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Analysis and Remedies for Factors Responsible for Time Between Overhaul: A Case Study of DO-228 Aircraft Starter Generator

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Abstract
The starter generator is used for cranking the engine and to produce electricity for the aircraft system after a sustainable speed. A review of relevant literature reveals the time between the overhaul of the Do-228 aircraft starter generator but did not go in-depth to unravel the factors responsible. A survey research method is adopted to elicit information on the factors. Raosoft sample technique calculator: a software that primarily calculates or generates the sample size of a research or survey was used to obtain the minimum sample size from the study population with the nominal rolls of the technicians as the sampling frame. The questionnaire was vetted and validated by a professional focus group discussion team. The result shows that the factors responsible for the time between overhaul of the starter generator are Environmental Factors (10%), Mechanical Factors (20%), Poor Maintenance Factors (17%), Time Due (25%), Usage/Life Cycle (16%) and Aging (12%). 75% overhaul is unscheduled. It is recommended that the overhauling of the aircraft starter generators be done at 900 as against 1000 flight hour intervals to mitigate unscheduled maintenance.

Keywords: DO-228 Aircraft, Flight Hour, Sampling Frame, Starter Generator, Time between Overhaul

1.0 INTRODUCTION

Aircraft maintenance consists of several complex activities, typically referred to as, Maintenance, Repair and Overhaul (MRO). However, maintenance activities on aircraft have evolved but have remained complex, comprehensive and continuous process. In the past, all activities done on the aircraft are manually executed, however, maintenance tasks are now mostly done using digital and computerized methods [1]. The primary goal and responsibility of everyone in the aviation sector is the safety and reliability of people and systems respectively [2]. Towards this goal, manufacturers, mechanics and operators are not just to maximize power and performance, but also to maximize reliability [3]. Therefore, aircraft engine manufacturers give each of their products a recommended Time Between Overhauls (TBO). The engine is usually inspected, repaired if necessary, and returned to service based on whether it meets maintenance and performance requirements and airworthiness specified by the Original Equipment Manufacturers (OEMs). It may also be cycle-dependent and therefore, the OEM manual determines when the aircraft engine is due for an overhaul. The Do-228 aircraft (Figure 1), which uses the Honeywell TPE331 turboprop engine has a TBO of 5,400 hours[4], [5].

Figure 1: shows the picture of the Do-228 aircraft [6].

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The Do-228 is a twin-engine, multirole light transport aircraft designed and developed jointly by Indian aircraft manufacturer Hindustan Aeronautics Limited (HAL) and RUAG Aerospace, Germany [7]. Some of the key features of the aircraft include its long range, high utilization rates and high payload with an impressively low operational cost. The Do-228 aircraft can be deployed for passenger and cargo transportation, as an air taxi, for corporate purposes, for aircrew training, maritime surveillance, search and rescue, border patrolling, medical evacuation missions and for the very important person (VIP) liaison missions [7], [8]. The Do-228 aircraft is maintained by Unit 1 and Unit 2 (Engineering Groups), and unit 3 (Central Avionics Overhaul and Calibration Centre).

The Do-228 aircraft starter generator though a very small component of the engine is used for cranking the engine for start-up and to produce electrical power for the aircraft. Without this, the aircraft will not fly to execute the mission. The starter generator is permanently engaged with the engine shaft through the necessary drive gears, while the direct cranking starter must employ some means of disengaging the starter from the shaft after the engine has started [9]. The starter generator unit is a compound generator with an additional heavy series winding. This series winding is electrically connected to produce a strong field that produces very high torque for starting the engine (Fig 2). Also, starter generator units are desirable from an economic standpoint, since one unit performs the functions of both starter and generator thereby reducing the total weight of the starting system components and concomitantly the requirement for fewer spare parts [9], [10]. Figure 3 shows a pictorial view of the Do-228 aircraft starter generator [11] and Table 1 shows the starter generator components ranking.

