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Forensic Engineering: The Investigation of The Causes of Asymmetry Trailing Edge Flap During The Aircraft Boeing 737 Landing.

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Abstract. Forensic engineering is the application of engineering principles and methodology to answer questions of fact. These questions of fact are usually associated with accidents, crimes, catastrophic events, property degradation, and various types of failures. This research discusses a serious incident that occurred on a Boeing 737-300F aircraft operated by The XYZ airline which operates unscheduled domestic flights in Indonesia, with a flight route from Jakarta Soekarno International Airport (CGK) to Samsoedin Noor International Airport Banjarmasin (BDJ). When the plane was about to land, and the pilot operated the flaps from the 30o position to the 40o position, there was an asymmetry between the left and right flap trailing edges of more than 20o, which caused the plane to become unstable because it rolled to the left, and the pilot was unable to control the plane when landing, which causing a serious incident on the plane. This research aims to find the root cause of trailing edge flap asymmetry of more than 20o as an evaluation for companies in determining and implementing corrective and preventive actions so that this problem does not happen again in the future. This research will use forensic engineering investigation methods and carry out chemical composition testing (Optical Emission Spectroscopy); metallographic testing (micro and macro structure observations); FESEM testing and microchemical composition testing (EDS); and hardness testing. Then for each test result an analysis is carried out based on scientific knowledge. The results of the investigative analysis were to find the root cause of the trailing edge flap asymmetry problem of more than 20o. After getting the root cause of each method, the author then compares the results of one method with another method to draw conclusions to consider and determine corrective and preventive actions to be taken and implemented in the company or organization.

Keywords. *The investigation, Incident, Fracture, Failure, and Forensic Engineering*.

1. Introduction

The aviation industry faces a variety of risks. For this reason, risk management is self-evident in this industry. But the aviation industry also faces a greater density of regulations concerning risk management than other industries [Ref 1]. The most urgent risk at this time is the possibility of technical malfunctions with the aircraft due to maintenance procedures performed by the airline. Phenomena that cause serious risk are technical problems caused by a material failure in several aircraft components resulting from maintenance errors. An accident investigation is a systematic process whereby all the possible causes of an adverse event are evaluated and eliminated until the remaining causes are identified as applicable to that investigation [Ref 2]. The problem to be investigated is the root cause of the trailing edge flap asymmetry with an angle difference of more than 3 degrees, which caused a serious incident on the aircraft Boeing 737 – 300F, which occurred on August 2022, at Samsoedin Noor Airport, Banjarmasin in Indonesia. Finding and identifying the actual problem is very important for the organization to take corrective action and preventive action to avoid the problem and its effect in the future, minimize losses, and make safe air conditions. Otherwise, root cause analysis (RCA) is the method of problem-solving used for identifying the root causes of faults or problems [Ref 3].

That is to say, “specific” normal accidents are highly unlikely to reoccur. Where there are a billion possible "billion-to-one events" that can instigate an accident, it is logical to anticipate an accident but not the same accident twice [Ref 4]. Forensic Engineering is the application of engineering principles and methods to answer questions about facts. Questions of fact are usually related to accidents, crimes, catastrophic events, property degradation, and various types of failure. Forensic engineering is similar to failure analysis and root cause analysis with respect to the scientific methods and techniques used [Ref 5].

Forensic engineering includes a systematic search for knowledge requiring observation and problem definition; data collection through observation, research, experiment and/or calculation; data analysis; and development and evaluation of findings and opinions. [Ref 6]. In the investigation of this asymmetry flap serious incident to seek conformity with the facts, analysis of the failure that occurred from the components that caused the serious incident using several scientific methods such as: Chemical composition testing (Optical Emission Spectroscopy), metallographic testing (observation of macrostructure and observation of microstructure), FESEM testing and microchemical composition test (EDS), Vickers hardness testing. The results of the tests found several facts that the components that failed and caused the serious incident were made of AISI 4140 and AISI 4340 steel materials. Thus this research was carried out only for the purpose of scientific study carried out objectively based on scientific facts.

Description Trailing edge flap system Boeing 737-300F

The trailing edge flap system was installed to provide additional lift during takeoff and landing by increasing wing camber. [Ref 7]. The flaps are faired with wings when retracted and mechanically separated to form slots when extended. Slots provide increased lift by reducing the stagnation of air flowing over the surface of the enclosure. With the flaps extended, the area of the flaps was greatly increased. The trailing edge flap system consisted of two sets of triple slot flaps on each wing (show in figure 1). During normal operation, the flap actuation system is hydraulically actuated. During alternate flap operation, the propulsion system is electrically powered. Each trailing edge flap is actuated by two flap transmission assemblies.

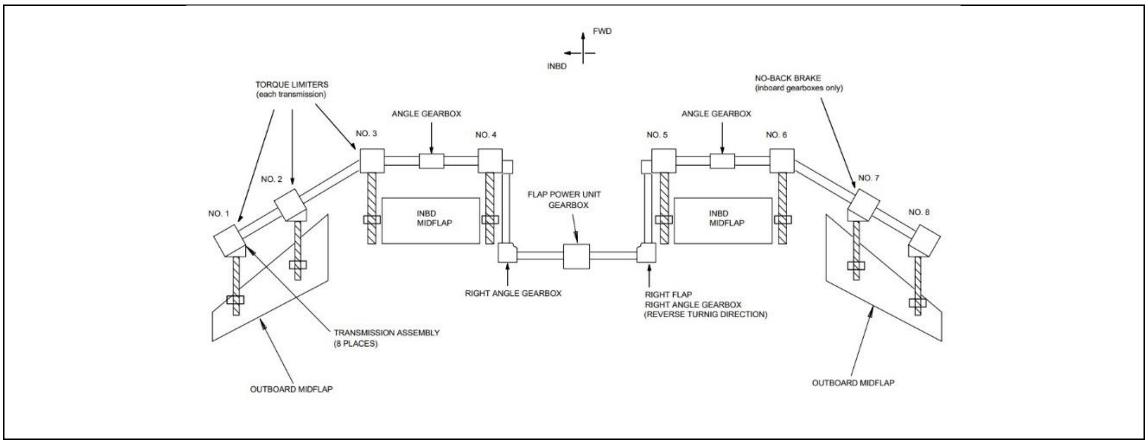

Figure 1. The schematic trailing edge flap system [Ref 8].

2. Methodology

Accident investigation methodology and the scientific method have the same goal, to explain observed phenomena or events using formal methods of data collection and analysis [Ref 9]. The investigation process that will be carried out is as follows:

a. When a serious incident occurs, the crew on duty reports the initial report of the incident to the SSQ department and Chief inspector in the following report:

1) Trip report.

