

U.S. Department of
Homeland Security
**United States
Coast Guard
Auxiliary**



Auxiliary Aircraft Facility Maintenance Standards



The Case For A Fresh Approach



RP Group Proposal
AUG 01 2014

Auxiliary Aircraft Facility Maintenance Standards

The Case For A Fresh Approach

References:

- (a) Auxiliary Operations Policy Manual, M16798.3 (series)
- (b) Auxiliary Manual, M16790.1 (series)

Executive Summary

This document discusses issues surrounding a Coast Guard regulation pertaining to the Auxiliary Aviation Program, AUXAIR. Items discussed include the AUXAIR regulatory structure, facility inspection process, relevant Federal Aviation Regulations, and the origin of the subject regulation, colloquially referred to as the "TBO Rule".

TBO, manufacturer's recommended Time Between Overhauls, is discussed in the context of civil aviation and the Auxiliary. All mentions and instances of "TBO" throughout this document refer to Manufacturers' Recommended TBO. The rule's effects on the AUXAIR program are explained, including its unintended consequences.

The Auxiliary proposes a fresh approach to this issue, which is discussed in detail. Evidence is offered that the Auxiliary proposal will reduce costs and reduce risk while providing tangible, measurable benefits, both to the Auxiliary and to the Coast Guard.

Background

USCG Auxiliary Aviation (AUXAIR) was implemented as a civil aviation program that would operate utilizing the guidelines of the Federal Aviation Administration's regulations while simultaneously providing Coast Guard authorized and regulated flight.

The initial paragraphs the Aviation Annex of reference (a) detail this relationship:

1.A.1. Auxiliary aircraft, while assigned to authorized Coast Guard duty, shall be deemed to be Coast Guard aircraft, public vessels of the United States, and vessels of the Coast Guard within the meaning of 14 U.S.C. § 646 and 647 and other applicable provisions of law. Subject to the provisions of 14 U.S.C. § 823(a) and 831, while assigned to duty, qualified Auxiliary pilots shall be deemed to be Coast Guard pilots.

1.A.. The Federal Aviation Administration (FAA) is the authority that licenses Auxiliary pilots. The policies in this manual supplement, rather than supersede, other governing directives, such as the Federal Aviation Regulations (FAR). Auxiliarists may use an Auxiliary aircraft on any authorized mission with the approval of the Air Station Commanding officer, including the transportation of local, state, or federal officials authorized in the patrol order.

The Federal Aviation Regulations (FARs) relating to Auxiliary air are found in the Code of Federal Regulations (CFR) Title 14. General operating and flight rules are found in 14 CFR Part 91. FAR part 61 includes regulations pertaining to certification of airmen, and FAR Part 43¹ includes the rules regarding aircraft maintenance.

Auxiliarists, when flying, are required to adhere to the FARs while also following Coast Guard regulations governing AUXAIR.

Ref (a): 1.1.2. Auxiliary pilots must conduct all flights under applicable FARs and local air traffic rules...

This regulatory framework helps ensure that AUXAIR serves the Coast Guard effectively, while managing risk to acceptable levels through adherence to civil flying standards. AUXAIR's goals are to be safe and effective while providing mission support to the Coast Guard.

The FARs (CFR 14 Part 91.409)² require that all civil aircraft be inspected annually or that they be on a progressive inspection (PI) program. All progressive inspection programs must be specifically approved by the FAA for each aircraft. **Aircraft annual inspections must be conducted by an FAA certificated Airframe and Powerplant mechanic (A&P) with Inspection Authorization (IA) and must be properly recorded in the aircraft maintenance records (logbooks).** Falsification of aircraft maintenance records is a violation of the FARs with serious penalties.

Facility Inspections

¹ Electronic Code of Federal Regulations, Title 14, Part 43, Appendix 1

² Electronic Code of Federal Regulations, Title 14, Part 91 E, Appendix 2

The Auxiliary inspects each aircraft annually when it is offered to the Coast Guard for use in the following year, to ensure compliance with regulations. An inspector, designated by DIRAUX, (who is usually an Auxiliarist Instructor Pilot or Flight Examiner, but may be an active duty member familiar with civil aircraft) looks at the aircraft and checks the aircraft logbooks. The inspection is recorded on the ANSC 7005 Auxiliary Aircraft Facility Inspection and Offer of Use form (7005). This form contains a checklist on which the inspector confirms the aircraft acceptability for missions. The aircraft logbooks are checked to see that the aircraft has had its FAA required annual inspection and that other required checks are current. The checklist includes verification of registration documents and other items necessary for operation as an AUXAIR facility. When the 7005 form has been completed and signed by the aircraft owner and by the inspector, it is submitted to the District Staff Officer for Aviation (DSO-AV). After the DSO-AV checks the form for completeness, it is submitted to the District DIRAUX for acceptance and the entry of relevant information into the AUXDATA system. This mechanism ensures that each Auxiliary Aircraft facility has been checked each year for compliance with all applicable FAA and Coast Guard regulatory requirements.

Genesis of the TBO Rule

In 2005 there was a mishap involving an Auxiliary twin-engine aircraft in which one engine was shut down in flight as a precaution. The aircraft landed safely with no injuries or other damage. Although the subsequent investigation report was incomplete, it appears that the subject engine had been installed by the aircraft's mechanic as a temporary replacement with improper or missing log information, rendering calculation of "time in service" impossible. If the assumptions the investigation arrived at are correct (and an argument can be made that they are not), then this flight was in violation of Federal Aviation Regulations, irrespective of any consideration of TBO requirements. This would have made it in violation of Auxiliary regulations as well, rendering the pilot liable to disciplinary action by both the Coast Guard and FAA.

This mishap resulted in a new policy statement requiring all AUXAIR aircraft to follow manufacturers' recommended TBO (Time Between Overhaul) for engines and propellers. It is important to note that the factors behind this incident included violations of FAA regulations which AUXAIR pilots are required to follow, and so were already covered under existing policy. Despite this, a requirement was mandated that policy be modified to cover the specific facts of this incident, regardless of the existing regulations. While the policy change was initially intended to address what some perceived as a gap in Auxiliary aviation regulations, it was later viewed and debated as a being a measure to enhance safety.

The current "TBO Rule":

R 042014Z OCT 06 ZUI ASN-A00277000032 ZYB FM COMDT COGARD WASHINGTON
DC TO AIG 8907 BT UNCLAS //N03710//

SUBJ: AUXILIARY AVIATION UPDATES
REF A: COMDTINST M16798.3, AUXILIARY OPERATIONS POLICY MANUAL 1.
THIS MESSAGE OUTLINES UPDATES TO THE AVIATION SECTION OF THE
AUXILIARY OPERATIONS POLICY MANUAL. THE UPDATES WILL BE INCLUDED IN
CHANGE 1 TO REF A AND ARE EFFECTIVE IMMEDIATELY.

2. THE FIRST UPDATE IS INTENDED TO PROVIDE GUIDANCE FOR STANDARDIZED OPERATION OF AUX AIR FACILITIES IN INSTANCES WHEN CRITICAL FLIGHT SYSTEMS OR COMPONENTS ARE BEYOND THE MANUFACTURER'S RECOMMENDED TIME BETWEEN OVERHAUL (TBO). CRITICAL SYSTEMS CAN BE DEFINED AS ANY LOGGED OR TRACKED AIRCRAFT COMPONENT OR ASSEMBLY CONTAINING A CRITICAL CHARACTERISTIC WHO'S FAILURE, MALFUNCTION, OR ABSENCE MAY CAUSE CATASTROPHIC FAILURE RESULTING IN A LOSS OR SERIOUS DAMAGE TO THE AIRCRAFT.

A. ALL AUX AIR FACILITIES MUST COMPLY WITH MANUFACTURERS' TBO LIMITATIONS AS THEY APPLY TO POWER PLANTS AND OTHER CRITICAL SYSTEMS IN ORDER TO BE OFFERED FOR USE, AND TO OPERATE UNDER ORDERS. EXCEPTIONS MAY BE MADE FOR THOSE AIRCRAFT WHICH ARE OPERATING UNDER AN FAA-APPROVED MAINTENANCE SCHEDULE THAT IS CONSISTANT WITH THOSE OUTLINED UNDER FAR PART 91.409 (E) AND (F). AIRCRAFT THAT ARE IN FULL COMPLIANCE WITH ALL ASPECTS OF AN FAA-APPROVED MAINTENANCE PROGRAM WILL BE ALLOWED TO BE OFFERED FOR USE, AND TO OPERATE UNDER ORDERS

Although the original rule was intended to permit aircraft on progressive inspection programs to be used under the terms of those PI programs, irrespective of TBO, this exception was later reinterpreted, essentially removing it from consideration.

As a result of this TBO rule, a new field was added to the 7005 form checklist, "TBO checked". The inspector is to confirm with the aircraft owner and logs that the aircraft is in compliance with the manufacturer's TBO recommendations.

TBO and Civil Aviation

For FAA regulatory purposes, Auxiliary aviation falls into the segment called General Aviation (GA). GA is defined as all civil aviation that does not provide scheduled or commuter airline operations. It is important to understand that in the world of civil aviation, and specifically in GA, overhaul of engines at recommended TBO is not required. FAR Part 91 (under which GA falls) does not require engines to be overhauled at TBO. In fact, overhauling engines at TBO is not required by the FARs, even for commercial operations. For those operating under FAR Part 135 (air taxi), overhaul at TBO may be required by their operating specifications, but this is not always the case. Many Part 135 commercial operators are permitted to operate past TBO when using PI programs and Reliability Centered Maintenance procedures. Many GA operators run their engines well past TBO without incident.

TBO is established by engine manufacturers and is published in the form of a Service Bulletin. These are non-mandatory advisories. This is in contrast to Airworthiness Directives (ADs), which are approved and issued by the FAA, and with FAA-specified life-limited components, both of which require mandatory compliance.

TBO is derived actuarially and is conservatively modified by arbitrary and proprietary methodology, as method of predicting the average useful life of a given class of engines. Both engine manufacturers and maintenance experts agree that TBO cannot be used as a predictor of the condition of any individual engine. The actual condition of any given engine can only be determined by inspection, testing and operational analysis of that specific engine. Accordingly, considering TBO as a maintenance tool is inappropriate.

One industry maintenance expert³ puts it clearly, "An engine may be long past TBO and still be legally airworthy. (An engine may also become unairworthy long before reaching TBO.) This is supported by engine manufacturer Teledyne Continental Motors⁴ who makes it explicitly clear in their Service Bulletin detailing TBO recommendations that:

- Published TBO is strictly advisory, not compulsory.
- Operation beyond recommended TBO is permitted at the operator's discretion.
- Operation beyond recommended TBO does not void the manufacturer's warranty.
- Engine overhaul should be performed "on condition" based on the inspecting mechanic's evaluation of engine condition, based on compression checks, spectrographic oil analysis, oil consumption, and subjective assessment of engine performance (e.g., throttle response, power, smoothness of operation).

The Effect of TBO on AUXAIR

When the TBO rule went into effect, a number of Auxiliarists were operating engines that were past the manufacturer's TBO recommendations. As noted, this is very common in General Aviation. Those Auxiliarists were faced with a difficult choice; either overhaul their engines, or withdraw their aircraft as facilities, essentially leaving the AUXAIR program. Prior to 2006 there was no regulatory requirement whatsoever to overhaul a perfectly good, well-running engine.

Aircraft owners will typically plan and budget for potential engine replacement at the hours manufacturers recommend for TBO. That is probably one of the most important functions of TBO: its usefulness in planning for eventual engine replacement costs. TBO may be a useful tool for planning, but the actual overhaul time is dependent on engine health. While the hours-in-service portion of TBO has this limited planning benefit, the calendar element of TBO is even less useful as it is based on presumptions that are completely unverified and unproven.

The importance of budgeting is due to the fact that overhauling an engine is very expensive. Although the cost varies with the type of engine, overhaul costs for most common General Aviation engines overhaul costs run from about twenty thousand to over fifty thousand dollars. The cost of engine removal and replacement is usually in addition to the overhaul cost. Thus, an owner of a twin-engine aircraft could be faced with costs exceeding one hundred thousand dollars to overhaul both engines. It was these staggering costs, not a reluctance to comply with reasonable rules, that forced many Auxiliarists to withdraw their aircraft from service, to leave the AUXAIR program, and for many, to ultimately to leave the Auxiliary altogether. Committing this expense to replacing an otherwise airworthy engine is a very difficult proposition for most owners.

In the years from 2010 to 2013 the Auxiliary aviation program lost 37 aircraft from the fleet (~20%) due to this regulation. An additional 15 are expected to be lost this year. Generally, it is the more experienced pilots that are lost, along with their aircraft, due to this TBO regulation. Since the TBO policy went into effect, we have lost almost 45% of

³ Mike Busch – The Savvy Aviator #4 – Debunking TBO, the Savvy Maintenance Corporation, Appendix 3

⁴ Teledyne Continental Motors, Service Bulletin M918

the AUXAIR fleet and pilots over that time frame, directly due to the effects of the TBO mandate.

TBO and Safety – Separating Reality from Illusion

As noted earlier, the TBO rule was created to fill a perceived gap in AUXAIR regulations. It was later defended as a requirement for airworthiness and contentions were made that the regulation must be in place for the program to remain safe. But does it actually provide a measurable increase in the safety of aviation operations?

It has been argued that there have been no serious mishaps attributable to engine failure in the Auxiliary since the TBO rule went into effect. While a correct statement, this is a specious argument, since, with the exception of the one arguable incident leading to this rule-making, there have been no incidents, ever, in 70 years of AUXAIR missions, which are attributable to engine operation beyond recommended TBO limits.

While the TBO regulation for the Auxiliary may have been instituted in the interests of safety, as can be demonstrated, observance of TBO has had very little GA safety impact. Data from the NTSB⁵ shows some 11,284 GA accidents/incidents over the last 10 years. Of these 340 had engine failure listed as a cause. Of these, the total where exceeding TBO was a contributing factor: 1. Of these, the total where exceeding TBO was a probable cause: 0.

The total GA accident rate continues in this time frame to be in the range of 6.5 per 100,000 hours, or approximately 1,500/year. Considering the impact of TBO on GA accidents, it falls in the range of 0.009% of total incidents over the ten year period. TBO demonstrably has a *de minimis* effect on GA safety under present maintenance and certification standards.

Unfortunately the AUXAIR TBO regulation has had some unintended consequences. The rule, in its final iteration, did not improve safety as much as it created an illusory perception of increased safety while having a very real adverse impact on the integrity of the program.

The Dark Side of Overhaul at TBO

There is another significant safety concern lurking in all that NTSB data, a concern quite the opposite of the intent of the TBO rule. That concern: the chances of an engine failure significantly increase in the first few hundred hours of operation following an engine overhaul. In other words, the most likely time for a catastrophic engine failure is when the engine is young, not when it's old.

Studies⁶ have clearly shown that aircraft engines are far more likely to fail within the first few years and the first few hundred hours after the engine is built, rebuilt or overhauled.

⁵ Data summarized from NTSB Aviation Accident data base, 2003-2013. Appendix 6

⁶ Waddington, C. H. 'O. R. in World War 2: Operational Research against the U-boat', London: Paul Elek (Scientific Books) Ltd. 1973.

F.S. Nowlan, Howard F. Heap, Reliability-Centered Maintenance, United Airlines, San Francisco, CA, US Department of Commerce, Dec 1978

Latent defects in components, coupled with Maintenance Induced Failures (MIF), cause a high frequency of “infant mortality” failures and accidents. Accordingly, requiring that well-running engines be overhauled at an arbitrarily determined time actually increases the chances of failure, rather than decreasing it. Paradoxically, although the intent of the TBO regulation was to increase the safety of the AUXAIR program, it actually has the effect of decreasing safety.

Auxiliary aviation has direct experience with these maintenance-induced failures. On at least six occasions within the past 6 years Auxiliarists have reported their Auxiliary facilities experiencing major problems with newly-overhauled engines. In each case the engine overhauls were done to comply with the TBO requirements, with engines otherwise properly performing and airworthy.

This “infant mortality” is a result of data we know well from our CRM training – that most mishaps are caused by human error. Machines have become very reliable, but humans still make errors. This is why we have to keep trying to reduce errors by using sound CRM principles.

Aircraft mechanics are human, and are not immune from making errors. When they make errors while maintaining our aircraft, those machines become less reliable. Sometimes aircraft fail because of errors that mechanics make; they either did something, or failed to do something that caused a failure. Some new parts will have latent defects that cause failures. These factors combine to create Maintenance Induced Failures (MIFs); the more invasive the maintenance, the greater the likelihood that MIFs will occur. Overhauling engines is as invasive a maintenance procedure as there can be.

This tells us that there is little point in removing engines that are still functioning well, unless there is strong evidence that removal would result in some overall gain, such as a lower failure rate. Absent that evidence, it makes much more sense to inspect engines (and the aircraft in which they are installed), in order to detect unsatisfactory conditions, and take corrective actions before failures occur.

A Fresh Approach

Given the previous issues and outcomes, the Auxiliary aviation team has and continues to champion a fresh approach to engine and propeller maintenance. This fresh approach applies Operational Risk Management concepts. Risk Analysis would have us pay attention to that which provides an opportunity to prevent failures rather than hoping an arbitrary hours/time limit does so.

- Overhauling at TBO, absent any physical indications to do so, arguably has no impact on safety in the air and actually may increase, rather than decrease, the chances of failure.
- The AUXAIR TBO policy, albeit well intentioned, has had a debilitating effect on the AUXAIR program, all while producing no measurable benefit.

We submit that it is time for a fresh approach to AUXAIR facility maintenance standards. We propose a standard based on sound risk management and Reliability Centered Maintenance principles.

Our proposed language:

Ref (a): COMDTINST M16798.3, AUXILIARY OPERATIONS POLICY MANUAL Update to the Auxiliary Operations Policy Manual, to be included with Change 1 to REF A and is effective immediately.

- 1. Paragraph 2 of message R042014 OCT 06 from COMDT COGARD is cancelled.**
- 2. Effective immediately, Auxiliary aircraft must have, within the past 100 hours of flight, completed a current 100-hour or annual inspection, to FAA standards, to be acceptable for receipt of operational orders. Ongoing oil analysis and trend monitoring is required for all such inspections.**

We propose that all Auxiliary aircraft facilities must have 100 hour inspections (as defined by the FAA) or an annual inspection, provided that not more than 100 hours in service has passed, to be operated under orders. In addition to that, we propose that each aircraft have ongoing oil spectrographic oil analysis and trend monitoring at those inspections.⁷

Such an inspection-based approach would provide an opportunity to detect issues that may lead to failure and allow them to be corrected. This is the heart of the FAA's risk management based approach used in commercial operators' maintenance plans and is a core concept in Reliability-Centered Maintenance. There is ample evidence of the efficacy of such an approach.

Spectrographic Oil Analysis

In the late 1950s and early 1960s, the US Navy was one of the largest operators of air-cooled piston aircraft engines (the same kind that AUXAIR uses) on the planet. In 1955 the Navy initiated a project to determine whether the techniques of spectrographic oil analysis could be applied to aircraft engines. The goal was to minimize inflight engine failures and to extend engine operating intervals, reducing overhauls and associated costs. The study was very successful⁸.

“By use of spectrographic oil analysis, we are detecting engine problems earlier than they can be detected any other way. We give direction and velocity to trouble shooting and engine conditioning procedures. We can verify the effectiveness of a repair. We can and do alert the operator to many problems which if left undetected could result in inflight engine failures.”

Based on the results of this study, the Navy expanded the practice of oil analysis, moved away from overhauling engines at specific TBO intervals, and toward overhauling engines on condition.

⁷ AV Results, Oil Analysis trend, Appendix 8

⁸ US Navy, AD 268-205, “Determination of Engine Condition by Spectrographic Analysis of Engine Oil Samples”, NAS Pensacola. Appendix 5.

100-Hour Inspections and Expense

Per FAR Part 43, 100-hour inspections must be conducted by an FAA certificated Airframe and Powerplant mechanic (A&P). Also per FAR Part 43, all other inspections, such as annual inspections, must be conducted by an A&P mechanic with Inspection Authorization (IA). The regulations surrounding the certification of mechanics and inspection authorization are found in 14 CFR Part 65. Every GA aircraft must be inspected annually in order to be found airworthy and be permitted to fly.

The scope of Annual and 100 hour inspections is detailed in FAR Part 43 Appendix D. The annual and 100-hour inspections are identical in scope and detail. The only difference is in the performance and approval of the annual inspection, which must be accomplished by an A&P with IA. FAR Part 91 does not require aircraft to undergo 100-hour inspections unless they are carrying passengers for hire or conducting flight instruction.

Regular inspections by FAA-certified mechanics, as described above, will minimize surprises and provides opportunity to catch problems early. This is sensible risk management and is endorsed by the FAA.

Routine monitoring provides the opportunity to identify wear trends and other problems before they become problematic. Failures that cause catastrophic results rarely occur unannounced. Most component failures do not cause engine stoppages. They more often result in reduced power or other problems that are easily dealt with in flight and allow for a safe return to land. In fact, this was the case in the event that precipitated the imposition of the TBO policy.

Our proposal would raise the bar set by FAR part 91 for non-commercial operators, and would hold AUXAIR to a higher standard. Private GA aircraft are generally flown by their owners between 90-200 hours per year⁹. An analysis of Auxiliary aviation operations for 2013 indicates that approximately 80% of aircraft facilities fly less than 125 hours per year on missions.¹⁰ For members who fly 125 hours or less per year, there would be no (or small) additional expense along with the addition of oil analysis, if not already being performed. This is typically a relatively minor expense (\$20-\$30 per sample inspected) with great value returned. Members who fly more than this would have to inspect some months sooner than their "annual" would otherwise require. This should be of minimal impact compared to the eventual cost of replacement of an otherwise well-operating engine.

The only change to Auxiliary inspection procedures would be to have Auxiliary inspectors examine aircraft logbooks to verify that 100-hour inspections had been accomplished and that the oil analysis trend monitoring reports were on file. Auxiliary Assistant District Staff Officers for Management (ADSO-AVM), an existing position at the district level, are responsible for collecting and tracking the copies of the data as

⁹ AOPA Aircraft Usage data, 2013, from AOPA Web site

¹⁰ Auxiliary Facility Usage Analysis, Appendix 9

provided by the inspectors. The 7005 form would be modified as needed to add these items to the check list. This process would not require any other change to the current way that Auxiliary Aircraft facilities are inspected and accepted for use. After approval and acceptance, the 7005 forms and other data would be available to the Air Stations, as they are now.

Administrative changes required by this fresh approach would be minimal and at little expense:

- **No additional operating costs are contemplated under this proposal. In fact, recruiting, training and certification efforts and associated costs should diminish.**
- **No additional SAMA funding or allocations are planned in regard to this proposal. Maintenance costs should be minimally impacted for most operators, especially given a comparison of overhaul costs to inspections.**
- **CG-BSX would issue an ALAUX detailing the changes and placing it in the update list for the next issuance of the AOPM.**
- **The R and IT Directorates would modify the online 7005 form to comply with the 100-hour and oil analysis requirements**
- **The R Directorate would send out a bulletin to the districts detailing the new procedures required by the ALAUX and place it on the Web site.**
- **A training point would be added to the relevant schools and Workshops.**
- **The position of Auxiliary Branch Chief for Aviation Maintenance would assume oversight of the program to assist the districts and the ADSO-AVMs with any issues.**

Summary

The current policy regarding compliance with manufacturer's recommended TBO has been counter-productive. Absent other indications, risk analysis indicates that there is no demonstrable benefit to overhaul at TBO. The policy may actually increase the risk of failure by arbitrarily forcing an otherwise-healthy engine or propeller to be overhauled.

