Contaminants Analysis in Aircraft Engine Oil and its Interpretation for the Overhaul of the Engine

LEAL B., ORDIERES J., CAPUZ-RIZO S.F., CIFUENTES P.

Abstract In this work, the authors will try to determine, by means of techniques based on Artificial Intelligence, the actual possibilities of using spectrometric analysis, done periodically to the engine oil, as predictors of the condition of the engine. Some similar works have led to a simple linear regression model, but in the particular case of this work it is intended to evaluate if the specific environmental conditions of the region and the low use of aircrafts allow discussing the convenience of making use of the same criterion or elaborating some specific variant.

***Keywords*— Oils contaminants, wearing models, artificial intelligence techniques.**

I. INTRODUCTION

Filters oil captured a lot of tribological information on the operation of an aircraft. Retrieval and analysis of filters waste has been shown as useful tool for managing the health of those units engines. [1]

It´s necessary to emphasize that the analysis is tedious as it requires a careful technique, great experience, the evaluator and homogeneous cleaning filters, involving a comprehensive operating procedure and a railway mechanics assurance, penalty so that the results will become little valuable by your swing.

The Ministry of Defence of the United Kingdom has evolved its Flet and Usage Management System (FUMS TM) towards a system of diagnosis and continuous prognosis based on the system of support for the decision for aircraft and/or helicopter engines. The system enables intelligent building user without rewriting of software applications.

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It also includes as a key element of the diagnosis and prognosis, lubrication, whose subsystem has been baptized as HUMS (Health and Usage Management System) system filters waste. The system relies on routine and systematic implementation of procedures for a consolidated database.

The Ministry of Defence reports significant benefits within the military as a result of its daily application [2].

The advantages reported using information from system lubrication and more waste management specifically on the aircraft engines oil filters are related to the prediction of useful life of the equipment to maximize availability of the planning and running maintenance operations, not on the basis of fixed hours but when necessary [3] internationally known as "condition-based maintenance" (Condition Monitorig), which combines the prediction with proactive. Obviously in all cases is highlighted as essential a very robust system monitoring subsystem of the aircraft engines have thorough on which to base estimation methods and reliable data.

This work aims to study the applicability of these techniques to the case of the Venezuelan aerospace industry where there are both environmental and structural factors that may pose an interesting setting worthy of a specific treatment. Be determined if the results of the analysis of waste oils are affected by variables such as the repeatability of the instrumental analytical employee in this work, hours of operation of average oil consumption oil / hours of operation of periods of inactivity, among others.

Analyses of oils are undertaken by civil and military sectors in Venezuela as a tool in predictive maintenance based on condition in teams comprising of both their propulsion plant (internal combustion engines and turbines) and its peripheral equipment fixed and rotary wing aircraft (gearboxes, hydraulics, among others)., accumulate during this decade more than 5,000 results corresponding to more than 1,000 aircraft.

The analysis and monitoring common oils allowed users to keep track of processes of wear and changes in the fundamental properties of its lubricating whose changes have been warning signs to perform functional checks and perform preventive operations to avoid failures which, by the nature of the service they provide, would have disastrous consequences.

II. PROBLEM FORMULATION

A. Review Stage

In April of 2004 entered force the circular of advice N ° 43-50 for the implementation of a "Programme of Maintenance Based in Conditions" (PMBC) by the National Institute of civil aviation [4], for “reciprocals” engines or installed piston in private aircraft (do not include loading or passenger transport) maximum take-off certified to five thousand seven hundreds Kg (5.700) weight laying down an alternative to extend the service up to eight (8) additional to those engines for twelve (12) years calendar time needed to the refurbishment or overhaul but not reaching the limit in flight (1200 to 1700) hours indicated by the manufacturers of engines marks Textron Lycoming and Teledyne Continental Motors (TCM), for which analysis of every fifty (50) hours of operation, oils have been doing so close to oil change as established in the circular although they are results in many places in this range for over one hundred (100) aircraft engines such that have joined the programme. Focuses on the results of the analysis of oils and their individual trends identified the need for the overhaul when there are significant changes (above or by default). On the other hand, the fleet under study can be viewed influenced to exposure to the climatic conditions of the tropics can impact corrosion processes / rust in periods of inactivity.