2) Telephone communication.

b. Based on these serious incidents and to find the root causes of serious incidents, it is necessary to conduct research to investigate and find the root causes of the causes of these serious incidents. The research was started based on the following:

1) The results of the company's internal coordination meeting.

2) Letter of Appointment and establishment of an internal investigation team.

3) Results of coordination meetings with the Authority.

c. The research was initiated with a thorough investigation of the trailing edge flap system of the Boeing 737-300F aircraft. A fault tree analysis structure was devised to effectively summarize the system and identify possible factors contributing to the malfunction of the trailing edge flap system.

d. At the beginning the research, data was collected from the company's Box application and BMKG:

1) Personnel data.

2) Environmental data.

3) Aircraft data for the six months prior to the serious incident.

e. Performed initial investigation of the aircraft at the state of occurrence together with the NTSC team, and the competent authority team.

f. After that the team began to collect data at the incident location and data on aircraft damage, as follows:

1) Interview result.

2) The results of data collection on the surrounding environment.

3) Results of data collection on the condition and damage of the aircraft.

g. After the data has been collected, the investigation team studies the data and begins to observe and look for Non-conformity that occurs, in several aspects as follows:

1) Look for Non-conformity in the human aspect.

2) Look for Non-conformity in the environmental aspect.

3) Look for Non-conformity in the aircraft condition.

4) Look for Non-conformity in the maintenance aspect.

h. After collecting all Non-conformity, all of the Non-conformance are studied and implemented to find the cause of the failure of the trailing edge flap.

i. After obtaining the results of the non-conformance analysis, to obtain the accuracy of the analysis, tests, and measurements were carried out on several objects suspected of being the cause of the asymmetry of the trailing edge flap or the failure of the trailing edge flap system's work function, while the test and measurement methods carried out were as follows:

1) Perform micro & macro structure metallographic testing of components.

2) Perform chemical composition testing – OES, of components.

3) Perform FE SEM-EDS testing.

4) Perform hardness Vickers testing of components.

j. The results of these tests and measurements are studied and evaluated based on existing and applicable theories in accordance with the results of these tests and measurements, an analysis and verification of the serious incident is carried out.

k. After analyzing and verifying the serious incidents of the Boeing 737 aircraft, conclusions and suggestions are made to the company as a reference for taking corrective and preventive actions so that these incidents do not recur in the future, and after that the research is complete.

Initial data includes several aspects, namely, data on personnel on duty, aircraft data for the last six months, airport technical data. The data taken during the initial investigation was carried out after a serious aircraft incident by observing and collecting data in several conditions, including marking data on aircraft tracks found on the runway, and the condition of the airport and runway. In the data taken, there are scratch marks from the aircraft's paint on the left side of the runway which forms a white scratch line, and scratch marks on the tip of the left wing of the aircraft and the left engine of the aircraft on the runway which form a white scratch line. As can be seen in Figure 2, this could be the starting point for a streak of white paint that is not an official marking or airport runway marking.

Figure 2. The starting point of the scratch on the runway

Referring to Figure 3, it should be noted that there is a visible scratch on the runway that extends towards the center, exactly parallel to the plane's landing direction.

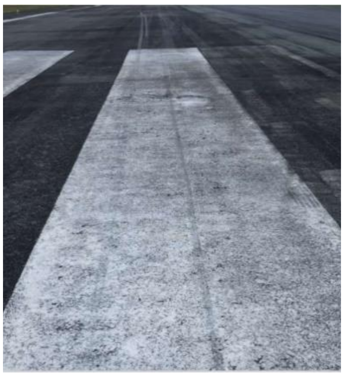

Figure 3. White paint stripes towards the center of the Runway

Airport data taken from AIP Indonesia Vol. II, revised 27 January 2022 and 14 July 2022 issued by the Director General of Civil Aviation, Ministry of Transportation of the Republic of Indonesia, with the following data:

Table 1. Data airport Runway width, surface, and strength. [Ref 10].

No	Designations RWY NR	True BRG	Dimensions of RWY (M)	Strength (PCN) and surface of RWY and SWY	THR coordinates RWY end coordinates THR geoid undulation
1	10	100.40°	2 500 x 45	68/F/B/X/T Asphalt	THR 032625.01S 1144505.66E
2	28	280.40°	2 500 x 45	68/F/B/X/T Asphalt	THR 032639.72S 1144625.35E

Figure 4 is data from AIP Indonesia Volume 2, which shows the classification number of the Boeing 737-300 aircraft with a maximum empty operating mass value of 140,000 lbs and a minimum value of 72,500 lbs, obtained from the AIP Indonesia data table with the maximum ACN value being 35, and the minimum value being 18.

Aircraft type	All-up Mass[1] (Maximum Apron Mass) (Operating Mass Empty)		Load on one main gear leg (%)	Standard Aircraft Tire Pressure			ACN relative to							
							Rigid pavement subgrades				Flexible pavement subgrades			
							High K = 150 MN/m³	Medium K = 80 MN/m³	Low K = 40 MN/m³	Ultralow K = 20 MN/m³	High CBR = 15%	Medium CBR = 10%	Low CBR = 6%	Very low CBR = 3%
	lbs	kgs		psi	kg/cm²	mPa	A	B	C	D	A	B	C	D
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B737-200	100800 57200	45722 25945	46.4	141	9.91	0.97	24 12	25 13	27 14	29 15	22 11	23 12	26 13	30 15
B737-200 (Advanced)	117500 63700	53297 28894	46.4	166	11.67	1.14	30 15	32 15	34 17	35 17	27 13	28 14	32 15	36 17
B737-200/200QC (Advanced)	117500 63700	53297 28894	46.4	96	6.75	0.66	25 12	27 13	30 14	32 15	22 11	26 13	30 14	35 17
B737-200/200QC (Advanced)	128600 64200	58332 29121	46.0	182	12.80	1.25	34 14	36 14	38 15	39 17	30 15	31 16	35 17	39 18
B737-300	135500 72500	61462 32885	46.2	195	13.71	1.34	37 18	39 19	41 20	42 21	32 16	34 16	38 17	42 20
B737-300	140000 72500	63503 32885	45.4	201	14.13	1.39	38 15	40 16	42 17	43 20	33 18	35 18	39 20	43 20
B737-400	139000 72000	63049 32659	47.0	204	14.34	1.41	40 18	41 19	43 20	45 21	34 16	36 16	40 17	44 20
B737-400	150500 72000	68266 32659	46.9	185	13.08	1.28	42 18	44 19	47 20	48 21	37 16	39 16	44 17	48 20
B737-500	134000 72000	60781 32659	46.0	194	13.64	1.34	37 18	38 18	40 20	42 20	32 16	33 16	37 17	41 20
B737-600	146000 80200	66224 36378	45.3	186	13.08	1.28	37 18	39 19	41 21	43 22	33 17	34 17	38 18	43 21
B737-700	155000 83000	70307 37648	45.8	197	13.85	1.36	41 20	43 21	45 22	47 23	36 18	38 18	42 19	47 22