Many facilities have been lost to the program and a number of members have left the program rather than overhaul an otherwise-healthy engine. Some members who have stayed have endured financial hardship in order to retain the privilege of flying missions for the Coast Guard. Recruitment efforts have suffered, as potential members have lost interest after learning about the TBO requirement.

The cost to the Coast Guard and Auxiliary for replacing these lost pilots and facilities is high, both in direct training costs, recruitment efforts, and in the new members' reduced mission capability until they are seasoned. While the costs of the current policy are demonstrably high, there is no discernable benefit in safety or performance.

Adoption of our proposal would mean that engines and propellers would not arbitrarily be required to be overhauled and thereby returned to a time of high risk of "infant mortality." Long-term, productive members and facilities would be retained. This fresh approach reduces risk and provides specific benefits in terms of safety and mission capability.

Appendices

1. 14 CFR 43 Appendix D – Scope And Detail Of Items To Be Included In Annual And 100 Hour Inspections
2. 14 CFR 91.409 – Inspections
3. Busch – Debunking TBO
4. Busch Article Compilation
5. Determination of Engine Condition by Spectrographic Analysis of Engine Oil Samples, Jack F. Witten, Bureau of Naval Weapons, Bernard B. Bond, NAS Pensacola, April, 1961
6. NTSB Aviation Data and TBO Analysis, Response Directorate
7. ANSC 7005 Auxiliary Aircraft Facility Inspection and Offer For Use form
8. Sample Oil Analysis Report - AvResults - Engine Oil Sample Report
9. Auxiliary Facility Flight Hour Analysis

APPENDIX 1

ELECTRONIC CODE OF FEDERAL REGULATIONS

e-CFR Data is current as of June 17, 2014

Title 14: Aeronautics and Space

PART 43—MAINTENANCE, PREVENTIVE MAINTENANCE, REBUILDING, AND ALTERATION

APPENDIX D TO PART 43—SCOPE AND DETAIL OF ITEMS (AS APPLICABLE TO THE PARTICULAR AIRCRAFT) TO BE INCLUDED IN ANNUAL AND 100-HOUR INSPECTIONS

(a) Each person performing an annual or 100-hour inspection shall, before that inspection, remove or open all necessary inspection plates, access doors, fairing, and cowling. He shall thoroughly clean the aircraft and aircraft engine.

(b) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the fuselage and hull group:

(1) Fabric and skin—for deterioration, distortion, other evidence of failure, and defective or insecure attachment of fittings.

(2) Systems and components—for improper installation, apparent defects, and unsatisfactory operation.

(3) Envelope, gas bags, ballast tanks, and related parts—for poor condition.

(c) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the cabin and cockpit group:

(1) Generally—for uncleanliness and loose equipment that might foul the controls.

(2) Seats and safety belts—for poor condition and apparent defects.

(3) Windows and windshields—for deterioration and breakage.

(4) Instruments—for poor condition, mounting, marking, and (where practicable) improper operation.

(5) Flight and engine controls—for improper installation and improper operation.

(6) Batteries—for improper installation and improper charge.

(7) All systems—for improper installation, poor general condition, apparent and obvious defects, and insecurity of attachment.

(d) Each person performing an annual or 100-hour inspection shall inspect (where applicable) components of the engine and nacelle group as follows:

(1) Engine section—for visual evidence of excessive oil, fuel, or hydraulic leaks, and sources of such leaks.

(2) Studs and nuts—for improper torquing and obvious defects.

(3) Internal engine—for cylinder compression and for metal particles or foreign matter on screens and sump drain plugs. If there is weak cylinder compression, for improper internal condition and improper internal tolerances.

(4) Engine mount—for cracks, looseness of mounting, and looseness of engine to mount.

(5) Flexible vibration dampeners—for poor condition and deterioration.

(6) Engine controls—for defects, improper travel, and improper safetying.

(7) Lines, hoses, and clamps—for leaks, improper condition and looseness.

(8) Exhaust stacks—for cracks, defects, and improper attachment.

(9) Accessories—for apparent defects in security of mounting.

(10) All systems—for improper installation, poor general condition, defects, and insecure attachment.

(11) Cowling—for cracks, and defects.

(e) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the landing gear group:

(1) All units—for poor condition and insecurity of attachment.

(2) Shock absorbing devices—for improper oleo fluid level.

(3) Linkages, trusses, and members—for undue or excessive wear fatigue, and distortion.

(4) Retracting and locking mechanism—for improper operation.

(5) Hydraulic lines—for leakage.

(6) Electrical system—for chafing and improper operation of switches.

(7) Wheels—for cracks, defects, and condition of bearings.

(8) Tires—for wear and cuts.

(9) Brakes—for improper adjustment.

(10) Floats and skis—for insecure attachment and obvious or apparent defects.

(f) Each person performing an annual or 100-hour inspection shall inspect (where applicable) all components of the wing and center section assembly for poor general condition, fabric or skin deterioration, distortion, evidence of failure, and insecurity of attachment.

(g) Each person performing an annual or 100-hour inspection shall inspect (where applicable) all components and systems that make up the complete empennage assembly for poor general condition, fabric or skin deterioration, distortion, evidence of failure, insecure attachment, improper component installation, and improper component operation.

(h) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the propeller group:

(1) Propeller assembly—for cracks, nicks, binds, and oil leakage.

(2) Bolts—for improper torquing and lack of safetying.

(3) Anti-icing devices—for improper operations and obvious defects.

(4) Control mechanisms—for improper operation, insecure mounting, and restricted travel.

(i) Each person performing an annual or 100-hour inspection shall inspect (where applicable) the following components of the radio group:

(1) Radio and electronic equipment—for improper installation and insecure mounting.

(2) Wiring and conduits—for improper routing, insecure mounting, and obvious defects.

(3) Bonding and shielding—for improper installation and poor condition.

(4) Antenna including trailing antenna—for poor condition, insecure mounting, and improper operation.

(j) Each person performing an annual or 100-hour inspection shall inspect (where applicable) each installed miscellaneous item that is not otherwise covered by this listing for improper installation and improper operation.

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APPENDIX 2

ELECTRONIC CODE OF FEDERAL REGULATIONS

e-CFR Data is current as of July 9, 2014

Title 14: Aeronautics and Space

PART 91—GENERAL OPERATING AND FLIGHT RULES

Subpart E—Maintenance, Preventive Maintenance, and Alterations

§91.409 Inspections.

(a) Except as provided in paragraph (c) of this section, no person may operate an aircraft unless, within the preceding 12 calendar months, it has had—

(1) An annual inspection in accordance with part 43 of this chapter and has been approved for return to service by a person authorized by §43.7 of this chapter; or

(2) An inspection for the issuance of an airworthiness certificate in accordance with part 21 of this chapter.

No inspection performed under paragraph (b) of this section may be substituted for any inspection required by this paragraph unless it is performed by a person authorized to perform annual inspections and is entered as an “annual” inspection in the required maintenance records.

(b) Except as provided in paragraph (c) of this section, no person may operate an aircraft carrying any person (other than a crewmember) for hire, and no person may give flight instruction for hire in an aircraft which that person provides, unless within the preceding 100 hours of time in service the aircraft has received an annual or 100-hour inspection and been approved for return to service in accordance with part 43 of this chapter or has received an inspection for the issuance of an airworthiness certificate in accordance with part 21 of this chapter. The 100-hour limitation may be exceeded by not more than 10 hours while en route to reach a place where the inspection can be done. The excess time used to reach a place where the inspection can be done must be included in computing the next 100 hours of time in service.

(c) Paragraphs (a) and (b) of this section do not apply to—

(1) An aircraft that carries a special flight permit, a current experimental certificate, or a light-sport or provisional airworthiness certificate;

(2) An aircraft inspected in accordance with an approved aircraft inspection program under part 125 or 135 of this chapter and so identified by the registration number in the operations specifications of the certificate holder having the approved inspection program;

(3) An aircraft subject to the requirements of paragraph (d) or (e) of this section; or

(4) Turbine-powered rotorcraft when the operator elects to inspect that rotorcraft in accordance with paragraph (e) of this section.

(d) *Progressive inspection.* Each registered owner or operator of an aircraft desiring to use a progressive inspection program must submit a written request to the FAA Flight Standards district office having jurisdiction over the area in which the applicant is located, and shall provide—

(1) A certificated mechanic holding an inspection authorization, a certificated airframe repair station, or the manufacturer of the aircraft to supervise or conduct the progressive inspection;

(2) A current inspection procedures manual available and readily understandable to pilot and maintenance personnel containing, in detail—

(i) An explanation of the progressive inspection, including the continuity of inspection responsibility, the making of reports, and the keeping of records and technical reference material;

(ii) An inspection schedule, specifying the intervals in hours or days when routine and detailed inspections will be performed and including instructions for exceeding an inspection interval by not more than 10 hours while en route and for changing an inspection interval because of service experience;

(iii) Sample routine and detailed inspection forms and instructions for their use; and

(iv) Sample reports and records and instructions for their use;

(3) Enough housing and equipment for necessary disassembly and proper inspection of the aircraft; and

(4) Appropriate current technical information for the aircraft.

The frequency and detail of the progressive inspection shall provide for the complete inspection of the aircraft within each 12 calendar months and be consistent with the manufacturer's recommendations, field service experience, and the kind of operation in which the aircraft is engaged. The progressive inspection schedule must ensure that the aircraft, at all times, will be airworthy and will conform to all applicable FAA aircraft specifications, type certificate data sheets, airworthiness directives, and other approved data. If the progressive inspection is discontinued, the owner or operator shall immediately notify the local FAA Flight Standards district office, in writing, of the discontinuance. After the discontinuance, the first annual inspection under §91.409(a)(1) is due within 12 calendar months after the last complete inspection of the aircraft under the progressive inspection. The 100-hour inspection under §91.409(b) is due within 100 hours after that complete inspection. A complete inspection of the aircraft, for the purpose of determining when the annual and 100-hour inspections are due, requires a detailed inspection of the aircraft and all its components in accordance with the progressive inspection. A routine inspection of the aircraft and a detailed inspection of several components is not considered to be a complete inspection.

(e) *Large airplanes (to which part 125 is not applicable), turbojet multiengine airplanes, turbopropeller-powered multiengine airplanes, and turbine-powered rotorcraft.* No person may operate a large airplane, turbojet multiengine airplane, turbopropeller-powered multiengine airplane, or turbine-powered rotorcraft unless the replacement times for life-limited parts specified in the aircraft specifications, type data sheets, or other documents approved by the Administrator are complied with and the airplane or turbine-powered rotorcraft, including the airframe, engines, propellers, rotors, appliances, survival equipment, and emergency equipment, is inspected in accordance with an inspection program selected under the provisions of paragraph (f) of this section, except that, the owner or operator of a turbine-powered rotorcraft may elect to use the inspection provisions of §91.409(a), (b), (c), or (d) in lieu of an inspection option of §91.409(f).

(f) *Selection of inspection program under paragraph (e) of this section.* The registered owner or operator of each airplane or turbine-powered rotorcraft described in paragraph (e) of this section must select, identify in the aircraft maintenance records, and use one of the following programs for the inspection of the aircraft:

(1) A continuous airworthiness inspection program that is part of a continuous airworthiness maintenance program currently in use by a person holding an air carrier operating certificate or an operating certificate issued under part 121 or 135 of this chapter and operating that make and model

aircraft under part 121 of this chapter or operating that make and model under part 135 of this chapter and maintaining it under §135.411(a)(2) of this chapter.

(2) An approved aircraft inspection program approved under §135.419 of this chapter and currently in use by a person holding an operating certificate issued under part 135 of this chapter.

(3) A current inspection program recommended by the manufacturer.

(4) Any other inspection program established by the registered owner or operator of that airplane or turbine-powered rotorcraft and approved by the Administrator under paragraph (g) of this section. However, the Administrator may require revision of this inspection program in accordance with the provisions of §91.415.

Each operator shall include in the selected program the name and address of the person responsible for scheduling the inspections required by the program and make a copy of that program available to the person performing inspections on the aircraft and, upon request, to the Administrator.

(g) *Inspection program approved under paragraph (e) of this section.* Each operator of an airplane or turbine-powered rotorcraft desiring to establish or change an approved inspection program under paragraph (f)(4) of this section must submit the program for approval to the local FAA Flight Standards district office having jurisdiction over the area in which the aircraft is based. The program must be in writing and include at least the following information:

(1) Instructions and procedures for the conduct of inspections for the particular make and model airplane or turbine-powered rotorcraft, including necessary tests and checks. The instructions and procedures must set forth in detail the parts and areas of the airframe, engines, propellers, rotors, and appliances, including survival and emergency equipment required to be inspected.

(2) A schedule for performing the inspections that must be performed under the program expressed in terms of the time in service, calendar time, number of system operations, or any combination of these.

(h) *Changes from one inspection program to another.* When an operator changes from one inspection program under paragraph (f) of this section to another, the time in service, calendar times, or cycles of operation accumulated under the previous program must be applied in determining inspection due times under the new program.

(Approved by the Office of Management and Budget under control number 2120-0005)

[Doc. No. 18334, 54 FR 34311, Aug. 18, 1989; Amdt. 91-211, 54 FR 41211, Oct. 5, 1989; Amdt. 91-267, 66 FR 21066, Apr. 27, 2001; Amdt. 91-282, 69 FR 44882, July 27, 2004]

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The Savvy Aviator on TBO



Mike Busch is arguably the best-known A&P/IA in general aviation, honored by the FAA in 2008 as National Aviation Maintenance Technician of the Year. Mike began flying in 1964, and today has logged more than 7,500 hours. He is a commercial pilot with instrument, single- and multi-engine land, single-engine sea, and glider ratings; a certificated flight instructor for airplanes, instruments and multiengine; and a certificated A&P mechanic with Inspection Authorization. He has been an aircraft owner for 45 years.

Mike is a mathematician by training, having earned his BA in Mathematics at Dartmouth College (Magna Cum Laude). He did graduate studies at Princeton University and Columbia University and was the recipient of a National Science Foundation fellowship. He enjoyed a long and successful career as a software entrepreneur.

He is a prolific aviation author, co-founder of AVweb, and presently heads a team of world-class GA maintenance experts at Savvy Aircraft Maintenance Management, Inc., the world's largest company providing professional maintenance management services for owner-flown aircraft. Mike is on the technical staff of the Cessna Pilots Association and provides technical support to the American Bonanza Society and the Cirrus owners & Pilots Association.

The following is an article that was published on AvWeb, in April of 2004. AvWeb, is an online aviation magazine and aviation news resource.

The Savvy Aviator #4: Debunking TBO

By Mike Busch

Engine TBO (time between overhauls) seems to be one of the most misunderstood concepts in aviation maintenance. There are lots of TBO-related old wives tales that are widely believed by owners and mechanic alike, and they can cost owners a great deal of money.

Mike Busch endeavors to clear up these misconceptions, and explain what TBO really means.

Ask any aircraft owner what the TBO is for the engine(s) on his aircraft and you'll almost always get the correct answer without hesitation: "My engine has a 1,700hour TBO." But ask that owner to explain the significance of that TBO figure and you'll get all sorts of answers, most of them flat wrong. Here are a few of the most common misapprehensions about TBO:

"It's illegal to fly an airplane if the engine is past the TBO established by the manufacturer."

Nonsense. The TBO figures published by Lycoming and TCM are not airworthiness limitations. An engine may be long past TBO and still be legally airworthy. (An engine may also become unairworthy long before reaching TBO.)

"While it's true that manufacturer's TBO isn't compulsory for noncommercial (Part 91) operators, commercial (Part 121/135) operators are required to overhaul an engine when it reaches TBO."

Not so. Both Lycoming and TCM publish engine TBOs in the form of nonmandatory

service bulletins. Some Part 121/135 operators have Operations Specifications that require them to comply with all manufacturer's service bulletins (even nonmandatory ones), while others have Op Specs that require compliance only with mandatory service bulletins. Those in the latter group are no more obligated to comply with published TBO than are Part 91 operators. Those in the former group might theoretically be required to overhaul at published TBO, but most such operators request TBO extensions from their FSDO and these are routinely granted, often for as much as 50% over the engine manufacturer's published TBO. So, in actual practice, published TBO is hardly ever compulsory for any operators commercial or noncommercial.

"Continuing to fly an engine beyond TBO could void your aircraft insurance."

Poppycock. I've yet to see any aircraft insurance policy that requires compliance with nonmandatory service bulletins as a condition of coverage. Most policies only require that the aircraft be airworthy and in compliance with FAA inspection requirements.

"Continuing to fly an engine beyond TBO is dangerous because doing so increases the chance of an inflight engine failure."

To the contrary, an engine is much more likely to fail during the first few hundred hours after major overhaul than during the first few hundred hours after passing published TBO. If you exclude fuel starvation or exhaustion (i.e., pilot error), most engine stoppages involve mechanical failure of some "top end" engine component like a cylinder, exhaust valve, piston, magneto, turbocharger, exhaust stack, etc. Such bolt on components are routinely replaced during normal maintenance without any need to overhaul the engine. The purpose of a major engine overhaul is to inspect, recondition and or replace the engine's "bottom end" components crankshaft, camshaft, crankcase, gears, bearings, etc. that cannot be accessed without splitting the case. But these "bottom end" components are seldom implicated in catastrophic

engine failures. Furthermore, in those rare cases when these components do fail (e.g., crankshaft fracture), the failure is almost never correlated with time since overhaul. (If a crankshaft is going to fail, it's most likely to fail during the first few hundred hours after manufacture, or after a prop strike.)

"Continuing to fly an engine beyond TBO is false economy, because doing so just makes the inevitable major overhaul more expensive."

This old wives tale probably originated back in the days when new cylinders were very expensive and most engines were field overhauled using reconditioned (chromed or oversized) jugs. In those days, if you pushed an engine to the point that its cylinders could not be reconditioned, you'd have to spend more at overhaul to buy new ones. Nowadays, however, the cost of new cylinders has come down to the point where most major overhauls include all new jugs as standard procedure. Consequently, there's no longer any real advantage to overhauling sooner rather than later. The only things that will impact the overhaul cost are an unserviceable crankshaft or a cracked crankcase, and neither of those items are any more probable for an engine operated beyond TBO. By the way, it's not just owners who hold these misconceptions. Plenty of A&P mechanics believe these things, too.

TBO From The Horse's Mouth

The definitive word on the subject of TBO for engines manufactured by Teledyne Continental Motors is TCM Service Bulletin M918 "Recommended Overhaul Periods for All Teledyne Continental Motors Aircraft Engines" dated July 10, 1991. This is the document in which TCM publishes a table of recommended TBOs for all TCM engine models.

TCM service bulletins come in three different grades: recommended, mandatory, and critical. Critical service bulletins are typically reserved for items that are considered so urgent that TCM asks the FAA to issue an Airworthiness Directive to mandate

compliance. Mandatory service bulletins are less urgent, normally not accompanied by an AD, and normally "mandatory" only for commercial operators. Recommended service bulletins are used for conveying helpful hints to owners and mechanics, but they are merely suggestions and compliance is strictly up to the individual operator.

M918 is one of these lowest priority service bulletins. It offers recommendations, but they are not intended by TCM to be obligatory for any operator. To underscore this point, let's take a look at exactly what TCM says in M918 (emphasis mine):

Thousands of hours of operating experience indicate that Teledyne Continental Motors (TCM) aircraft engines, when operated within prescribed limitations, instructions and recommendations, can be operated between overhauls for the number of hours listed in the following table. The overhaul periods listed are recommendations only. They are predicated on the use of genuine TCM parts, compliance with all applicable Service Bulletins and ADs, as well as all required preventive maintenance, periodic inspections, manufacturer's specifications, and the determination by a qualified mechanic that the engine is operating normally and is airworthy. The accomplishment of cylinder leakage checks and spectrographic oil analysis may be helpful in making this determination. Any operation beyond these periods is at the operator's discretion and should be based on the inspecting mechanic's evaluation of engine condition and operating environment. Calendar time also affects this condition and should be taken into account.

Particular attention should be paid to throttle response, power, smoothness of operation, oil consumption, to the proper use and maintenance of oil and air filters, and adherence to the recommended oil change periods. Emphasis should also be placed on recommended fuel management. These recommended overhaul periods in no way alter TCM's warranty policies.

The wording of TCM's service bulletin M918 makes it explicitly clear that:

- Published TBO is strictly advisory, not compulsory.
- Operation beyond recommended TBO is permitted at the operator's discretion.

- Operation beyond recommended TBO does not void the manufacturer's warranty.
- Engine overhaul should be performed "on condition" based on the inspecting mechanic's evaluation of engine condition, based on compression checks, spectrographic oil analysis, oil consumption, and subjective assessment of engine performance (e.g., throttle response, power, smoothness of operation).

Bottom line is that if an engine is still going strong when it reaches TBO, there's absolutely no reason to consider removing it from service for major overhaul, and every reason to continue flying until it starts showing signs that overhaul is warranted.

So What Good Is TBO?

Does this mean that the manufacturer's TBO is a worthless figure that should be ignored? No, not at all. In my view, the best way to think about published TBO is the way we think about human life expectancy statistics.

According to the National Vital Statistics Report (http://www.cdc.gov/nchs/data/nvsr/nvsr52/nvsr52_14.pdf) published by the Centers for Disease Control, the current life expectancy at birth for a white male in the United States is 75 years. This statistic might be quite useful in figuring out what premium to charge for a life insurance policy, or how to plan for retirement.

Does this mean that white U.S. males should be euthanized (removed from service) when they reach age 75? I certainly hope not! In fact, the same CDC figures show that the current life expectancy for a 75-year-old white male in the U.S. is 11 years. In other words, if you're still kicking at age 75, you can expect on average to live until age 86. Furthermore, if you are still alive at age 86, your life expectancy is 6 years so on average you can be expected to live until age 92.

Similarly, according to TCM Service Bulletin M918, the "life expectancy at birth" (recommended TBO) of TSIO520BB engines (like the ones in my 1979 Cessna T310R) is 1,400 hours. This statistic might be quite useful in figuring out a suitable dollar amount for amortizing overhaul expense. Since it costs about \$30,000 to overhaul one of these engines, a reasonable "reserve for overhaul" would be \$21.43 per hour (i.e., \$30,000 divided by 1,400 hours). This figure would also be appropriate for adjusting the "blue book" value of my airplane to account for higher or lower than average engine time.

Does this mean that I should have euthanized my engines when they reached 1,400 hours SMOH (since major overhaul), despite the fact that they were running great, had excellent compressions, low oil consumption, no metal in the oil filters, and excellent oil analysis reports? No, I don't think so. Although TCM doesn't publish figures for "life expectancy at 1,400 hours" for these engines, it only stands to reason that TSIO520BB engines that are in good shape at 1,400 hours surely have a good deal of useful life left in them. (As previously noted, many commercial operators routinely run their engines to 150% of manufacturer's TBO with the FAA's official blessing.)

Some Real World Experience

When I purchased my T310R in 1987, it had 1,300 hours total time on the airframe and engines. Since TCM's published TBO for its TSIO520BB engines is 1400 hours, those engines were pretty much "run out" when I acquired the airplane (and the price I paid was adjusted downward accordingly).

At 1,400 hours those engines were still running superbly, and all signs pointed to them being in great shape. I wound up flying those engines trouble free to 1,900 hours (500 hours past published TBO), at which time I started getting nervous and pulled the engines for major overhaul.

