_{g(SP)} = \frac{T_{z(SP)}}{T_{(SP)}}, \tag{4}$$

where:
$T_{z\,(SP)}$ – total considered period of the aircraft exploitation (e.g. the number of days in a month, quarter, year).

The indices characterising the factors, which are the aircraft non-airworthiness cause, can be defined as a quotient of time of the aircraft's staying in the non-airworthiness state due to the specific cause category and the sum of time of the airworthiness and non-airworthiness states that is the period of use in the considered period.

$$K_{nzy(SP)} = \frac{T_{nzy(SP)}}{T_{z(SP)} + T_{nz(SP)}} = \frac{T_{nzy(SP)}}{T_{(SP)}}, \tag{5}$$

where:
$T_{nzy(SP)}$ – time (number of days), in which the aircraft was in the non-airworthiness state due to the specified cause category in a given considered period.

However, the indices determining the aircraft non-airworthiness time-share in a specific cause category within the complete aircraft non-airworthiness time can be presented in the following form:

$$K_{nzy(SP)} = \frac{T_{nzy(SP)}}{\sum_{y=1}^{k} T_{nzy(SP)}}, \tag{6}$$

where:
k – the total number of the non-airworthiness cause categories in the considered period).

It is useful only to consider which of the "y" non-airworthiness categories has the greatest impact on the total aircraft non-airworthiness time in the considered period.

For the practical purposes, the indices calculated with the use of the formula (5) seem to be more useful. They present participation of the specific aircraft non-airworthiness cause category in the entire analysed period of its use. However, the formula (6) is not so useful in case of determining the non-airworthiness index values for the aircraft fleet. The value of the mentioned indices is then directly dependent on the number of aircraft which are excluded from technical readiness for other reasons in a given time period.

In the presented classification of the aircraft exploitation states, it was assumed that a concept of *technical services* includes all kinds of services determined in the descriptive and exploitation documentation of a given type of aircraft or helicopter, as well as maintenance and additional inspections temporarily recommended by the aviation and engineering service, and the work related to the implementation of technical bulletins and other additional tasks. This concept does not include the repairs performed by the repair and production plants.

The $K_{nzo(SP)}$ non-airworthiness index illustrates the impact of technical services on the aircraft technical readiness state within the considered period of its exploitation. In practice, it means the time (number of days), in which the aircraft was non-airworthy due to the executed technical services. This index can be determined by the following dependency:

$$K_{nzo(SP)} = \frac{T_{nzo(SP)}}{T_{z(SP)} + T_{nz(SP)}} = \frac{T_{nzo(SP)}}{T_{(SP)}}, \tag{7}$$

where:

$T_{nzy(SP)}$ – time (number of days), in which the aircraft stayed in the non-airworthiness state due to the executed technical services.

It should be remembered that the period, in which the aircraft stayed in the non-airworthiness state due to technical services, covers the total time from the moment of its exclusion from the technical readiness state to return to this state again. Therefore, $T_{nzo(SP)}$ can be written as follows:

$$T_{nzo(SP)} = \sum [T_{(1)} + T_{(2)} + T_{(3)} + T_{(4)} + T_{(5)}] = \sum_{i=1}^{5} T_{(i)}, \tag{8}$$

where:

$T_{(1)}$ – total waiting time to start the technical services, including the ferry (if necessary) and transferring the aircraft to the organisational unit that performs the service,

$T_{(2)}$ – total time of the technical service performance,

$T_{(3)}$ – total time of the additional work execution (e.g. removing the malfunctions and damage detected during the maintenance, the performance of technical bulletins, etc.),

$T_{(4)}$ – total time of control tests after the technical service performance, including the test flight, if necessary,

$T_{(5)}$ – total time of transferring the aircraft to the user, including the ferry, if necessary.

