Aircraft Maintenance Philosophy

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Abstract: Unlike other means of transportation, the aircraft need extensive and elaborate maintenance procedures owing to flight safety considerations. The aircraft maintenance philosophy essentially covers four distinct phases i.e. proactive detection of any abnormality/failure, fault identification/diagnosis, appropriate remedy/rectifications and finally verification/testing of corrective action. This paper lays more stress on the first phase of maintenance philosophy namely "Proactive fault detection", which consumes maximum time, efforts and money and need detailed analysis by the aircraft maintenance engineers. Additional proactive remedial measures to prevent likely failure of certain components/sub-systems are also implemented during this phase. Broadly fault detection process comprises of certain periodic maintenance schedules and condition monitoring/observations by the pilots (during flying) and technical staff during maintenance. Maintenance schedules for typical military aircraft (both of Russian and western origin) and civil aircraft with particular reference to the mechanical systems of aircraft are listed. The paper comprehensively describes all facets of the maintenance both in the military and civil domain. There are distinct differences in the maintenance philosophies followed in the civil and military aviation. While military aircraft are designed and maintained with "survivability" as the key consideration, the civil aircraft on the other hand consider "cost" as the driving factor for maintenance philosophy.

I. INTRODUCTION

The broad aim of aircraft maintenance philosophy is to guarantee trouble free field exploitation of an aircraft despite wear, corrosion and fatigue of its parts and systems with minimal loss in performance. The role of maintenance is to take adequate actions so as to predict and prevent failures. Therefore, a preventive maintenance approach is followed to check the degradation of equipment during its use. This means carrying out tasks that are required to maintain or restore an aircraft's systems, components, and structure in airworthy condition as per the standards defined by the regulatory authority. The aircraft maintenance philosophy is dictated by the design and reliability of on-board systems, the experience gained with their usage in the past and operational requirements. The maintenance activities are aimed to ensure that the aircraft remains in a serviceable and reliable condition to fulfill its desired role, the physical deterioration of the aircraft is minimal and the standards for repair, replacements, servicing and periodic overhauls, as laid down by the regulatory authority, are satisfied by carrying out the airworthiness maintenance and inspection program through individuals certified and qualified to issue an airworthiness certificate.

Maintenance Activities

Various types of maintenance procedures generally followed include the following:

- **Preventive maintenance** – comprises of
  - **(a)** Scheduled servicing, which could be ***Periodic*** (based on operating hours, or calendar life, or number of landings, or number of cycles or operations, etc.) or ***Aperiodic***, such as Out of Phase servicing.
  - **(b)** Unscheduled servicing based on Service Bulletins (SBs), Servicing Instructions (SIs), etc., which are issued by the manufacturers or the regulatory authorities, snag analyses, Special Servicing Instructions, reported occurrences, etc.
- **Repairs**
- **Replacements**

- **Modifications and compliance with various maintenance directives.**
- **Overhauls**

Maintenance of Military Aircraft (1),(2)

A military aircraft, functioning as a weapon delivery platform, must be maintained in the highest state of operational preparedness. Since it has to be exploited in a hostile environment needing highest considerations of redundancies of operational delivery systems, its survivability in the hostile operational becomes a key consideration. This requires continuous "health checks" and up-gradation of its systems. The philosophy of servicing is guided by the design and reliability requirement of its on-board systems. When an aircraft component or assembly or system is put into service, all the maintenance activities during its service use, along with the snags observed and rectifications/repairs/ replacements carried out, are documented systematically. This maintenance database helps the manufactures to set the life of components, know their reliability and prepare the servicing schedules covering all the maintenance activities and thereby ensuring flight and maintenance safety, economy of effort and improvement in performance of aircraft. Thus, the history of service life becomes the basis for fixing the periodicities and levels of servicing. With the induction of sophisticated and reliable systems on aircraft, 'on-condition maintenance' and 'health monitoring systems' are currently being introduced.

Preventive Maintenance Schedule

All the activities discussed below are documented and signed in the aircraft servicing form by the concerned tradesmen.