As it turned out, my nervousness about flying those engines 500 hours past published TBO were completely unfounded. The overhaul shop reported that all 12 cylinders were still within new limits, as was pretty much everything else. It was clear from the results of the teardown inspection that those engines could have gone considerably longer at least another 500 hours with no problem.

Those engines received minimalist (i.e., el cheapo) major overhauls in 1990. The cylinders had their valves replaced, their barrels lightly honed, new pistons and rings installed, and were bolted back on for another run. I saved about \$12,000 by not replacing the cylinders at overhaul, but I figured that there was probably no way these jugs would survive another 1,400 hours.

I figured wrong. Those engines and cylinders now have accumulated another 1,600 hours since the overhaul, and so those cylinders have 3,500 hours on them. I am just wrapping up my 2004 annual inspection as I write this. The compressions are all 75/80 or better, the oil consumption remains about a quart in 15 hours, the oil filters are clean, the oil analysis is excellent, and the engines are running as well as they ever have. I imagine I'll be flying behind them for a while longer (knock on wood).

This time around, I'm not even the slightest bit nervous about continuing to fly past TBO. I know that so long as I continue to keep a watchful eye on compression, oil consumption, oil filter inspection, oil analysis, temperatures and performance, I'll know when the engines are getting tired and it's time to overhaul them. That could be next year, or it might be five years from now. I'm not even going to try to predict how much more useful life those engines have left, but when the time comes to major them, they'll tell me.

I haven't yet decided exactly what I'll do when that time comes. Will I have the engines field overhauled again, or exchange them for factory rebuilt engines? Will I recondition the cylinders or install new ones? Install TCM factory cylinders, Superior

Milleniums, or ECI Titans? These are complex decisions that I discuss at considerable length in my Savvy Owner Seminar (/sponsors/savvy/). In my own case, I'll make those decisions when the time comes, based on the best information available at the time.

But I can tell you one thing for sure: When those freshly overhauled or rebuilt engines are installed back in the airplane and it's time for me to get back in the air, that's when I'll be nervous!

Mike Busch on TBO



Mike Busch is arguably the best-known A&P/IA in general aviation, honored by the FAA in 2008 as National Aviation Maintenance Technician of the Year. Mike began flying in 1964, and today has logged more than 7,500 hours. He is a commercial pilot with instrument, single- and multi-engine land, single-engine sea, and glider ratings; a certificated flight instructor for airplanes, instruments and multiengine; and a certificated A&P mechanic with Inspection Authorization. He has been an aircraft owner for 45 years.

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This collection includes a series of articles published by the Aircraft Owners and Pilots Association. The AOPA is the largest aviation association in the world. The dates of publication range from January to June of 2014.

The Waddington Effect

January 14th, 2014 by Mike Busch



In 1943, a British scientist named Conrad Hal (C.H.) Waddington made a remarkable discovery about aircraft maintenance. He was a most unlikely person to make this discovery, because he wasn't an aeronautical engineer or an aircraft mechanic or even a pilot. Actually, he was a gifted developmental biologist, paleontologist, geneticist, embryologist, philosopher, poet and painter who wasn't particularly interested in aviation. But like many other British scientists at that time, his career was interrupted by the outbreak of the Second World War and he found himself pressed into service with the Royal Air Force (RAF).

C.H. Waddington (1905-1975)

Waddington wound up reporting to the RAF Coastal Command, heading up a group of fellow scientists in the Coastal Command Operational Research Section. Its job was to advise the British military on how it could more effectively combat the threat from German submarines. In that capacity, Waddington and his colleagues developed a series of astonishing recommendations that defied military conventional wisdom of the time.

For example, the bombers used to hunt and kill U-boats were mostly painted black in order to make them difficult to see. But Waddington's group ran a series of experiments that proved that bombers painted white were not spotted by the U-boats until they were 20% closer, resulting in a 30% increase in successful sinkings. Waddington's group also recommended that the depth charges dropped by the bombers be set to explode at a depth of 25 feet instead of 100 feet. This recommendation—initially resisted strongly by RAF commanders—ultimately resulted in a sevenfold increase in the number of U-boats destroyed.

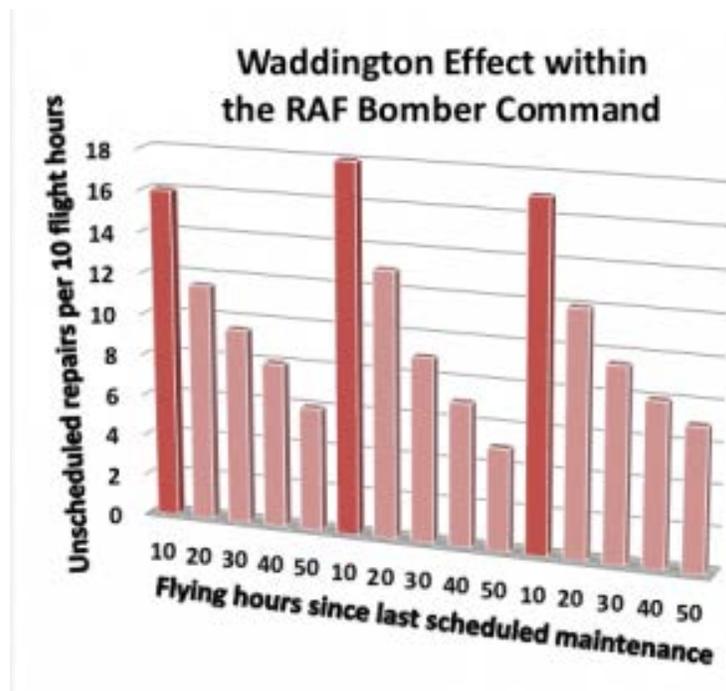


Consolidated B-24 "Liberator" bomber

Waddington subsequently turned his attention to the problem of “force readiness” of the bombers. The Coastal Command’s B-24 “Liberator” bombers were spending an inordinate amount of time in the maintenance shop instead of hunting U-boats. In July 1943, the two British Liberator squadrons located at Ballykelly, Northern Ireland, consisted of 40 aircraft, but at any given time only about 20 were flight-ready. The other aircraft were down for any number of reasons, but mostly undergoing or awaiting maintenance—either scheduled or unscheduled—or waiting for replacement parts.

At that time, conventional wisdom held that if more preventive maintenance were performed on each aircraft, fewer problems would arise and more incipient problems would be caught and fixed—and thus fleet readiness would surely improve. It turned out that conventional wisdom was wrong. It would take C.H. Waddington and his Operational Research team to prove just how wrong.

Waddington and his team started gathering data about the scheduled and unscheduled maintenance of these aircraft, and began crunching and analyzing the numbers. When he plotted the number of unscheduled aircraft repairs as a function of flight time, Waddington discovered something both unexpected and significant: The number of unscheduled repairs spiked sharply right after each aircraft underwent its regular 50-hour scheduled maintenance, and then declined steadily over time until the next scheduled 50-hour maintenance, at which time they spiked up once again.



When Waddington examined the plot of this repair data, he concluded that the scheduled maintenance (in Waddington’s own words) “tends to INCREASE breakdowns, and this can only be because it is doing positive harm by disturbing a relatively satisfactory state of affairs. There is no sign that the rate of breakdowns is starting to increase again after 40-50 flying hours when the aircraft is coming due for its next scheduled maintenance.” In other words, the observed

pattern of unscheduled repairs demonstrated that the scheduled preventive maintenance was actually doing more harm than good, and that the 50-hour preventive maintenance interval was inappropriately short.

The solution proposed by Waddington's team—and ultimately accepted by the RAF commanders over the howls of the maintenance personnel—was to increase the time interval between scheduled maintenance cycles, and to eliminate all preventive maintenance tasks that couldn't be demonstrably proven to be beneficial. **Once these recommendations were implemented, the number of effective flying hours of the RAF Coastal Command bomber fleet increased by 60 percent!**

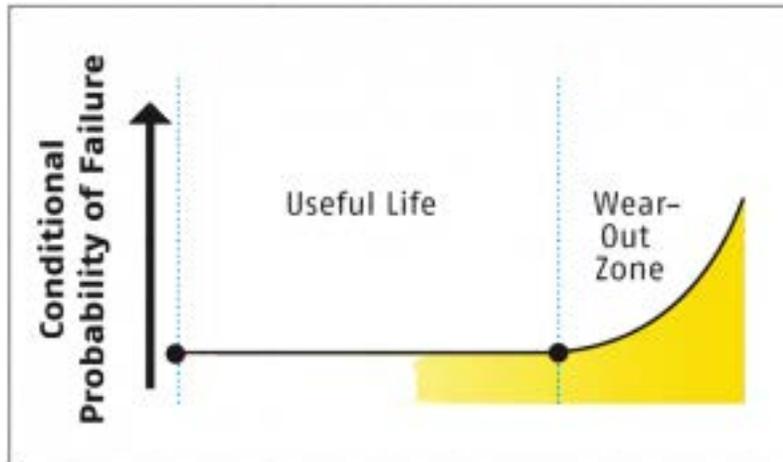
Fast forward two decades to the 1960s, when a pair of gifted scientists who worked for United Airlines—aeronautical engineer Stanley Nowlan and mathematician Howard Heap—independently rediscovered these principles in their pioneering research on optimizing maintenance that revolutionized the way maintenance is done in air transport, military aviation, high-end bizjets and many non-aviation industrial applications. They were almost certainly unaware of the work of C.H. Waddington and his colleagues in Britain in the 1940s because that work remained classified until 1973, when Waddington's meticulously-kept diary of his wartime research activities was declassified and published.

Next time, I'll discuss the fascinating work of Nowlan and Heap on what came to be known as "Reliability Centered Maintenance." But for now, I will leave you with the major takeaway from Waddington's research during World War II: **Maintenance isn't an inherently good thing (like exercise); it's a necessary evil (like surgery). We have to do it from time to time, but we sure don't want to do more than absolutely necessary to keep our aircraft safe and reliable. Doing more maintenance than necessary actually degrades safety and reliability.**

Roots of Reliability-Centered Maintenance

February 11th, 2014 by Mike Busch

Last month, I discussed the pioneering WWII-era work of the eminent British scientist C.H. Waddington, who discovered that the scheduled preventive maintenance (PM) being performed on RAF B-24 bombers was actually doing more harm than good, and that drastically cutting back on such PM resulted in spectacular improvement in dispatch reliability of those aircraft. **Two decades later, a pair of brilliant American engineers at United Airlines—Stan Nowlan and Howard Heap—independently rediscovered the utter wrongheadedness of traditional scheduled PM**, and took things to the next level by formulating a rigorous engineering methodology for creating an optimal maintenance program to maximize safety and dispatch reliability while minimizing cost and downtime. **Their approach became known as “Reliability-Centered Maintenance” (RCM)**, and revolutionized the way maintenance is done in the airline industry, military aviation, high-end bizjets, space flight, and numerous non-aviation applications from nuclear power plants to auto factories.



The traditional approach to PM assumes that most components start out reliable, and then at some point start becoming unreliable as they age

The “useful life” fallacy

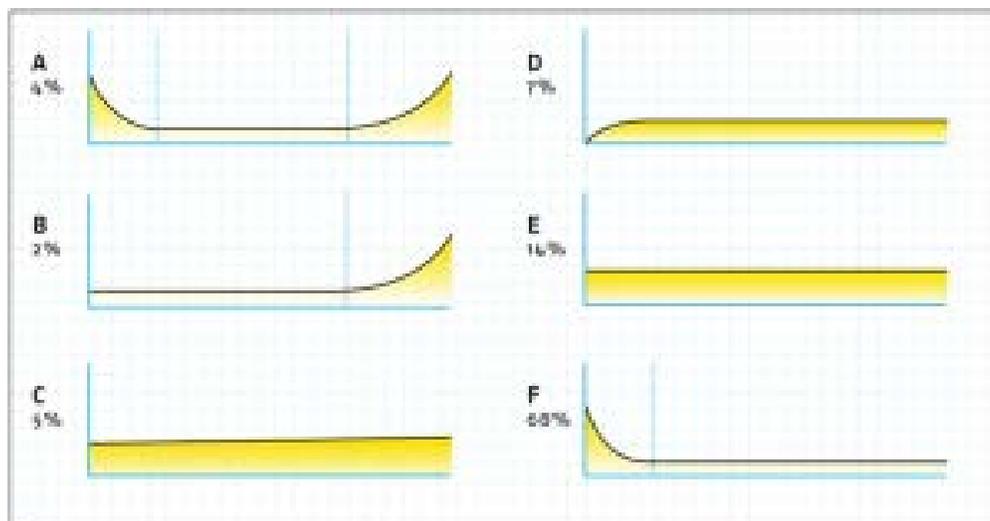
Nowlan and Heap¹ showed the fallacy of two fundamental principles underlying traditional scheduled PM:

- Components start off being reliable, but their reliability deteriorates with age.
- The useful life of components can be established statistically, so components can be retired or overhauled before they fail.

It turns out that both of these principles are wrong. To quote Nowlan and Heap:

¹ [F. Stanley Nowlan and Howard F. Heap, “Reliability-Centered Maintenance” 1978, DoD Report Number AD-A066579.]

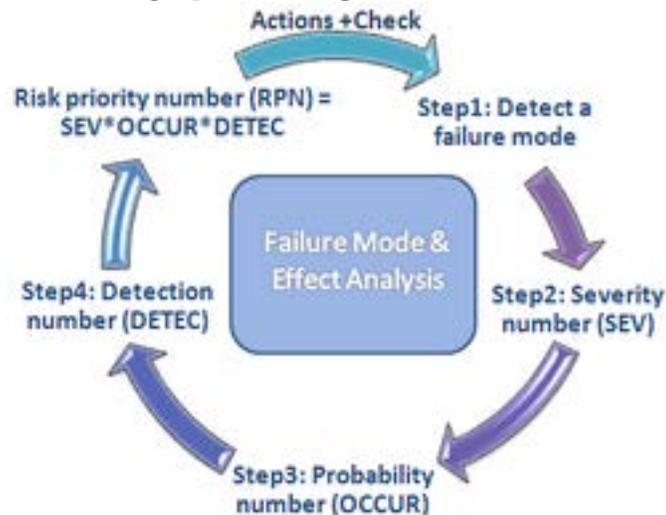
“One of the underlying assumptions of maintenance theory has always been that there is a fundamental cause-and-effect relationship between scheduled maintenance and operating reliability. **This assumption was based on the intuitive belief that because mechanical parts wear out, the reliability of any equipment is directly related to operating age.** It therefore followed that the more frequently equipment was overhauled, the better protected it was against the likelihood of failure. The only problem was in determining what age limit was necessary to assure reliable operation. “In the case of aircraft it was also commonly assumed that all reliability problems were directly related to operating safety. **Over the years, however, it was found that many types of failures could not be prevented no matter how intensive the maintenance activities.** [Aircraft] designers were able to cope with this problem, not by preventing failures, but by preventing such failures from affecting safety. In most aircraft essential functions are protected by redundancy features which ensure that, in the event of a failure, the necessary function will still be available from some other source.



RCM researchers found that only 2% of aircraft components have failures that are predominantly age-related (curve B), and that 68% have failures that are primarily infant mortality (curve F).

“Despite the time-honored belief that reliability was directly related to the intervals between scheduled overhauls, searching studies based on actuarial analysis of failure data suggested that the traditional hard-time policies were, apart from their expense, ineffective in controlling failure rates. This was not because the intervals were not short enough, and surely not because the tear down inspections were not sufficiently thorough. Rather, it was because, contrary to expectations, for many items the likelihood of failure did not in fact increase with increasing age. Consequently a maintenance policy based exclusively on some maximum operating age would, no matter what the age limit, have little or no effect on the failure rate.”

Winning the war by picking our battles



Another traditional maintenance fallacy was the intuitive notion that aircraft component failures are dangerous and need to be prevented through PM. A major focus of RCM was to identify the ways that various components fail, and then evaluate the frequency and consequences of those failures. This is known as “Failure Modes and Effects Analysis” (FMEA). Researchers found that while certain failure modes have serious consequences that can compromise safety (e.g., a cracked wing spar), **the overwhelming majority of component failures have no safety impact** and have consequences that are quite acceptable (e.g., a failed #2 comm radio or #3 hydraulic pump). **Under the RCM philosophy, it makes no sense whatsoever to perform PM on components whose failure has acceptable consequences; the optimal maintenance approach for such components is simply to leave them alone, wait until they fail, and then replace or repair them when they do.** This strategy is known as “run to failure” and is a major tenet of RCM.

A maintenance revolution...



The 747, DC-10 and L-1011 were the first airliners that had RCM-based maintenance programs.

As a direct result of this research, airline maintenance practices changed radically. RCM-inspired maintenance programs were developed for the Boeing 747, Douglas DC-10 and Lockheed L-1011, and for all subsequent airliners. The contrast with the traditional (pre-RCM) maintenance programs for the Boeing 707 and 727 and Douglas DC-8 was astonishing. **The vast**

majority of component TBOs and life-limits were abandoned in favor of an on-condition approach based on monitoring the actual condition of engines and other components and keeping them in service until their condition demonstrably deteriorated to an unacceptable degree. For example, DC-8 had 339 components with TBOs or life limits, whereas the DC-10 had only seven—and none of them were engines. (Research showed clearly that overhauling engines at a specific TBO didn't make them safer, and actually did the opposite.) **In addition, the amount of scheduled maintenance was drastically reduced.** For example, the DC-8 maintenance program required 4,000,000 labor hours of major structural inspections during the aircraft's first 20,000 hours in service, while the 747 maintenance program called for only 66,000 labor hours, a reduction of nearly two orders of magnitude.



Owner-flown GA, particularly piston GA, is the only remaining segment of aviation that does things the bad old-fashioned way.

Of course, **these changes saved the airlines a king's ransom in reduced maintenance costs and scheduled downtime.** At the same time, the airplanes had far fewer maintenance squawks and much better dispatch reliability. (This was the same phenomenon that the RAF experienced during WWII when they followed Waddington's advice to slash scheduled PM.)

...that hasn't yet reached piston GA

Today, there's only one segment of aviation that has NOT adopted the enlightened RCM approach to maintenance, and still does scheduled PM the bad old-fashioned way. Sadly, that segment is owner-flown GA—particularly piston GA—at the bottom of the aviation food chain where a lot of us hang out. I'll offer some thoughts about that next month.

Do Piston Engine TBOs Make Sense?

March 13th, 2014 by Mike Busch

Last month, I discussed the pioneering work on Reliability-Centered Maintenance (RCM) done by United Airlines scientists Stan Nowlan and Howard Heap in the 1960s, and I bemoaned the fact that RCM has not trickled down the aviation food chain to piston GA. Even in the 21st century, maintenance of piston aircraft remains largely time-based rather than condition-based.



Most owners of piston GA aircraft dutifully overhaul their engines at TBO, overhaul their propellers every 5 to 7 years, and replace their alternators and vacuum pumps every 500 hours just as Continental, Lycoming, Hartzell, McCauley, HET and Parker Aerospace call for. Many Bonanza and Baron owners have their wing bolts pulled every five years, and most Cirrus owners have their batteries replaced every two years for no good reason (other than that it's in the manufacturer's maintenance manual).

Despite an overwhelming body of scientific research demonstrating that this sort of 1950s-vintage time-based preventive maintenance is counterproductive, worthless, unnecessary, wasteful and incredibly costly, we're still doing it. Why?

Mostly, I think, because of fear of litigation. The manufacturers are afraid to change anything for fear of being sued (because if they change anything, that could be construed to mean that what they were doing before was wrong). Our shops and mechanics are afraid to deviate from what the manufacturers recommend for fear of being sued (because they deviated from manufacturers' guidance).

Let's face it: Neither the manufacturers nor the maintainers have any real incentive to change. The cost of doing all this counterproductive, worthless, unnecessary and wasteful preventive maintenance (that actually doesn't prevent anything) is not coming out of their pockets. Actually, it's going into their pockets.

If we're going to drag piston GA maintenance kicking and screaming into the 21st century (or at least out of the 1950s and into the 1960s), it's going to have to be aircraft owners who force the change. Owners are the ones with the incentive to change the way things are being done. Owners are the ones who can exert power over the manufacturers and maintainers by voting with their feet and their credit cards.

For this to happen, owners of piston GA aircraft need to understand the right way to do maintenance—the RCM way. Then they need to direct their shops and mechanics to maintain their aircraft that way, or take their maintenance business to someone who will. This means that owners need both knowledge and courage. Providing aircraft owners both of these things is precisely why I'm contributing to this AOPA Opinion Leaders Blog.

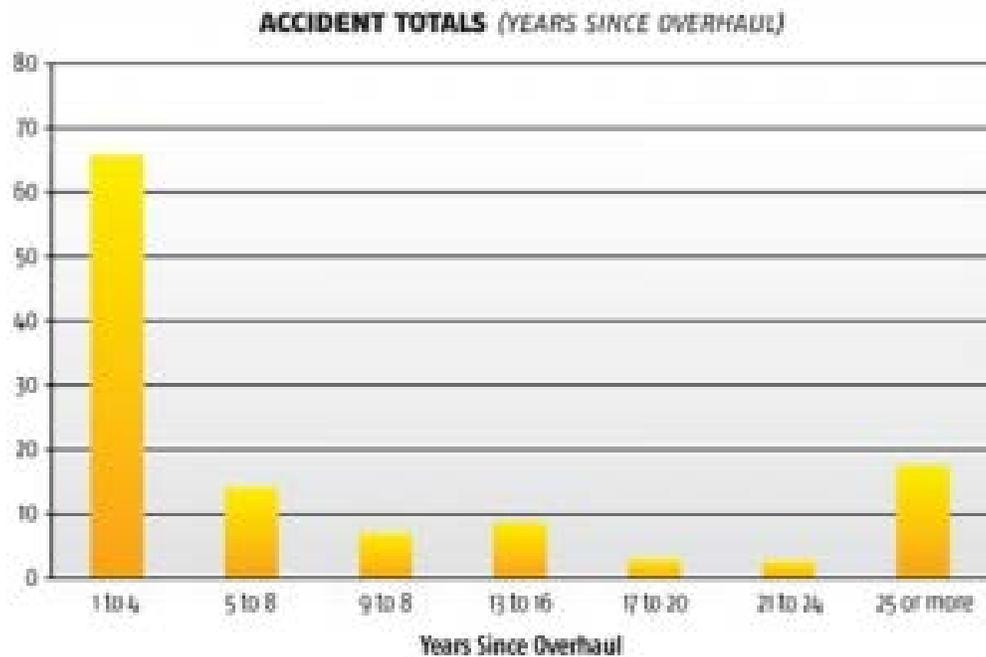
When are piston aircraft engines most likely to hurt you?

Fifty years ago, RCM researches proved conclusively that overhauling turbine engines at a fixed TBO is counterproductive, and that engine overhauls should be done strictly on-condition. But how can we be sure that this also applies to piston aircraft engines?

In a perfect world, Continental and Lycoming would study this issue and publish their findings. But for reasons mentioned earlier, this ain't gonna happen. Continental and Lycoming have consistently refused to release any data on engine failure history of their engines, and likewise have consistently refused to explain how they arrive at the TBOs that they publish. For years, one aggressive plaintiff lawyer after another have tried to compel Continental and Lycoming to answer these questions in court. All have failed miserably.

So if we're going to get answers to these critical questions, we're going to have to rely on engine failure data that we can get our hands on. The most obvious source of such data is the NTSB accident database. That's precisely what brilliant mechanical engineer Nathan T. Ulrich Ph.D. of Lee NH did in 2007. (Dr. Ulrich also was a US Coast Guard Auxiliary pilot who was unhappy that USCGA policy forbade him from flying volunteer search-and-rescue missions if his Bonanza's engine was past TBO.)