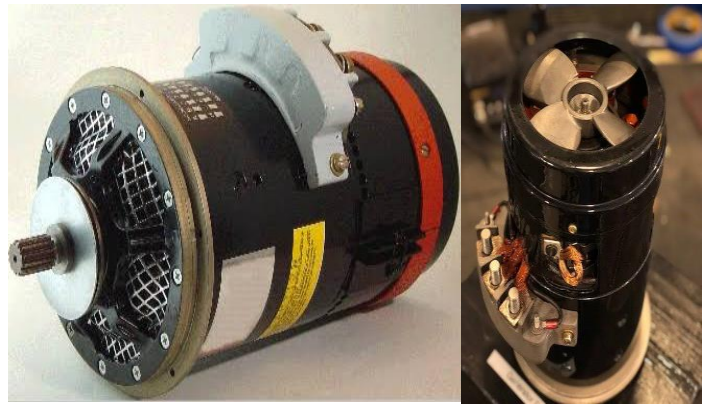

Figure 2: Do-228 Aircraft Starter Generator [11].

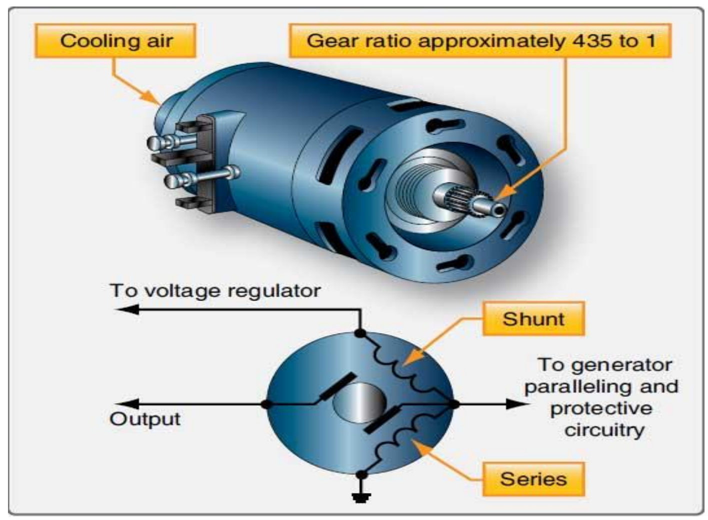

Figure 3: Starter Generator with Series Winding [10].

Table 1: Do-228 Aircraft Starter Generator Components Analysis and Ranking [12].

Serial	Components	Effects	Faults Generated	Occurrence	Ranking	Remark
1.	Air inlet.	Low efficiency, accumulated carbons.	Low power output.	0	E10^{-3}	Minor
2.	Fan cover.	Unwanted particles.	Block easy rotation.	1	E10^{-3}	Minor
3.	Brush cover.	Unwanted particles.	Block easy rotation.	0	E10^{-3}	Minor
4.	Locking nut.	Loss of components.	Generator malfunction	0	E10^{-5}	Major
5.	Brush spring.	Low efficiency.	Low power output.	13	E10^{-5}	Major
6.	Bearing.	Low efficiency, vibration.	Low power output.	21	E10^{-5}	Major
7.	Fan.	Low efficiency, overheating.	Generator damage/burnt.	3	E10^{-7}	Hazardous
8.	Bearing retainer.	Low efficiency, vibration.	Low power output.	0	E10^{-5}	Major
9.	Nameplate.	Data records will miss.	Nill.	1	E10^{-1}	No effect
10.	Terminal block.	No output connecting point.	No power output.	5	E10^{-5}	Major
11.	Commutator end.	No output.	No output power.	0	E10^{-5}	Major
12.	Drive end bell.	Vibration.	Excessive vibration.	0	E10^{-5}	Major

13.	Driveshaft.	Low efficiency, vibration.	Low power output or no power.	5	E10^{-5}	Major
14.	Armature.	No power will be generated.	Generator failure.	4	E10^{-5}	Major
15.	Stator.	No power will be generated.	Generator failure.	4	E10^{-5}	Major
16.	Screen.	Unwanted particles.	Block easy rotation.	2	E10^{-3}	Minor
17.	Carbon brush.	Low efficiency.	Low power output, or no power output.	47	E10^{-5}	Major

The starter generator internal circuit has four field windings: a series field winding, a shunt field winding, a compensating field winding, and an inter-pole or commutating winding. During starting, the series field, compensating, and commutating windings are used. The unit is similar to a direct cranking starter since all of the windings used during starting are in series with the source. While acting as a starter, the unit makes no practical use of its shunt field. A source of 24 volts and 1,500 peak amperes is usually required for starting [10]. Figure 4 shows the starter generator internal circuit.