Figure 4. Aircraft Classification Number (ACN) table data. [Ref 11]

So to find the ACN value of the Aircraft Classification Number is as follows:

ACN = ACNMax – (Max Take off Mass – Massa Aktual) X (ACNMax - ACNEmpty)

(Max Take off Mass – Misa Kosong)

ACN = 35 – (63503 – 56868) x (35 – 18)

= (63503 – 32885) = 31,3

The conclusion from the calculation above which refers to the ACN and PCN tables is that the power of the

Runway, Taxiway A, Taxiway C, and Apron can be used by Boeing 737 – 300F aircraft which have a maximum ACN of 35 and a minimum of 18.

As a first step, the problems that occur in the trailing edge flap system are identified by studying the system on the trailing edge flap using the fault tree analysis method and data collection. After obtaining the component data and studying the trailing edge flap system, a fault tree analysis was made to find the root cause of the trailing edge system malfunction. This analysis method is primarily used in safety engineering and reliability engineering to understand how a system can fail [2]. In Figure Below, you can see a fault tree analysis of the trailing edge flap system of the Boeing 737-300F aircraft.

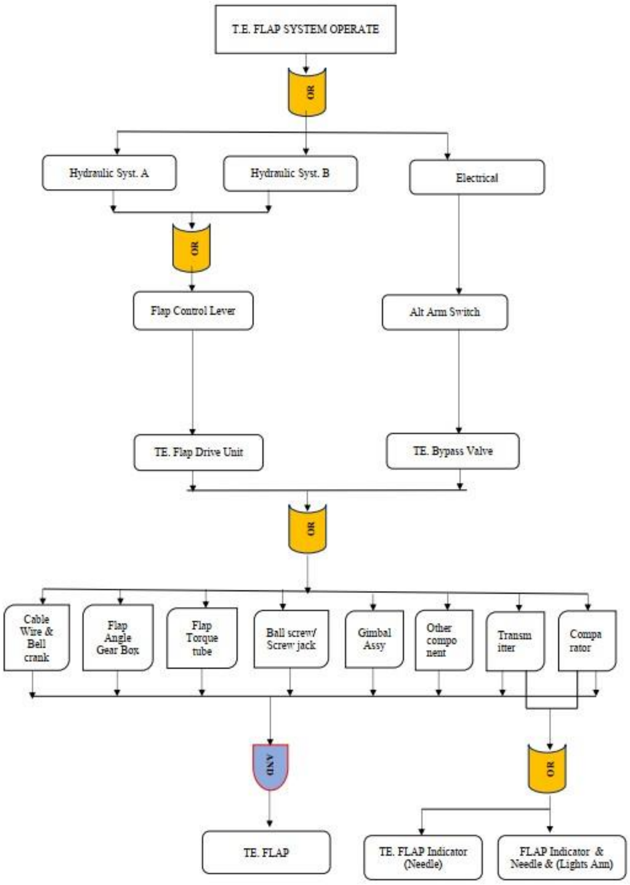

Figure 5. Fault tree analysis of the trailing edge flap system

Based on the fault tree diagram shown in Figure Above. then it can be identified the components that might cause the failure of the trailing edge flap system are as follows:

1. Hydraulic systems A and B include hydraulic pumps, tubing line, pressure regulator, etc.
2. Electrical system which includes: circuit breaker, cables, switches, relays, electric motors, etc.
3. Flap position indicator & transmitter.
4. Flap comparator
5. Flap the trailing edge bypass valve.
6. Cable wire and bellcrank.
7. Flap drive unit.
8. Flap angle gearbox

9. Flap asymmetry shutoff relay.
10. Ballscrew or screwjack.
11. Gimbal assy.
12. Torque tube.

During the identification process and to ensure that from several possible sources of problems the occurrence of asymmetry in the trailing edge flap system, a problem search was carried out based on the Boeing 737-300F AMM, by going through the process of problem identification stages, the easiest stage and process is to remove and test components. The problem identification stage on the component is as follows:

1. Performed the functional check on the aircraft hydraulic system, it was found that the hydraulic pressure reached 3000 psi, which means that the pump system pressure was normal.
2. The Investigator conducted inspections on the electrical cable connections, connectors, and relays of the trailing edge flap system and measured the resistance value and volts. These tasks were done in accordance with the Boeing AMM standard and no issues were found.
3. Performed the inspection on the flap position indicator and transmitter, and after checking is done to ensure the flap position indicator and transmitter a on other aircraft of the same type, it is found that when operated the flap system, the indicator shows normal indications and the flaps work normally.
4. Performed the inspection on the flap comparator, and after checking is carried out to ensure that the flap comparator has been tested on other aircraft of the same type, found while operating the flap system, found in several functional tests, operational flap system under normal conditions has no problems.
5. Performed the inspections on all cable wires and bell cranks, and re-measuring the cable tension with a cable tension meter in accordance with the Boeing AMM standard, found no problems with cable wire, cable tension, and bell cranks.
6. Performed the inspection on the flap trailing edge bypass valve, and after checking is done to ensure the flap trailing edge bypass valve is tested on other aircraft of the same type, found while operating the flap system, found in several functional tests, flap system operation under normal conditions has no problems.
7. Performed the inspection on the flap drive unit, and after inspection is carried out to ensure the flap drive unit is tested on other aircraft of the same type, found while operating the flap system, found in several functional tests, flap system operation under normal conditions has no problems.
8. Performed the inspection on the flap angle gearbox, and after inspection is carried out to ensure that the flap angle gearbox is tested on other aircraft of the same type, it is found when operating the flap system, found in several functional tests, the flap system operation in normal conditions has no problems.
9. Performed the inspection on the flap asymmetry shutoff relay, and after checking to ensure the flap asymmetry shutoff relay was tested on another aircraft of the same type, it was found while operating the flap system, it was found in several functional tests, the flap system operation under normal conditions had no problems.
10. Performed a visual inspection of all the ballscrews, and after inspection, it was found that all four ballscrews which were found all of the ballscrew on the left wing of the aircraft had corrosion on their surfaces and there was sharpening of the threads on two of the ballscrews.
11. Performed the inspection on eight gimbal assy, and after inspection, it was found that all gimbal assemblies on the left wing of the aircraft (four gimbal assy.) were dry without any lubricating oil (fluid 4) which is used to lubricate the ballscrew when the trailing edge flap moves.
12. Pcrformed the inspections on all torque tubes, and after inspection, it was found that the torque tube on the left wing had wear on its teeth. The torque tube that experiences wear on all of its teeth is the torque tube that connects the flap power unit to the flap angle gearbox.