Dr. Ulrich analyzed five years' worth of NTSB accident data for the period 2001-2005 inclusive, examining all accidents involving small piston-powered airplanes (under 12,500 lbs. gross weight) for which the NTSB identified "engine failure" as either the probable cause or a contributing factor. From this population of accidents, Dr. Ulrich eliminated those involving air-race and agricultural-application aircraft. Then he analyzed the relationship between the frequency of engine-failure accidents and the number of hours on the engine since it was last built, rebuilt or overhauled. He did a similar analysis based on the calendar age of the engine since it was last built, rebuilt or overhauled. The following histograms show the results of his study:



If these histograms have a vaguely familiar look, it might be because they look an awful lot like the histograms generated by British scientist C.H. Waddington in 1943.

Now, we have to be careful about how we interpret Dr. Ulrich's findings. Ulrich would be the first to agree that NTSB accident data can't tell us much about the risk of engine failures beyond TBO, simply because most piston aircraft engines are voluntarily euthanized at or near TBO. So it shouldn't be surprising that we don't see very many engine failure accidents involving engines significantly past TBO, since there are so few of them flying. (The engines on my Cessna 310 are at more than 205% of TBO, but there just aren't a lot of RCM true believers like me in the piston GA community...yet.)

What Dr. Ulrich's research demonstrates unequivocally is striking and disturbing frequency of "infant-mortality" engine-failure accidents during the first few years and first few hundred hours after an engine is built, rebuilt or overhauled. Ulrich's findings makes it indisputably clear that **by far the most likely time for you to fall out of the sky due to a catastrophic engine failure is when the engine is young, not when it's old.**

(The next most likely time for you to fall out of the sky is shortly after invasive engine maintenance in the field, particularly cylinder replacement, but that's a subject for a future blog post...stay tuned!)

So...Is there a good reason to overhaul your engine at TBO?



It doesn't take a rocket scientist (or a Ph.D. in mechanical engineering) to figure out what all this means. **If your engine reaches TBO and still gives every indication of being healthy** (good performance, not making metal, healthy-looking oil analysis and borescope results, etc.), **overhauling it will clearly degrade safety, not improve it. That's simply because it will convert your low-risk old engine into a high-risk young engine.** I don't know about you, but that certainly strikes me as a remarkably dumb thing to do.

So why is overhauling on-condition such a tough sell to our mechanics and the engine manufacturers? The counter-argument goes something like this: "Since we have so little data about the reliability of past-TBO engines (because most engines are arbitrarily euthanized at TBO), how can we be sure that it's safe to operate them beyond TBO?" RCM researchers refer to this as "the Resnikoff Conundrum" (after mathematician H.L. Resnikoff).

To me, it looks an awful lot like the same circular argument that was used for decades to justify arbitrarily euthanizing airline pilots at age 60, despite the fact that aeromedical experts were unanimous that this policy made no sense whatsoever. Think about it...

How Do Piston Aircraft Engines Fail?

April 9th, 2014 by Mike Busch

Last month, I tried to make the case that piston aircraft engines should be overhauled strictly on-condition, not at some fixed TBO. If we're going to do that, we need to understand how these engines fail and how we can protect ourselves against such failures. The RCM way of doing that is called Failure Modes and Effects Analysis (FMEA), and involves examining each critical component of these engines and looking at how they fail, what consequences those failures have, and what practical and cost-efficient maintenance actions we can take to prevent or mitigate those failures. Here's my quick back-of-the-envelope attempt at doing that...

Crankshaft



There's no more serious failure mode than crankshaft failure. If it fails, the engine quits.

Yet crankshafts are rarely replaced at overhaul. Lycoming did a study that showed their crankshafts often remain in service for more than 14,000 hours (that's 7+ TBOs) and 50 years. Continental hasn't published any data on this, but their crankshafts probably have similar longevity.

Crankshafts fail in three ways: (1) infant-mortality failures due to improper materials or manufacture; (2) failures following unreported prop strikes; and (3) failures secondary to oil starvation and/or bearing failure.

Over the past 15 years, we've seen a rash of infant-mortality failures of crankshafts. Both Continental and Lycoming have had major recalls of crankshafts that were either forged from bad steel or were damaged during manufacture. These failures invariably occurred within the first 200 hours after the new crankshaft entered service. If the crankshaft survived its first 200 hours, we can be confident that it was manufactured correctly and should perform reliably for numerous TBOs.

Unreported prop strikes seem to be getting rare because owners and mechanics are becoming smarter about the high risk of operating an engine after a prop strike. There's now an AD mandating a post-prop-strike engine teardown for Lycoming engines, and a strongly worded

service bulletin for Continental engines. Insurance will always pay for the teardown and any necessary repairs, so it's a no-brainer.

That leaves failures due to oil starvation and/or bearing failure. I'll address that shortly.



Crankcase

Crankcases are also rarely replaced at major overhaul. They are typically repaired as necessary, align-bored to restore critical fits and limits, and often provide reliable service for many TBOs. If the case remains in service long enough, it will eventually crack. The good news is that case cracks propagate slowly enough that a detailed visual inspection once a year is sufficient to detect such cracks before they pose a threat to safety. Engine failures caused by case cracks are extremely rare—so rare that I don't think I ever remember hearing or reading about one.



Camshaft and Lifters

The cam/lifter interface endures more pressure and friction than any other moving parts in the engine. The cam lobes and lifter faces must be hard and smooth in order to function and survive. Even tiny corrosion pits (caused by disuse or acid buildup in the oil) can lead to rapid destruction (spalling) of the surfaces and dictate the need for a premature engine teardown. Cam and lifter spalling is the number one reason that engines fail to make TBO, and it's becoming an epidemic in the owner-flown fleet where aircraft tend to fly irregularly and sit unflown for weeks at a time.

The good news is that cam and lifter problems almost never cause catastrophic engine failures. Even with a badly spalled cam lobe (like the one pictured at right), the engine continues to run and make good power. Typically, a problem like this is discovered at a routine oil change when the oil filter is cut open and found to contain a substantial quantity of ferrous metal, or else a cylinder is removed for some reason and the worn cam lobe can be inspected visually.

If the engine is flown regularly, the cam and lifters can remain in pristine condition for thousands of hours. At overhaul, the cam and lifters are often replaced with new ones, although a reground cam and reground lifters are sometimes used and can be just as reliable.

Gears

The engine has lots of gears: crankshaft and camshaft gears, oil pump gears, accessory drive gears for fuel pump, magnetos, prop governor, and sometimes alternator. These gears are made of case-hardened steel and typically have a very long useful life. They are not usually replaced at overhaul unless obvious damage is found. Engine gears rarely cause catastrophic engine failures.

Oil Pump

Failure of the oil pump is rarely responsible for catastrophic engine failures. If oil pressure is lost, the engine will seize quickly. But the oil pump is dead-simple, consisting of two steel gears inside a close-tolerance aluminum housing, and usually operates trouble free. The pump housing can get scored if a chunk of metal passes through the oil pump—although the oil pickup tube has a suction screen to make sure that doesn't happen—but even if the pump housing is damaged, the pump normally has ample output to maintain adequate oil pressure in flight, and the problem is mainly noticeable during idle and taxi. If the pump output seems deficient at idle, the oil pump housing can be removed and replaced without tearing down the engine.



Bearings

Bearing failure is responsible for a significant number of catastrophic engine failures. Under normal circumstances, bearings have a long useful life. They are always replaced at major overhaul, but it's not unusual for bearings removed at overhaul to be in pristine condition with little detectable wear.

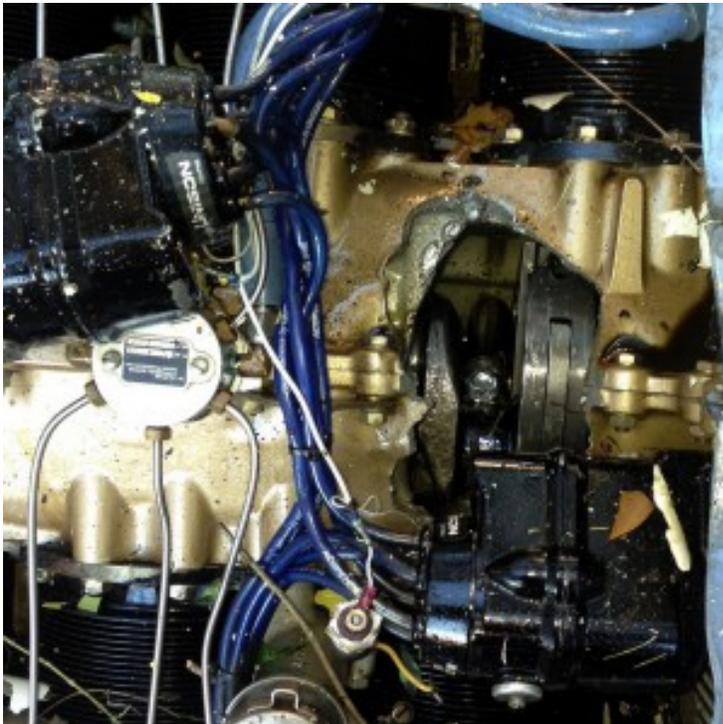
Bearings fail prematurely for three reasons: (1) they become contaminated with metal from some other failure; (2) they become oil-starved when oil pressure is lost; or (3) main bearings become oil-starved because they shift in their crankcase supports to the point where their oil supply holes become misaligned (as with the “spun bearing” pictured at right).

Contamination failures can generally be prevented by using a full-flow oil filter and inspecting the filter for metal at every oil change. So long as the filter is changed before its filtering capacity is exceeded, metal particles will be caught by the filter and won't get into the engine's oil galleries and contaminate the bearings. If a significant quantity of metal is found in the filter,

the aircraft should be grounded until the source of the metal is found and corrected.

Oil-starvation failures are fairly rare. Pilots tend to be well-trained to respond to decreasing oil pressure by reducing power and landing at the first opportunity. Bearings will continue to function properly at partial power even with fairly low oil pressure.

Spun bearings are usually infant-mortality failures that occur either shortly after an engine is overhauled (due to an assembly error) or shortly after cylinder replacement (due to lack of preload on the through bolts). Failures occasionally occur after a long period of crankcase fretting, but such fretting is usually detectable through oil filter inspection and oil analysis). They can also occur after extreme unpreheated cold starts, but that is quite rare.



Connecting Rods

Connecting rod failure is responsible for a significant number of catastrophic engine failures. When a rod fails in flight, it often punches a hole in the crankcase (“thrown rod”) and causes loss of engine oil and subsequent oil starvation. Rod failure have also been known to cause camshaft breakage. The result is invariably a rapid and often total loss of engine power.

Connecting rods usually have a long useful life and are not normally replaced at overhaul. (Rod bearings, like all bearings, are always replaced at overhaul.) Many rod failures are infant-

mortality failures caused by improper tightening of the rod cap bolts during engine assembly. Rod failures can also be caused by the failure of the rod bearings, often due to oil starvation. Such failures are usually random failures unrelated to time since overhaul.

Pistons and Rings

Piston and ring failures usually cause only partial power loss, but in rare cases can cause complete power loss. Piston and ring failures are of two types: (1) infant-mortality failures due to improper manufacturer or assembly; and (2) heat-distress failures caused by pre-ignition or destructive detonation events. Heat-distress failures can be caused by contaminated fuel (e.g., 100LL laced with Jet A), or by improper engine operation. They are generally unrelated to hours or years since overhaul. A digital engine monitor can alert the pilot to pre-ignition or destructive detonation events in time for the pilot to take corrective action before heat-distress damage is done.



Cylinders

Cylinder failures usually cause only partial power loss, but occasionally can cause complete power loss. A cylinder consists of a forged steel barrel mated to an aluminum alloy head casting. Cylinder barrels typically wear slowly, and excessive wear is detected at annual inspection by means of compression tests and borescope inspections. Cylinder heads can suffer fatigue failures, and occasionally the head can separate from the barrel. As dramatic as it sounds, a head separation causes only a partial loss of power; a six-cylinder engine with a head-to-barrel

separation can still make better than 80% power. Cylinder failures can be infant-mortality failures (due to improper manufacture) or age-related failures (especially if the cylinder head remains in service for more than two or three TBOs). Nowadays, most major overhauls include new cylinders, so age-related cylinder failures have become quite rare.



Valves and Valve Guides

It is quite common for exhaust valves and valve guides to develop problems well short of TBO. Actual valve failures are becoming much less common nowadays because incipient problems can usually be detected by means of borescope inspections and digital engine monitor surveillance. Even if a valve fails completely, the result is usually only partial power loss and an on-airport emergency landing.

Rocker Arms and Pushrods

Rocker arms and pushrods (which operate the valves) typically have a long useful life and are not normally replaced at overhaul. (Rocker bushings, like all bearings, are always replaced at overhaul.) Rocker arm failure is quite rare. Pushrod failures are caused by stuck valves, and can almost always be avoided through regular borescope inspections. Even when they happen, such failures usually result in only partial power loss.



Magnetos and Other Ignition Components

Magneto failure is uncomfortably commonplace. Mags are full of plastic components that are less than robust; plastic is used because it's non-conductive. Fortunately, our aircraft engines are equipped with dual magnetos for redundancy, and the probability of both magnetos failing simultaneously is extremely remote. Mag checks during preflight runup can detect gross ignition system failures, but in-flight mag checks are far better at detecting subtle or incipient failures. Digital engine monitors can reliably detect ignition system malfunctions in real time if the pilot is trained to interpret the data. Magnetos should religiously be disassembled, inspected and serviced every 500 hours; doing so drastically reduces the likelihood of an in-flight magneto failure.

The Bottom Line

The bottom-end components of our piston aircraft engines—crankcase, crankshaft, camshaft, bearings, gears, oil pump, etc.—**are very robust.** They normally exhibit long useful life that are many multiples of published TBOs. Most of these bottom-end components (with the notable exception of bearings) are routinely reused at major overhaul and not replaced on a routine basis. When these items do fail prematurely, the failures are mostly infant-mortality failures that occur shortly after the engine is built, rebuilt or overhauled, or they are random failures unrelated to hours or years in service. The vast majority of random failures can be detected long before they get bad enough to cause an in-flight engine failure simply by means of routine oil-filter inspection and laboratory oil analysis.

The top-end components—pistons, cylinders, valves, etc.—**are considerably less robust.** It is not at all unusual for top-end components to fail prior to TBO. However, most of these failures can be prevented by regular borescope inspections and by use of modern digital engine monitors. Even when they happen, top-end failures usually result in only partial power loss and a successful on-airport landing, and they usually can be resolved without having to remove the engine from the aircraft and sending it to an engine shop. Most top-end failures are infant-mortality or random failures that do not correlate with time since overhaul.

The bottom line is that a detailed FMEA of piston aircraft engines strongly suggests that the traditional practice of fixed-interval engine overhaul or replacement is unwarranted and counterproductive. **A conscientiously applied program of condition monitoring** that includes regular oil filter inspection, oil analysis, borescope inspections and digital engine monitor data analysis **can yield improved reliability and much reduced expense and downtime.**

Quest for a TBO-Free Engine

May 13th, 2014 by Mike Busch

“It just makes no sense,” Jimmy told me, the frustration evident in his voice. “It’s unfair. How can they do this?”

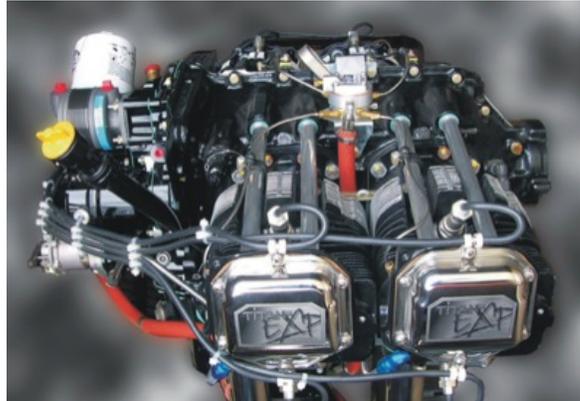


Jimmy Tubbs, ECI's legendary VP of Engineering

I was on the phone with my friend Jimmy Tubbs, the legendary Vice President of Engineering for **Engine Components Inc. (ECi)** in San Antonio, Texas. ECi began its life in the 1940s as a cylinder electroplating firm and grew to dominate that business. Starting in the mid-1970s and accelerating in the late 1990s—largely under Jimmy’s technical stewardship—the company transformed itself into one of the two major manufacturers of new FAA/PMA engine parts for Continental, Lycoming and Pratt & Whitney engines (along with its rival **Superior Air Parts**).

By the mid-2000s, ECi had FAA approval to manufacture thousands of different PMA-approved engine parts, including virtually every component of four-cylinder Lycoming 320- and 360-series engines (other than the Lycoming data plate). So the company decided to take the next logical step: building complete engines. ECi’s engine program began modestly with the company offering engines in kit form for the Experimental/Amateur-Built (E-AB) market. They opened an engine-build facility where homebuilders could assemble their own ECi “Lycoming-style” engines under expert guidance and supervision. Then in 2013, with more than 1,600 kit-built engines flying, ECi began delivering fully-built engines to the E-AB market under the “Titan Engines” brand name.

Catch 22, FAA-style



A Titan engine for experimental airplanes.

Jimmy is now working on taking ECI's Titan engine program to the next level by seeking FAA approval for these engines to be used in certificated aircraft. In theory, this ought to be relatively easy (as FAA certification efforts go) because the Titan engines are nearly identical in design to Lycoming 320 and 360 engines, and almost all the ECI-built parts are already PMA approved for use in Lycoming engines. In practice, nothing involving the FAA is as easy as it looks.

"They told me the FAA couldn't approve an initial TBO for these engines longer than 1,000 hours," Jimmy said to me with a sigh. He had just returned from a meeting with representatives from the FAA Aircraft Certification Office and the Engine & Propeller Directorate. "I explained that our engines are virtually identical in all critical design respects to Lycoming engines that have a 2,000-hour TBO, and that every critical part in our engines is PMA approved for use in those 2,000-hour engines."

"But they said they could only approve a 1,000-hour TBO to begin with," Jimmy continued, "and would consider incrementally increasing the TBO after the engines had proven themselves in the field. Problem is that nobody is going to buy one of our certified engines if it has only a 1,000-hour TBO, so the engines will never get to prove themselves. It makes no sense, Mike. It's not reasonable. Not logical. Doesn't seem fair."

I certainly understood where Jimmy was coming from. But I also understood where the FAA was coming from.

A brief history of TBO

To quote a 1999 memorandum from the FAA Engine & Propeller Directorate:

The initial models of today's horizontally opposed piston engines were certified in the late 1940s and 1950s. These engines initially entered service with recommended TBOs of 500 to 750 hours. Over the next 50 years, the designs of these engines have remained largely unchanged but the

manufacturers have gradually increased their recommended TBOs for existing engine designs to intervals as long as 2,000 hours. FAA acceptance of these TBO increases was based on successful service, engineering design, and test experience. New engine designs, however, are still introduced with relatively short TBOs, in the range of 600 hours to 1,000 hours.

From the FAA's perspective, ECi's Titan engines are new engines, despite the fact that they are virtually clones of engines that have been flying for six decades, have a Lycoming-recommended TBO of 2,000 hours, and routinely make it to 4,000 or 5,000 hours between overhauls.

Is it any wonder we're still flying behind engine technology designed in the '40s and '50s? If the FAA won't grant a competitive TBO to a Lycoming clone, imagine the difficulties that would be faced by a company endeavoring to certify a new-technology engine. Catch 22.



Preparing for an engine test cell endurance run.

Incidentally, there's a common misconception that engine TBOs are based on the results of endurance testing by the manufacturer. They aren't. The regulations that govern certification of engines (FAR Part 33) require only that a new engine design be endurance tested for 150 hours in order to earn certification. Granted, the 150-hour endurance test is fairly brutal: About two-thirds of the 150 hours involves operating the engine at full takeoff power with CHT and oil

temperature at red-line. (See [FAR 33.49](#) for the gory details.) But once the engine survives its 150-hour endurance test, the FAA considers it good to go.

In essence, the only endurance testing for engine TBO occurs in the field. Whether we realize it or not, those of us who fly behind piston aircraft engines have been pressed into service as involuntary beta testers.

What about a TBO-free engine?



“Jimmy, this might be a bit radical” I said, “but where exactly in FAR Part 33 does it state that a certificated engine has to have a recommended TBO?” (I didn’t know the answer, but I was sure Jimmy had Part 33 committed to memory.)

“Actually, it doesn’t,” Jimmy answered. “The only place TBO is addressed at all is in [FAR 33.19](#), where it says that ‘engine design and construction must minimize the development of an unsafe condition of the engine between overhaul periods.’ But nowhere in Part 33 does it say that any specific overhaul interval must be prescribed.”

“So you’re saying that engine TBO is a matter of tradition rather than a requirement of regulation?”

“I suppose so,” Jimmy admitted.

“Well then how about trying to certify your Titan engines without any TBO?” I suggested. “If you could pull that off, you’d change our world, and help drag piston aircraft engine maintenance kicking and screaming into the 21st century.”

An FAA-inspired roadmap

I pointed out to Jimmy that there was already a precedent for this in FAR Part 23, the portion of the FARs that governs the certification of normal, utility, aerobatic and commuter category airplanes. In essence, Part 23 is to non-transport airplanes what Part 33 is to engines. On the subject of airframe longevity, Part 23 prescribes an approach that struck me as being also appropriate for dealing with engine longevity.

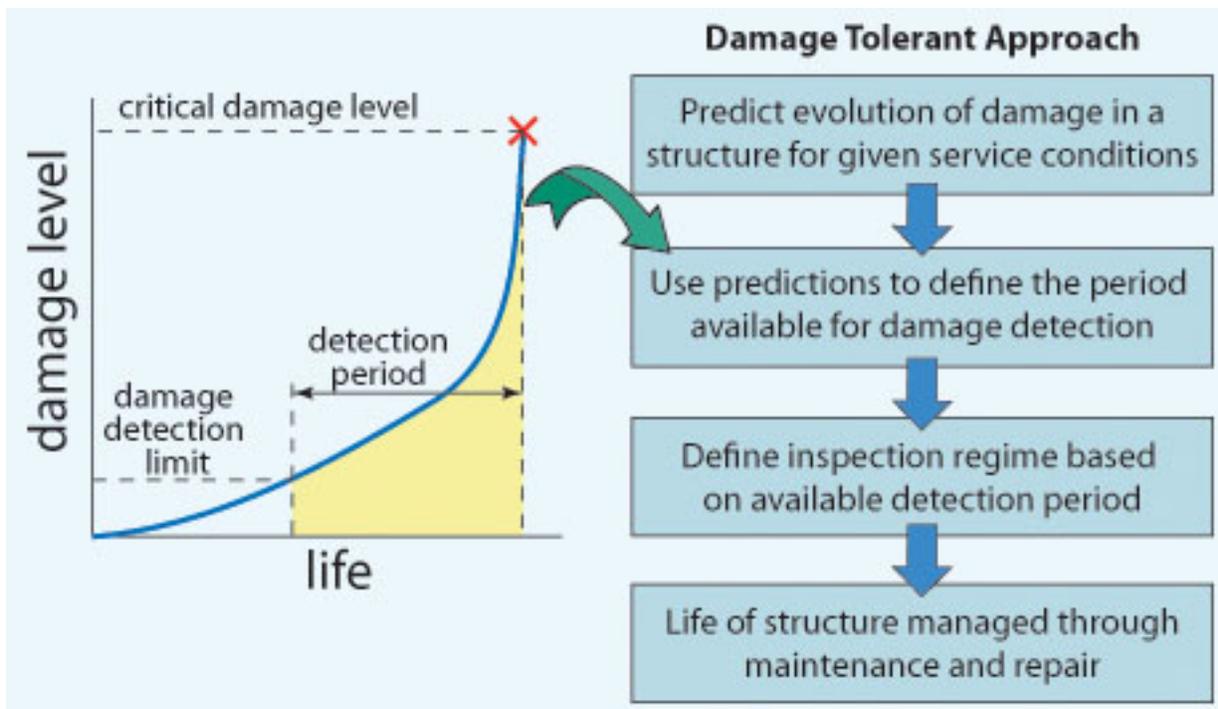
Since 1993, Part 23 has required that an applicant for an airplane Type Certificate must provide the FAA with a longevity evaluation of metallic wing, empennage and pressurized cabin structures. The applicant has the choice of three alternative methods for performing this evaluation. It’s up to the applicant to choose which of these methods to use:

“**Safe-Life**” —The applicant must define a “safe-life” (usually measured in either

hours or cycles) after which the structure must be taken out of service. The safe-life is normally established by torture-testing the structure until it starts to fail, then dividing the time-to-failure by a safety factor (“scatter factor”) that is typically in the range of 3 to 5 to calculate the approved safe-life of the structure. For example, the Beech Baron 58TC wing structure has a life limit (safe-life) of 10,000 hours, after which the aircraft is grounded. This means that Beech probably had to torture-test the wing spar for at least 30,000 hours and demonstrate that it didn’t develop cracks.