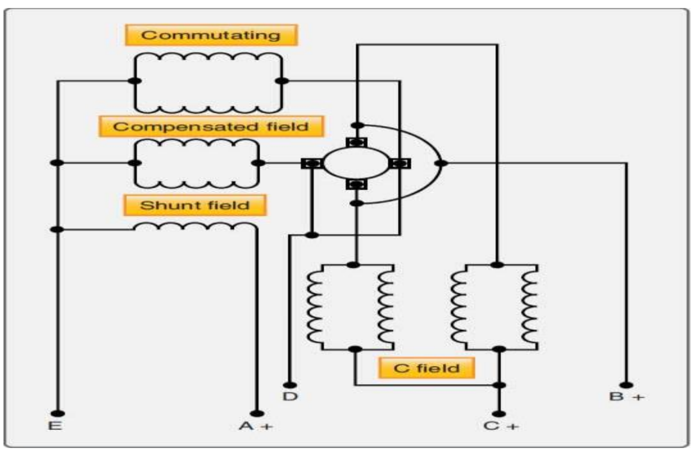

Figure 4: Starter Generator Internal Circuit [10].

There are many things that come into play when determining how to overhaul an aircraft starter generator, but the major factor is the TBO. The TBO is the number of running hours of the aircraft starter generator recommended by the manufacturer before it requires an overhaul. There are two types of starter generator overhaul: top-level starter generator overhaul and major starter generator overhaul of the component [13].

1.1 Top-level Overhaul of Starter Generator

Top-level Overhaul of the Starter Generator entails physical inspection of the components, cleaning, adjustments, and inspection of carbon brush springs, brush holder, and rotor collector. In addition, to examine all the carbon brushes for damage, wear and replace them accordingly if a new part is necessary and restore them to the serviceable condition [5], [14], [15]. These parts of the starter generator can be accomplished without completely disassembling the entire system. Figure 5 shows the starter generator during the top-level overhaul. The top-level overhauling of the starter generator is usually carried-out, out at every 300 hours interval of the flight operation of the starter generator on the aircraft engine [16], [17].

1.2 Major Overhaul of the Starter Generator

Major Overhaul of the starter generator involves


Figure 5: Starter Generator Top-level Overhaul [10].


Figure 6: Starter Generator Major Overhaul [10].

generator. The whole part is physically inspected, cleaned, washed, changed of bearing, brushes, check the diameter of the diamond surface refinishing, if it is below the required range change the complete armature, check the terminal block capacitance, check the gasket diameter. In addition, conduct a Non-Destructive Test (NDT) on the shaft [5], [14]. Figure 6 below shows the starter generator's disassemble parts for a major overhaul. The major overhaul of the starter generator is usually carried-out, out at every 1000 hours interval of the flight operation of the starter generator on the aircraft engine [17].

After the overhauling of the starter generators is removed from the aircraft, it is necessary to carry out a functional check of the starter generator before fixing it on the aircraft. Figure 7 shows the starter generator test bench and Figure 8 shows the display parameters obtained from the starter generator during the functional check. To certify the overhaul work carried out on the starter generator, it is mandatory to perform a functional check of the starter generator on the test bench by test running the starter generator and obtaining all required parameters as it is supposed to be on the aircraft. If the readings obtained from the test are in range, with the set down values by the overhaul manual, the starter generator is released to be fixed on the aircraft. However, if the values are not in range, troubleshooting is performed to detect the problem and remedy it [17], [18]. The key operation involved in the two levels of starter generator overhaul is summarised in Table.2.

The ideal hours for overhauling the starter generator of Do-228 aircraft is 1000 flight hours; presently it is still done at 1000 flight hours as recommended in the aircraft manual [16], [19]. However, the starter generator fails before the due time as a result of some extraneous factors that tend to undermine the recommended TBO thereby creating undesirable high unscheduled maintenance and downtime that undermines the availability and capability of the aircraft for security missions. To determine these factors and proffer remedies is the essence of this study. According to [16], [19], some of the factors are Environmental factors, Mechanical factors, Poor maintenance culture, Time Due, Usage/Life cycle and Age of the aircraft. This research investigates the case of the starter generator on Do-228 aircraft and possibly proffer a solution to mitigate the factors.

2.0 RESEARCH METHODOLOGY

The study adopts the survey research method through the construction and administration questionnaires and verbal interviews to elicit information from randomly selected technicians of the maintenance units. These are the units that are responsible for the operation, maintenance and overhaul of the Do-228 aircraft fleet. The questionnaire was designed to meet the three aspects of questionnaire construction such as its general form, question sequence, formulation and wording with alternative replies for understanding. The questions were structured for definite, concrete and predetermined

Table 2: Do-228 Aircraft Starter Generator Overhaul Summary and Analysis [12].