2. FIRST LINE SERVICING

The first line servicing on an aircraft is carried out at the operator location, that is, at the **squadron level,** and comprises of routine activities like daily servicing, functional checks, replenishments, minor snag rectifications, re-arming and role change on aircraft to maintain it fit for immediate use. It covers the following types:

(a) **First Flight Servicing (FFS).** These checks are carried out before first flight of the day, to ensure serviceability of aircraft and include checks for leakage, examination of panels for security of attachment, checks on under-carriage, tyre pressure etc. Once signed, the FFS remains valid for 8 hours.

(b) **Turn Round Servicing (TRS)**. These checks are carried out when the aircraft is expected to fly another sortie on the same day after the first flight. They include replenishment of fuel, oil, compressed air, oxygen and ammunitions and general external examination to ensure that the aircraft is ready for one more flight. The TRS remains valid for 6 hours.

(c) **Last Flight Servicing (LFS)**. These checks are carried out after the last flight and include replenishments, irrespective of the state of aircraft serviceability, examination of under-carriage for damage and leaks, examination of tyres for correct pressure, creep and cuts, securing of aircraft and fitting of protective devices, like flying control locks, covers etc. Unserviceability of any system is to be recorded in the aircraft servicing form by the supervisor. LFS is to be carried out if

  (i) after TRS the aircraft has not flown within 6 hrs, or

  (ii) after the last LFS the aircraft has not flown for more than 72 hrs, or

  (iii) after any periodic servicing and after any major rectification.

In case of night flying, ***Night Servicing operations*** are carried out in addition to FFS/TRS/LFS and are signed in **RED INK**. Additionally, the ***Armament servicing***, like loading and un-loading of armament stores, is carried out after the armament sortie under strict supervision and is signed in **RED INK**.

3. SECOND LINE SERVICING

The second line servicing is done on aircraft which are temporarily out of use and is carried out at higher than the squadron level, i.e., at ***Wing level***. It may include calendar servicing; operational hour- or cycle-based servicing, bay servicing of assemblies, electrical equipment and instruments, radio and radar equipment, and rectification of defects beyond first line. It calls for dismantling, minor servicing, bench test of equipment, replacement of faulty assemblies, incorporation of simple modifications, role equipment servicing etc. and is done by skilled tradesmen and requires use of ground and special test equipment. In calendar based servicing the aircraft is serviced at set periods, which are determined by days, weeks or months since the last servicing. For example, ejection seat servicing is done at 12 months interval. The operational hour based servicing is subjecting the aircraft for servicing after it has flown for certain number of hours. Typically second line servicing intervals are 50, 100, 200, and 400 flying hours. Certain servicing checks are also based on number of landings. For the transport aircraft operating on trunk routes that remain away from base for many days, to ensure minimum interruption of flight schedules, the outstation servicing scope is reduced to minimum. The concept of such a progressive servicing is called ***'Opportunity Servicing'.*** It means doing servicing activities as and when opportunity is available without hampering mission worthiness of aircraft.

4. EXTENDED SECOND LINE SERVICING

Extended second line servicing includes replacement of modules, electronic parts, PCBs/cards, repair and adjustment of various aggregates. These are carried out in specialized labs which have testing and repair facilities. *However, component level replacements and repair are strictly prohibited at extended second line servicing*.

5. THIRD LINE SERVICING

These are the specialized processes such as salvaging through repair on site, compliance with special technical instructions, embodiment of the prescribed modifications and limited repair of aircraft. These require high degree of knowledge and skill and use of special equipment. Structural repair or modification and reconditioning that is short of complete strip, are carried out by special teams.

6. FOURTH LINE SERVICING

The fourth line servicing, also called fourth line maintenance or major overhaul, is the full reconditioning on completion of ***time-between-overhaul (TBO) life*** of aircraft/component. After overhaul, the aircraft or the component is assigned a new lease of life. Fourth line servicing comprises of detailed technical processes, which require extensive technical facilities and are established at Base Repair Depots in the IAF or at HAL/OEM facility.

7. OUT OF PHASE SERVICING

Out of phase servicing comprises of scheduled maintenance activities with periodicity different from the normal maintenance cycle. At times, components are to be serviced at irregular intervals based on manufacturer's recommendations.

8. SUPPLEMENTARY SERVICING INSTRUCTIONS

These are Special Technical Instructions (STIs), Servicing Instructions (SIs), or other instructions issued by Air Headquarters/regulatory authority/OEM in the form of special instructions or preliminary warnings and are to be complied during the scheduled maintenance.