Depending on the analysed period duration, as well as the aircraft use intensity and the functioning exploitation system organisational structure, the technical services can be executed by one, two or more organisations. If the technical services are executed by more than one organisation, it is advisable to determine the non-airworthiness indices individually for each of them. It will allow to reliably assessing the efficiency of the work carried out by individual organisations and identify the weakest link. This index, i.e. $K_{nzo(SP)}$ can be determined as follows:

$$K_{nzo(SP)} = \sum_{m=1}^{M} K_{nzo(SP)_m}, \tag{9}$$

where:

m – organisational unit performing the technical service in the aircraft,

M – total number of organisational units performing the technical services in the aircraft.

As in case of the $K_{nzo(SP)}$ index, it is also possible to determine other indices characterising the aircraft non-airworthiness state individual categories, such as malfunctions and damage, repairs and modernisation or other causes. For example, the non-airworthiness index due to malfunctions and damage $K_{nzu(SP)}$ can be written as:

$$K_{nzu(SP)} = \frac{T_{nzu(SP)}}{T_{z(SP)} + T_{nz(SP)}} = \frac{T_{nzu(SP)}}{T_{(SP)}}, \tag{10}$$

where:
$T_{nzu(SP)}$ – time (number of days), in which the aircraft stayed in the non-airworthiness state due to technical malfunctions or damage.

4. Indices characterising the aircraft fleet technical readiness state

Within the exploitation process, the results of the analysis and the entire aircraft fleet technical readiness state have application that is more significant. Due to these reasons, it is necessary to determine the technical readiness index as well as the aircraft fleet individual non-airworthiness indices.

The $K_{g(FSP)}$ aircraft fleet technical readiness index can be determined by the following dependency:

$$K_{g(FSP)} = \sum_{i=1}^{n} \frac{T_{z(SP_i)}}{T_{z(SP_i)} + T_{nz(SP_i)}} = \sum_{i=1}^{n} \frac{T_{z(SP_i)}}{T_{(SP_i)}}, \tag{11}$$

where:
i – the aircraft next number in a given fleet,
n – the number of aircraft in a given fleet,
$T_{z(SP_i)}$ – total time of the i aircraft's staying in the airworthiness state in a given (considered) time period,
$T_{nz(SP_i)}$ – total time of the i aircraft's staying in the non-airworthiness state in a given (considered) period.

If the aircraft of a given fleet are operated in several bases, then it is useful to specify the $K_{g(FSP)}$ index individually for each of them. As a result, it will be possible to assess the exploitation system efficiency of a given aircraft in each of the subordinate bases separately. In this case the $K_{g(FSP)}$ index will be determined by the following dependency:

$$K_{g(FSP)} = \sum_{b=1}^{B} K_{g(FSP)_b}, \tag{12}$$

where:
b – the number of the next base that operates the aircraft of a given fleet,
B – the number of the bases that operate the aircraft of a given fleet.

In turn, the $K_{nz(FSP)}$ aircraft fleet non-airworthiness index can be determined by the following dependency:

$$K_{nz(FSP)} = \sum_{i=1}^{n} \frac{T_{nz(SP_i)}}{T_{z(SP_i)} + T_{nz(SP_i)}}. \tag{13}$$

When the user wants to know which of the determined "y" malfunction cause categories has the greatest impact on the total time of the aircraft exploitation, it is advisable to determine the $K_{nzy(FSP)}$ index using the following formula:

$$K_{nzy(FSP)} = \sum_{i=1}^{n} \frac{T_{nzy(SP_i)}}{T_{z(SP_i)} + T_{nz(SP_i)}}. \tag{14}$$

The $K_{nzo(FSP)}$ fleet non-airworthiness index due to the executed maintenance (e.g. periodic ones) can be determined similarly, i.e. by the following dependency:

$$K_{nzo(FSP)} = \sum_{i=1}^{n} \frac{T_{nzo(SP_i)}}{T_{z(SP_i)} + T_{nz(SP_i)}} . \tag{15}$$

If the services are executed by several different organisations (units), this index can be calculated as follows:

$$K_{nzo(FSP)} = \sum_{m=1}^{M} \left[\sum_{i=1}^{n} \frac{T_{nzo(SP_i)}}{T_{z(SP_i)} + T_{nz(SP_i)}} \right]_m , \tag{16}$$

so:

$$K_{nzo(FSP)} = \sum_{m=1}^{M} K_{nzo(FSP)_m} , \tag{17}$$

$$K_{nzo(FSP)} = \sum_{m=1}^{M} [K_{nzo(FSP)_1} + K_{nzo(FSP)_2} + \ldots + K_{nzo(FSP)_M}] . \tag{18}$$

