Mean corrective maintenance time for a medium courier turboprop aircraft

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Abstract: *Logistics can be seen as the compound of all the considerations needed to ensure the efficient and economical support of a system throughout its life cycle. The unscheduled actions, performed as a result of a failure or a perceived failure, that are necessary to restore a system to its required level of performance is corrective maintenance. Such activities may include troubleshooting, disassembly to gain access to the faulty item, repair, remove and replace, reassembly, alignment and adjustment and checkout. The frequency of maintenance for a given item is highly dependent on the reliability of that item. In general, as the reliability of a system increases, the frequency of maintenance will decrease and, conversely, the frequency of maintenance will increase as system reliability is degraded.*

Key Words: *aviation, critical parts, turboprop aircraft, corrective maintenance, reliability*

1. INTRODUCTION

Logistics can be seen as the sum of all the activities necessary to ensure the efficient and economic support of a system throughout its life cycle. It is an integral part of all aspects of system planning, design and development, testing and evaluation, production and / or construction, use and withdrawal of the system. Logistics elements must be developed on an integrated basis with all other segments of the system [1].

To ensure that logistics is properly applied throughout the life cycle, we need to establish the appropriate logistics support requirements in the early stages of conceptual design. Logistical requirements must be specified initially, both in quantitative and qualitative terms. As the system development progresses, the defined configuration should be evaluated against the specified requirements and changes in predictions, analyzes, and the use of physical models for testing and demonstration.

Intuitive in the process of defining the system requirements, specifications and evaluation is the aspect of identifying appropriate quantitative logistics measures for a particular system configuration. These measures may vary from system to system, as customer needs and mission requirements will vary from application to application [2]. Moreover, there can be several factors for any given situation. Thus, it is impossible to cover all the conditions and it is certainly not feasible. However, qualitative measures of logistics need to be addressed. When determining the system support requirements, the frequency of maintenance becomes an important parameter. The frequency of maintenance of a given system depends largely on its reliability. In general, as the reliability of an equipment increases, the frequency of maintenance will decrease and, conversely, the frequency of maintenance will increase as the reliability of the system is degraded. Unsafe systems will usually require extensive maintenance [3]. In any case, the requirements of logistical assistance are strongly influenced by reliability factors.

2. IDENTIFICATION OF THE MEAN CORRECTIVE MAINTENANCE TIME FOR A MEDIUM COURIER TURBOPROP AIRCRAFT

Corrective maintenance can be defined as the totality of actions initiated as a result of the failure (or presumption of failure) of an equipment, necessary to restore its operation to the initial level of performance.

These activities may include actions such as diagnostics, disassembly (repair), repair, replacement, reassembly, alignment and adjustments, checks, etc. [4].

Each time a system fails, it is necessary to follow a series of steps to repair it or restore it to its full operability. These steps include: diagnosing the defect, isolating it, disassembling the equipment to gain access to the defective part, repairing it, and as can be seen in Figure 1, completing these steps is a corrective maintenance cycle.