The results of inspection and functional tests of the above components for points number 1 to number 9, were not found to cause a malfunction of the aircraft's trailing edge flap system. However, the problems with the components mentioned in numbers 9 to 12 are thought to be the cause of the asymmetry in the trailing edge flap system of the Boeing 737 aircraft.

3. Case study and results

The author conducted FESEM testing and a micro chemical composition test (EDS) using the FE-SEM FEI INSPECT F50 test machine. The results are as follows:

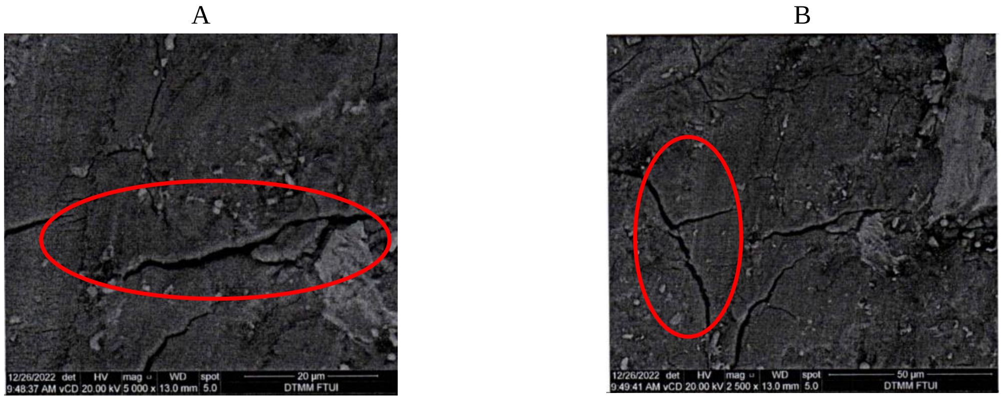

Figure 6. FESEM test results. A). FESEM test results with 5000 times magnification. B). FESEM test results with 2500 times magnification.

The results of the FESEM test performed on the component parts of the Ball screw or screw jack with part number 57022243670 are illustrated in the figures 6 and figure 7 presented above and below. These findings provide valuable insights into the quality and performance of the tested components.

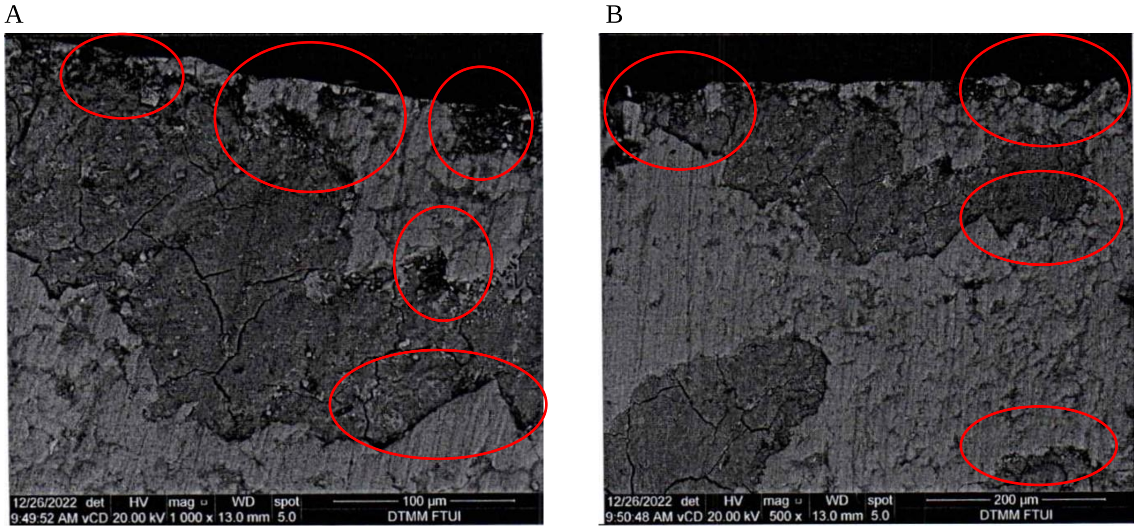

Figure 7. FESEM test results. A). FESEM test results with 1000 times magnification. B). FESEM test results 500 times magnification.

Based on the attached figure 8 on below which shows the results of the Field Emission Scanning Electron Microscope (FESEM) test carried out on the ball screw or screw jack component parts with part number 57022243670. Based on observations, it appears that this part is experiencing problems with corrosion and thread sharpness. In Figure 6, the results of the FESEM test are taken from other parts of the ballscrew or screwjack components which are the same as P/N: 57022243670 which are experiencing corrosion and thread sharpness. In figure 6A marked with a red circle oxidation occurs which causes corrosion on the ballscrew, is the result of the FESEM test with 1000x magnification, and the figure 8B, is the result of the FESEM test with 500x magnification.

A

B

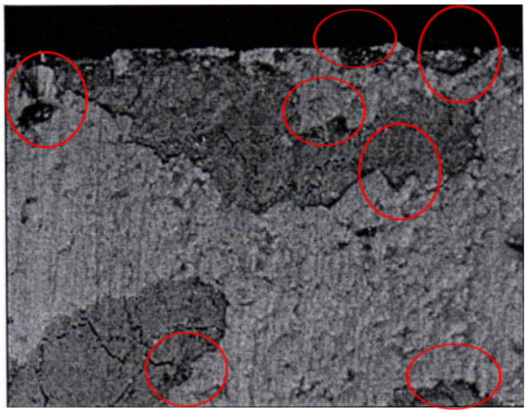

Figure 8. FESEM test results. A). FESEM test results with 1000 times magnification. B). FESEM test results 500 times magnification.

Such information can prove instrumental in gaining a more comprehensive understanding of the nature and extent of the corrosion present, allowing us to make more informed decisions regarding the necessary repairs or maintenance.

Table 2. FESEM test results of sample 1, sample 2, and sample 3 from the ballscrew with P/N: 57022243670.