A greater reconditioning (overhaul) consists of a series of complex and costly procedures such as the removal of the aircraft, disarmament, inspection, parts, replacement engine renewable, test under microscope, until its approval for the return to service. Takes into consideration that these aircraft are not commercial utility, the refurbishment is a wasted time might be premature, since only by time calendar determines its removal without requiring security [5].

The (PMBC) programme includes some preventive parameters measurement / predictive such as compression, inspection cylinders boroscopic, oil with complete inspection of the engine, with the inclusion of the predictive proactive tool known as analysis of oils consumption verification filters inspection check-ups. [6].

Given the low operation of this air sector of the country associated mainly with the cost of flight hours owners operate their units less than one hundred (100) annual hours submitting to any aircraft to conditions (heat and humidity) tropical climate which tends to accelerate corrosion processes / antiqued without engine lost compression in the early stages of this process of wear, but are evidenced by the results of the analysis of waste oils. Variable input that probably should be taken into account.

Even more issues were detected many assessments of waste oil filters, and especially in records of consumption of oil, both of the utmost importance to establish performance models and, probably, a latter a variable to be considered as a result of this study.

Used oil analysis is a general term to describe scientific evidence and assessments on oils in order to determine whether they can be kept in operation must be removed, as well as provide wear generated by the friction of metal surfaces in relative motion evaluated teams status information.

In United States, the joint analysis of the oil of the Department of Defense DoD "Joint Oil Analysis Program" (JOAP) programme has existed for more than fifty (50) years providing technical services in all systems (computers) condition-based maintenance lubricated of DoD "DoD Joint Oil Analysis Program" program. More than 40 years (40), the principal method of the JOAP has been oils by emission spectrometry analysis "Atomic emission spectroscopy"(AES) using a rotary disc electrode "Rotating disc electrode" (CSG) due to its excellent sensitivity to low concentrations in parts by million (ppm) design and operation allowing you to great mobility [7].

The "Joint Oil Analysis Technical Support Center" (JOAP-TSC)-JOAP-TSC programmehas been very successful because it has standardized the instrumentation and procedures and techniques of diagnosis for all laboratories that give service to the armed forces, establishing trends wear limits to almost one hundred (100 %) teams operating in their sea and air, land units both combat logistics for establishing and maintaining a standard program in order to use the analysis of oil as a tool support of diagnosis for the maintenance of drives, increase Its goal is flight safety, especially the safety of flights, improving the provision of equipment to reduce maintenance costs and extend its useful life [8].

The lubrication is essential to the work of a machinery, but typically, your control has limited the oil level supervision and their possible visual oil changes and your filters in the programs of preventive maintenance [9].

In all mechanical system there is contact metal-metal between metal surfaces in motion, especially in times of start and end of movement (boot and stop) generating powders of different sizes from very small metallic contact product in the above stages (soft adhesive wear), corrosion processes / rust by prolonged exposure to ambient (wear corrosion), and even large, action in such particles into circulation (abrasive wear, fatigue, among others) string result.

Espinoza and Lara (2007) and Altmann (2005) reflect any condition which increase the normal friction between parts moving, usually accelerate the rate or wear speed will increase the amount of metal wear particles produced. Therefore all the necessary information will be in circulation lube oil and may determine through analyses of oils to help diagnose and predict failures that can decrease the useful life of the motor itself to be a new tool in any program maintenance to be deploy especially when reliability and safety of operation is more important than in aviation. [10]- [11],

Many maintenance departments have implemented within their programs of predictive maintenance, the programs analysis oils, also known of Tribological applied that together with other techniques such as thermograph, vibration, boroscopic among others allow them to schedule interventions [12]- [13]- [14]. .

The results of the analysis of waste oils allow set intervals of oil changes based on the real status of computer, benefit can only be achieved if oil samples are taken frequently, for thus set trends of wear or contamination on the computer and have the advantage that the operations team do not have because be interrupted for the abstraction of samples. [15].