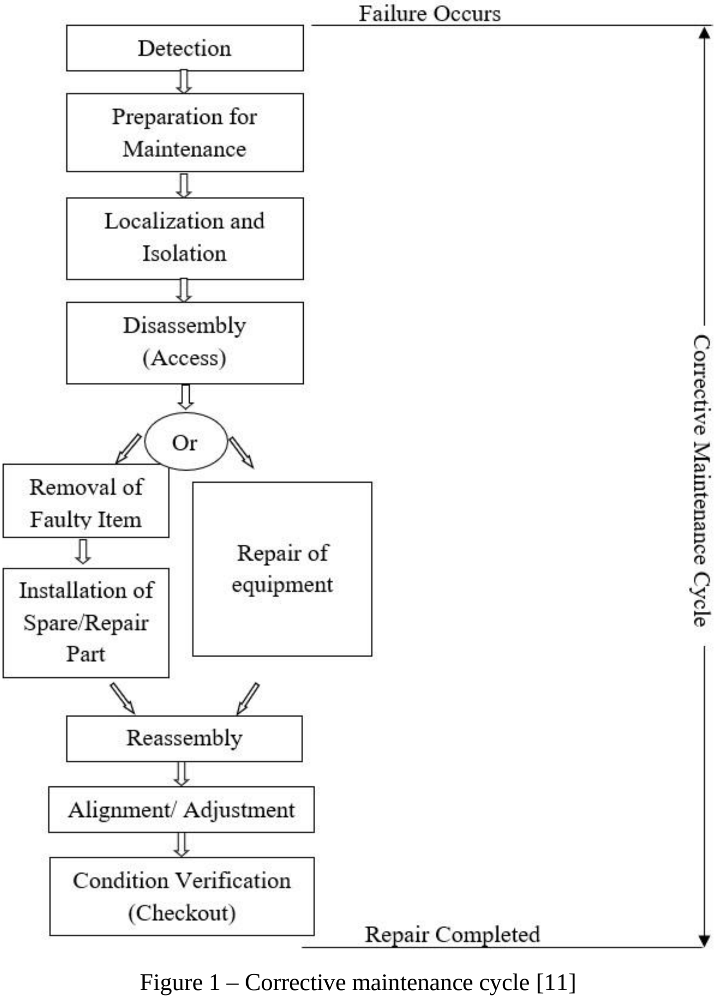

Figure 1 – Corrective maintenance cycle [11]

This type of maintenance occurs as a reaction to a fault (reactive) or as a correction of a malfunction (corrective), it is not planned and it is used in cases where the failure of the technical system is not of paramount importance and the cost to be restored to its original state of operation (by repair or replacement) is small [5].

The disadvantage of this type of maintenance is that it involves the purchase of a large quantity of spare parts to be ready when needed (involving high costs) and requires the constant application of crisis management. Maintenance personnel are usually overworked and face daily (unforeseen) emergencies that may arise. The aircraft subject of this paper is a tourboprop medium courier aircraft operated by a squadron of the Romanian Air Force.

We made a situation with all the failures occurred on two aircrafts (generically named as Aircraft A and Aircraft B), during two years of operation, between January 2018 and December 2019, a total of 275 defects resulted, of which 167 on plane A and 108 on plane B.

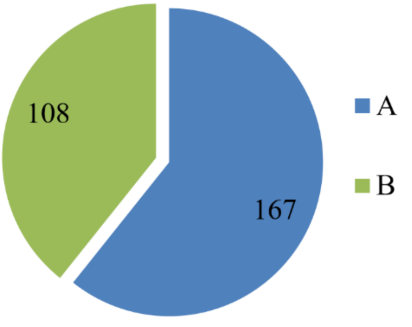

Figure 2 – Total failures on both aircraft

During the study we found out that most of the failures were noticed by the pilots during the flight, a total of 187, representing 109 at aircraft A and 78 at aircraft B, while on the ground, the aircraft maintenance service discovered 88, representing 58 on aircraft A and 30 on aircraft B.

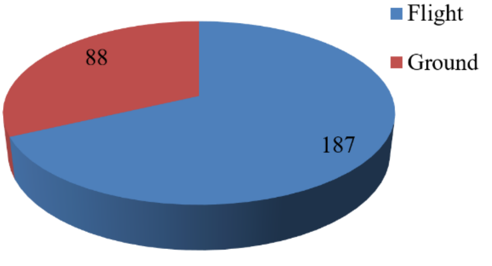

Figure 3 – Failures repartition

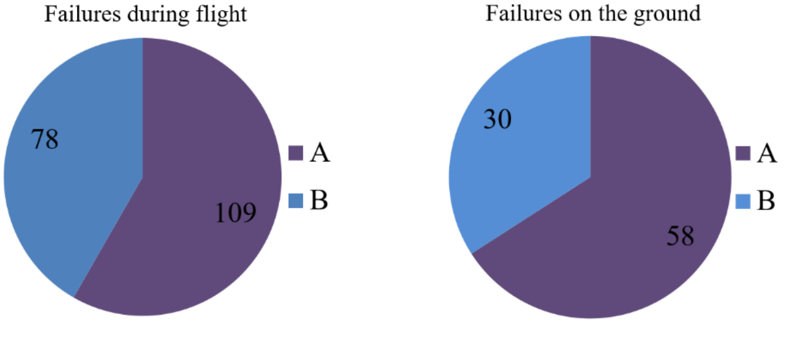

Figure 4 – Total failures during flight/on the ground

To find out the time duration of the corrective maintenance cycle for each failure, we consulted the Aircraft Operating Manual together with its forms and noted them in the following two tables.