Serial	Types of Overhaul	Work Carried Out	Flight Period	Nature of Work	Equipment Used	Time Taken
1.	Top-level Overhaul of Starter Generator	Physical Inspection. Cleaning. Adjustments. Inspection of carbon brushes. Inspection of carbon brush springs and holder. Inspection of rotor collector.	Every interval of 300 flight hours	It does not involve the complete disassembling of parts	Carbon brush extractor. Multi-meter. Blower.	12- 24 hours
2.	Major Overhaul of Starter Generator	Physical Inspection. Cleaning. Washing. Adjustments. Replacement of carbon brushes. Inspection of carbon brush springs and holder. Inspection of rotor collector. Change of bearings. Armature inspection. Terminal block capacitance inspection. NDT test on the shaft. Inspection of gasket diameter.	Every interval of 1000 flight hours	It involves the complete disassembling of parts	Carbon brush extractor. Multi-meter. Blower. Diameter armature balancer. Growler armature tester. Temperature tester. Baroscopic tester. Starter generator test bench.	5 – 7 days

responses and further vetted and validated by a professional focus group discussion team in the field of study. The questions which were essentially close types of "yes", "no" or "not sure" are on training undergone, knowledgeable of the aircraft, factors responsible for TBO of starter generators on the aircraft, and how often starter generators overhaul was carried out on the aircraft, challenges affecting the serviceability of starter generator on Do-228 aircraft and how much impact it has on the availability of Do-228 aircraft fleet.

Stratified random sampling was adopted in administrating the questionnaire whereby the population was divided into three groups to form relevant and significant strata based on their function in the operation and maintenance of the Do-228 aircraft. A simple random sample was drawn from each of the units (strata) using the nominal roll of the three homogenous subsets as the sampling frame. The Raosoft sampling calculator was used to determine the minimum sample size of 151 at a 95% confidence level, 18% desired accuracy level and 80% "yes" proportion for the study (population size not disclosed for security reasons). In administering the questionnaire, however, 250 participants were served. The process, therefore, ensured that the questionnaires are distributed without bias in order to elicit the opinion of all the interested parties involved in the maintenance, repair and overhaul (MRO) of the aircraft understudy Do-228. Three-week response period was allowed, after which the questionnaires were collected from the units involved, through the help of the Hanger Chief and the Unit Commanding Officers.

3.0 DATA ANALYSIS AND RESULT

A total number of 250 questionnaires were distributed to the participants out of which 224 participants returned their questionnaires. By using the Raosoft sample size calculator with a confidence level of 95% and an error margin of 5%, the expected sample size to be used was 151. Hence, the 224 participant's responses meet the required sample size and can be said that the participant's responses satisfied the minimum requirement as specified in the Raosoft sample size calculator for data analysis. Additionally, the participant's responses were distributed across gender, ranks, training level and other relevant characterization

Table 3 presents the gender distributions of participants maintaining the Do-228 aircraft. From the result presented it was clear that 86% of the personnel maintaining the aircraft were male, while 10% are female. However, 4% prefer not to disclose their gender.

Table 3: Gender Distribution of Participants

Response	No. of respondents	Percentage of Respondents (%)
Male	192	86
Female	23	10
Prefer Not to Say	9	4

From the result represented depicted in Table 4, it is deduced that the highest number of the personnel involved in the maintenance of the Do-228 aircraft obtained Secondary School Certificate and or a National Diploma (71%).

Table 4: Educational Qualification of Participants.

Response	No. of respondents	Percentage of Respondents (%)
SSCE/ND	159	71
HND/BSc/B. Eng	63	28
MBA/MSc/M. Eng	2	1
PhD	0	0

The minimum requirement an officer should possess is Higher National Diploma or bachelor's degree, while the minimum required for airmen/airwomen is SSCE/ND. However, some of the airmen/airwomen have HND/BSc. This shows that the participants have more than basic knowledge to read and write. Table 5 presents the participant's years of experience on the job not necessary the numbers of years spent on the Do-228 aircraft.