The lubricant can be solid, almost fluid or fluid state depending on the speed and load parts to lubricate and up to gaseous as in the case of large telescopes. Usually lubricants are composed of a base package of additives whose functions are to improve, to provide, or to delete a property that the Basic does not have or want to delete, helping to improve the performance and extend the useful life of lubricants. As [16] in fluid lubrication can exist three types of lubrication, hydrodynamic lubrication in which there is a total separation of the roughness of the surface therefore reduces the likelihood of occurring friction and wear adhesive being replaced by fluid friction caused by the friction of the lubricant molecules.

Here emerges the concept of Tribology, which comes from the term (tribes - logos, friction - treated), it was related in principle only friction. Currently this term applies to all the phenomena that limit teams, especially the interrelationship of life: friction, wear and lubrication. And based its importance in which is a source for saving energy material resources increases the life of the machinery and decreases the lost by friction and wear and achieves greater durability mechanisms in operation and high productivity of equipment.

Currently [17], considered in its broader acceptance internationally Tribology is: Science and technology systems in motion and mutual contact and includes friction, lubrication wear and much aspects related to engineering, physics, chemistry, metallurgy, philosophy, etc, is what is regarded as an interdisciplinary science. There would be no life without the Tribology. Everything what moves form part of a system tribológico, which can involve two or more solids, liquids and solids well as solids and gases.

According to[18], predictive maintenance is to study the temporal evolution of certain parameters and associate them with the evolution of failures, so determine period of time, this failure will take an important relevance and allow plan all interventions with long enough, so that failure don't have serious consequences.

Used oil analysis is a general term to describe scientific evidence and assessments on oils in order to determine whether they can be kept in operation must be removed, as well as provide wear generated by the friction of metal surfaces in relative motion evaluated teams status information. It attempts to determine whether the oil may be retained or must be changed. A wealth of evidence used to evaluate lubricants. As [19], the specified evidence, should cover three areas:

- Status of the equipment.
- Status of pollution.
- Status of the lubricant.

Generally, is necessary to carry out the tests in all three areas, to prevent the failure of computers, although occasionally some test work in two or more areas, this is used to make us the evidence of any abnormal condition.

Additionally, the manual procedures JOAP (Oil Analysis Program Joint) of the air of United States force, 2007 [20] release reports:

-Spectrometric oil analysis. It is a diagnostic maintenance tool used to determine the type and amount of wear on lubricant fluid samples powders. Engines, transmissions, reducing boxes and hydraulic systems are the most frequently monitored computers types. The presence of unusual concentrations of an item in the sample fluid may indicate an abnormal wear on your computer. Once the abnormal wear has been verified, the computer may be repaired or put out of service before a serious failure in one of the lubricated components. Analysis spectrometric oils streamlines the safety of staff and the availability of materials at minimal cost, and serves as a vital tool of preventive maintenance.

-Analysis of physical properties. The physical properties of lubricants analyses provide data in standard conditions of measurement to determine the quality of the lubricant. These analyses help determine degradation or pollution due to combustion, oxidation by overheating, moisture by leakage of coolant, lubricant consumption additives and so on. These analyses have highly beneficial for the aviation if they are used in conjunction with spectrometric analysis equipment applications.

-Benefits of the lubricants analysis. The data obtained spectrometric analyses and/or physical properties of lubricants can be used as guidelines to assist in identifying emerging mechanical failures or to determine the quality and oil life. Therefore, wear and potential gaps in equipment components and lubricants, premature failures can be detected before severe failures of teams and have to make repairs or costly reconstructions. Oil analysis can also be used to identify inadequate maintenance procedures and parts, components or unsatisfactory assemblage's equipment (AVCO Lycoming Division).

-Wear metal particles. The powders loosened the surfaces of metallic alloys always have the same chemical composition as metal alloys where come from. The level and the normal rate of each type of metal particle production can be set for each type of computer through analysis of oil in a certain period of time.

When a level and/or an abnormal wear powders production rate is detected, the chemical identity of abnormally particulate will provide concerning tracks to the identity of the parties that are eroding abnormally. Metal elements specify a witty problem permanently while others will provide only general information that is happening abnormal wear. For example, quantities of iron are very common since this element is present in many components and parts of computers, and the skill and knowledge of the evaluator is important to diagnose the conditions of a computer and a wear metal supply.