Table 1 – Repair times for aircraft A

Aircraft **A**	Repair times (minutes)																							
	Structure					Engine						Special systems										Radio		
Jan-18	132	217	-	-	-	95	47	191	-	-	-	114	93	-	-	-	-		-	-	-	155	-	-
Feb-18	115	-	-	-	-	-	-	-	-	-	-	73	201	194	191	242	115	84	168	257	186	-	-	-
Mar-18	215	124	290	-	-	465	84	518	305	-	-	197	181	211	-	-	-	-	-	-	-	-	-	-
Apr-18	193	221	170	225	-	55	188	286	-	-	-	79	115	107	205	97	-	-	-	-	-	-	-	-
May-18	122	-	-	-	-	129	303	214	-	-	-	104	185	201	201	211	-	-	-	-	-	319	-	-
Jun-18	205	63	76	-	-	121	317	86	119	87	472	168	218	29	-	-	-	-	-	-	-	135	-	-
Jul-18	55	129	-	-	-	238	-	-	-	-	-	125	24	49	104	129	88	-	-	-	-	-	-	-
Aug-18	84	149	121	-	-	65	87	287	179	241	-	129	157	162	93	189	143	174	-	-	-	-	-	-
Sep-18	-	-	-	-	-	-	-	-	-	-	-	124	-	-	-	-	-	-	-	-	-	317	-	-
Oct-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov-18	24	-	-	-	-	161	-	-	-	-	-	94	307	-	-	-	-	-	-	-	-	243	-	-
Dec-18	179	94	-	-	-	275	153	-	-	-	-	141	129	-	-	-	-	-	-	-	-	179	-	-
Jan-19	92	147	-	-	-	-	-	-	-	-	-	213	51	49	-	-	-	-	-	-	-	-	-	-
Feb-19	-	-	-	-	-	138	315	-	-	-	-	129	59	112	97	105	-	-	-	-	-	-	-	-
Mar-19	124	-	-	-	-	186	190	257	-	-	-	113	158	98	75	132	95	87	-	-	-	104	-	-
Apr-19	283	124	-	-	-	127	-	-	-	-	-	67	115	148	139	-	-	-	-	-	-	95	-	-
May-19	107	249	148	-	-	94	-	-	-	-	-	105	-	-	-	-	-	-	-	-	-	107	-	-
Jun-19	21	-	-	-	-	82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jul-19	187	97	118	205	158	208	153	243	-	-	-	57	213	-	-	-	-	-	-	-	-	121	39	89
Aug-19	241	205	-	-	-	138	117	125	175	-	-	-	-	-	-	-	-	-	-	-	-	43	118	-
Sep-19	-	-	-	-	-	287	56	136	197	-	-	99	-	-	-	-	-	-	-	-	-	-	-	-
Oct-19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nov-19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2 – Repair times for aircraft B

Aircraft **B**	Repair times (minutes)																							
	Structure					Engine						Special systems										Radio		
Jan-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
Feb-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mar-18	215	259	-	-	-	281	119	123	-	-	-	136	240	127	87	58	62	175	-	-	-	105	145	139
Apr-18	-	-	-	-	-	166	-	-	-	-	-	195	124	-	-	-	-	-	-	-	-	-	-	-
May-18	84	92	227	115	-	154	-	-	-	-	-	146	162	-	-	-	-	-	-	-	-	122	-	-
Jun-18	65	311	-	-	-	491	-	-	-	-	-	94	-	-	-	-	-	-	-	-	-	-	-	-
Jul-18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-18	81	-	-	-	-	304	-	-	-	-	-	133	-	-	-	-	-	-	-	-	-	97	-	-
Sep-18	212	-	-	-	-	95	128	-	-	-	-	195	107	124	45	309	156	-	-	-	-	201	245	-
Oct-18	198	-	-	-	-	207	126	204	-	-	-	172	-	-	-	-	-	-	-	-	-	-	-	-
Nov-18	163	192	-	-	-	278	-	-	-	-	-	177	-	-	-	-	-	-	-	-	-	132	198	-
Dec-18	234	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	-	-
Jan-19	185	221	-	-	-	-	-	-	-	-	-	192	-	-	-	-	-	-	-	-	-	-	-	-
Feb-19	-	-	-	-	-	84	382	-	-	-	-	62	-	-	-	-	-	-	-	-	-	91	-	-
Mar-19	-	-	-	-	-	283	195	317	-	-	-	139	-	-	-	-	-	-	-	-	-	-	-	-
Apr-19	-	-	-	-	-	584	376	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May-19	-	-	-	-	-	209	146	153	-	-	-	174	-	-	-	-	-	-	-	-	-	-	-	-
Jun-19	556	124	311	39	-	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	86	-	-
Jul-19	207	-	-	-	-	177	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug-19	61	65	-	-	-	-	-	-	-	-	-	303	80	-	-	-	-	-	-	-	-	96	-	-
Sep-19	208	-	-	-	-	84	-	-	-	-	-	117	96	-	-	-	-	-	-	-	-	-	-	-
Oct-19	-	-	-	-	-	248	195	169	108	-	-	139	218	173	74	139	-	-	-	-	-	-	-	-
Nov-19	207	-	-	-	-	219	119	-	-	-	-	87	192	-	-	-	-	-	-	-	-	161	-	-

During the operation phase of a system, there will always be a certain number of maintenance actions that will involve the steps shown in Figure 1. The mean corrective maintenance time (Mct) or the average repair time that are equivalent, is a value consisting of the arithmetic mean of these individual maintenance cycles.