Element	Sample 1		Sample 2		Sample 3	
	Wt %	At %	Wt %	At %	Wt %	At %
CK	04.45	11.63	13.83	29.75	CK	15.44
OK	22.80	44.69	23.26	37.57	OK	43.91
AlK	02.18	02.53	03.51	03.37	AlK	01.43
SiK	01.65	01.84	02.55	02.35	SiK	01.93
CaK	00.92	00.72	01.56	01.01	CaK	00.80
CrK	09.82	05.92	06.82	03.39	CrK	03.83
MnK	01.12	00.64	01.40	00.66	MnK	00.66
FeK	57.05	32.03	44.75	20.71	FeK	32.00
CuK	-	-	01.92	00.78	-	-
MgK	-	-	00.40	00.42	-	-
Matrix	Correction	ZAF	Correction	ZAF	Correction	ZAF

Based on table 1, the conclusions from the results of the FESEM test are as follows:

1. The results of the FESEM test from ballscrew or screwjack samples that experienced corrosion were shown to have a high oxygen content value of more than 20%, which should have an oxygen content value of 0% as can be seen in the table 2.

2. The results of the FESEM test from ballscrew or screwjack samples can be seen in Figure 6B is a photo with a magnification of 500x (times) and the figure 7B is a photo with a magnification of 1000x (times), that the material is corroded and brittle on its surface, and oxidation occurs on its surface.

The conclusions from the results of the FESEM test are as follows:

1. Based on the findings from the FESEM test, it is evident that ball screws or screw jacks that have undergone corrosion exhibit a notable oxygen content of over 20%. Ideally, the oxygen content in such components should be at 0%, as reflected in the table 2
2. FESEM test results from ball screw or screw jack samples can be seen in the figure 6A photos with a magnification of 5000x and the figure 6B photos with a magnification of 2500x, that the material is corroded and brittle on its surface, and oxidation occurs on its surface.s can be seen in Tables 2.

Testing of Chemical Composition

The chemical composition test was carried out using the Optical Emission Spectroscopy test method, using the WAS Foundry Master (*) testing machine. The tested components are: two items of screw jack components, and two items of Torque tube components, there are one torque tube was a failure on the gear, and another one was the excellent condition or serviceable of the torque tube.

Torque Tube

Based on the information received regarding the Torque Tube Coupling material from a representative of Boeing aircraft manufacturing. According to them, the two possible types of materials used for manufacturing are Steel 4140 and Steel 4340. The results of the chemical composition test on two of the sample of the Torque tube that is experiencing wear and tear can be seen in Table 3, and the Torque tube with serviceable condition in Table 4, as follows:

Table 3, The result of the chemical composition test of the torque tube with the condition has wear on all the gears.

Table 3. The result of chemical composition with torque tube sample 1.

Material Composi-tion	**C %**	**Si %**	**Mn %**	**P %**	**S %**	**Cr %**	**Mo %**	**Test Sample**
	0.417	0.252	0.806	0.014	0.010	0.841	0.249	Torque tube 1
Material Composi-tion	**Ni %**	**Al %**	**Cu %**	**Nb %**	**Ti %**	**V %**	**Fe %**	**Test Sample**
	0.170	0.027	0.150	< 0.002 **	0.006	0.007	95.4	Torque tube 1

The results of the chemical composition test of the sample of the torque tube with the serviceable condition can be seen in Table 4, as follow:

Table 4, The result of the chemical composition test of the torque tube with good condition

Material Composi-tion	C %	Si %	Mn %	P %	S %	Cr %	Mo %	Test Sample
	0.417	0.252	0.806	0.014	0.010	0.841	0.249	Torque tube 2
Material Composi-tion	**Ni %**	**Al %**	**Cu %**	**Nb %**	**Ti %**	**V %**	**Fe %**	**Test Sample**
	0.170	0.027	0.150	< 0.002 **	0.006	0.007	95.4	Torque tube 2

Based on the microstructure material composition table above and the material composition test results in Tables 3 and 4 for the torque tube gear, it can be concluded that the gear material for the torque tube is Steel 4340. AISI 4340 is one of the most widely used steels in high-risk industries such as military, nuclear, and aerospace. [Ref 15]. The table 5 shows the composition of AISI 4340 steel.

Table 5, the chemical composition of the AISI 4340 steel. [Ref 16]

Alloy elements	C	Mn	Cr	Ni	Si	Mo	S	P	Fe
Wt.%	0.38	0.68	0.98	1.805	0.32	0.31	0.018	0.011	Balance

Metallographic Testing with Micro Structure Observations

The metallographic test was carried out using the Microstructure Observation test method, using the Inverted Metallurgical Microscope testing machine, Olympus BX41M – LED. The tests were taken for the components, were: screw jack or ball screw with P/N: 57022243670, on the torque tube, was a failure that worn on the gears, and gimbal components are fused to the screw jack, which has thread sharpening

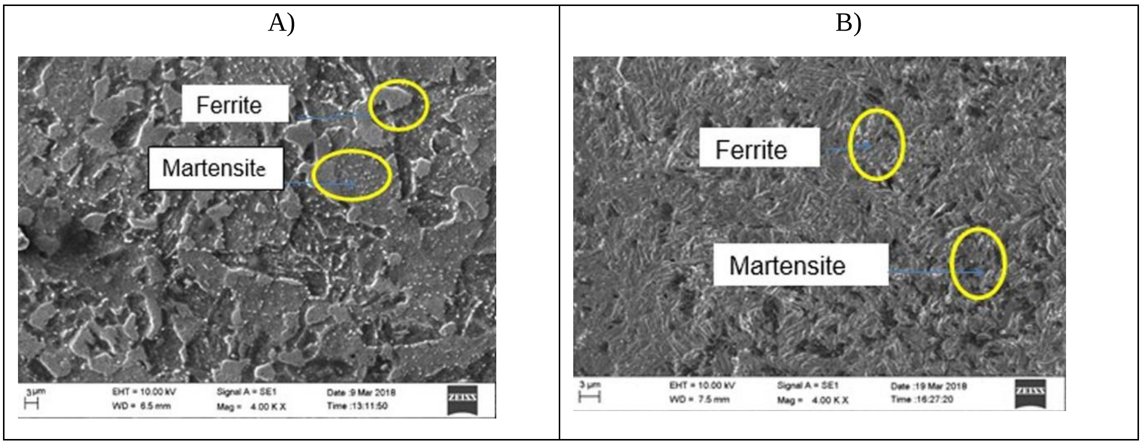

Figure 9. Ferrite-martensite structural phase in AISI 4140. A) Ferrite-martensite structural phase in AISI 4140 steel at 770oC. B) Ferrite-martensite structural phase in AISI 4140 steel at a temperature of 790ºC. [Ref 17]

Torque Tube

Please take a moment to review the enclosed illustration. It provides a detailed analysis of the torque tube portion that is currently experiencing material degradation. It is worth noting that Figure A has been magnified by a factor of 500 to enhance clarity and ensure a comprehensive understanding of the issue at hand. Thank you for your attention to this matter.