5. Analysis of the results of the selected aircraft exploitation states

Based on the above-presented assumptions, the research aimed at assessing the actual impact of the executed technical services as well as malfunctions and damage on the fleet technical readiness state of the selected aircraft was conducted. In order to make the obtained results allow conducting comparative analyses. It was assumed that the tested aircraft should represent a similar category and it should be used in a similar exploitation system. In addition, each of the fleets should consist of no less than 16 aircraft. Finally, the tests involved five different types of twin-engined helicopters used in the national aviation. The tested helicopters were marked as A, B, C, D and E types. Each of them is operated according to the exploitation potential that is the technical service life resource determining the permitted number of flight or working hours, or the calendar resource defining the permissible period of use.

The average exploitation period of different helicopter types was as follows:

– A type – 32 years (on average since 1984),
– B type – 32 years (on average since 1984),
– C type – 38 years (on average since 1978),
– D type – 21 years (on average since 1995),
– E type – 38 years (on average since 1978).

The helicopters of A, B, C and D types represent a similar class, however, the on-board systems of the first one are the most complex and technically advanced, while the on-board equipment level, including avionic systems of other types, is very similar. However, the E type helicopters are characterised by the lower take-off mass and poorer on-board equipment. Each of the mentioned helicopter types occurs in several usable versions.

The conducted research was based on determining and analysing the fleet technical readiness indices of the various helicopter types and non-airworthiness indices for individual specified cause categories of this state. The research related to the period covering different seasons, including summer and winter. At that time, a few A, C and E type helicopters were in the repair plants. The conducted analysis results show that the technical services as well as the occurred malfunctions and damage had the most serious impact on technical readiness of the tested helicopter types. Depending on the helicopter type, they were a cause of exclusion from technical readiness, on average, from 26% to 39%, and in case of the D type helicopter even more than 46% of machines. In Tab. 1 and in Fig. 1, the average values of the selected non-airworthiness indices were presented. In case of the $K_{nzo(FSP)}$ index, the $K_{nzo1(FSP)}$ index related to the maintenance executed by the user's personnel as well as the $K_{nzo2(FSP)}$ index connected with the maintenance executed by other organisational units was additionally specified.

Tab. 1. The comparison of the non-airworthiness index average values of the selected helicopter types due to malfunctions and damage

Helicopter type	$K_{nzo1(FSP)}$	$K_{nzo2(FSP)}$	$K_{nzo(FSP)}$	$K_{nzu(FSP)}$	In total $K_{nzo(FSP)}$ and $K_{nzu(FSP)}$
A type	0.066	0.102	0.168	0.204	0.372
B type	0.113	0.189	0.302	0.083	0.385
C type	0.046	0.223	0.269	0.069	0.338
D type	0.139	0.213	0.352	0.112	0.464
E type	0.071	0.083	0.154	0.106	0.260

It was found that the $K_{nzo(FSP)}$ index reaches generally higher values than the $K_{nzu(FSP)}$ index. It means that the technical services are the most common cause of the aircraft's staying in the non-airworthiness state. The exception includes the fleet of the A type helicopters which are characterised by the most complex on-board equipment. In this case, the $K_{nzu(FSP)}$ average index is higher than the $K_{nzo(FSP)}$ average index by about 21%. While analysing the $K_{nzo1\ (FSP)}$ and $K_{nzo2(FSP)}$ indices, it should be noted that the lower level periodic maintenance is, at the same time, part of the higher-level maintenance. Due to the fact that the higher-level technical services are usually not executed by the user's personnel, but rather by other organisations, the relationships between the $K_{nzo1\ (FSP)}$ and $K_{nzo2(FSP)}$ indices in subsequent periods of use will be constantly changing.