9. SUPERVISORY ACTIVITIES

Servicing items marked with single asterisk (*) and double asterisk (**) indicate that the activities require involvement of supervisors and specialist engineering officers respectively. The single asterisk '*' items are ***to be supervised by*** authorized supervisors. Supervisors will sign the Form 700 after worker's signature. 10% check of these items is to be carried out by a senior supervisor of warrant rank/officer. The checks should be so selected that all the systems of the aircraft are covered systematically over a period of time. The items marked '**' are ***to be performed by*** authorized supervisors only, who is a senior supervisor of the warrant rank/officer**.** At least 10% of these checks are to be supervised during every servicing by the Engineering Officers. The checks by the Engineering Officers are to be selected in such a way that all double star items are covered over a period of time.

Servicing periodicities of a typical Fighter Aircraft(3)

The servicing periodicities are either based on flying hours or on calendar life completed. A mix of these periodicities is also used as given below:

Flight Servicing Schedule

- First Flight Servicing (FFS) - before the first flight of the day. Validity 8 hrs.
- Turn Round Servicing (TRS) - when aircraft is to go for flying again in the same day. Validity 6 hrs.
- Last Flight Servicing (LFS) - after last flight of the day. Validity 72 hrs.

Activities based on flying hours

- 15+2 Hrs OOPS : Cycle 15+2 hrs
- 30+5 Hrs OOPS : Cycle 30+5 hrs
- 60+5 Hrs OOPS : Cycle 60+5 hrs
- Primary (P) : Cycle-125 hrs
- Primary Star (P*) : Cycle-250 hrs
- Minor (M) : Cycle-500 hrs
- Minor Star (M*) : Cycle-1000 hrs
- Major (MJ) : Cycle-2000 hrs

Activities based on Calendar Time

- Weekly OOPS
- Monthly OOPS
- Six Monthly OOPS
- Yearly OOPS
- Corrosion Prevention Control Programme

Life monitoring based on elapsed events/cycles

Life monitoring based on number of landings and number of parachute streamings.

Preventive Maintenance in Western origin aircraft

'O', 'I' and 'D' level servicing

Largely conceived and applicable on all aircraft of western origin with higher level of sophistication in avionics, this maintenance philosophy is found to be more efficient in terms of time requirement and increases mission availability of the aircraft and systems. As per this, ***'O' Level*** or ***Operator Level*** servicing is equivalent to First Line Servicing with essential activities such as lubrication, change of ***Line Replaceable Units (LRUs),*** sub-assemblies, automatic or semi-automatic check-out of serviceability of system and troubleshooting. Serviceability of system and troubleshooting is mainly achieved by means of ***BITE*** (***Built In Test Equipment)*** on the aircraft itself or with the help of external checks on the aircraft. The ***'I' Level*** or the ***Intermediate Level*** servicing is similar to Second Line Servicing. It consists primarily of repairing external pods or trouble shooting and repair of LRUs returned from the flight line, replacement of ***Shop Replaceable Units (SRUs)***, aero engine modules, and aircraft periodic inspections. Fault detection is performed using 'I' Level ***Automatic Test Equipment (ATE)***. The ***'D' Level*** or the ***Depot Level*** servicing consists of third and fourth line servicing. This maintenance consists of repairs of LRUs/SRUs at component level. Testing would be completed using 'D' Level ATE. It includes overhaul of engines and aircraft and its major modifications and repairs.

Maintenance of Civil Aircraft

Unlike military aircraft, the maintenance philosophy on civil aircraft is driven by the commercial considerations. While flight safety is paramount in both the civil and military aircraft, the cost considerations play a pivotal role in scheduling various maintenance checks. A cost effective maintenance programme is developed with flexibility of periodic checks and continuous inspection schedule duly approved by the airworthiness authority of the country where the aircraft is registered. In India, Director General Civil Aviation (DGCA) exercises control while in Europe, European Aviation Safety Agency (EASA), in USA, Federal Aviation Administration (FAA) and in Canada, Transport Canada approves an aircraft maintenance programme. These agencies recognize the airworthiness requirements of the aircraft registering country in terms of adequacy of the maintenance programme management, training of the maintenance staff, organizational structure, etc.