To illustrate the above, we have extracted from Table 1 and 2 all the 275 corrective maintenance actions performed on the equipments of the C-130 Hercules aircraft and included them in the following table.

Table 3 – Corrective maintenance times

132	217	95	47	191	114	93	155	115	73	201	194	191	242	115	84	168	257	186	215	124	290	465	84	518
305	197	181	211	193	221	170	225	55	188	286	79	115	107	205	97	122	129	303	214	104	185	201	201	211
319	205	63	76	121	317	86	119	87	472	168	218	29	135	55	129	238	125	24	49	104	129	88	84	149
121	65	87	287	179	241	129	157	162	93	189	143	174	124	317	24	161	94	307	243	179	94	275	153	141
129	179	92	147	138	315	213	51	49	129	59	112	97	105	124	186	190	257	113	158	98	75	132	95	87
104	283	124	127	67	115	148	139	95	107	249	148	94	105	107	21	82	187	97	118	205	158	208	153	243
57	213	121	39	89	241	205	138	117	125	175	43	118	287	56	136	197	99	215	259	281	119	123	136	240
127	87	58	62	175	105	145	139	166	195	124	84	92	227	115	154	146	162	122	65	311	491	94	81	304
133	97	212	95	128	195	107	124	45	309	156	201	245	198	207	126	204	172	163	192	278	177	132	198	234
29	185	221	84	382	192	62	91	283	195	317	139	584	376	209	146	153	174	86	556	124	311	39	47	207
177	61	65	303	80	96	208	84	117	96	248	195	169	108	139	218	173	74	139	207	219	119	87	192	161

Each number in the table represents the time of a complete corrective maintenance cycle, and based on them, we made the frequency table and the frequency histogram.The mean time between failure in case of AC generator is 357,10 hours.

As can be seen in Table 3, the minimum time in which a cycle was performed was 21 minutes, and the maximum was 584 minutes. To make the frequency table and histogram, we will conveniently divide the repair times into classes of 30 minutes each and we will establish that the separation points between classes will be 30.5, 60.5, 90.5, etc.

Table 4 – Frequency distribution of repair cycles

Repair time (minutes)	Frequency	Total
0-30.5	5	5
30.5-60.5	15	20
60.5-90.5	31	51
90.5-120.5	47	98
120.5-150.5	48	146
150.5-180.5	30	176
180.5-210.5	39	215
210.5-240.5	19	234
240.5-270.5	11	245
270.5-300.5	9	254
300.5-330.5	13	267
330.5-360.5	0	267
360.5-390.5	2	269
390.5-420.5	0	269
420.5-450.5	0	269
450.5-480.5	2	271
480.5-510.5	1	272
510.5-540.5	1	273
540.5-570.5	1	274
570.5-600.5	1	275

The probable distribution of repair times can take one of three forms [6, 7]:

a. Normal distribution, which generally applies to simple maintenance activities, such as the replacement of defective equipment, which requires an approximately fixed repair time each time.

b. Exponential distribution, which generally applies to equipment with an excellent built-in test capability and a pre-established repair and replacement concept. The maintenance rate is constant.

c. Continuous probability distribution ("log-normal distribution"), which applies in most maintenance actions where the repair time and frequency vary. Experience has shown that in most cases, the distribution of maintenance times for complex systems and equipment is "log-normal".