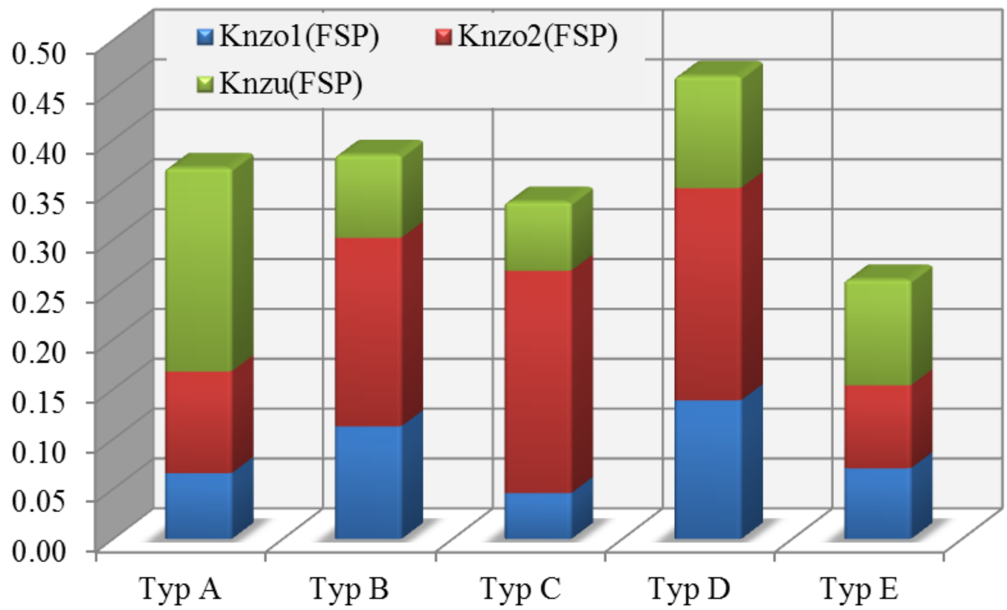

Fig. 1. Non-airworthiness indices of the selected helicopter types due to technical services

In the following months of the tested period, the non-airworthiness indices related to the various helicopter types were subject to some fluctuations. In Tab. 2, the extreme values of the recorded $K_{nzo(FSP)}$ and $K_{nzu(FSP)}$ indices were presented.

Tab. 2. The comparison of the non-airworthiness index extreme values due to malfunctions and damage

Helicopter type	Index $K_{nzo(FSP)}$		Index $K_{nzu(FSP)}$	
	Min. value	Max. value	Min. value	Max. value
A type	0.111	0.225	0.179	0.259
B type	0.158	0.421	0.0	0.158
C type	0.182	0.391	0.0	0.227
D type	0.275	0.406	0.058	0.174
E type	0.113	0.241	0.038	0.173

It was found that the $K_{nzo(FSP)}$ index extreme values of almost all tested helicopter types differ by more than 100%, and the B type helicopter fleets even by 166 %. Only in case of the D type helicopters, the difference is less than 50%. These results show not so precise planning of the individual aircraft exploitation process, or some certain problems connected with the timely implementation of technical services.

6. Conclusion

The frequency and scope, and the resulting effort of technical services are largely the result of individual characteristics of the aircraft type, such as durability and reliability or exploitation vulnerability. However, the organisation and efficiency of the technical service system and logistical security system are also crucial. The user has a relatively limited impact on the aircraft characteristics. The user can only carry out the work, which are covered by the technical bulletins recommended by the producer, or modernisation programmes, the aim of which is to improve the operated aircraft characteristics. A different situation occurs with regard to the technical service system and the logistical security one. In this case, the user has a number of opportunities to increase the efficiency of both mentioned systems' functioning. For this purpose, it is necessary continuously to control fleet technical readiness of the individual aircraft types and the non-airworthiness index categories. The properly prepared aircraft exploitation process support system is very helpful in this task implementation.

The systematic analysis of the non-airworthiness indices allows not only to control the current situation and tendencies of changes, but also to identify the factors which adversely affect the technical readiness state. Consequently, on this basis, it is possible to take reasonable measures aimed at raising the technical readiness level, and thus the aircraft exploitation system efficiency.

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