The image depicted in Figure B showcases a highly magnified view of the torque tube segment that has undergone material degradation. The microscopic details have been amplified by a factor of 1000, providing a comprehensive and detailed view of the affected area.

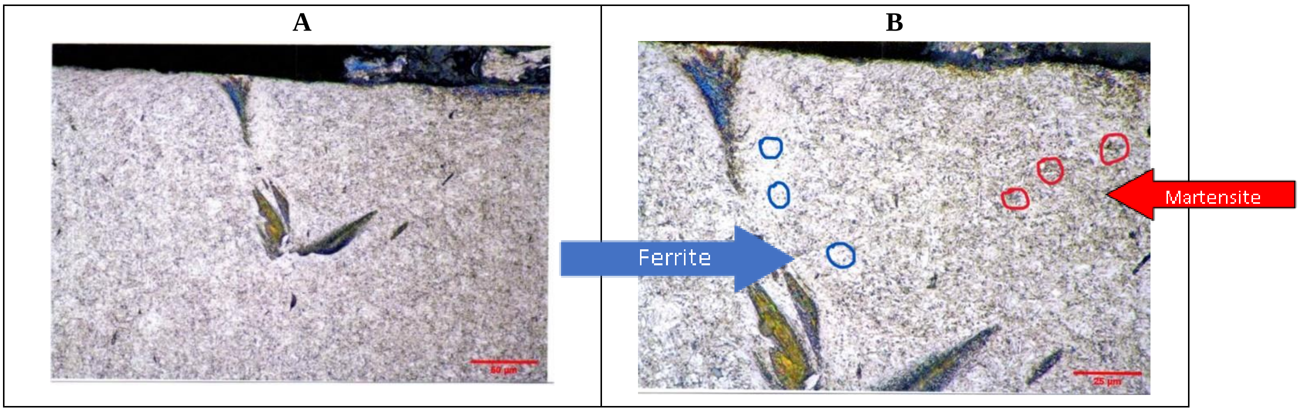

Figure 10. The microstructure Observation test method of the torque tube which is worn out condition, A) Figure A has been magnified by a factor of 500; B) Figure B has been magnified by a factor of 1000.

Analysis of Phase microstructure of the torque tube components

1. Shown from a photo in figure 10B is the 1000x microstructure component of the torque tube made of AISI 4340 steel, marked with a blue circle is the ferrite phase of the material, this crystalline structure gives the magnetic properties of steel and cast iron, and is a simple example of a ferromagnetic material. The mark circled in red is the martensite phase of the material, martensite is formed on very fast cooling from the austenite phase, so the diffusion process does not take place. Martensite is hard, strong, but brittle. Martensite is a microscopic structure formed when a metal or metal alloy is subjected to rapid heat treatment.
2. In the torque tube component, it can be seen that the microstructure of the ferrite and martensite phases is almost balanced or almost the same amount, only slightly more martensite phase microstructure, but not like the martensite composition found in gimbals. Therefore the hardness test results for the torque tube component material show a slightly higher hardness value than the ballscrew component material hardness value. Then when compared with the hardness value of the gimbal component material, the hardness value of the torque tube component material is lower.

Ball screw or Screw jack.

Presented in Figure 11A is a microscopic photograph showcasing a ball screw or screw jack that has undergone corrosion, magnified to 500 times its original size. The image aptly captures the intricate details of the screw's surface, which is remarkably sharp and well-defined.

The accompanying image depicts a highly magnified view of a corroded screw jack. With a 1000x zoom, the image in Figure 5B provides a clear depiction of the screw's surface and its sharpness.

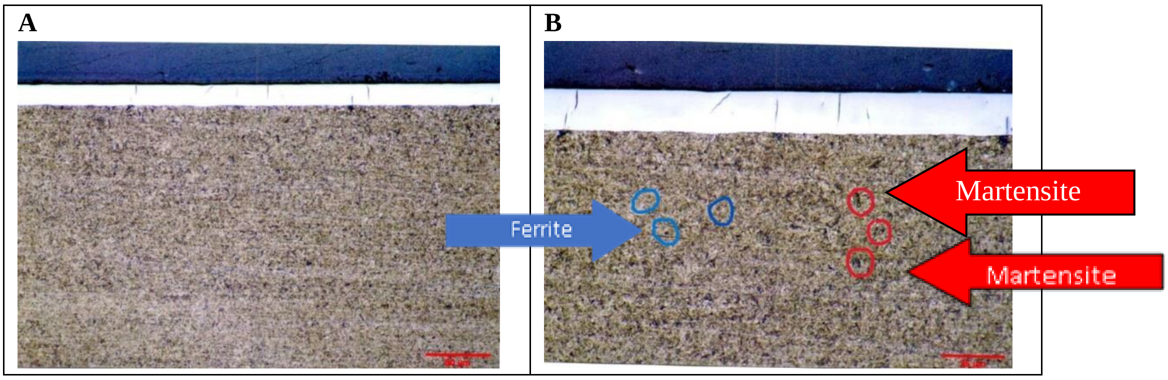

Figure 11. The microstructure Observation test method of the ballscrew or screw jack which is corrosion condition, A) Figure A has been magnified by a factor of 500; Figure B has been magnified by a factor of 1000.

Analysis of Phase microstructure of the ballscrew components

1. It is shown in figure 11B is the photo of the 1000x microstructure component of the ballscrew or screwjack made of AISI 4140 steel, marked with a blue circle is the ferrite phase of the material, and given a red circle is the martensite phase of the material.
2. There are more ferrite microstructures in the ballscrew, an allotrope of iron that is stable at high temperatures and pressures. The ferrite phase is called alpha iron (α) and is a solid interstitial solution with a crystal cell in the form of a BCC (Body Centered Cubic). The space between the atoms is small and tight so the solubility of carbon is very small. At room temperature the carbon content is only 0.008% so it can be considered pure iron. The maximum level of alpha iron is 0.02% at temperature A1 or 7270C. Ferrite is ferromagnetic up to 7680C and is ductile. In general, the ferrite phase is soft, ductile, and magnetic up to a certain temperature. The solubility of carbon in this phase is relatively smaller than the solubility of carbon in another solid solution phase in steel, namely the Austenite phase.

Torque tube Hardness Testing.