In a manner contrary growing amounts of a rare item such as silver can specify exactly the part or component that has problems. For a part or part of team that operates normally wear metal particles are produced to a constant rat. In some cases, this rat may be negligible, but is similar for all computers on the same model operating normally. Concentrations of metal powders wear also increased steadily to a completely closed system operate normally without any fluid consumption.

Any condition that alter the normal relationship or increase the normal friction between the parties in movement generally accelerate wear rat and increase the amount of metal wear particles produced. An abnormal condition such sharply increase the concentration and accumulation of wear particles in stable fluid systems rat. If the condition is not discovered and fixed, deterioration and wear will continue accelerating, usually causing severe damage secondary to other parts of the Assembly. (Which have been repaired deeply or they have been Overhaul recently, tend to produce wear particles in larger during the period of settlement or break-in assemblages.

-Identification and measurement of particles wear.

The wear particles produced in mechanical assemblages lubricated fluid wear metal particle measurement can be measured in concentrations extremely low by analyzing Assembly fluid samples spectrometric.) While there are various technologies for assessment of particles suspended in oil such as "broadcast by plasma induced" [21] and absorption Atomic [22] only is used and approved the computers by emision rotating disk CSG) [23], given the versatility of the instrumentation requiring no transfer of gas compressed in military operations.

Furthermore, the physic -chemical analysis acidity and kinematic viscosity provide standard conditions of measurement data to determine the quality of the lubricant and significant changes therein help determine degradation or contamination of the lubricant for service by conditions of operation and/or defective maintenance time. The American society for testing and materials (ASTM) establishes standards for assessing such properties in new oils and oils including methods standardized for laboratories engaged in these analyses. Lubricants manufacturers set the maximum and minimum that can reach these properties to keep their lubrication properties.

Some contributions [24] have been considered in this study, as regards the monitoring of the State or degree of internal wear engine, who considers preventive maintenance, based on the rule of oil analysis is a tool to maximize the life and the availability of computers, oil-based application that helps both to prevent and reduce or eliminate costly failures such as reducing unnecessary services unavailability and the maintenance.

The Shell company reported[25] to approximately seventy (70)% aviation engines service failures were due to contamination, of which fifty (50) % had to do with problems of metallic abrasion and wear.

For the evaluation of particulates that are present in the fluid lubricant (by wear, contamination or additives) have with techniques such as: analysis (plasma, spark and atomic absorption), espectrométrico scanning electron microscopy, scanning x-ray scattering both with how fluorescence, optical microscopy, ferrografía, count of particles and more recently the monitoring particulates optical known as LASERNET evaluated from particles smaller hydrodynamic gap to large particles which are eventually retained in filtration, severe wear product systems.

However, regardless of the technique used the basic principles are the same: data State requiring to be interpreted and, accordingly, appropriate action should be undertaken.

Generally, those cases in which the State can be exactly determined by the data there is a stochastic relationship between data concerning the predictive maintenance and (not observable) status of the monitoring team [24]

Predictive maintenance can take nature continuous, periodic or be based on surveys with variable time. Also values to study, normally associated with physical nature trials will have a nature scale, although it might be possible to define representation of useful information vector nature or other structures.

In this regard, should highlight the fact that the predictive maintenance is not an end in itself, but posed an organized process of decision-making considered aspects of security, unavailability or reliability of the equipment.

For example [26] reported that the Canadian railway system implemented a predictive maintenance based on analysis of data (3 or 4 samples per week during the fifty-two and locomotive, 52, weeks of the year) and failures in reducing boxes during operation were reduced in a ninety (90%) per cent.

The methodology used in the aircraft in particular industry can understand as sampling in accordance with a protocol based initially on hours flown by the engine and for them, carry out an analysis laboratory to assess its contents in metals, as well as viscosity and other microbial factors [27]

Once obtained these values is carried out an interpretation thereof which seeks to establish the desirability for a minor repair (Top Overhaul) or total repair thereof (overhaul), or click continue their operation, cycle after the relevant oil change.

This technique and its associated criteria depend on for their precise interpretation of experience certain conditions of frequencies and the rest of factors that may involve some kind of distortion in the normal evolution of the oil control.

In the Venezuelan case, there are ranges of aircraft and a few hours flight for significant periods, market segments which together with the environmental conditions of heat and humidity prevailing in this territory can significantly influence certain little influence in the theoretical formalizations that link the state engine to the presence of particulate in oil for a given flight regime considered factors. The discussion of this phenomenon is the interest of this work.