From Table 5 more than half of the responses are within 0 to 10 years in service to fall within the Flying Officer to Wing Commander Rank for the officers and Aircraftmen/Aircraftwomen to Corporal for the airmen/airwomen category. The years of experience of the participants shows a measure of what the worker brings to the job and hence his competence on the job. Table 6 shows that 10% of the participant were from Unit 1 which was responsible for the operation and first line maintenance of the aircraft, 74% from Unit 2 which was responsible for third line maintenance of the aircraft, while 16% are from Unit 3 which was responsible for maintenance and overhaul of the electrical and avionics components of the Do-228 aircraft.

Table 7 shows that the major participants in the survey are airmen/airwomen, which signified that most of the personnel involved in the maintenance of Do-228 aircraft are airmen/airwomen technicians.

Table 5: Participants' Years of Experience in the Job.

Ranks	0-5 Years	6-10 Years	11-15 Years	16-20 Years	21-25 Years	26-40 Years
1	64	4	0	0	0	0
2	5	42	23	18	0	0
3	0	0	11	25	4	0
4	0	0	0	0	9	4
5	0	2	3	0	0	5
6	0	5	0	0	0	0
Total	69	53	37	43	13	9
Percentage	31	24	16	19	6	4

Table 6: Units of the Participated Personnel

Units	No. of Respondents	Percentage (%)	No. of Distributed Questionnaires	No. of Returned Questionnaires	Responsibility
1	22	10	28	22	Operation and first-line maintenance of the aircraft
2	167	74	16	167	Third-line maintenance of the aircraft
3	35	16	39	35	In-depth Maintenance and overhaul of the electrical and avionics components

Table7: Rank Distribution of Participants

Response	No. of respondents	Percentage of Respondents (%)
Officers	14	6
Airmen/Airwomen	208	93
Prefer Not to say	2	1

Table 8: Personnel Initially Trained on the Aircraft

Response	No. of respondents	Percentage of Respondents (%)
Yes	210	94
No	11	5
Neutral	3	1

A minuscule number of participants (2) preferred not to disclose their rank bracket, however, the major participants in the survey are airmen/airwomen (93%) to signify that most of the personnel involved in the maintenance of Do-228 aircraft are airmen/airwomen technicians- Table 8 shows the distribution of personnel initially trained on aircraft

This is to know from the response of the participants, those who have undergone the initial training on aircraft maintenance generally conducted at AFIT Kaduna for technicians. Airmen/airwomen are higher which shows about 94%. The table also shows that 5% of the participants are yet to undergo initial aircraft training, while 1% did not specify if they have been trained or not trained. Table 9 presents the response of participants on those rated on Do-228 aircraft. It is obvious from the Table 9 that 63% of the participants are type-rated on Do-228 aircraft; while 36% are not type-rated on the aircraft whiled 1% did not disclose their rating.

When compared to the percentage of participants' responses on those initially trained on aircraft - Table 6 which is 201 to those type-rated on Do-228 aircraft as shown in Table 7 which is 141, it is obvious that not all the initially trained participants are type-rated on Do-228 aircraft. Table 10 shows the level of participants' training on Do-228 aircraft. The categorization of aircraft maintenance training is divided into three levels, which are basic, intermediate, and advanced training.

Table 9: Personnel Rated on NAF Do-228 Aircraft

Response	No. of respondents	Percentage of Respondents (%)
Yes	141	63
No	81	36
Neutral	2	1

Table 10: Level of Training on Do-228 Aircraft

Response	No. of respondents	Percentage of Respondents (%)
Basic	131	58
Intermediate	47	21
Advanced	20	9
Prefer Not to Say	26	12

Therefore, the training level distribution in Table 10 shows the categories of trained participants on Do-228 aircraft. The result in the Table 10 shows that 58% of the participants have undergone only basic training on the aircraft, 21% trained up to intermediate, and only 9% have been trained to an advanced level. However, 12% decided not to indicate the level of training received. As discussed in the earlier sections of this paper overhauling aircraft starter generators requires special skills and expertise to carry out. Hence, the level of training is a determining factor for effective aircraft maintenance and especially starter generator overhaul as it is a good measure of the competence of the maintenance crew that affects output and the qualities of respondents. Table 11 shows the level of awareness of TBO on the starter generator on Do-228 aircraft.