The hardness, denoted H (SI unit: MPa) of a material is measured by pressing a sharpened diamond or hardened steel ball into the surface of the material [Ref 18]. Refer to the table provided below to review the specific hardness checks carried out on torsion tube sections. Hardness tests on torsion tube components are specified in the table provided below.

Table 6. The Hardness Vickers test result of the new torque tube components

Sample Code	Identation	Harness Value	Average	Remark
Torque tube (New)	1	346 HV 0.3	-	Vickers Load: 300 gf, 10 seconds
	2	366 HV 0.3	-	
	3	349 HV 0.3	-	
	4	357 HV 0.3	-	
	5	355 HV 0.3	-	

The results of the hardness Vickers test on the Torque tube component, which is in good condition, are listed in Table 10. Vickers was used with a load of 300 gf in 10 seconds, and the results can be found in the Hardness Value column of Table 5. Based on the data in Table 10, the average hardness value is approximately 354 HV. Then 354 HV can be converted to 3472 MPa.

In the Table 7, it can be seen the results of the hardness test of the Torque tube component whose conditions were experiencing wear on the teeth in sample 1, using Vickers with a load of 300 gf in 10 seconds, with the following test results:

Table 7. The Hardness Vickers test result of the torque tube components which fail (1).

Sample Code	Identation	Harness Value	Average	Remark
Torque tube (Fail 1)	1	327 HV 0.3	-	Vickers Load: 300 gf, 10 detik
	2	348 HV 0.3	-	
	3	348 HV 0.3	-	
	4	361 HV 0.3	-	
	5	339 HV 0.3	-	

It can be concluded that the average value of the hardness test results from table 11 is 344.6 HV ≈ 344 HV. Then it can be converted 344 HV = 3372 MPa.

Based on the data presented in the above table, it can be inferred that the average hardness test results have a value of approximately 335 HV or 335.6 HV. This is equivalent to 3285 MPa.

The conclusion can be drawn from the results of the hardness test that the material of the Torque tube is AISI 4340 Steel, normalized, 100 mm (4 in.) round is shown in the table 8. The AISI 4340 has a favorable response to heat treatment (usually oil quenching followed by tempering) and exhibits a good combination of ductility and strength when treated. Uses include piston pins, bearings, ordnance, gears, dies, and pressure vessels.

Table 8, Mechanical properties of steel AISI 4340 with processing by normalized, 100 mm (4 in.) round. [Ref 19].

Physical Properties	Metric	English
Density	7.85 g/cc	0.284 lb/in³
Mechanical Properties	**Metric**	**English**
Hardness, Brinell	321	321
Hardness, Knoop	348	348
Hardness, Rockwell B	99	99
Hardness, Rockwell C	35	35
Hardness, Vickers	339	339
Tensile Strength, Ultimate	1110 MPa	161000 psi
Tensile Strength, Yield	710 MPa	103000 psi
Elongation at Break	13.2 %	13.2 %
Reduction of Area	36 %	36 %
Modulus of Elasticity	200 GPa	29000 ksi
Bulk Modulus	159 GPa	23100 ksi
Poissons Ratio	0.29	0.29
Machinability	50 %	50 %
Shear Modulus	78.0 GPa	11300 ksi

Data On The Damage That Occurred To The Aircraft

a. Left Wing

On the left wing, the upper surface of the left wing of the aircraft, the leading edge was found to have damage, dents and wrinkles, as can be seen in Figure 12.

Figure 12. Photo of the upper surface of the left wing of the aircraft.

b. Left Wing Tip

The figure 13 is shown the damage found on the tip of the left wing of the plane, which rubs against the runway when the plane is about to land, is measured for the length of the damage.

Figure 13. The left-hand wing cover lamp logo

c. Left-hand Engine

The data presented in Figure 14, indicates that the engine situated on the left side, alternatively known as engine 1 or L/H engine, has sustained damage to the left side of its fan cowl, specifically towards the rear.

Figure 14. The left-hand engine cowl.

Conduct The Investigation Of Non-Conformances In Aircraft Components Related To The Trailing Flap System

However, the proper function of most components is essential to the safe operation of the unit. In this investigation, it was necessary to look at each component relative to its fitness for service and potential contribution to the system failure. The system/component design was evaluated relative to the accident events [Ref 12]. Found several aircraft components that experienced failure and damage, which are suspected to be the cause of the serious incident, are as follows:

a. Torque tube

In the figure 15, it can be seen that the gear from the Torque tube, which is experiencing wear which is connected from the Flap drive unit to the flap angle gearbox, was found during the investigation and rectification of the aircraft at the scene.

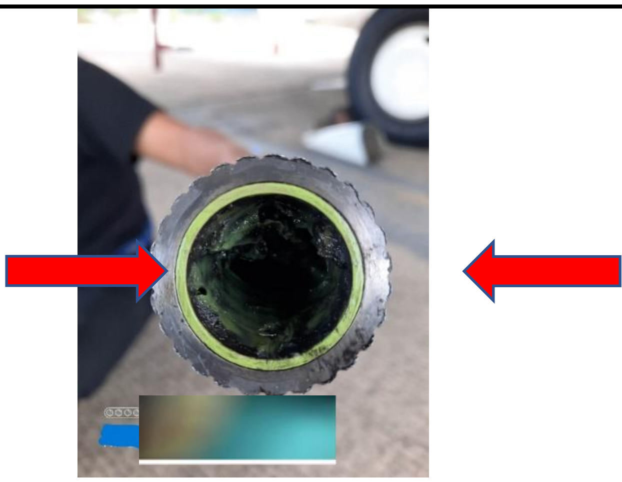

Figure 15. The torque tube that has wear on all the gears

b. Screw jack or Ball screw

Upon inspection, the screw jack or ball screw displayed signs of corrosion in multiple areas. Furthermore, the picture reveals that the threads of the screw jack have lost their sharpness please see in the figure 16.

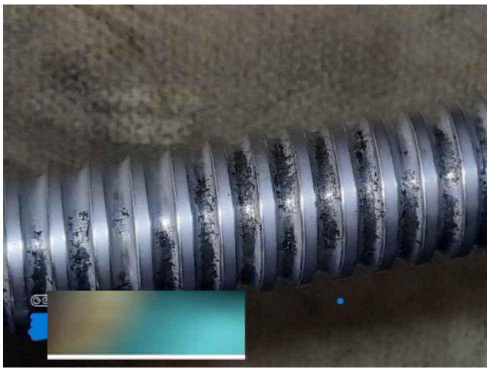

Figure 16. The ball screw or screw jack corroded on its surface and sharply of threaded

c. Gimbal Components

After conducting a thorough examination of the gimbal component, we have found that the section housing the screw jack/ball screw with pointed threads is devoid of any lubrication, which is clearly visible in the attached picture is shown in the figure 17.