“**Fail-Safe**” —The applicant must demonstrate that the structure has sufficient redundancy that it can still meet its ultimate strength requirements even after the complete failure of any one principal structural element. For example, a three-spar wing that can meet all certification requirements with any one of the three spars hacksawed in half would be considered fail-safe and would require no life limitation.

“**Damage Tolerance**” —The applicant must define a repetitive inspection program that can be shown with very high confidence to detect structural damage before catastrophic failure can occur. This inspection program must be incorporated into the Airworthiness Limitations section of the airplane’s Maintenance Manual or Instructions for Continued Airworthiness, and thereby becomes part of the aircraft’s certification basis.



If we were to translate these Part 23 (airplane) concepts to the universe of FAR Part 33 (engines):

Safe-life would be the direct analog of **TBO**; i.e., prescribing a fixed interval between overhauls.

Fail-safe would probably be **impractical**, because an engine that included enough redundancy to meet all certification requirements despite the failure of any principal

structural element (e.g., a crankcase half, cylinder head or piston) would almost surely be too heavy.

Damage tolerance would be the direct analog of overhauling the engine strictly **on-condition** (based on a prescribed inspection program) with no fixed life limit. (This is precisely what I have been practicing and preaching for decades.)

How would it work?



Engine monitor data would be uploaded regularly to a central repository for analysis. Jimmy and I have had several follow-on conversations about this, and he's starting to draft a detailed proposal for an inspection protocol that we hope might be acceptable to the FAA as a basis of certifying the Titan engines on the basis of damage tolerance and eliminate the need for any recommended TBO. This is still very much a work-in-progress, but here are some of the thoughts we have so far:

The engine installation would be required to include a **digital engine monitor** that records EGTs and CHTs for each cylinder plus various other critical engine parameters (e.g., oil pressure and temperature, fuel flow, RPM). The engine monitor data memory would be required to be dumped on a regular basis and uploaded via the Internet to a central repository prescribed by ECi for analysis. The uploaded data would be scanned automatically by software for evidence of abnormalities like high CHTs, low fuel flow, failing exhaust valves, non-firing spark plugs, improper ignition timing, clogged fuel nozzles, detonation and pre-ignition. The data would also be available online for analysis by mechanics and ECi technical specialists.

At each oil-change interval, the following would be required: (1) An oil sample would be taken for spectrographic analysis (SOAP) by a designated laboratory, and a copy of the SOAP reports would be transmitted electronically to ECi; and (2) The oil filter would be cut open for inspection, digital photos of the filter media would be taken,

when appropriate the filter media would be sent for scanning electron microscope (SEM) evaluation by a designated laboratory, and the media photos and SEM reports would be transmitted electronically to ECi.

At each annual or 100-hour inspection, the following would be required: (1) Each cylinder would undergo a borescope inspection of the valves, cylinder bores and piston crowns using a borescope capable of capturing digital images, and the borescope images would be transmitted electronically to ECi; (2) Each cylinder rocker cover would be removed and digital photographs of the visible valve train components would be transmitted electronically to ECi; (3) The spark plugs would be removed for cleaning/gapping/rotation, and digital photographs of the electrode ends of the spark plugs would be taken and transmitted electronically to ECi; and (4) Each cylinder would undergo a hot compression test and the test results be transmitted electronically to ECi.



The details still need to be ironed out, but you get the drift. If such a protocol were implemented for these engines (and blessed by the FAA), ECi would have the ability to keep very close tabs on the mechanical condition and operating parameters of each its engines—something that no piston aircraft engine manufacturer has ever been able to do before—and provide advice to each individual Titan engine owner about when each individual engine is in need of an overhaul, teardown inspection, cylinder replacement, etc.

Jimmy even thinks that if such a protocol could be implemented and approved, ECi might even be in a position to offer a warranty for these engines far beyond what engine manufacturers and overhaul shops have been able to offer in the past. That would be frosting on the cake.

I've got my fingers, toes and eyes crossed that the FAA will go along with this idea of an engine certified on the basis of damage tolerance rather than safe-life. It would be a total game-changer, a long overdue nail in the coffin of the whole misguided notion that fixed-interval TBOs for aircraft engines make sense. And if ECi succeeds in getting its Titan engine certified on the basis of condition monitoring rather than fixed TBO, maybe Continental and Lycoming might jump on the overhaul-on-condition bandwagon. Wouldn't that be something?

The Dark Side of Maintenance

June 10th, 2014 by Mike Busch



Have you ever put your airplane in the shop—perhaps for an annual inspection, a squawk, or a routine oil change—only to find when you fly it for the first time after maintenance that something that was working fine no longer does? Every aircraft owner has had this happen. I sure have.

Maintenance has a dark side that isn't usually discussed in polite company: **It sometimes breaks aircraft instead of fixing them.**

When something in an aircraft fails because of something a mechanic did—or failed to do—we refer to it as a “**maintenance-induced failure**”...or “**MIF**” for short. Such MIFs occur a lot more often than anyone cares to admit.

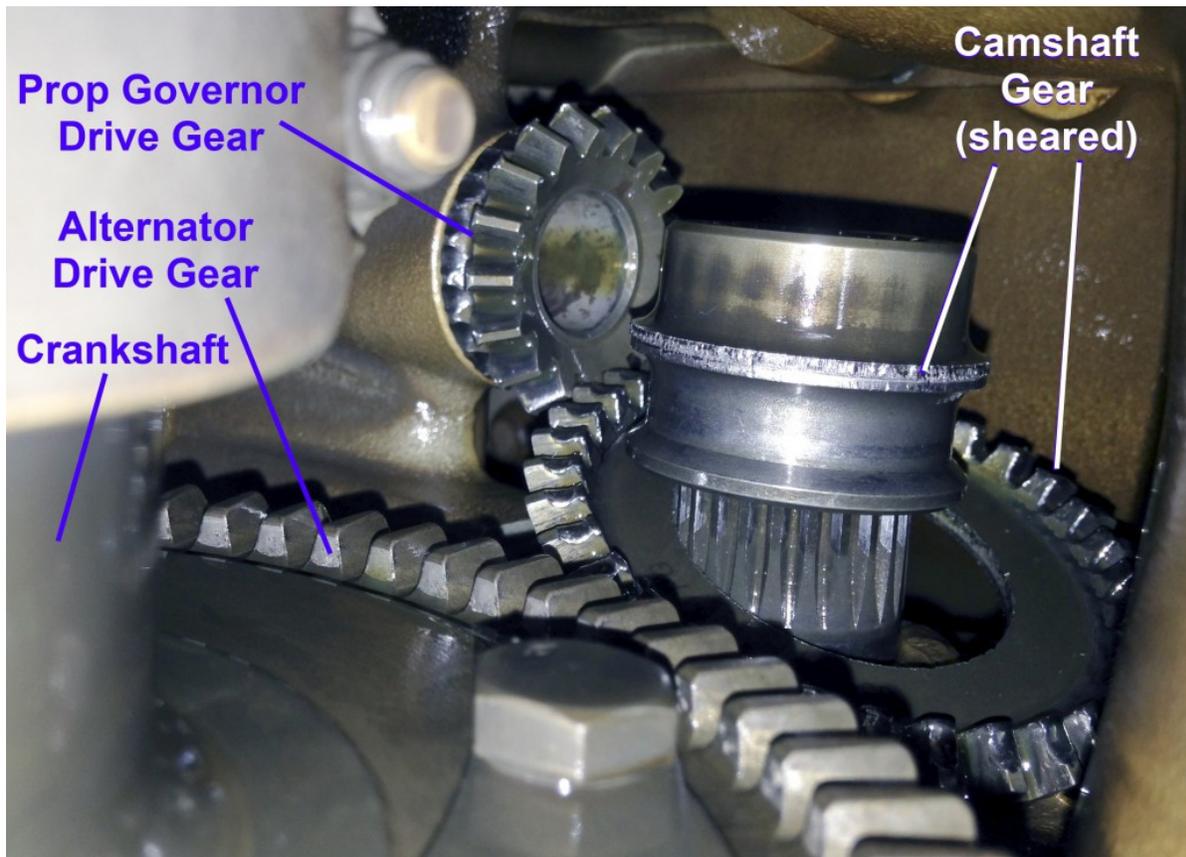
Why do high-time engines fail?

I started thinking seriously about MIFs in 2007 while corresponding with Nathan Ulrich Ph.D. about his ground-breaking research into the causes of catastrophic piston aircraft engine failures (based on five years' worth of NTSB accident data) that I discussed in [an earlier post](#). Dr. Ulrich's analysis showed conclusively that by far the highest risk of catastrophic engine failure occurs when the engine is young—during the first two years and 200 hours after it is

built, rebuilt or overhauled—due to “infant-mortality failures.”

But the NTSB data was of little statistical value in analyzing the failure risk of high-time engines beyond TBO, simply because so few engines are operated past TBO; most are arbitrarily euthanized at TBO. We don't have good data on how many engines are flying past TBO, but it's a relatively small number. So it's no surprise that the NTSB database contains very few accidents attributed to failures of over-TBO engines. Because there are so few, Ulrich and I decided to study all such NTSB reports for 2001 through 2005 to see if we could detect some pattern of what made these high-time engines fail. Sure enough, we did detect a pattern.

About half the reported failures of past-TBO engines stated that the reason for the engine failure could not be determined by investigators. Of the half where the cause could be determined, we found that **about 80% were MIFs**. In other words, those engines failed not because they were past TBO, but because mechanics worked on the engines and screwed something up!



Case in point: I received a call from an aircraft owner whose Bonanza was undergoing annual inspection. The shop convinced the owner to have his propeller and prop governor sent out for 6-year overhauls. (Had the owner asked my advice, I'd have urged him not to do this, but that's another story for another blog post.)

The overhauled prop and governor came back from the prop shop and were reinstalled. The mechanic had trouble getting the prop to cycle properly, and he wound up removing and reinstalling the governor three times. During the third engine runup, the the prop still wouldn't cycle properly. The mechanic decided to take the airplane up on a test flight anyway (!) which resulted in an engine overspeed. The mechanic then removed the prop governor yet again and discovered that the governor drive wasn't turning when the crankshaft was rotated.

I told the owner that I'd seen this before, and the cause was always the same: improper installation of the prop governor. If the splined drive and gears aren't meshed properly before the governor is torqued, the camshaft gear is damaged, and the only fix is a teardown. (A couple of engine shops and a Continental tech rep all told the owner the same thing.)

This could turn out to be a \$20,000 MIF. Ouch!

How often do MIFs happen?

They happen a lot. Hardly a day goes by that I don't receive an email or a phone call from an exasperated owner complaining about some aircraft problem that is obviously a MIF.

A Cessna 182 owner emailed me that several months earlier, he'd put the plane in the shop for an oil change and installation of an STC'd exhaust fairing. A couple of months later, he decided to have a digital engine monitor installed. The new engine monitor revealed that the right bank of cylinders (#1, #3 and #5) all had very high CHTs well above 400°F. This had not shown up on the factory CHT gauge because its probe was installed on cylinder #2. (Every piston aircraft should have an engine monitor IMHO.) At the next annual inspection at a different shop, the IA discovered found some induction airbox seals missing, apparently left off when the exhaust fairing was installed. The seals were installed and CHTs returned to normal.

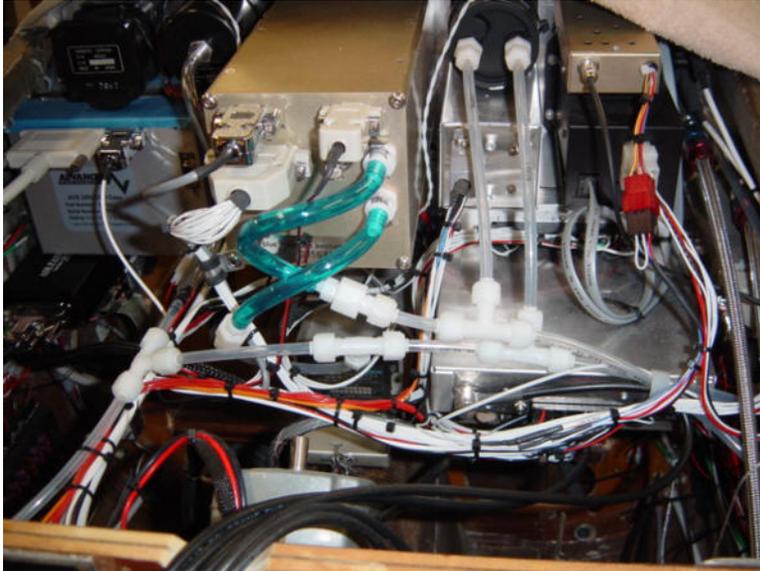
Sadly, the problem wasn't caught early enough to prevent serious heat-related damage to the right-bank cylinders. All three jugs had compressions down in the 30s with leakage past the rings, and visible damage to the cylinder bores was visible under the borescope. The owner was faced with replacing three cylinders, around \$6,000.



The next day, I heard from the owner of an older Cirrus SR22 complaining about intermittent heading errors on his Sandel SN3308 electronic HSI. These problems started occurring intermittently about three years earlier when the shop pull the instrument for a scheduled 200-hour lamp replacement.

Coincidence?

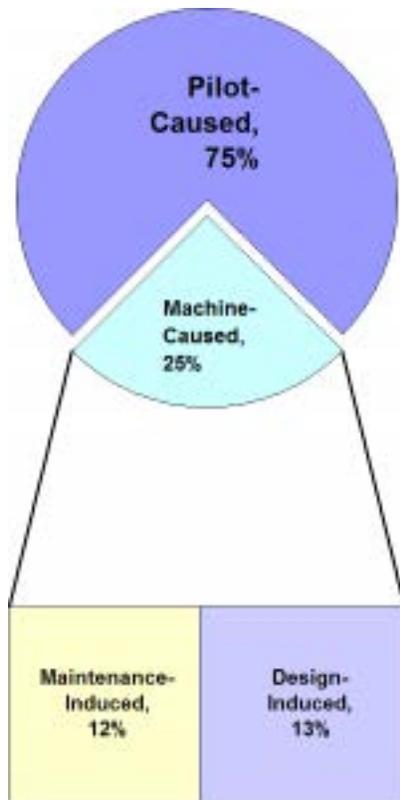
I've seen this in my own Sandel-equipped Cessna 310, and it's invariably due to inadequate engagement between the connectors on the back of the instrument and the mating connectors in the mounting tray. You must slide the instrument into the tray just as far as possible before tightening the clamp; otherwise, you've set the stage for flaky electrical problems. This poor Cirrus owner had been suffering the consequences for three years. It took five minutes to re-rack the instrument and cure the problem.



Not long after that, I got a panicked phone call from one of my managed-maintenance clients who'd departed into actual IMC in his Cessna 340 with his family on board on the first flight after some minor avionics work. (Not smart IMHO.) As he entered the clag and climbed through 3,000 feet, all three of his static instruments—airspeed, altimeter, VSI—quit cold. Switching to alternate static didn't cure the problem. The pilot kept his cool, confessed his predicament to ATC, successfully shot an ILS back to his home airport, then called me.

The moment I heard the symptoms, I knew exactly what happened because I'd seen it before. "Take the airplane back to the avionics shop," I told the owner, "and ask the tech to reconnect the static line that he disconnected." A disconnected static line in a pressurized aircraft causes the static instruments to be referenced to cabin pressure. The moment the cabin pressurizes, those instruments stop working. MIF!

I know of at least three other similar incidents in pressurized singles and twins, all caused by failure of a mechanic to reconnect a disconnected static line. One resulted in a fatal accident, the others in underwear changes. The FARs require a static system leak test any time the static system is opened up, but clearly some technicians are not taking this seriously.



Why do MIFs happen?

Numerous studies indicate that three-quarters of accidents are the fault of the pilot. The remaining one-quarter are machine-caused, and those are just about evenly divided between ones caused by aircraft design flaws and ones caused by MIFs. **That suggests one-eighth of accidents are maintenance-induced, a significant number.**

The lion's share of MIFs are errors of omission. These include fasteners left uninstalled or untightened, inspection panels left loose, fuel and oil caps left off, things left disconnected (e.g., static lines), and other reassembly tasks left undone.

Distractions play a big part in many of these omissions. A mechanic installs some fasteners finger-tight, then gets a phone call or goes on lunch break and forgets to finish the job by torquing the fasteners. I have seen some of the best, most experienced mechanics I know fall victim to such seemingly rookie mistakes, and I know of several fatal accidents caused by such omissions.

Maintenance is invasive!

Whenever a mechanic takes something apart and puts it back together, there's a risk that something won't go back together quite right. Some procedures are more invasive than others, and invasive maintenance is especially risky.

Invasiveness is something we think about a lot in medicine. The standard treatment for gallstones used to be cholecystectomy (gall bladder removal), major abdominal surgery requiring a 5- to 8-inch incision. Recovery involved a week of hospitalization and several weeks of recovery at home. The risks were significant: My dad very nearly died as the result of complications following this procedure.

Nowadays there's a far less invasive procedure—laproscopic cholecystectomy—that involves three tiny incisions and performed using a videoscope inserted through one incision and various microsurgery instruments inserted through the others. It is far less invasive than the open procedure. Recovery usually involves only one night in the hospital and a few days at home. The risk of complications is greatly reduced.

Similarly, some aircraft maintenance procedures are far more invasive than others. The more invasive the maintenance, the greater the risk of a MIF. When considering any maintenance task, we should always think carefully about how invasive it is, whether the benefit of performing the procedure is really worth the risk, and whether less invasive alternatives are available.



For example, I was contacted by an aircraft owner who said that he'd recently received an oil analysis report showing an alarming increase in iron. The oil filter on his Continental IO-520 showed no visible metal. The lab report suggested flying another 25 hours and then submitting another oil sample for analysis.

The owner showed the oil analysis report to his A&P, who expressed grave concern that the elevated iron might indicate that one or more cam lobes were coming apart. The mechanic suggested pulling one or two cylinders and inspecting the camshaft.

Yikes! What was this mechanic thinking? No airplane has ever fallen out of the sky because of a cam or lifter problem. Many have done so following cylinder removal, the second most invasive thing you can do to an engine. (Only teardown is more invasive.)

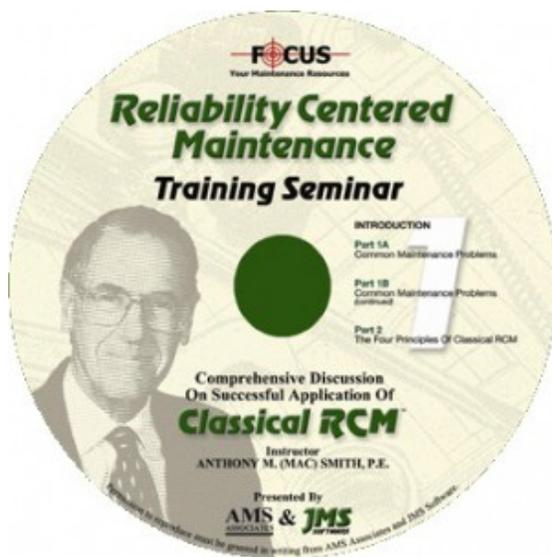
The owner wisely decided to seek a second opinion before authorizing this exploratory surgery. I told him the elevated iron was almost certainly NOT due to cam lobe spalling. A disintegrating cam lobe throws off fairly large steel particles or whiskers that are usually visible during oil filter inspection. The fact that the oil filter was clean suggested that the elevated iron was coming from microscopic metal particles less than 25 microns in diameter, too small to be detectable in a filter inspection, but easily detectable via oil analysis. Such tiny particles were probably coming either from light rust on the cylinder walls or from some very slow wear process.

I suggested the owner have a borescope inspection of his cylinders to see whether the bores showed evidence of rust. I also advised that no invasive procedure (like cylinder removal) should ever be undertaken solely on the basis of a single oil analysis report. The oil lab was spot-on in recommending that the aircraft be flown another 25 hours. The A&P wasn't thinking clearly.

Even if a cam inspection was warranted, there's a far less invasive method. Instead of a 10-hour cylinder removal, the mechanic could pull the intake and exhaust lifters, and then determine the condition of the cam by inspecting it with a borescope through the lifter boss and, if warranted, probing the cam lobe with a sharp pick. Not only would this procedure require just 15% as much labor, but the risk of a MIF would be nil.

Sometimes, less is more

Many owners believe—and many mechanics preach—that preventive maintenance is inherently a good thing, and the more of it you do the better. I consider this wrongheaded. Mechanics often do far more preventive maintenance than necessary and often do it using unnecessarily invasive procedures, thereby increasing the likelihood that their efforts will actually cause failures rather than preventing them.



[Another of my earlier posts](#) discussed **Reliability-Centered Maintenance (RCM)** developed at United Airlines in the late 1960s, and universally adopted by the airlines and the military during the 1970s. One of the major findings of RCM researchers was that preventive maintenance often does more harm than good, and that safety and reliability can often be improved dramatically by reducing the amount of PM and using minimally invasive techniques.

Unfortunately, this thinking doesn't seem to have trickled down to piston GA, and is considered heresy by many GA mechanics because it contradicts everything they were taught in A&P school. The long-term solution is for GA mechanics to be trained in RCM principles, but that's not likely to happen any time soon. In the short term, aircraft owners must think carefully before authorizing an A&P to perform invasive maintenance on their aircraft. When in doubt, get a second opinion.

The last line of defense

The most likely time for a mechanical failure to occur is the first flight after maintenance. Since the risk of such MIFs is substantial, it's imperative that owners conduct a post-maintenance test flight—in VMC, without passengers, preferably close to the airport—before launching into the clag or putting passengers at risk. I think even the most innocuous maintenance task—even a routine oil change—deserves such a post-maintenance test flight. I do this any time I swing a wrench on my airplane.

You should, too.