A typical maintenance and servicing plan as per Ref. (5) is given in the Table 1:

Continuous Airworthiness Maintenance Program (CAMP)(6)

In civil parlance, the entire gamut of maintenance activities, being continuous in nature and focused towards meeting the airworthiness requirements are named as a part of the Continuous Airworthiness Maintenance Program (CAMP), which includes both

Table 1. Typical Airline Maintenance and Service Plan (5)

When Service is Performed	Type of Service Performed	Impact on Airline Service
Prior to each flight	''Walk-around"—visual check of aircraft exterior and engines for damage, leakage, and brake and tire wear	None
Every 45 hours (domestic) or 65 hours (international) flight time	Specific checks on engine oils, hydraulics, oxygen, and specified unique aircraft requirements	Overnight layover service
Every 200–450 hours (22–37 days) flight time	"A" check—detailed check of aircraft and engine interior, services and lubrication of systems such as ignition, generators, cabin, air conditioning, hydraulics, structure, and landing gear	Overnight layover service
Every 400–900 hours (45–75 days) flight time	"B" check (or "L" check)—torque tests, internal checks, and flight controls	Overnight layover service
Every 13–15 months	"C" check—detailed inspection and repair program on aircraft engines and systems	Out of service for 3–5 days
Every 2 years (narrow-body aircraft)	Inspection and reapplication of corrosion protective coatings	Out of service up to 30 days
Every 3–5 years	Major structural inspections with attention to fatigue damage, corrosion, etc. Aircraft is dismantled, repaired, and rebuilt. Aircraft is repainted as needed	Out of service up to 30 days

routine and detailed inspections. The type of checks are named alphabetically with Check A comprising of light & routine activities/simple inspection procedures and Check D being a heavy duty inspection with elaborate maintenance requirements

- **A Check -** This comprises general inspection of the interior/exterior of the airplane with limited number of panels being opened during the servicing. It is carried out biweekly to monthly or every 500 flight hours, however, depending on the aircraft type the timing can change. Typical activities of A Check are oil replenishing for effective lubrication, filter replacement, operational checks of critical systems and visual inspections.

- **B check -** This is also a light check and is normally performed every 3 months or even after 6-8 months by modifying some of the inspection activities of A Check. The main difference is that in this the aircraft is usually grounded for 2-3 days and taken to a hangar for the maintenance schedule. B Checks may also be incorporated into successive A checks, i.e., A-1 through A-10 Checks, which complete all the B Check items.

- **C-Check** – This check is considered to be a heavy check with periodicity being annual or more and also requires disassembly of critical parts. Needless to mention that this check can only be performed in a hangar dedicated for this purpose with extensive maintenance support infrastructure. C-checks are broadly of two types namely C- Light and C-Heavy and have different costs and scope of maintenance activities. All OEMs constitute several committees to cut cost by optimizing maintenance activities based on the user feedback and performance of the fleet as a whole. Several checks are combined with C checks and some of the activities of D checks are also waived to cut cost. In Table-2 below are listed the periodicities and costs for these checks for some of the current aircrafts.

D-Check or Heavy Maintenance Visit (HMV) - This is also known as a C4 or C8 check depending on the aircraft type. This check is performed every six years and the entire aircraft is basically dismantled and put back together. Everything in the cabin is taken out (seats, toilets, galleys, overhead bins) so engineers can inspect the metal skin of the aircraft, inside out. The engines are taken off. The landing gear is removed and overhauled with the aircraft supported on massive jacks. All of the aircraft systems are taken apart, checked, repaired or replaced and reinstalled. Each D Check costs several million dollars and takes about three to six weeks,

Table 2. Sample C-Light and C-Heavy Check Costs (6)

A/C Type	Check	Interval	C-Light-2010 $	C-Heavy -2010 $
B737-800	C-Light/C-Heavy	20 Months	$120K-$160K	$220K-$320K
B747-400	C-Light/C-Heavy	18 Months	$600K-$800K	$1.0M-$1.2M
B767-300 ER	C-Light/C-Heavy	16-18 Months	$450K-$550K	$600K-$700K
B777-300 ER	C-Light/C-Heavy	18-20 Months	$375K-$475K	$550K-$650K
A320-200	C-Light/C-Heavy	18 Months	$150K-$180K	$250K-$350K
A330-300	C-Light/C-Heavy	18 Months	$375K-$475K	$550K-$650K

but it's almost like a brand new plane by the end of it. Table 3 gives the data in respect of intervals and cost implications for Heavy Checks for some of the current aircraft.