And others works enrich this research are [28], this paper is to find out some modern technical solutions, which eliminate or diminish as much as reasonably possible the chemical and physical noxes and establish some measures aimed at reducing the exposure of the power sector personnel to the noxious environment.

The purpose of machine condition monitoring is to determine the present health of machineries. Capturing the abnormal symptoms of machineries from vibration signatures involves the use of signal processing algorithms on measured vibrations. The paper studies utilize of RCM strategy according an optimal maintenance cycle for a distribution and transformer substation - DTS. The objective of this maintenance is decrease of the costs operation, keep inevitable level of the reliability, safety and discretion on living environment so that standing time of maintenance of the operation facilities has been reduced or stand on. There are new algorithms in the paper for determination of an optimal maintenance cycle of DTS by analyzed from databases delivered from the distribution company, creation of the computational procedures for RCM software and the first pieces of knowledge from the implementation of RCM to the system operation. [29]

The discussion of this phenomenon will be the interest of this work.

B. Field study

The fabricants of reciprocal engines for private aircrafts, such as Teledyne Continental Motors [30], and Textron Lycoming [31], recommend that the calendar time or limit for the reconditioning (Time Between Overhaul, TBO) of the reciprocal engines is practiced at the expiration of the 12 calendar years, or between the 1200 and 1700 hours of flight approximately.

At the same time, and because of its importance for the establishment of the wear metals production on cylinder level, there were selected the results of the analysis of a set formed by engines that haven't achieved its maximum reconditioning time (TBO), but that had already reached 12 calendar years, which would require to perform the reconditioning (Overhaul).

This condition is very common internationally in this sector, and has required attention from the Federal Aviation Administration, as well as from Latin-American countries, including Venezuela, for this, there have been created condition monitoring programs that allow them to evaluate the conditions of aeronavigation year by year, reaching even 18 calendar years Federal Aviation Administration, [32]- [33];, and for which the aircrafts must undertake functional checkups and used oils analysis every 50 hours or every year (whichever comes first) in workshops certified by air institutes in each country. This checkups are directed toward the evaluation of the conditions of the combustion chamber's components (temperature/ compression/ visual evaluation with a borescope) and, to some extent, of the lubrication system, through the evaluation of the residues in the oil filters (filtergraphy), of the spectrometric analysis and of the physicochemical properties of the oils in use [35]- [36]- [37]- [38]- [39]- [40]. It is worth noting that predictive techniques, such as ferrography [41], filtergraphy and spectrometry [42], requires expertise from the evaluator.

The aircrafts studied do not operate frequently, that is, less than 100 hours annually. Therefore, they are exposed to environmental conditions typical of the tropics (high humidity and heat), which can promote the corrosion/rusting process of non-lubricated components' pieces, such as combustion chambers (cylinders/ rings/ pistons), camshafts and valve systems, while this does not means that the engines are not in conditions to operate.

From the observation of some of the lab samples it is concluded that it exists an underlying phenomenon of metals transport, because when the samples are taken before the established hours of flight, it is confirmed that the contaminants levels do not reach the average values for that engine. (Table 1.)

			MODEL:TSIO-520-E
47163	47161	47165	SAMPLE
11/30/08	12/12/08	12/31/08	DATE TAKEN
49	23	36	SERVICE TIME
179	223	336	TSO (OVERHAUL)
869	913	1026	EQUIPMENT (total hours)
19,53	18,89	19,23	VISCOSITY 100° C cSt
3,56	1,76	2,57	T.A.N. mgKOH/g
9,37	8,37	7,16	SOOT A/0,1 mm
10,11	5,21	10,18	NITRATION Ab/0,1 mm
13,61	8,16	10,88	OXIDATION Ab/0,1 mm
141	64	143	IRON Fe
43	17	58	CHROMIUM Cr
2237	1744	1649	LEAD Pb
4	2	4	TIN Sn
39	12	49	ALUMINIUM Al
20	6	28	COPPER Cu
45	24	38	NICKEL Ni
20	8	21	MOLYBDENUM Mo
1	1	1	TITANIUM Ti
20	8	27	SILICON Si
3	1	4	SODIUM Na
1	1	2	MAGNESIUM Mg
7	7	5	CALCIUM Ca
5	2	5	ZINC Zn