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PROGRESS REPORT

ASTIA 268305
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Determination of Engine Condition

by

Spectrographic Analysis of Engine

Oil Samples

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Progress Report
Determination of Engine Condition
by
Spectrographic Analysis of
Engine Oil Samples
Jack F Witten Bureau of Naval Weapons
Maintenance Research and Analysis FWWS-22
Bernard B. Bond Materials Engineering Supt.
O&R Department NAS Pensacola

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64984

Presented to SAE
National Aeronautic Meeting
April 5, 1961

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In 1955, the activity now known as the Fleet Readiness group of the Bureau of Naval Weapons initiated a project at NAS Pensacola, Fla. to determine whether the concept employed by the railroads for determining the condition of diesel engines by means of oil analysis could be applied to aircraft engines. If these techniques could be applied, inflight engine failures could be minimized, extension of engine operating intervals could be justified and reductions in engine overhaul costs could be achieved.

Consideration of this concept has been restrained for some time by concern over the many conditions which could mitigate against development of successful techniques.. These were:

- A. The many sources of lubricating oil base stock.
- B. The variety of engines.
- C. The High Engine oil consumption coupled with relatively small aircraft oil tanks.
- D. Differences in oil drain intervals for various engines.
- E. An anticipated necessity for developing metallic contamination threshold limits related to engine operating hours. The belief that it would be necessary to develop a trend on each engine before valid action could be taken on sample data.
- G. The time and cost involved in sample analysis.
- H. The sample handling and data communication problem -- most of these proved to be of no consequence -- the others we have found ways to eliminate or minimize.

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At the present time, we are monitoring 2200 engines and helicopter transmissions. These include 120 R-2000s, 50-2800s, 360 R-3350s, over 1000 R-1820s, a wide variety of other engine models, gas turbines and helicopter transmissions. We are servicing activities scattered throughout the eastern three fourths of the U. S. Samples are taken every 30 flight hours and air mailed to the NAS Pensacola Laboratory. There, under the direction of the Project Leader, Mr. B. B. Bond, the samples are processed and action on the results taken. The average sample is processed within 48 hours from the time it was taken.

Diagnosis of engine condition requires consideration of intelligence obtained in many ways. To detect subtle defects and latent sources of trouble in people or engines, requires the use of many diagnostic aids.

FIRST SLIDE: (Exhibit 1)

In this slide, you can see that oil analysis does not stand alone. It does fill a major gap in our knowledge by giving us a technically valid insight into the condition of the vital dynamic parts in the oil wetted portion of the engine.

Let us follow a typical sample from the operating unit to the laboratory.

SECOND SLIDE: (Exhibit 2)

Oil samples are taken at 30 hour intervals. Kits comprized of sample bottle, tube, data sheet and mailing carton are provided to the operating unit. Throwaway tubes and bottles are used.

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THIRD SLIDE: (Exhibit 3)

To take a sample, the tube is inserted in the oil tank filler neck, a finger is placed over the end of the tube and a sample is withdrawn and placed in the bottle. The engine operating hours and serial number are entered on the data sheet. The data sheet and sample are air mailed to Pensacola.

FOURTH SLIDE: (Exhibit 4)

These are the elements we will identify and measure. Their sources are indicated to the right.

FIFTH SLIDE: (Exhibit 5)

The liquid sample is analyzed in the "as received condition" using a direct reading spectrometer with rotating disc electrode and spark excitation.

SIXTH SLIDE: (Exhibit 6)

The sample is handled only once; you shake it and pour a small amount of oil into the cap and place the cap in the spark stand.

SEVENTH SLIDE: (Exhibit 7)

Reduced to its simplest elements, this is how this spectrometer functions. The disc electrode rotates and carries a thin film of oil to the area under the fixed electrode. The oil film is burned by a high energy spark discharge between these electrodes. The spectrum is separated by a diffraction grating (represented by the prism) for the sake of simplicity. Photo multiplier tubes are placed to intercept light of the wave lengths produced by the elements we are seeking. The signal from the photo multiplier tubes is converted to simple dial readings, which indicate the type and quantity of wear metals present in parts per million.

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The sample analysis process takes 55 seconds.

EIGHTH SLIDE: (Exhibit 8)

The quantity of the elements present in the oil sample are entered on the engine history card and the condition of the engine is noted. Condition is determined by comparing the results with previous samples to detect sharp increases in the quantity of wear metals. The results are also compared to the threshold limits for that engine.

NINTH SLIDE: (Exhibit 9)

The history of this engine is shown graphically on this chart. The threshold limits we are using for the R-1820 engines in PPM are 35 iron, 10 chromium, 8 aluminum, 4 PPM silver. This engine has exceeded the aluminum threshold limits. Traces of silver have also been detected. A check sample is requested by dispatch. The check sample indicates aluminum levels have doubled since the last sample, iron is approaching the threshold limit and copper and chromium are increasing.

TENTH SLIDE: (Exhibit 10)

The squadron is notified and engine removal is recommended.

ELEVENTH SLIDE: (Exhibit 11)

The engine is removed and a disassembly inspection report is requested. A report of the condition found during disassembly is received by the lab. It indicates failure of #6 piston top land, a broken top ring, a split master rod bearing which also failed in the locking splines.

TWELVETH SLIDE: (Exhibit 12)

This is the way the piston and the master rod bearing looked upon disassembly.

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This engine had 721 hours of service and had given no evidence of impending trouble at the time the samples were taken.

We are running from 200 to 300 samples per day at Pensacola -- an average of 20 phone calls or telegrams are sent to advise operating units of engine problems detected by oil analysis. When a squadron is notified of potential engine troubles, they take a check sample and send it to the laboratory and perform a trouble shooting procedure on the engine involving:

Engine oil screen examination for gross particles

Compression checks

Borescope examination of the cylinders

Rocker box inspections

About half of the advisories result in the correction of difficulties by cylinder replacement or other repair. After the engine has been repaired or if the trouble shooting revealed no discrepancies, the engine is monitored by taking a sample each five flight hours until the level of wear metals in the oil returns to normal or the difficulty is located. If the engine does not stabilize and the levels remain above threshold limits, the engine is removed from service. We are detecting failing pistons, cylinder, ring, accessory drive bearing, valve springs, valve guides, reduction gears etc. We even stimulated a search for trouble on one engine that resulted in detection of a cracked nose section.

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Just a few case histories might illustrate how this works:

R-2000 engine in a Navy R5D. The first R-2000 we sampled. In parts per million, the first sample showed 46 copper, 12 silver, 411 iron, 14 chrome, 27 aluminum. We cross checked this heavily contaminated sample with the other three engines in the aircraft as this was all the R-2000 data we had. Results: the engine was removed; disassembly revealed the pinion gears were badly worn; one pinon thrust bearing race and retainer was missing, one other pinion thrust bearing had failed. The crew chief had insisted that this was a good engine. R-2000 at NAS Glenview sampled Feb 26. In parts per million 18 copper, 2 silver, 115 iron, 15 chrome and 50 aluminum. Glenview was requested to pull a compression check, number 14 cylinder was low on compression, the top piston land had broken out and the top piston ring was missing. A new cylinder was installed. The oil was changed and the aircraft was flown 5 hours. A check sample was taken, the sample was within limits. Results were phoned to NAS Glenview and the aircraft left for Africa within an hour. This crew left with reasonable assurance that all was well in the engine and the cylinder change had not introduced additional problems.

R-2800-54. Sample was taken Jan 11 and for some reason did not get to Pensacola until Jan 15. In parts per million, the sample showed 10 copper, 4 silver, 116 iron, 6 chrome and 54 aluminum. The squadron was called. They stated that on the 13th, two days after the sample was taken, the engine suffered a temporary loss of power in flight. Compression check revealed #4 cylinder to be low in compression. The cylinder was changed and the aircraft was flown two hours and a new sample was taken. This sample indicated 6 copper, 3 silver, 105 iron, 4 chrome, and 48 aluminum. These results indicated the condition had not been corrected. On a subsequent test flight, the backfiring

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and temporary loss of power re-occurred and re-examination revealed seven additional cylinders were damaged. The engine was removed from service.

R-3350 sample -- the first one received on this aircraft, indicated high aluminum, 14 parts per million. The squadron was called; they stated #2 cylinder blew it's head 1.5 hours after this sample was taken. I believe this may be when we qualified for the title of this discussion. We have learned that each engine model has it's own characteristic levels of wear metal concentrations. Normals vary from less than 20 parts per million of iron in some to 400 parts per million of iron in other models. We have found that the wear metals in normal engines are either in solution or a colloidal suspension. They do not settle out of the oil. Samples taken from the main oil screen, nose section, bottom of the oil tank, etc. are comparable. Samples from the bottom of the oil tank appear to be the most valid, however, to simplify the burden on the operator and to obtain diet free samples, we are continuing our present method.

During the last few months out of 483 R-2000, 2800 and 3350 engines monitored, 34 actions were taken as the result of oil analysis data; 16 of the engines were removed for overhaul for reasons verified by disassembly inspection, 17 were returned to service after cylinder change or other repairs. One engine was returned for overhaul and no defects of any significance were found. We have not completed a summary of the data on the number of engine failures which occurred on engines that we are monitoring which failed for reasons potentially detectable by these techniques. We do have reasonably complete data on one engine -- this is as follows:

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113 Early Removals

17 Had no detectable defects.

12 of these were removed on the basis of gross metal
in the screen not backed up by sample analysis.

The oil sample indicated the engine was all right.

37 Were fast failures of the type we do not expect to detect.

59 Were gradual failures.

19 of these were detected on the basis of oil analysis alone.

40 We detected by screen examination backed up by oil analysis.

This particular engine is plagued with many problems which cause fast failures, particularly piston pin boss failures. Our performance on other engines is better, and we have improved considerably on this engine since this data was collected.

Our work on helicopter transmissions indicates that these techniques can be used to good effect on transmissions. At the present time, we are monitoring 157 H-23D's for the Army. We have not developed any conclusive data on the 200 jet engines we have monitored, as the engine we were watching is singularly free of problems in the oil wetted areas.

We have learned that the metallic content in engines in normal condition remains relatively constant. Apparently the loss of oil together with the wear metals in suspension, coupled with the addition of oil between flights results in establishment of a condition of equilibrium. We know that engines of the same model have the same average levels of wear metal in the oil. We know

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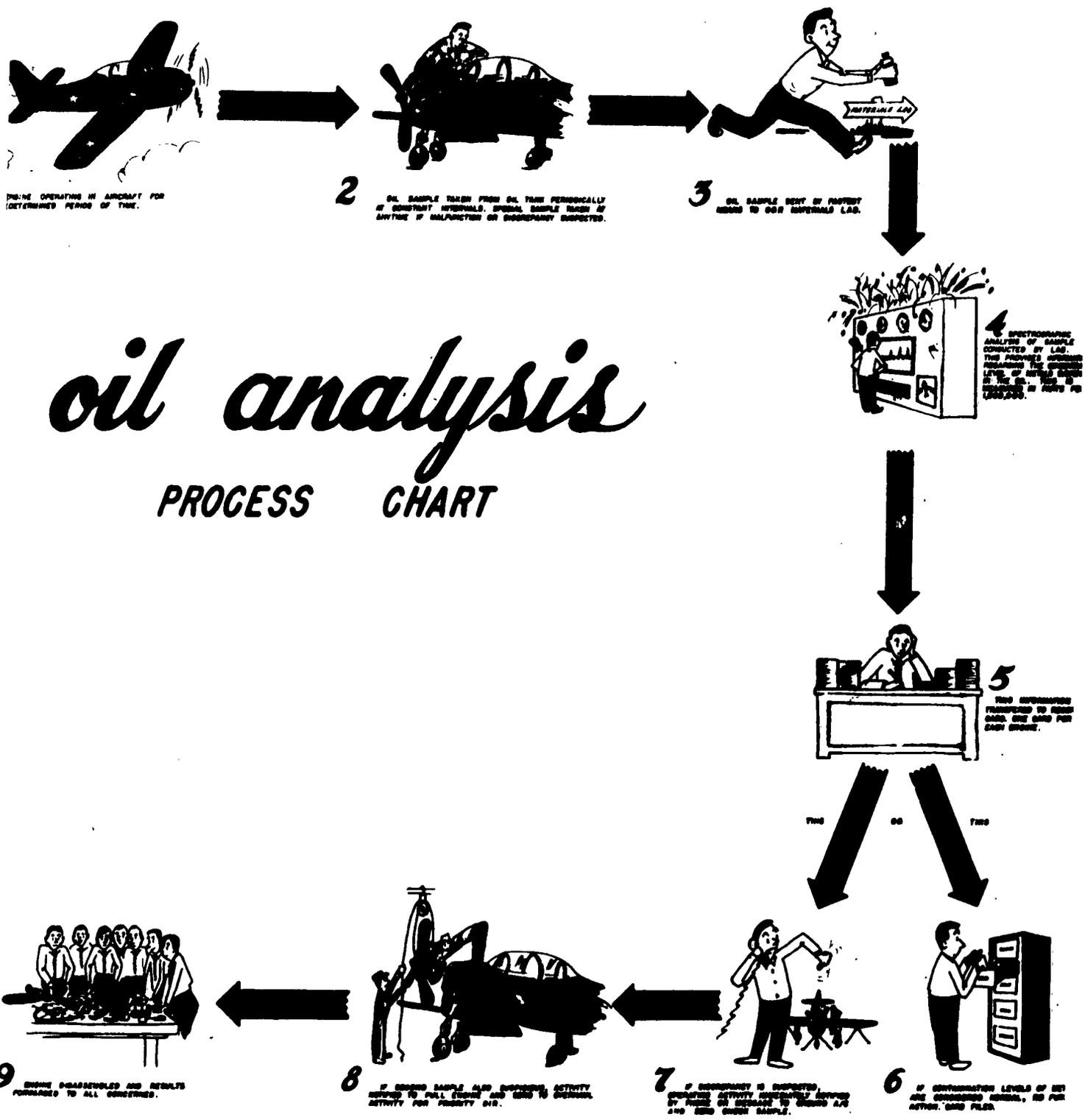
that the level of wear metals in the oil is relatively independent of engine operating time; we know we can establish threshold limits for engines and have developed them for a considerable number of models. We can live with various oil drain intervals including aircraft operations which do not have any oil drain intervals.

We have sufficient sensitivity to detect very minor problems and must be careful to have threshold limits high enough to avoid needless removal of engines. We know that the failure characteristics of engines of different models and those made by different manufacturers vary widely. Some fail with very little time between the initial trouble and failure; others give very adequate warning. On those that give adequate warning, we have had such a high order of success, I hesitate to give the numbers for fear of overselling this program. We have confirmed the fact that master rod bearing failures are very fast failures. We learned this the hard way -- we miss too many of them. The pilot production phase of this project has been completed. The NAS Pensacola management control and production engineering groups are in the process of streamlining the analytical, data handling, and communications procedures. We have developed specifications for a direct reading spectrometer with automatic print out of the data on the engine history card and a separate key punched card for automatic data processing. This equipment, which will double our capacity and serve as the prototype for additional installation, should be in operation by 1 Jan 1962. The major technical problems related to this process have been resolved. The remaining problems relate to management of the system, data handling and communications problems.

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We will initiate work in the near future on the T-56 engine and two gas turbines which currently are experiencing bearing problems. When additional capacity becomes available, we also plan to investigate the application of these techniques to cabin pressurization equipment, constant speed drives and hydraulic systems.

By use of spectrographic oil analysis, we are detecting engine problems earlier than they can be detected any other way. We give direction and velocity to trouble shooting and engine conditioning procedures. We can verify the effectiveness of a repair. We can and do alert the operator to many problems which if left undetected could result in-- inflight engine failures.



oil analysis

PROCESS CHART

AIDS TO DIAGNOSING TROUBLES
COMMON TO INTERNAL COMBUSTION DEVICES

ENGINES	PEOPLE
CYLINDER HEAD TEMPERATURE	ORAL TEMPERATURE
OIL TEMPERATURE	RECTAL TEMPERATURE
OIL PRESSURE	BLOOD PRESSURE/PULSE
FUEL PRESSURE/FLOW	FOOD INTAKE
FUEL MIXTURE	NUTRITIONAL BALANCE
TORQUE	MUSCULAR DEVELOPMENT
RPM	MUSCULAR RESPONSE
VIBRATION PICK-UP	REFLEXES
IGNITION ANALYZER	NERVOUS SYSTEM
BMEP	METABOLISM
MANIFOLD PRESSURE	RESPIRATION
EXHAUST GAS ANALYSIS	URINALYSIS
CHIP DETECTOR	FECES ANALYSIS
ENGINE OIL ANALYSIS	BLOOD CHEMISTRY

SAMPLE BEING TAKEN FROM AIRCRAFT OIL TANK

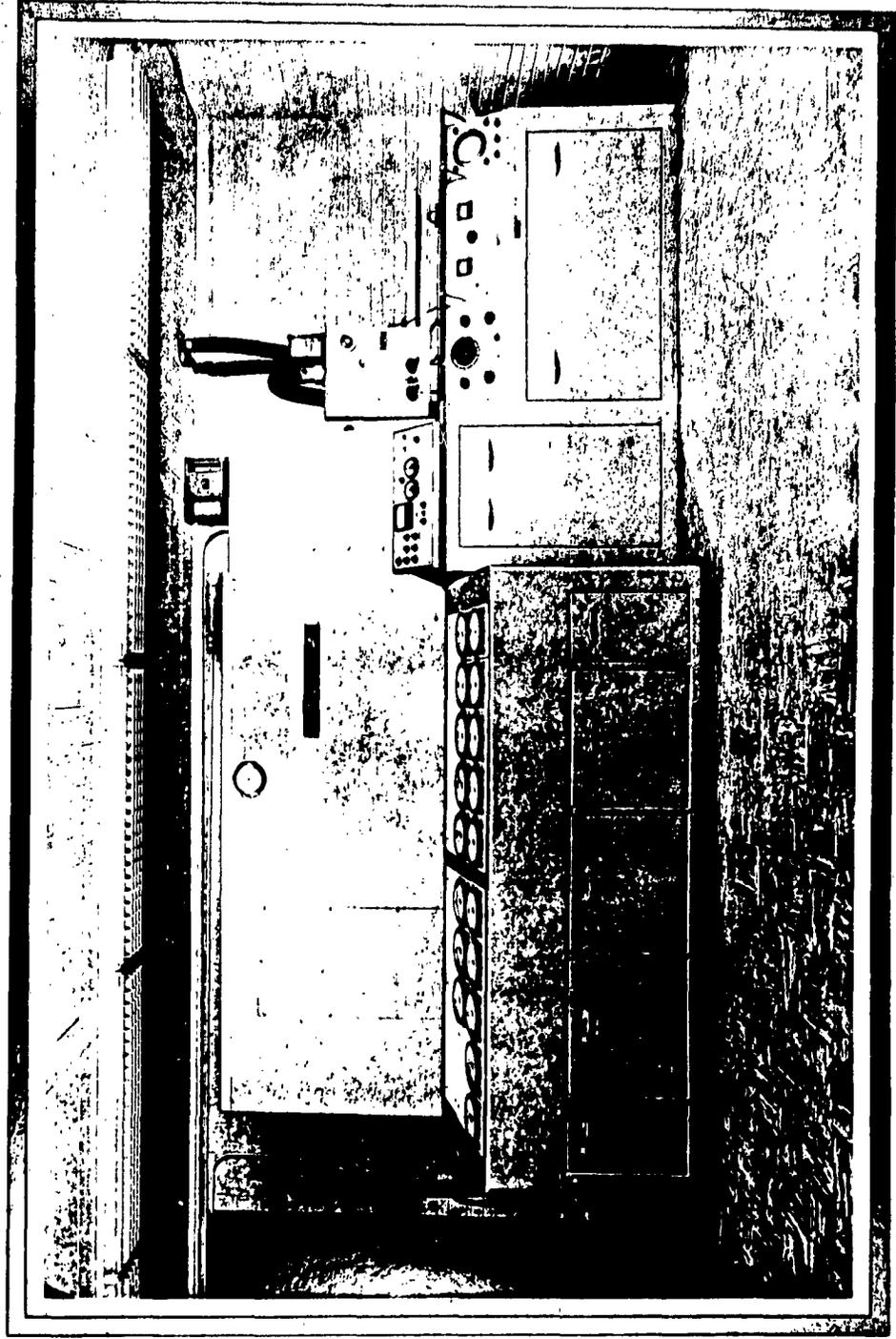


CHART SHOWING PROBABLE SOURCES OF WEAR METALS IN AIRCRAFT ENGINE OIL

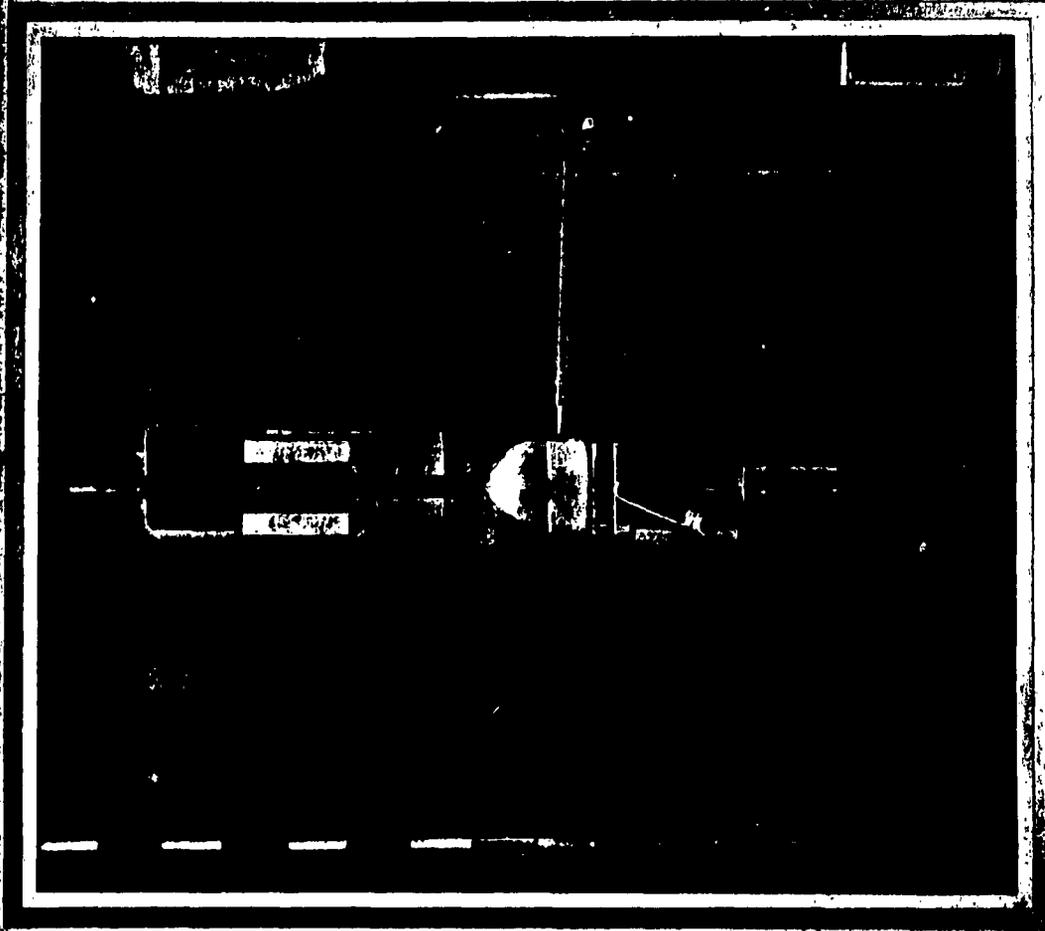
R-1820-86

ALUMINUM	PISTONS, PISTON PIN PLUGS, REDUCTION DRIVING GEAR PINION LOCK NUTS, INTAKE VALVE GUIDES, CYLINDER HEADS, IMPELLER & FRONT & REAR OIL PUMP BODIES.
CHROMIUM	UPPER PISTON RINGS, EXHAUST VALVE GUIDES & CONSTITUENT OF MOST STEEL PARTS.
COPPER	ALL ACCESSORY DRIVE SHAFT BUSHINGS, REDUCTION DRIVING GEAR PINION LOCK NUTS, PROP SHAFT FRONT & REAR BUSHINGS, COUNTERWEIGHT ASSEMBLIES (PLATED AREA), MASTER & ARTICULATING ROD BUSHINGS & INTAKE VALVE GUIDES.
IRON	ALL GEARING & ACCESSORY DRIVE SHAFTS, THRUST BEARING, MAIN BEARINGS, CAM, COUNTERWEIGHT ASSEMBLIES, CYLINDER BARRELS, PISTON RINGS, VALVE SPRINGS, VALVE TAPPET ROLLERS, EXHAUST VALVE GUIDES & IMPELLER CLUTCH PLATES.
NICKEL	PISTONS & EXHAUST VALVE GUIDES.
SILICON	NORMAL ASPIRATION OR OIL CONTAMINATION.
SILVER	CAM SUPPORT BEARING SURFACE & MASTER CONNECTING ROD BEARING.
TIN	ALL BUSHING, MASTER CONNECTING ROD BEARING, CAM SUPPORT BEARING SURFACE & PLATED STEEL PARTS.