Aircraft Repairs

Repairs are required to rectify the structural damages. Major sources of damages include:

- damage from ramp and maintenance equipment,
- damages due to corrosion, wear and fatigue,
- damages to composites and ***multi-site damages (MSD)***.

Current design practices have significantly improved the corrosion resistance capability and hence enabled retarded corrosion. While wear and fatigue are somewhat predictable, corrosion is very difficult to predict. The extent of corrosion, however, can be controlled by improved design, material selection, component processing, operational environments and maintenance checks. Typical multi-sight damages to composites are formation of cracks around fastener holes caused by fatigue. Repair schemes as provided in the Maintenance Manual involve covering the damage with adhesive-backed aluminium foil or by bonding a sealant-coated metal sheet.

As a part of aircraft documentation, every aircraft is supplied with a Structural Repair Manual (SRM). Control and repair of all damages on the aircraft is done using this manual. The SRM is made and issued by the Original Equipment Manufacturer (OEM) and is considered like a bible for any structural repair on the aircraft.

Maintenance Programme Supporting Documents (7)

The documents generally required to support rectification of discovered problems, covering both routine and non-routine scheduled maintenance, are illustrated in the Fig 1.(7):

New Concepts

- **<u>IRAN</u> (Inspect and Repair as Necessary).** The concept of IRAN is primarily based on manufacturer's recommendations as modified by the operator's conditions. The manufacturer draws up the servicing schedules with a theoretical bias, coupled with an orthodox approach of lifing and preventive

Table 3. Sample Heavy Check Costs (6)

A/C Type	Check	Interval	Costs- 2010 $
B737-800	C6-C8 Equivalent	120/144 Months	$1.3M-$1.5M
B747-400	D-Check	72 Months	$4.0M-$4.5M
B767-300ER	S4C	72 Months	$2.0M-$2.4M
B777-300ER	C4/SI	96 Months	$2.5M-$2.8M
A320-200	4C/ 6YR SI	72 Months	$750M-$850M
A320-200	8C/ 12YR SI	144 Months	$1.6M-$1.8M
A330-300	4C/6YR SI	72 Months	$1.4M-$1.6M
A330-300	8C/ 12YR SI	144 Months	$2.9M-$3.3M

maintenance. This concept is implemented only after certain expertise has been developed on the system and a pattern of behavior of equipment has emerged. The principles of IRAN are followed to optimize cost effective maintenance and to avoid over-servicing and subsequent un-serviceability induced by it.

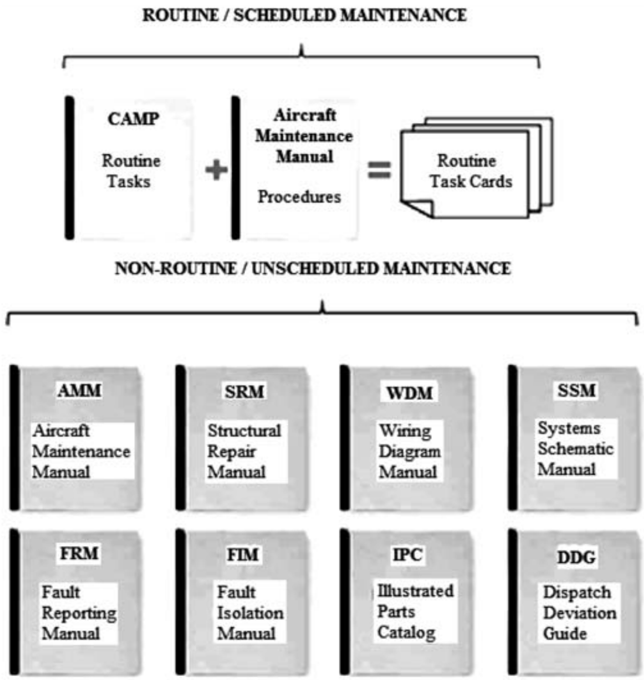

Fig 1.