From the participant's responses, about 68% of the participants are fully aware of the TBO of the starter generator on Do-228 aircraft, while 26% indicate neutral and 6% of the participants indicated not being aware of the TBO of the starter generator. Hence high numbers of the participants indicated being aware of TBO for starter generators. Figure 8 identifies the factors responsible for the TBO of starter generator on Do-228 aircraft and ranked them in a pie chart

The participants were requested to identify various types of factors responsible for the TBO of the starter generator on Do-228 aircraft. From the participant's responses as depicted in Figure 8, 10% of the participants consider environmental factors responsible, 20% opined that mechanical factors are responsible, and 17% attributed the factor that undermines the time between overhaul of the starter generator to poor maintenance culture, 25% consider the problem to emanate from time due for maintenance (scheduled maintenance), 16% of the respondents believe that usage/life cycle is responsible and the rest 12% of the respondents consider the aircraft age as a factor responsible for the unacceptable TBO of the Do-228 starter generator. The result presented, shows that the participants are fully aware of the different types of factors responsible for the reduction in TBO of starter generators of Do-228 aircraft.

Table 11: Awareness of TBO on Starter Generator

Response	No. of respondents	Percentage of Respondents (%)
Yes	153	68
No	13	6
Neutral	58	26

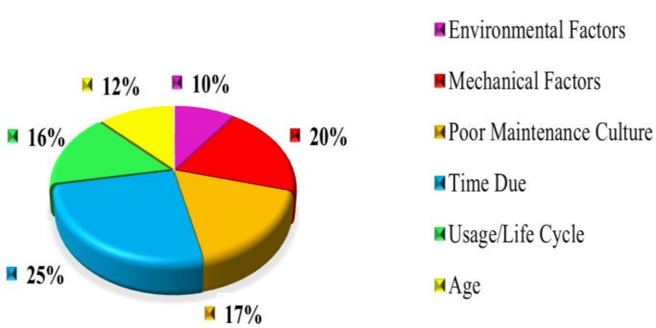

Figure 8: Factors Responsible for TBO of Starter Generator on Do-228 Aircraft

To determine the impact of the factors enumerated above the respondents were asked if the factors affecting the TBO of the starter generator on Do-228 were remedied and if it would improve the availability of the Do-228 aircraft. About 81% believed that if the factors are remedied it will increase the availability and serviceability of the aircraft, 6% did not agree with that assertion while 13% are ambivalent. Table 12 contains the result of the responses.

Table 13 shows how the unserviceability of the starter generator will affect the operational capability of the aircraft.

Table 12: Result of Remedy to Improve Availability of Do-228 Aircraft

Response	No. of respondents	Percentage of Respondents (%)
Yes	182	81
No	13	6
Neutral	29	13

Table 13: Effect of Starter Generator on Operational Capability

Response	No. of respondents	Percentage of Respondents (%)
Yes	200	89
No	9	4
Neutral	15	7

From the result present in the Table 13, 89% of the respondents accept and believe that the unserviceability of the starter generator will affect the operational capability of the Do-228 aircraft, while 4% did not accept and 7% indicated neutral. The participant's responses from the result prove that the unserviceability of the starter generator on Do-228 aircraft will affect the operational capability of the aircraft. In the alternative question to the above Table 14 shows that Do-228 aircraft serviceability will increase the operational capability of the company by 70%.

Table 14: Response on the effect of serviceability on Do-228 Aircraft Capability

Response	No. of respondents	Percentage of Respondents (%)
Yes	157	70
No	24	11
Neutral	43	19

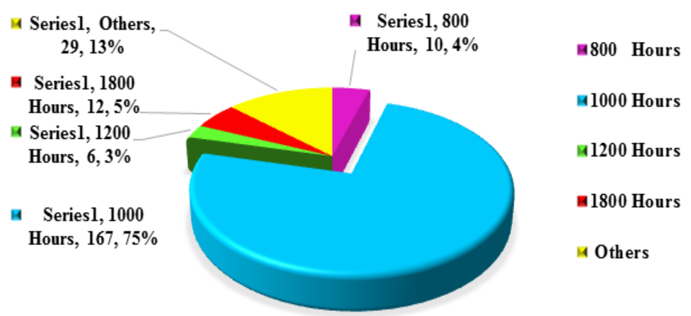

Figure 9: Flight Hours for Overhaul of Starter Generator of Do-228Aircraft.

Figure 9 presents the different flight hours of the starter generator of Do-228 aircraft. The participants were requested to select the actual flight hour at which the starter generator is overhauled. About 75% specified the correct flight hours which is 1000 hours and 13% did not know about the flight hours. The specified hours by the manufacturer for overhauling of starter generators on Do-228 aircraft is 1000 flight hours. However, at every interval of 300 hours,' an inspection is carried out on the starter generators.