**GENERAL VIEW OF DIRECT READING SPECTROMETER
USED FOR ANALYSIS OF AIRCRAFT ENGINE OIL SAMPLES**



AIRCRAFT ENGINE OIL SAMPLE BEING SPARKED
IN DIRECT READING SPECTROMETER



ANALYSIS TECHNIQUE

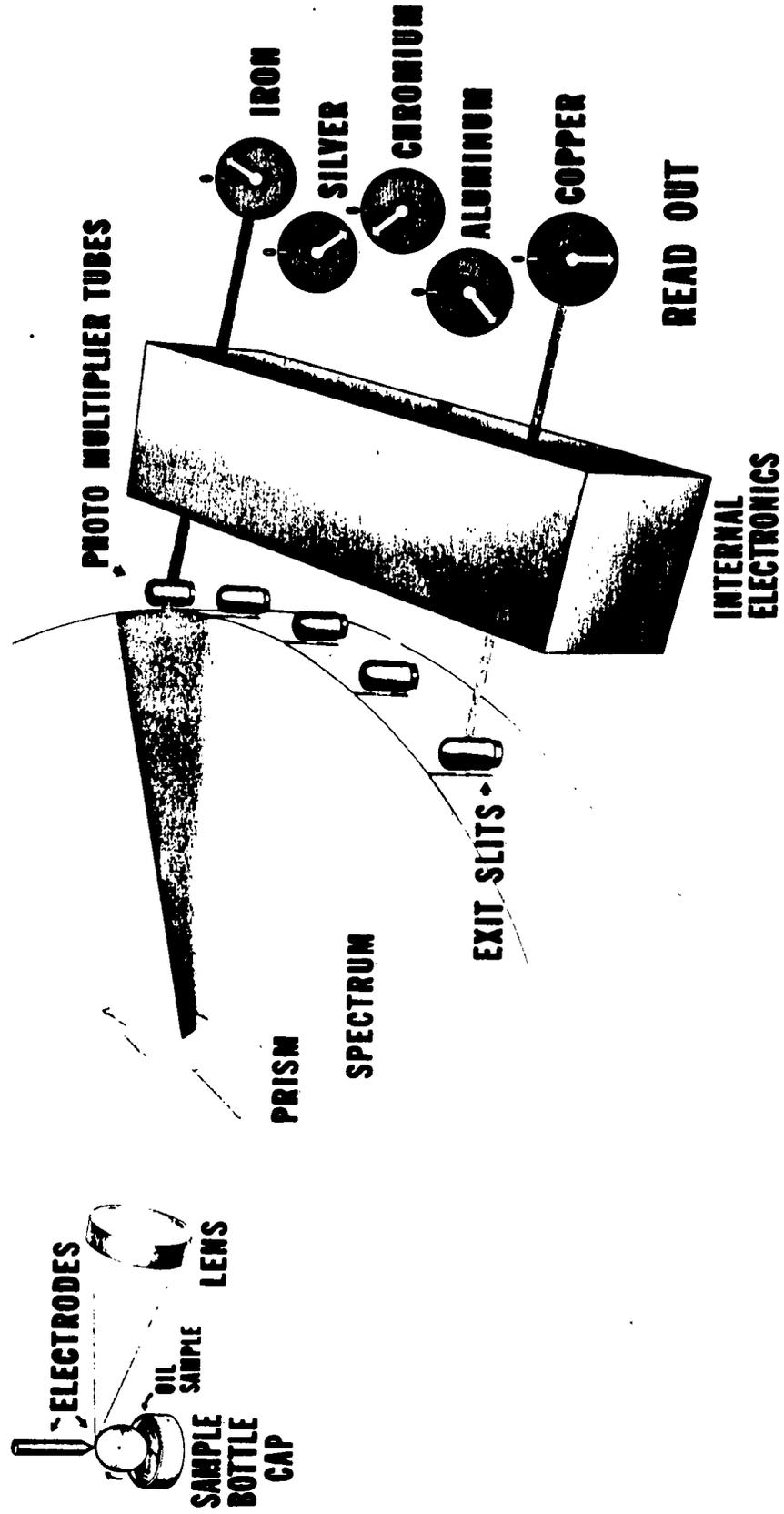
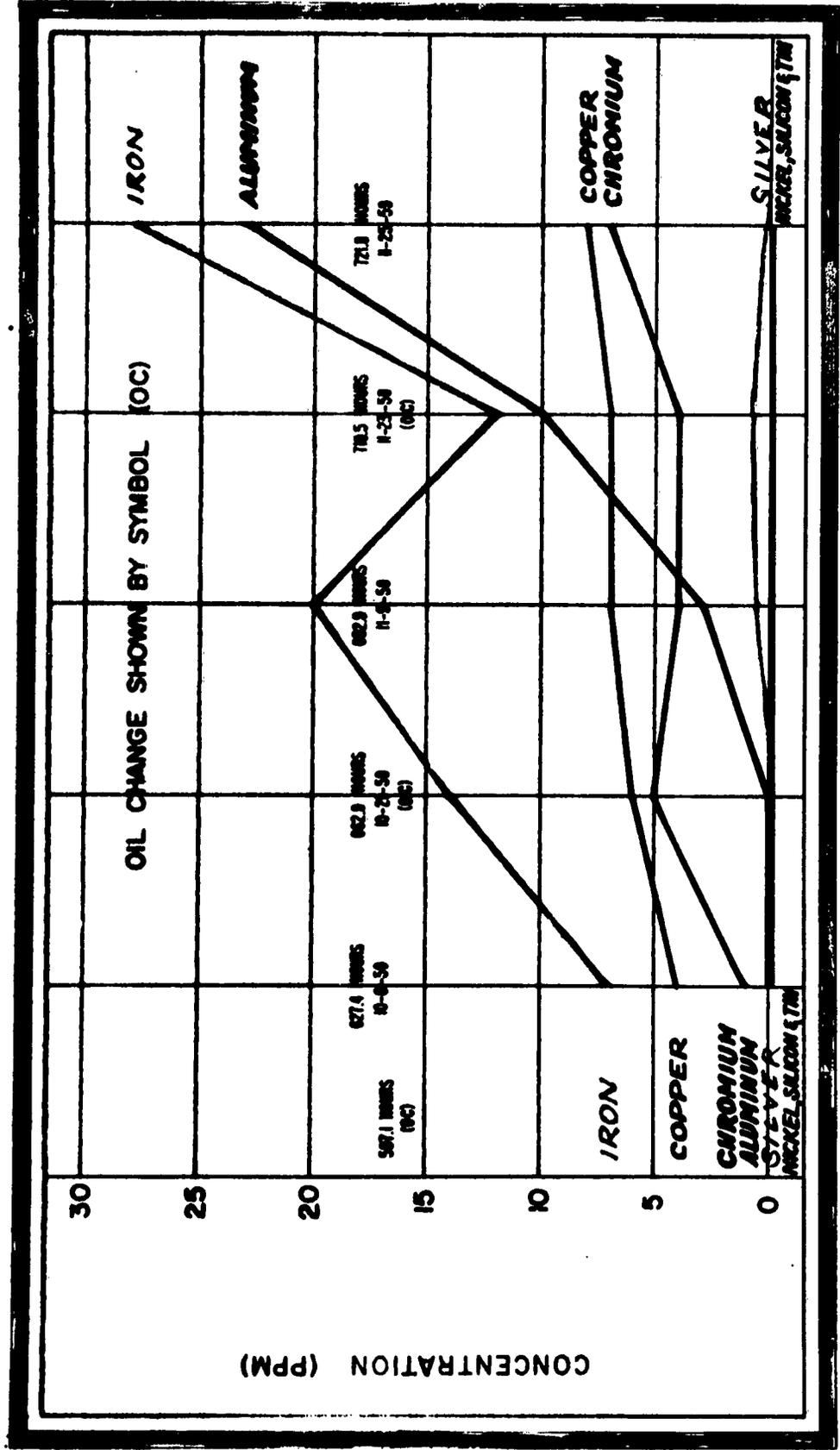


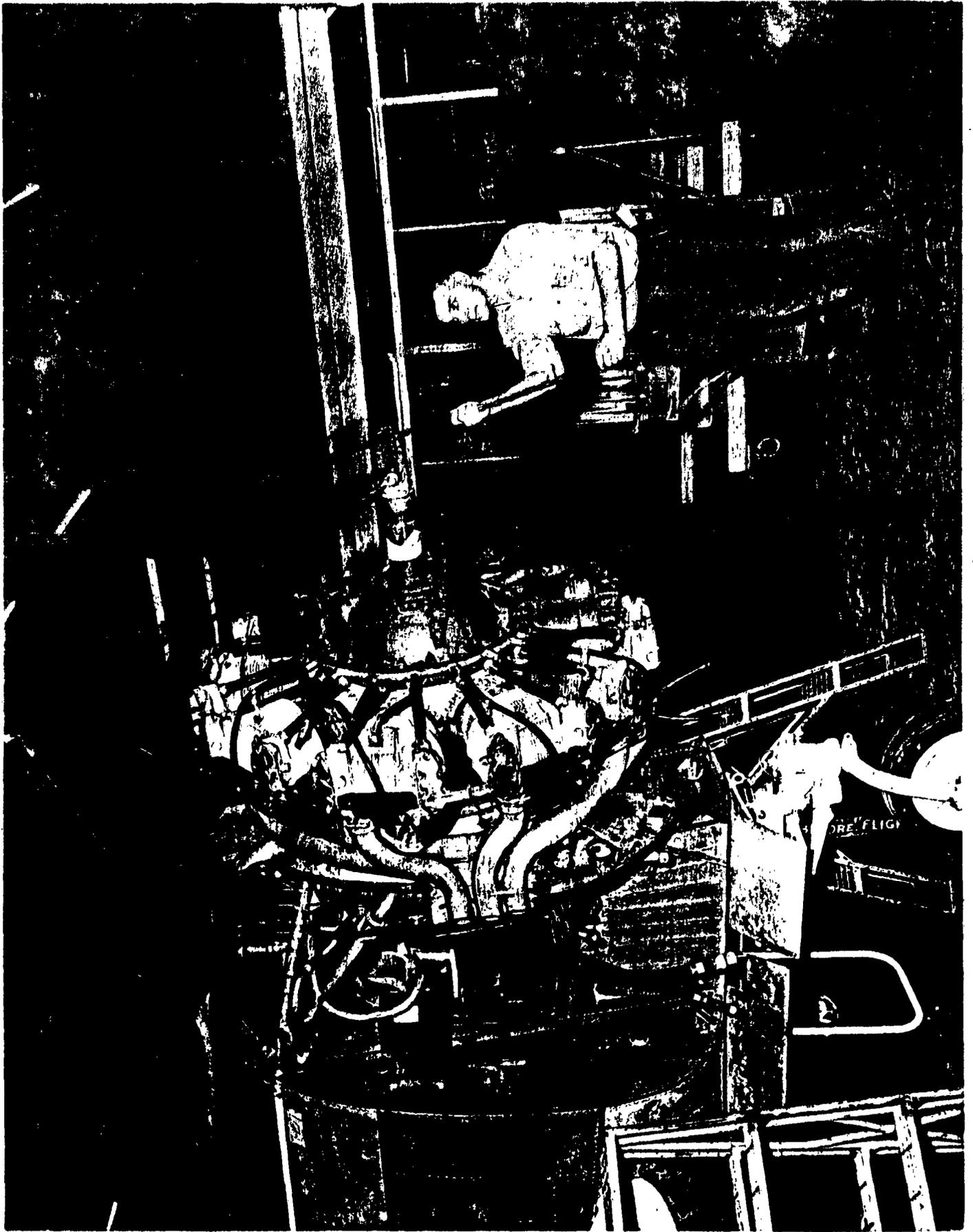
CHART SHOWING ALL ANALYSES OF OIL SAMPLES TAKEN FROM ONE AIRCRAFT ENGINE UP TO TIME OF FAILURE

R-1820-86 ENGINE BU NO 138108



**PHONE CALL FROM LABORATORY RECOMMENDING
REMOVAL OF ENGINE FOR DISASSEMBLY INSPECTION**





DISASSEMBLY INSPECTION REPORT OF ENGINE REMOVED FROM SERVICE ON THE BASIS OF OIL ANALYSIS

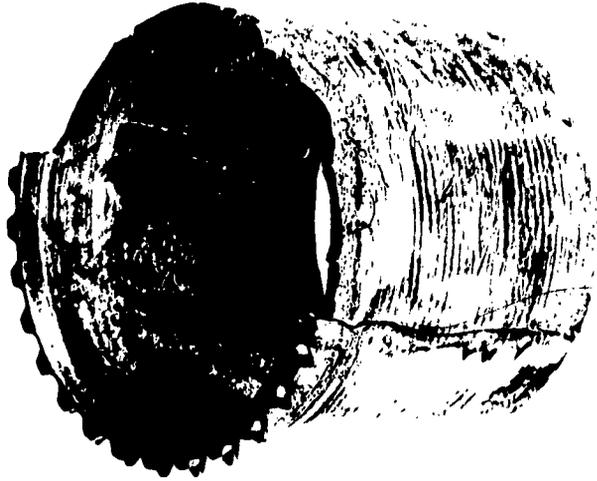
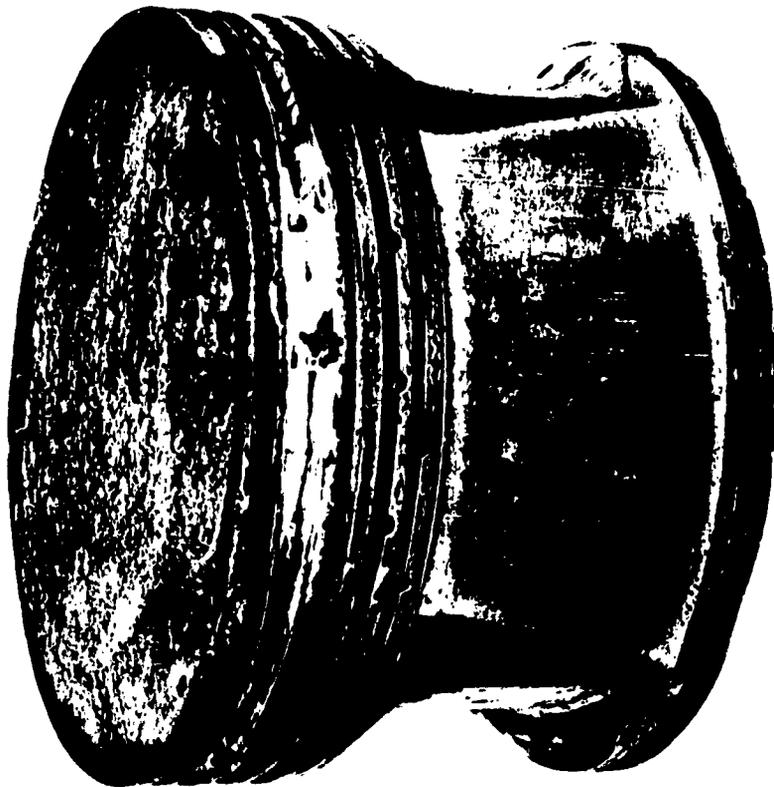
PRIORITY DIR NO. 30 OF 1-12-60

Findings:

1. Number 6 piston, P/N 136685, top piston ring groove excessively worn and installed piston ring, P/N 139619, worn on the tapered faces and broken.
2. Master connecting rod bearing, P/N 133641, fractured across fourteen locking splines. The bearing also contained one crack running the length of the bearing.

Conclusions: (Paragraph numbers correspond to "Findings")

1. The cause of excessive wear between the top piston ring and piston ring groove is presently under investigation.
2. The result of fatigue cracks originating at the roots of one or more locking splines.



APPENDIX 6

U.S. Department of
Homeland Security
**United States
Coast Guard
Auxiliary**



National Response Directorate

NTSB Accident Data and TBO – An Analysis

In order to learn how observance or exceedance of TBO affected actual aviation mishaps, the Response Directorate conducted a study of the National Transportation Safety Board (NTSB) aviation accident database. The time period studied included 01 JAN 2003 through 01 AUG 2013, a period of over ten years. The criteria studied included all aviation incidents and accidents that occurred in the United States during that time period. The study looked at those events that occurred involving airplanes (vice other aircraft categories), operated under CFR 14 Part 91 (general aviation) with reciprocating engines (no turbine engines). The study included all phases of flight, but excluded amateur built (experimental) aircraft.

This study of NTSB records found that the total number of aviation accidents and incidents, meeting the criteria above, from all causes, was 11,284. Of those, the total number listing engine failure or power loss as the cause was 340.

Of the 340 engine failure or power loss accidents or incidents, the term “TBO” was mentioned in the NTSB synopsis or narrative report in only 31 cases. Of those, 21 listed the TBO as under the manufacturers recommendations, 7 listed the TBO as above the manufacturers recommendations and 3 were listed as TBO unknown.

The total number of accidents or incidents where exceedance of TBO was listed as a contributing factor was one. The total number of accidents and incidents where exceedance of TBO was listed as probable cause was zero.

According to FAA Civil Aviation records, approximately 243,627,000 general aviation flight hours were flown over the last ten years, or about 24,362,000 flight hours per year. There were approximately 1,606 general aviation accidents (all causes, all operations, all engines, all types of aircraft) per year.

Over ten years, the General Aviation accident rate (all causes, all operations, all engines, all aircraft) was about 6.79 accidents per 100,000 flight hours. Over ten years, the accident rate from engine failure (as defined in the study above) was about 0.14 accidents per 100,000 flight hours. Over ten years, the accident rate involving engines over TBO was 0.002 accidents per 100,000 flight hours. Over ten years, the accident rate in which exceedance of TBO was identified as a contributing factor, was 0.0004 accidents per 100,000 flight hours. Over ten years, the accident rate in which exceedance of TBO was listed as a probable cause was zero.

The inescapable conclusion is that compliance with, or exceedance of, manufacturers TBO recommendations is irrelevant to aviation safety. Accordingly, the current AUXAIR TBO compliance requirements offer only the appearance of increased safety, with no substantive effect.

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NTSB Aviation Accident Database Query

Search period: 01 JAN 03 to 01 AUG 13

Search criteria: All Incident & Accident*, US, Airplane, Part 91, Reciprocating Engines, No Amateur Built, All Phases of Flight

- Total Accidents / Incidents (all causes) – 11,284 records
- Total Engine Failure (all causes, i.e., fuel starvation, no carb heat, undetermined, etc.) – 340 records
- Total where “TBO” was listed in synopsis or narrative – 31 records
 - Of those,
 - Total with hours < TBO – 21
 - Total with hours > TBO – 7
 - Total with hours UK – 3
- Total with exceedance of TBO listed as contributing factor – 1
- Total with exceedance of TBO listed as the probable cause - 0

* Accidents vs. Incidents:

49 CFR 830.2

Aircraft accident means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

Substantial damage means damage or failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component.

Incident means an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.

Synopsis of Query Results

1. Engine failure - hours < TBO
2. Engine failure, stall spin - hours < TBO – non-compliance w/ OH sched listed as contributing factor
3. Partial power loss – reason undetermined – hours < TBO
4. Pwr loss Undermined Reason - hours > TBO
5. Pwr Loss Undermined Reason - hours > TBO
6. Pwr Loss, PIC Error – hours > TBO Inadequate maintenance & inspection

AUXAIR Facility Maintenance Standards
APPENDIX 6

7. Pwr Loss -Fuel Starvation - hours UK
8. Power loss, pilot error – hours < TBO
9. Partial pwr loss, supercharger failure, - hours < TBO
10. Prop Failure- maintenance error – hours UK
11. VFR into IFR WX – hours > TBO (no power loss)
12. Pwr Loss/ Pilot Error Stall – hours < TBO
13. Engine Failure - hours < TBO
14. Prop Failure, - hours UK
15. Pwr loss – fuel mismanagement – hours < TBO
16. Engine Failure - hours < TBO
17. Fuel Starvation - hours < TBO (newly OH)
18. Engine Failure - hours < TBO
19. Pilot Error / Improper Maintenance / Pilot not certified - hours > TBO
20. Engine Failure - hours < TBO – improper maintenance of component
21. Engine Failure - hours < TBO
22. Fuel Starvation - hours < TBO
23. Pilot Error loss of pwr - hours < TBO – inadequate maintenance
24. Operation w/ known deficiencies - hours < TBO
25. Engine Failure / improper maintenance - hours < TBO
26. Prop Failure improper maintenance - hours < TBO
27. Improper maintenance - hours > TBO
28. Improper maintenance not airworthy - hours > TBO
29. Engine Failure - hours < TBO
30. Engine Failure - hours < TBO
31. Prop Failure, improper maintenance / repair - hours < TBO

31 records meet your search criteria.

A docket of supporting materials may exist for factual and probable cause reports. Please contact Records Management Division. Dockets are not available for preliminary reports.