Figure 17. The gimbal nut before testing.

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The other airlines which operated the same type of aircraft Boeing 737-300/400/500, have experience changing several of the Gimbal components can be seen in the figure 18 below, as outlined below from the company's standard software recording system.

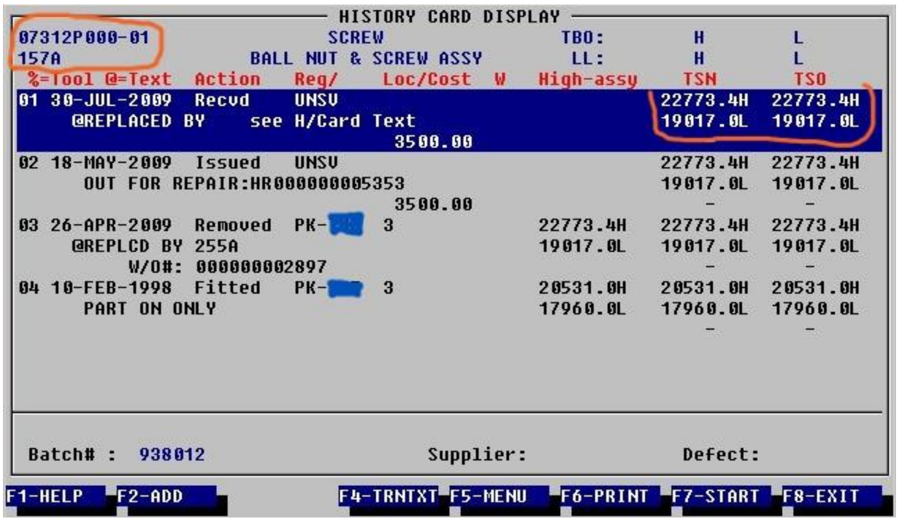

Figure 18. The system record data from the replacement of gimbal and ballscrew components at the other company or airline.

Based on the data mentioned above, it can be deduced that the replacement procedure for the Gimbal or Ball Nut component was executed after 22773.4 hours of aircraft flight, and after 19017 cycles of aircraft operation.
At the same company/airline, data was also obtained from the PPC Division regarding recording for ball nut or gimbal replacement other than the company's standard software system. Data was also obtained from the manual entry data to the computer was mentioned in the table 9 below as follows:

Table 9. The data on damage to the gimbal components from the other company or airline

No	Part Number	Serial Number	Time Since New (TSN)		Time Since Overhaul (TSO)		Reason For Removal
1	07313P000-01	181A	24866	Hours	From New	-	Leak/ bocor
2	07313P000-01	255A	26791	Hours	4018	Hours	Overhaul
3	07313P000-01	177A	45730.9	Hours	24781	Hours	Leak/ bocor
4	07313P000-01	161A	22772.9	Hours	From New	-	Overhaul
5	07313P000-01	157A	22773	Hours	From New	-	Overhaul

Based on the data found in the Table 9, the following conclusions can be drawn:

1. The component with serial number: 181A, is a new component or with 0 hours of use when installed on the aircraft, has a leak problem at 24866 hours.
2. The component with serial number: 255A, is a component of an overhaul workshop with 4018 hours of use, and experiences leakage problems in the total hours of use of new components or of the total hours of use, namely 26791 hours.

Then the usage age after Overhaul = 26.791 hours – 4.018 hours = 22773 hours.

3. The component with serial number 177A has been experiencing leakage problems during its use in the overhaul workshop. It has been used for 24781 hours, and when new components are used, there are no leakage issues for a total of 0 hours, or 45730.9 hours. To determine the usage age after overhaul, we subtract the initial

hours of use from the total hours of use, resulting in 20949.9 hours. The component's first use resulted in an age of 24781 hours, while the use of two components resulted in an age of 20949.9 hours.

4. The component with serial number:161A, is a new component or with 0 hours of use when installed on the aircraft, experiencing changes or problems at 22772.9 hours.

5. The component with serial number: 157A, is a new component or with 0 hours of use when installed on the aircraft, experiencing changes or problems during reached 22773 hours.

Then, from the five components data, the mean or average value of hours the gimbal component can be taken as follows:

The mean or average value = Sum of all values / The amount of data [Ref 13].

= 23155,9666 hours ≈ 23156 hours.

Then the Median Value from the gimbal components can be taken as follows:

Then the Median Value = $\frac{22773 \text{ hours} + 22773 \text{ hours}}{2}$ [Ref 14]

= 22773 hours.

Based on an extensive analysis and the experience of a reputable airline equipped with a state-of-the-art data recording system, it is advisable to establish a life limit threshold for the gimbal's component. This measure will effectively safeguard and preventive the ball screw and torque tube from any potential damage. Replacement of the component is recommended after a specific number of usage hours, ideally ranging between 22773 flight hours and 23156 flight hours.

4. Conclusion

Based on research results from investigations into the causes of asymmetry of the trailing edge flap more from 20o when the Boeing 737 – 300F will land, conclusions can be drawn as follows:

1. Based on the results of research and investigations, during the test flight which took place on August 10, 2022, four days before the incident serious problem occurs, the problem of the trailing edge flap is stuck at 27o which means rectification is not complete before the aircraft returns to operation this is not appropriate with CASR Part 43 clause 43.5 which is discussed in sub-chapter 2.1.2. And these activities are not written on the FML (Flight Maintenance Log Book) by the Pilot, this FML is not in accordance with CASR Part 121 clause 121.701.

2. The results of research and investigations found that the cause asymmetry of the trailing edge flap of more than 20o when the Boeing 737 – 300F aircraft landed was due to being stuck on the left trailing edge flap.

3. Based on the results of research and investigations, that was found to have occurred the problem with the assembly gimbal component is that there is no lubricating oil (fluid 4) to lubricate the ballscrew, or dryness occurs on the dreadlocks.

4. Based on the results of research and investigations, that was found to have occurred thread sharpening and corrosion on the ballscrew surface due to contact between metal and metal, namely, there is contact between the ballscrew and the bearing on gimbals without lubrication.

5. Based on the results of research and investigations that were found to occur wear on all gear components of the torque tube due to material fatigue.

6. Based on the results of research and investigations that were found in class III components have not yet been made a threshold age limit procedure for use maximum, such as gimbal components and ballscrew during maintenance the company's maintenance program to be limited to 22773.4 aircraft flight hours, and at the number of aircraft cycles is 19017 landing times so that there is no failure on class III components, such as: ballscrew, gimbal, and torque tube.

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