Table 15 shows awareness of Dornier Aviation's stipulated manual on TBO of starter generators. From the response, it shows that 60% of the participants are aware of the TBO of the starter generator stipulated by Dornier aviation, while 35% are indifferent and 5% did not know if there is any manual. The high percentage of participants' responses show the awareness of TBO for starter generators as stipulated by the manufacturer.TBO for the starter generator by the company.

Table 16 depicts the result of the responses with respect to adhering to the stipulated

Table 15: Response on Use Dornier Aviation Stipulated Manual for TBO of Starter Generator.

Response	No. of respondents	Percentage of Respondents (%)
Yes	134	60
No	12	5
Neutral	79	35

Table 16: Response on Respect of Stipulated TBO for Do-288 Starter Generator.

Response	No. of respondents	Percentage of Respondents (%)
Yes	126	56
No	15	7
Neutral	83	37

Table 17: Training Effect on Serviceability of Do-228 Starter Generator.

Response	No. of respondents	Percentage of Respondents (%)
Yes	176	79
No	21	9
Neutral	27	12

The result presented in Table 16 shows that 56% of the personnel are aware and agreed to keep the stipulated TBO of starter generator on Do-228 aircraft, while 37% indicate indifference and 7% have no idea. The result from Table 16 validates Table 15 that the participants are aware of the manufacturer manual stipulated TBO for the starter generator on Do-228 aircraft. Table 17 shows the effect of training on the serviceability status of the starter generator on Do-228 aircraft.

The result presented, in Table 17, the participants were asked their view on the question if they consider training an issue affecting the serviceability of starter generators on Do-228 aircraft. 79% of the participants believed that training affects the serviceability of starter generators on Do-228 aircraft, while about 12% indicate indifference and 9% did not believe training is an issue affecting the serviceability of starter generators. The result from Table 17validates the result presented in Table 10 which shows that 58% of the participants only obtained basic training which is not enough for the overhaul of the starter generator on Do-228 aircraft since it required advanced training and vast knowledge as earlier stated in chapter Two. From question 24, Table 18 shows that funding is an issue affecting the good maintenance of starter generators on Do-228 aircraft.

Table 18: Funding affecting Good Maintenance of Starter Generator.

Response	No. of respondents	Percentage of Respondents (%)
Yes	181	81
No	14	6
Neutral	29	13

The participant's response from Table 18 shows that the effect of funds affects good maintenance of starter generator on Do-228 aircraft. Response of 81% of participants believes that funding is an issue affecting good maintenance of starter generator, while 6% believed that funding is no effect and 13% indicated indifference. However, it is stated earlier that overhauling starter generators need advanced training and special tools, these require funding, which indirectly affects the maintenance of starter generator.

Table 19 shows the respondent's response on the relationship between flight hours and TBO of starter generators on Do-228 aircraft. The participants were asked if there is a relationship between flight hours and the TBO of the starter generator on Do-228 aircraft. The aim of the question is to receive responses from the participants in determining the relationship between the two parameters and to ensure means of validating or invalidating the first research hypothesis of this thesis, which says; "*there is no significant relationship between flight hours and TBO of starter generator on Do-228 aircraft".* From the analyzed responses about 71% of the participants agreed that there is a positive relationship between flight hours and TBO of starter generator on Do-228 aircraft, while about 26% indicated indifference and 3% did not believe there is a positive relationship between the two parameters. Since a high percentage of participants believed and agreed that there is a positive relationship between the two parameters. The first research hypothesis is rejected.

To confirm the assertion, the response is further subjected to statistical analysis using the chi-square contingency table for the test of difference of more than two proportions as shown in Table 20.

Table 19: Relationship between Flight Hours and TBO of Starter Generator

Response	No. of respondents	Percentage of Respondents (%)
Yes	158	71
No	7	3
Neutral	59	26

Table 20: Relationship between Flight Hours and TBO of Starter Generator- Chi-Square Significant Test.