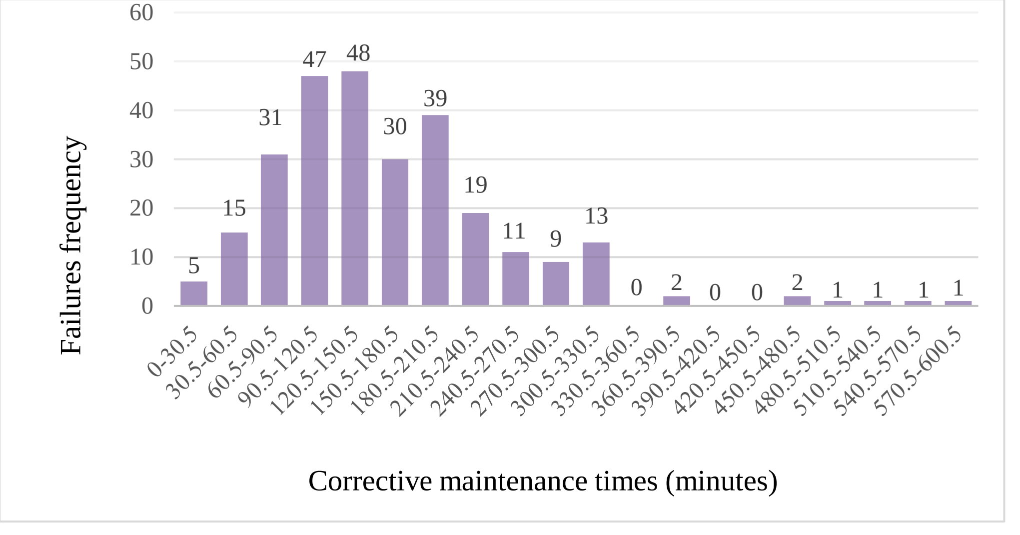

Figure 5 – Maintenance actions histogram

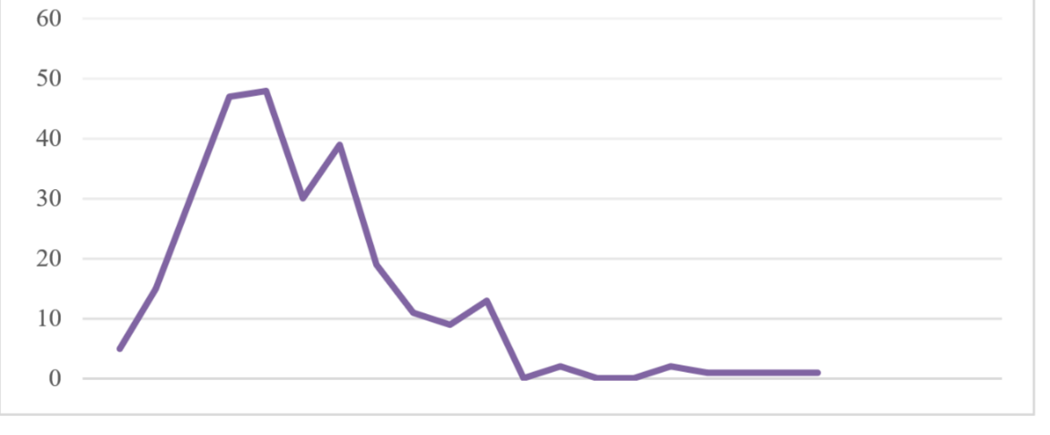

Figure 6 – Frequency poligon

As can be seen from the representation of the frequency polygon, the repair time and frequency vary, resulting in that it corresponds to the continuous probability distribution ("log-normal distribution"). The frequency polygon is defined by the arithmetic mean (X or Mct) and the standard deviation (σ) [8].

Regarding the repair times presented in table 5, the arithmetic mean is obtained as follows:

$$Mct = \frac{\sum_{i=1}^{n} Mct_i}{\mathrm{n}} = \frac{44528}{275} = 161{,}92 \text{ (we will consider 162 minutes)}, \quad (1)$$

where Mct_i is the total time of corrective maintenance, presented in table 3, n is the total number of cycles.

Finally, we obtained for 275 maintenance cycles, an average of 162 minutes.

3. CONCLUSIONS

The maintenance factors covered in this paper refer to elapsed times. Although elapsed times are extremely important in performing maintenance, also we must consider the hours of maintenance spent in the process. Elapsed times can be reduced (in many cases) by the additional involvement of human resources in performing specific tasks. However, this can prove to be a costly compromise, especially when high levels of skill are required to perform tasks that will be performed in a shorter time. In other words, maintainability is concerned with ease and economy in performing maintenance [9]. As such, one of the objectives is to achieve an appropriate balance between time elapsed, working time and staff skills, at a minimum maintenance cost.

In addition to the corrective maintenance aspect of the system, maintainability also deals with design features that minimize (if not eliminate) the preventive maintenance requirements for that system [10]. Sometimes, preventive maintenance requirements are added with the aim of improving the reliability of the system (for example, reducing failures by replacing defective components). However, the introduction of preventive maintenance can be quite costly if not carefully monitored. Moreover, performing preventive maintenance too often (especially for complex systems / products) often has a degrading effect on system reliability, as failures are frequently induced in the process [11]. Therefore, a sustainability objective is to provide an appropriate balance between corrective maintenance and preventive maintenance, at least in terms of overall cost.

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