Table 1. Data showing dependency with flight hours

At the same time, it can also be observed a weak correlation between some compounds, such as the iron contents and the elapsed time between sample-taking, related to the time spent without flying:

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

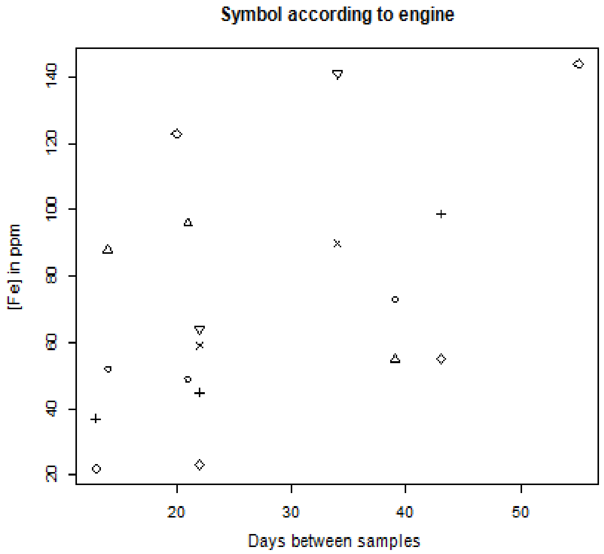

Fig. 1. Relation between time without flying and concentration of metals for engine.

In Venezuela, specifically in the "Universidad Metropolitana" (UNIMET) several studies have been developed by undergraduate students of the Engineering Faculty. These include comparative studies of the results of wore oil analysis in different sectors, as diesel engines, dual diesel / gas engines, public transport gas engines, as well as reciprocant aircraft engines. In the latter, in an attempt to establish wear patterns with statistical methodologies, there were found significant dispersion in the spectrometric result analysis.[43]- [44]- [45]- [46]- [47]- [48]- [49]

Correlation among the results and operational discrepancy of the engines could be established I one of these studies. In the other one, there were developed proposals for predictive models to determine wear metal concentration – Ferrum, Copper, Lead, Nickel, Silicon and Chromium, for two models / series of engines. A high level of confidence was achieved, implying that each model explains 70% to 90% of the studied metals wear causes.

It has to be noticed that these studies and models are adapted to flying conditions in Venezuela. Since those are relatively small private aircrafts with certificate maximum take off weight up to 5,700 kilograms (kg), operating in short runways in wet coastal environment, the need to a higher take off power demands over engines are higher. Thus, in most cases, an increase in the air intake is required, resulting in incoming contaminants –dust, sand, with high abrasive power and more.

These first studies were performed with income variables such as brand / model of engines and operation time of engines and lubricant, but not the oil consumption which can be so high that in one of the brands it depends on the power with a maximum allowed consumption between 0.5 and 1.0 quarter gallon per (Qt/ Hr). According to the lubrication systemas capacity -6 to 12 Qt is significative for 50 hour oil change intervals. [50]

C. Analytical Instruments. Measure errors and range.

The spectrometers for oil analysis have been utilized for metal wear, contamination an additives analysis in oils for more than 60 years. They represent the fundamental tool in condition based maintenance programs (Condition Monitoring) [51]. Results of spectrometric analysis depend upon the spectrometer, which can be one of two categories, atomic absorption and atomic emission. Atomic absorption consists in a flame instrumental (FL/AAS), and the emission equipment can be rotative disc (RDE/AES) or plasma (ICP/AES).

AAS technique [52] has been being gradually substituted by ICP/AES [53] for several reasons, among which should be outlined that since samples analyzed with ICP y AA require calibration pattern preparation, the former is capable of simultaneous detection of metal concentration of the order of parts per billion ppb (ppbm = µg of metal/ Kg of oil sample), which are of great importance in certain pieces of low wear equipment [54], in conjunction with the requirements of gases lower in ICP, it is only required an argon cylinder and an air compressor to generate the torch. However, for AA there is the need of acetylene, nitrate oxide cylinders an air compressor. Additionally, AAS instrumental equipment are inefficient for particles greater than 5 microns (µm) while ICP/AES detects around 10 µm.