Response	Unit 1	Unit 2	Unit 3	Sum	Expected	Unit 1	Unit 2	Unit 3	Chi-Square Calculation	Degree of Freedom	Chi-Square Critical Table
Yes	22	119	17	158	53	18	84	24			
No	2	4	1	7	2	0	1	1			
Neutral	17	33	9	59	20	0	9	6	142.7	4	9.5
Sum	41	156	27	224	75	15	89	30			

Table 21: Relationship between Operational Life Cycle and TBO of Starter Generator

Response	No. of respondents	Percentage of Respondents (%)
Yes	157	70
No	37	17
Neutral	30	13

Table 22: Relationship between Operational Life Cycle and TBO of Starter Generator- Chi-Square Significant Test.

Response	Unit 1	Unit 2	Unit 3	Sum	Expected	Unit 1	Unit 2	Unit 3	Chi-Square Calculation	Degree of Freedom	Chi-Square Critical Table
Yes	122	6	29	157	53	91	41	11			
No	20	3	14	37	2	134	0	58			
Neutral	18	4	8	30	20	0	12	7	355.1	4	9.488
Sum	160	13	51	224	75	98	51	8			

The test statistics follow a chi-square distribution with (3-1)(3-1) degree of freedom = 4 d.f. Therefore, the critical value at a 5% level of significance is 9.488. Since the computed value of the test statistics (142.7). Table 20 is larger than the critical value, we reject the null hypothesis at a 5% level of significance and conclude that there is a significant relationship between the flight hours and the TBO of the Do-228 aircraft starter generator. Table 21 shows the relationship between the operational life cycle and TBO of the starter generator on Do-228 aircraft.

In Table 21, the author asked the respondents to indicate if there is a relationship between the operational life cycle and TBO of the starter generator on Do-228 aircraft. The purpose of the question is to receive responses from the participants to determine if there is a direct relationship between the two parameters and to ensure means of validating or invalidating the second research hypothesis of this thesis, which says, "*there is no significant relationship between operational life cycle and TBO of starter generator on Do-228 aircraft".* From the responses received, as depicted in Table 21, some 71% of the participants agreed that there is a positive relationship between operational life cycle and TBO of starter generator on Do-228 aircraft, while about 13% are indifferent and 17% did not believe there is a positive relationship between the two parameters. Since a high percentage of participants believed and agreed that there is a positive relationship between the two parameters (that is, the operational life cycle and TBO of starter generator on Do-228 aircraft), the second research hypothesis is therefore rejected prima facia. The number of respondents for the responses is further subjected to a Chi-square test for significant level and the result is shown in Table 22.

The test statistics follow a chi-square distribution with (3-1) (3-1) degree of freedom = 4 d.f. Therefore, the critical value at a 5% level of significance is 9.488. Since the computed value (355.1) of the test statistics is larger than the critical value (9.488), we reject the null hypothesis at a 5% level of significance and conclude that there is a significant relationship between the flight hours and the TBO of Do-228 aircraft starter generator.

4.0 CONCLUSION

Findings show that the factors responsible for TBO of Do-228 aircraft starter generator are an environmental factor, mechanical factor, poor maintenance culture, usage/operational life cycle, time due and ageing. The percentage ranking puts time due at 25%, mechanical factors at 20%, poor maintenance culture at 17%, usage/operational life cycle at 16%, ageing at 12% and environmental factors at 10%. The factor that affects the TBO of the Do-228 aircraft starter generator most is time due for an overhaul (25%) while environmental factor accounts for only 10%. The forgoing means that there is only 25% scheduled maintenance and 75% unscheduled maintenance. The recommended flight hour of 1000 hours is therefore 75% flawed and should be reviewed. The study further sought and obtained the opinion of the respondents on the root causes for the preponderance of unscheduled maintenance. The multiple-choice response (sampling with replacement) has 78%, 81% and 71% of the respondents indicated untimely replacement of items, funding and frequent use of the aircraft respectively as the remote causes of the factors undermining scheduled maintenance of the starter generator. In testing the stated hypothesis (research objective) on the relation between flight hours'/operation life cycle and the TBO of the starter generator, the chi-square inferential statistics for non-parametric data show that there are significant relationships between flight hours'/operation life cycle to TBO of Do-228 aircraft starter generator (Table 20 and Table 22). Hence the scheduled TBO of the Do-228 starter generator based on the flight hours'/operation life cycle is justified. Further, expert/intensive inspection currently rendered by only 16% of the maintenance workforce and the minuscule number of the workforce (9%) Table 10 with advance maintenance level certification should be stepped up for more in-depth maintenance of such vital components to minimize breakdown maintenance, prevent failure of the aircraft and enhance availability as well as safety and security of life and property

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