[Accident Database & Synopses](#) [Download XML](#) [Download Delimited Text](#)

	Current Synopsis	PDF Report(s) (Published)	Event Date	Location	Make/Model	Regist. Number	NTSB No.	Event Severity	Type of Air Carrier Operation and Carrier Name (Doing Business As)
1	Factual	Factual (07/16/2013)	2/17/2012	Flat Rock, VA	CESSNA 172N	N4737D	ERA12LA191	Nonfatal	
2	Probable Cause	Factual (04/11/2013) Probable Cause (05/30/2013)	10/16/2011	Daggett, CA	BEECH E33	N7011N	WPR12FA012	Fatal(3)	
3	Probable Cause	Factual (05/07/2013) Probable Cause (07/18/2013)	6/2/2011	Pine Bluffs, WY	CESSNA A188B	N9496G	WPR11LA253	Nonfatal	
4	Probable Cause	Factual (10/31/2011) Probable Cause (10/12/2012)	1/12/2011	Venice, FL	BEECH A23-24	N3670Q	ERA11LA112	Nonfatal	
5	Probable Cause	Factual (12/27/2011) Probable Cause (02/23/2012)	9/19/2010	Barnwell, SC	PIPER PA-28R-200	N799SQ	ERA10LA486	Nonfatal	
6	Probable Cause	Factual (10/31/2011) Probable Cause (12/13/2011)	5/27/2010	High Springs, FL	CESSNA 337G	N72268	ERA10LA284	Nonfatal	
7	Probable Cause	Factual (09/30/2011) Probable Cause (11/17/2011)	4/3/2010	West Milford, NJ	CESSNA 172E	N5528T	ERA10FA202	Fatal(1)	
8	Probable Cause	Factual (08/30/2011) Probable Cause (11/17/2011)	3/23/2010	Homer, AK	CESSNA 206	N522HA	ANC10FA029	Nonfatal	Homer Air
9	Probable Cause	Factual (09/11/2009) Probable Cause	7/28/2009	Riverdale, CA	GRUMMAN G164	N8741H	WPR09LA373	Nonfatal	

	Cause (11/09/2009)							
10	Probable Cause Factual (05/19/2009) Probable Cause (07/14/2009)	1/5/2009	Milford, IN	GRUMMAN AMERICAN AVN. CORP. AA-5B	N28862	CEN09LA132	Nonfatal	
11	Probable Cause Factual (12/09/2008) Probable Cause (01/29/2009)	7/27/2008	McMurray, WA	CESSNA 172N	N75558	LAX08FA246	Fatal(3)	
12	Probable Cause Factual (12/23/2008) Probable Cause (12/28/2008)	10/7/2007	Castroville, TX	CESSNA 150L	N11467	DFW08FA004	Fatal(2)	
13	Probable Cause Factual (07/23/2008) Probable Cause (07/30/2008)	9/21/2007	McGrath, AK	Cessna U206	N8030Z	ANC07LA104	Nonfatal	
14	Probable Cause Factual (02/20/2008) Probable Cause (03/31/2008)	6/7/2007	New Smyrna Beac, FL	Piper PA-34-200	N15156	CHI07LA167	Nonfatal	
15	Probable Cause Factual (01/09/2007) Probable Cause (03/26/2007)	10/26/2006	Houston, TX	Beech F33	N1096W	DFW07LA016	Nonfatal	
16	Probable Cause Factual (04/17/2008) Probable Cause (04/30/2008)	10/3/2006	Hammonton, NJ	Piper PA-24-250	N5097P	NYC07LA001	Nonfatal	
17	Probable Cause Factual (11/01/2006) Probable Cause (01/31/2007)	7/3/2006	Montrose, CO	Beech A36TC	N1800Z	DEN06FA091	Fatal(2)	
18	Probable Cause Factual (02/28/2007) Probable Cause (04/25/2007)	7/1/2006	Gustavus, AK	Beech P35	N8690M	ANC06LA084	Nonfatal	
	Probable Cause Factual (12/31/2007)		East					

19	Cause	Probable Cause (01/31/2008)	10/23/2005	Hampton, NY	Cessna 411	N7345U	NYC06FA015	Fatal(1)	
20	Probable Cause	Factual (04/27/2006) Probable Cause (08/29/2006)	5/14/2005	Sonoma, CA	Great Lakes 2T-1A-2	N765GL	LAX05LA173	Nonfatal	
21	Probable Cause	Factual (06/24/2005) Probable Cause (09/13/2005)	5/9/2005	Lowell, ID	Piper PA-28- 235	N8805W	SEA05FA097	Nonfatal	
22	Probable Cause	Factual (11/25/2005) Probable Cause (02/28/2006)	1/10/2005	Charleston, SC	Piper PA-30	N7654Y	ATL05FA043	Fatal(1)	
23	Probable Cause	Factual (10/12/2005) Probable Cause (01/31/2006)	10/27/2004	Asheville, NC	Beech BE-60	N611JC	ATL05FA013	Fatal(4)	
24	Probable Cause	Factual (03/16/2006) Probable Cause (05/30/2006)	9/23/2004	Milton, FL	Cessna R182	N5157T	MIA04FA128	Fatal(4)	
25	Probable Cause	Factual (04/19/2005) Probable Cause (07/07/2005)	9/16/2004	Inverness, FL	Piper PA-22- 108	N4647Z	ATL04LA187	Nonfatal	
26	Probable Cause	Factual (12/05/2004) Probable Cause (01/24/2005)	7/16/2004	LaGrange, GA	Beech A45	N134BH	ATL04LA157	Nonfatal	
27	Probable Cause	Factual (04/26/2005) Probable Cause (07/07/2005)	7/5/2004	Spanish Fork, UT	Cessna T210N	N5408A	DEN04LA098	Nonfatal	
28	Probable Cause	Factual (10/28/2004) Probable Cause (12/28/2004)	10/22/2003	San Martin, CA	American AA- 1	N5968L	LAX04LA022	Nonfatal	
		Factual							

29	Probable Cause	(10/26/2004) Probable Cause (12/28/2004)	8/22/2003	Saint Johns, AZ	Ercoupe 415-C	N3182H	LAX03LA260	Nonfatal
30	Probable Cause	Factual (04/06/2004) Probable Cause (06/02/2004)	8/20/2003	La Crosse, WI	Boeing A-75	N806RB	CHI03LA274	Nonfatal
31	Probable Cause	Factual (08/01/2007) Probable Cause (09/14/2007)	1/24/2003	Rancho Cucamong, CA	Beech 95	N2733Y	LAX03FA074	Fatal(1)

NOTES:

- On Jan. 8, 2001, dynamic access to the accident data repository was implemented. Static files are no longer available.
- On Oct. 2, 2001, minor cases which do not fall under the definition of "accident" or "incident" were removed from the database; these entries were previously identified with "SA" in the accident number.
- On Sept. 18, 2002, data from 1962-1982 were added to the aviation accident information. The format and type of data contained in the earlier briefs may differ from later reports.

** - Do not use these fields as selection parameters if your date range includes pre-1982 dates, as they did not exist prior to 1982 and their use may falsely limit the data returned.

[Aviation Page](#) | [Switch to Monthly Lists](#)

APPENDIX 7

DEPARTMENT OF HOMELAND SECURITY U.S.C.G. AUXILIARY ANSC 7005 (08-10)		<h2 style="margin:0;">AUXILIARY AIRCRAFT FACILITY INSPECTION AND OFFER FOR USE</h2> (See instructions and Privacy Act Statement on page 2)			TYPE OF REPORT <input type="checkbox"/> INITIAL (NEW) REPORT <input type="checkbox"/> REINSPECTION (REOFFER) <input type="checkbox"/> CHANGE (UPDATE) YEAR 2010			
SECTION I - AIRCRAFT OWNER DATA - Completed by owner(s)								
OWNER'S MEMBER ID NUMBER		OWNER'S LAST NAME, FIRST NAME, MIDDLE INITIAL			TYPE OF OWNERSHIP (Check one) All owners must sign Section V <input type="checkbox"/> SOLE <input type="checkbox"/> AUX UNIT <input type="checkbox"/> GOV'T <input type="checkbox"/> MULTIPLE <input type="checkbox"/> CORPORATE			
CO-OWNER'S MEMBER ID NUMBER		CO-OWNER'S LAST NAME, FIRST NAME, MIDDLE INITIAL						
SECTION II - FACILITY DATA - Completed by owner								
FAA REGISTRATION NUMBER		IF THIS FACILITY REPLACES ONE CURRENTLY RECORDED, LIST OLD FAA REGISTRATION NUMBER HERE		FACILITY AVAILABILITY <input type="checkbox"/> All <input type="checkbox"/> Weeknights <input type="checkbox"/> Weekends				
LOCATION OF AIRCRAFT (CITY/STATE/AIRPORT ID)				LATITUDE		LONGITUDE		
TYPE OF AIRCRAFT	MANUFACTURER		MODEL	YEAR	TYPE CERTIFICATION			
# ENGINES	HP/ENGINE	ENGINE MFG.	ENGINE MODEL	WING COLOR	FUSELAGE COLOR			
NO. SEATS	USEFUL LOAD (LBS)	FUEL LOAD (LBS)	CRUISE SPEED (KTS)	RANGE (N MILES)	MAX. ENDURANCE (HRS)			
Radios With Required Frequencies: <input type="checkbox"/> MF/HF SSB <input type="checkbox"/> VHF-FM <input type="checkbox"/> VHF-AM								
<input type="checkbox"/> VOR <input type="checkbox"/> ADF <input type="checkbox"/> DME/TACAN <input type="checkbox"/> RADAR/SFERICS <input type="checkbox"/> GPS <input type="checkbox"/> LORAN <input type="checkbox"/> Instrument Flight Equipped								
OTHER SPECIAL EQUIPMENT - REMARKS:								
AIRFRAME VALUE		ENGINE VALUE		ELECTRONICS VALUE		OTHER VALUE		
SECTION III - FACILITY INSPECTION CHECK LIST (COMDTINST M16798.3 Series) - Completed by examiner								
OK	N/A	ITEM	OK	N/A	ITEM	OK	N/A	ITEM
		1. Airworthiness Certificate			10. Strobe Light			19. Inspector viewed Reg/Doc papers for ownership
		2. Annual Inspection in last 12 Mos.			11. Signal Mirror			20. Attached Assent & Authorization form for multiple owners
		3. Aircraft Registration Certificate			12. Life Raft			21. Attached info requirements for corp. owned facilities
		4. Aircraft Weight & Balance			13. Life Vests (Min 1 per seat)			22. Attached authorization for corporate offer for use
		5. Aircraft Operating Limitations			14. Pitot Static Check (within 24 Mos)			23 TBO Checked
		6. VHF-FM Radio or Suit. Ant. & Jack			15. Transponder Check (within 24 Mos.)			
		7. Shoulder Harness (Front Seat)			16. ELT Battery Date Current			
		8. First Aid Kit			17. EPIRB or Portable ELT			
		9. Day/Night Flares			18. Flight Helmet (Helicopter Only)			
SECTION IV - EXAMINER CERTIFICATION								
I have inspected the aircraft above as an aircraft facility and certify that it meets all requirements as such.								
FAC INSP DATE		EXAMINER LAST NAME, INITIALS		MEMBER ID NUMBER		SIGNATURE		DIST/DIV/FLOTILLA
								- -
SECTION V - OWNER STATEMENT, UNIT AND SIGNATURE - Completed by owner(s)								
<input type="checkbox"/> 1. I have knowledge of the findings of the facility inspector as set forth above and agree to notify DIRAUX of any changes made to this aircraft or equipment. All sections of this form are correct and up-to-date.							District Division Flotilla - -	
<input type="checkbox"/> 2. The above facility is hereby offered for use until withdrawn in accordance with the provisions of applicable laws and regulations that are in effect at the time the facility is accepted, used, and released.								
SIGNATURE OF OWNER			DATE		SIGNATURE OF CO-OWNER		DATE	
SECTION VI - DISTRICT STAFF OFFICER - AVIATION (DSO-AV) ENDORSEMENT								
This report has been checked and has been filled out in accordance with current instructions.								
DSO-AV SIGNATURE				DATE				
SECTION V - DIRAUX ENDORSEMENT								
This facility is <input type="checkbox"/> accepted <input type="checkbox"/> rejected as an Aircraft Facility of the U.S. Coast Guard Auxiliary.								
DIRAUX SIGNATURE			DATE		AUXDATA DATE:			

Previous editions are obsolete

COPY 1 - MEMBER

Print

ANALYSIS RESULTS - ENGINE S/N: SNT520

RPJ Aviation
ATTN:
910 Maria Street
Kenner LA 70062

Print Date:6/26/2014
Engine Model:CONT. T520
Aircraft Type:C 185
Aircraft S/N:0000
Tail No.:NRECIP

APPENDIX 8

Values in (parenthesis) below your results are average values from all our analysis data for the same engine model with similar engine hours and oil hours. See www.avlab.com/explain for detailed explanation of the statistical analysis used with your laboratory results.

** CURRENT ** SEE LAB COMMENTS **													
A.L.A.R.M. Meter: Normal Elevated High													
Sample Date: 2/24/2008 Analysis Date: 3/5/2008 Sample Number: P24 Cylinder Type: STEEL TSN/TSO: 1377 Oil Hours: 26 Filter Hours: Oil Added: 1 Filter Wt. (mgs): Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
	140.6 (51.1)	2.6 (4.5)	11.9 (12.8)	7.2 (8.2)	N/A	N/A	4.8 (8.1)	9560 (4,334)	7.1 (5.9)	N/A	< 0.1 (0.6)	N/A	
	*** FILTER ANALYSIS RESULTS ***												
	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
	Amount:												
	Type:												
	Form:												
	Comments: NOTE HIGH IRON AND LEAD. IRON CAN TYPICALLY BE FROM CORROSION FROM AIRCRAFT INACTIVITY, WEAR FROM CYLINDERS, ROTATING SHAFTS OR THE VALVE TRAIN. LEAD IS FROM THE FUEL. PLEASE CONTACT THE ENGINE MANUFACTURER'S SERVICE REP FOR FURTHER ASSISTANCE.												
	** PREVIOUS 1 ** SEE LAB COMMENTS **												
A.L.A.R.M. Meter: Normal Elevated High													
Sample Date: 10/18/2007 Analysis Date: 10/30/2007 Sample Number: P69 Cylinder Type: STEEL TSN/TSO: 1356 Oil Hours: 26 Filter Hours: 170 Oil Added: 1 Filter Wt. (mgs): Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
	160.5 (51.4)	6 (4.2)	19.6 (12.9)	15.6 (8.3)	N/A	N/A	11.3 (8.1)	11411 (4,480)	7.8 (5.8)	N/A	< 0.1 (0.6)	N/A	
	*** FILTER ANALYSIS RESULTS ***												
	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
	Amount:												
	Type:												
	Form:												
	Comments: NOTE HIGH IRON AND LEAD. IRON CAN TYPICALLY BE FROM CORROSION FROM AIRCRAFT INACTIVITY, WEAR FROM CYLINDERS, ROTATING SHAFTS OR THE VALVE TRAIN. LEAD IS FROM THE FUEL. PLEASE CONTACT THE ENGINE MANUFACTURER'S SERVICE REP FOR FURTHER ASSISTANCE. WE WILL CONTINUE TO MONITOR WEAR METAL TREND ON YOUR NEXT SAMPLE.												
	** PREVIOUS 2 ** SEE LAB COMMENTS **												
A.L.A.R.M. Meter: Normal Elevated High													
Sample Date: 9/8/2007 Analysis Date: 9/26/2007 Sample Number: P113 Cylinder Type: STEEL TSN/TSO: 1330 Oil Hours: 26 Filter Hours: 26 Oil Added: 1 Filter Wt. (mgs): Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
	140.5 (N/A)	6.1 (N/A)	17.3 (N/A)	14.5 (N/A)	N/A	N/A	16 (N/A)	10398 (N/A)	8.2 (N/A)	N/A	< 0.1 (N/A)	N/A	
	*** FILTER ANALYSIS RESULTS ***												
	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
	Amount:												
	Type:												
	Form:												
	Comments: NOTE ELEVATED IRON AND LEAD ON THIS SAMPLE.												

**** PREVIOUS 3 ** SEE LAB COMMENTS **** A.L.A.R.M. Meter: Normal Elevated High

*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
136.2 (50.8)	7.9 (4.3)	18.6 (12.6)	16.7 (8.3)	N/A	N/A	20.2 (8.1)	10695 (4,460)	10.4 (5.9)	N/A	< 0.1 (0.8)	N/A	
*** FILTER ANALYSIS RESULTS ***												
Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
Amount:												
Type:												
Form:												

Sample Date: 6/29/2007
Analysis Date: 7/23/2007
Sample Number: P117
Cylinder Type: STEEL
TSN/TSO: 1294
Oil Hours: 25
Filter Hours:
Oil Added: 1
Filter Wt. (mgs):
Flashpoint(deg. F):
H2O (ppm):
Total Acid No.:

Comments: THE DEBRIS SENT CONSISTED OF TINY CARBON STEEL FLAKES COATED IN LEAD. ABOUT HALF OF THE TOTAL AMOUNT OF CARBON STEEL FLAKES WERE AMS# 6370 OR 6371 AND THE OTHER HALF WERE AMS# 6440 OR 6444. WE ALSO FOUND TINY ALUMINUM FLAKES. THE MAJORITY OF THE MATERIAL

**** PREVIOUS 4 ** SEE LAB COMMENTS **** A.L.A.R.M. Meter: Normal Elevated High

*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
161.2 (57.7)	7.2 (5.2)	24.3 (15.7)	18.3 (8.7)	N/A	N/A	15.2 (8.1)	12064 (5,554)	8.9 (6.5)	N/A	< 0.1 (0.7)	N/A	
*** FILTER ANALYSIS RESULTS ***												
Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
Amount:												
Type:												
Form:												

Sample Date: 4/2/2007
Analysis Date: 4/10/2007
Sample Number: P53
Cylinder Type: STEEL
TSN/TSO: 1269
Oil Hours: 40
Filter Hours: 10
Oil Added: 2
Filter Wt. (mgs):
Flashpoint(deg. F):
H2O (ppm):
Total Acid No.:

Comments: IRON APPEARS TO BE BORDERLINE. HIGH IRON CAN BE CAUSED BY AIRCRAFT INACTIVITY, CYLINDER WEAR OR RING WEAR. A COMPRESSION CHECK MAY BE USEFUL IN DETERMINING CYLINDER CONDITION. LEAD ALSO LOOKS BORDERLINE. LEAD INDICATES THAT THE ENGINE'S FUEL MIXTURE IS AD

**** PREVIOUS 5 ** SEE LAB COMMENTS **** A.L.A.R.M. Meter: Normal Elevated High

*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
93.4 (46.7)	4.8 (4.1)	24.4 (11.0)	14.4 (7.3)	N/A	N/A	9.4 (8.3)	8949 (4,374)	6.2 (6.0)	N/A	< 0.1 (0.8)	N/A	
*** FILTER ANALYSIS RESULTS ***												
Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
Amount:												
Type:												
Form:												

Sample Date: 9/25/2006
Analysis Date: 10/17/2006
Sample Number: P08
Cylinder Type: STEEL
TSN/TSO: 1228
Oil Hours: 23
Filter Hours: 52
Oil Added: 1
Filter Wt. (mgs): 0
Flashpoint(deg. F):
H2O (ppm):
Total Acid No.:

Comments: NOTE HIGH LEAD. LEAD IS FROM THE FUEL. PLEASE CONTACT THE ENGINE MANUFACTURER'S SERVICE REP FOR FURTHER ASSISTANCE.

**** PREVIOUS 6 ** SEE LAB COMMENTS **** A.L.A.R.M. Meter: Normal Elevated High

*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***												
Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.	
138 (52.9)	7.8 (5.0)	46.2 (13.9)	21.4 (9.0)	N/A	N/A	8 (7.7)	9327 (4,968)	5.7 (6.0)	N/A	0.4 (0.7)	N/A	
*** FILTER ANALYSIS RESULTS ***												
Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
Amount:												
Type:												
Form:												

Sample Date: 7/29/2006
Analysis Date: 8/11/2006
Sample Number: P32
Cylinder Type: STEEL
TSN/TSO: 1205
Oil Hours: 29
Filter Hours: 29

Oil Added: 2 Filter Wt. (mgs): 0 Flashpoint(deg. F): H2O (ppm): Total Acid No.:	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.
	Amount:										
	Type:										
	Form:										

Comments: NOTE INCREASE IN NICKEL, HIGH NICKEL IS TYPICALLY CAUSED BY VALVE GUIDE WEAR. WE WILL MONITOR AT NEXT NORMAL INTERVAL.

**** PREVIOUS 7 **** SEE LAB COMMENTS ** A.L.A.R.M. Meter: Normal Elevated High

Sample Date: 7/9/2006 Analysis Date: 7/17/2006 Sample Number: P01 Cylinder Type: STEEL TSN/TSO: 1176 Oil Hours: 28 Filter Hours: 55 Oil Added: 1 Filter Wt. (mgs): 0 Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***											
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.
	131.1	6.9	31.7	18	N/A	N/A	10.1	9532	5.4	N/A	0.9	N/A
	(52.4)	(4.8)	(13.8)	(8.9)			(7.4)	(4,898)	(6.1)		(0.5)	
	*** FILTER ANALYSIS RESULTS ***											
	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.	
	Amount:		Trace 0-10%	Trace 0-10%					Trace 0-10%	Major 40-100%		
	Type:											
	Form:											

Comments: DEBRIS SENT WAS MOSTLY ALLOY STEEL, AMS# 6414 OR 6415. ALSO FOUND TRACE AMOUNTS OF CARBON STEEL AMS# 6370 OR 6371, ALUMINUM AND GRIT.

**** PREVIOUS 8 **** SAMPLE APPEARS NORMAL. Send next sample at normal interval. A.L.A.R.M. Meter: Normal Elevated High

Sample Date: 5/10/2006 Analysis Date: 6/26/2006 Sample Number: P81 Cylinder Type: STEEL TSN/TSO: 1148 Oil Hours: 37 Filter Hours: Oil Added: 1 Filter Wt. (mgs): 0 Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***											
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.
	91.7	4.6	21.6	17.9	N/A	N/A	12.1	8863	4.6	N/A	< 0.1	N/A
	(56.9)	(5.1)	(13.9)	(8.6)			(8.1)	(5,323)	(6.2)		(0.9)	
	*** FILTER ANALYSIS RESULTS ***											
	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.	
	Amount:											
	Type:											
	Form:											

Comments:

**** PREVIOUS 9 **** SAMPLE APPEARS NORMAL. Send next sample at normal interval. A.L.A.R.M. Meter: Normal Elevated High

Sample Date: 3/26/2006 Analysis Date: 4/4/2006 Sample Number: P40 Cylinder Type: STEEL TSN/TSO: 1101 Oil Hours: 22 Filter Hours: Oil Added: 1 Filter Wt. (mgs): 0 Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***											
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.
	57.3	4.1	14.3	9.7	N/A	N/A	9.7	6435	4.5	N/A	0.3	N/A
	(47.8)	(4.0)	(10.5)	(7.1)			(8.2)	(4,104)	(6.6)		(0.8)	
	*** FILTER ANALYSIS RESULTS ***											
	Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.	
	Amount:											
	Type:											
	Form:											

	Type:									
	Form:									

Comments:

**** PREVIOUS 10 ** SEE LAB COMMENTS ****

A.L.A.R.M. Meter: Normal Elevated High

Sample Date: 6/26/2005 Analysis Date: 10/18/2005 Sample Number: P50 Cylinder Type: STEEL TSN/TSO: 1020 Oil Hours: 27 Filter Hours: Oil Added: 1 Filter Wt. (mgs): 0 Flashpoint(deg. F): H2O (ppm): Total Acid No.:	*** OIL ANALYSIS RESULTS IN PARTS PER MILLION ***											
	Iron	Copper	Nickel	Chromium	Silver	Magn.	Alum.	Lead	Silicon	Titanium	Tin	Moly.
	114.6 (54.3)	4.6 (4.7)	23.6 (13.5)	17.1 (9.6)	N/A	N/A	13.3 (8.0)	12124 (4,722)	5.7 (6.7)	N/A	4.7 (0.9)	N/A
*** FILTER ANALYSIS RESULTS ***												
Material:	Stainless Steel	Carbon Steel	Alloy Steel	Bearing Alloy	Copper	Silver	Magn.	Alum.	Grit	Misc.		
Amount:												
Type:												
Form:												

Comments:



Auxiliary National Staff Response and Prevention Group

APPENDIX 9 Aircraft Facility Maintenance Standards

Analysis of Auxiliary Aviation Facility Utilization

Facility Flight Hours Reported for Calendar Year 2013

Number of Active Aircraft	185			
Flight Hours Total	15,481			
• Marine Patrol	9,156			
• Gov't Support	66			
• Ice Ops	404			
• MEP	71			
• MS	657			
• SAR	5,127			

Fac Flight Hours	Aircraft	% of fleet
1-100	131	71%
100-125	13	7%
125 +	41	22%

Facility Hours by aircraft