- **Special operations check list.** Some of the aircraft are utilized for certain special operations like para-dropping or ALG (Advanced Landing Ground) operations
- **Maintenance check lists and snag analysis software on mobiles / tablets**. With advancements in mobile communication, the specific apps have been indigenously developed to facilitate specific maintenance checks required and their execution with appropriate feedback and documentation.
- **Networking of Knowledge base.** Maintenance Service groups duly networked with a repository of knowledge base for operators
- **Flexi-scheduling**. This aims at providing flexibility in maintenance operations with tolerance.
- **Matching of PMS requirements of aircraft as per the mission systems**.
- **Maintenance scheduling as per actual utilization of aircraft.** Maintenance scheduling is revised based on critical flight parameters milked out/analyzed by the operator utilizing the OEM supplied application software
- **Life monitoring based on elapsed events/cycles and number of landings/streaming of brake parachute.**

Key Aspects in Maintenance

Maintenance Control Centre. The Maintenance Control Centre (MCC) is set up both in the civil and military setups for handling requirements, such as, Aircraft Safety, Airworthiness Compliance, Customer Needs, Environmental Restrictions, Economic Objectives given by stakeholders and issued from Operations Control Centre (OCC), Continuing Airworthiness Organization (CAMO) and Aircraft Maintenance Organizations (AMO's). It supports functions, such as, Maintenance Planning, Work Package Assignment to MRO's, Maintenance Control, Maintenance Support, MEL Dispatch Control, AOG Spares Supply and others. Elaborate and comprehensive database availability in Maintenance Control Centre (MCC) is crucial for an efficient and effective maintenance programme implementation. In the any aircraft maintenance setup, the MCC is the only central authority to authorise schedule and checklist of maintenance activities required to undertaken on a specific aircraft.

Preventive maintenance Schedules

- Calendar based
- Flying hours based
- Number of landing based
- Life/Trial Extension programme
- Certification maintenance requirements of regulatory body
- Out of Phase Servicing (OOPS)
- Corrosion Prevention Control Programme (CPCP)

Learning from Experience

It is said that our experience is the sum of our mistakes. However, by reading about others' experiences - some of them bad - we have the opportunity to learn and improve our own performance. Based on the experience so generated the following guiding concepts are developed:

(a) Standard Operating Procedures

The bottom line of al maintenance activities on an aircraft lies in strict adherence to the laid down Standard Operating Procedures (SOPs). A lot of analysis, experience and deliberations go in formulation of the SOPs by the OEM. That is why any aviator or aeronautical professional strictly and blindly follows the SOPs to ensure high levels of safety and workmanship.

(b) Servicing during Storage

Serviceable aircraft are kept in storage when not immediately required for training/operational flying. Storage servicing is carried out on such aircraft, as per schedule, provided it has not flown for 15 days. For unserviceable aircraft awaiting spares etc. inhibitions/storage servicing is carried out depending upon the serviceability /un-serviceability of the system.

(c) Check-lists

The SOPs are further elaborated by preparing checklist, a "to-do" list - a basic production and control tool, which can incorporate the tasks into a checklist format. Using check lists, the Aircraft Maintenance Engineers (AMEs) have an appropriate record of the maintenance performance and ensure better compliance of all that is required to be done the aircraft towards maintenance requirements. Even the key elements of an inspection schedule can be designed into any checklist in nearly any operation. You can make some decisions on what to designate as a safety check item. For example, in mounting an aero engine on the fuselage, a key part of the installation would be the mounting bolt torques and their subsequent securing with the appropriate locking wire. The checklist could be formatted to ensure verification of the subject application of torque and locking by a second person. One mechanic does the work and another is tasked with witnessing the torque. Additionally, the checklists also serve the purposes, such as, inspection diary and record of material history and component control.

10. CONCLUSION

The paper covers various aspects of aircraft maintenance and highlights the meticulous compliance of the maintenance procedures as an important pre-requisite to safe flying operations of an aircraft. Different levels of maintenance followed on military and civil aircraft have been discussed. Maintenance checks on a typical military aircraft of western origin are briefly mentioned and the range and complexities of various maintenance checks on civil passenger aircraft have been included. Role of regulatory authority in ensuring the compliance of the laid down procedures is final and the satisfactory compliance demands skill and experience on the parts of all maintenance personnel. Some of the key aspects of maintenance procedures have also been listed. The reader and the maintenance personnel working on any aircraft are encouraged to go through critically the maintenance manual supplied by the OEM and various publications and servicing instructions/ maintenance directives issued by the regulatory authority for satisfactory adherence to the laid down norms.

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