RDE/AES first equipments were developed in the 80 decade [55] to meet military industry needs of efficient robust equipment easy to translate.

By the years 1998 and 200, comparative studies of wore oils with both techniques were available. [56]- [57]. By 2007, the US Defense Department oil analysis program used exclusively this instrumental to monitor their aircraft units equipment [58] as well as ASTM, [59].

Even though in JOAP manual the absolute metallic concentration limits are shown in parts per million (ppm; 1 mg of metal/kg of oil sample), the manual of the equipment used in this study, Spectroil M, Spectro Incorporate, counts with allowable indexes of accuracy and repetitibility (standard deviation: Std), [50].

This consideration is remarkable, as standard deviations tend to increase with concentration. This should be taken into account for results exceeding 100 ppm for all metals to be analyzed.

As an example, repetitibility as a function of concentration was determined, and it was found that it adjusts to a straight line with reliability near 1(Figure 2), although the range increases from 200 ppm. These condition arise the need to consider ranges or classes, rather than absolute concentration.

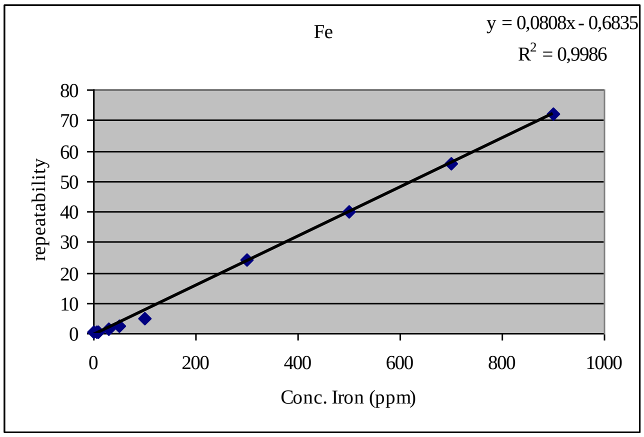

Fig 2. Repeatability vs Fe (ppm) (Minimum, Maximum)

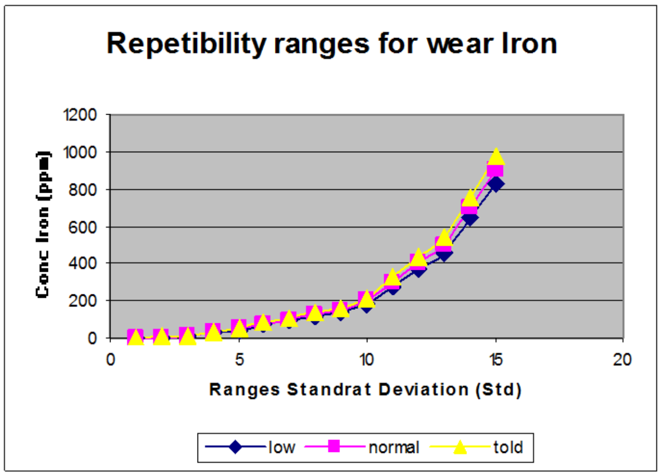

Fig 3. Concentrations Fe/ Ag/ Mo vs Mean Accuracy

Other problems as the sampling frequency are directly related to the probability of detecting impending failure which is, in turn, related to the rapidity of the failure mode. Although oil analysis is intended to provide a high probability of detection of impending failure, a reduced probability of detection may be tolerated in some cases for equipment with built in redundancy such as multiengined aircraft, or for systems with low safety risks associated with equipment malfunction or failure, such as aircraft auxiliary power units. Normal sampling frequency requirements, however, are determined by higher authority within each service, are mandatory, and are not subject to modification by laboratory or operating activities without official direction. Laboratories may, however, recommend increased sampling frequency for special samples when analysis results indicate the need for closer equipment monitoring on a temporary basis.

Erratic increases and decreases of trend level usually indicates a problem in sampling procedure,(oil addition or change without documentation, sample identification, etc.), or the effect of periodic fluid addition and a fluid change. In components such as some reciprocating engines, where oil depletion is rapid and replenishment is frequent, concentrations of wear metals will change erratically

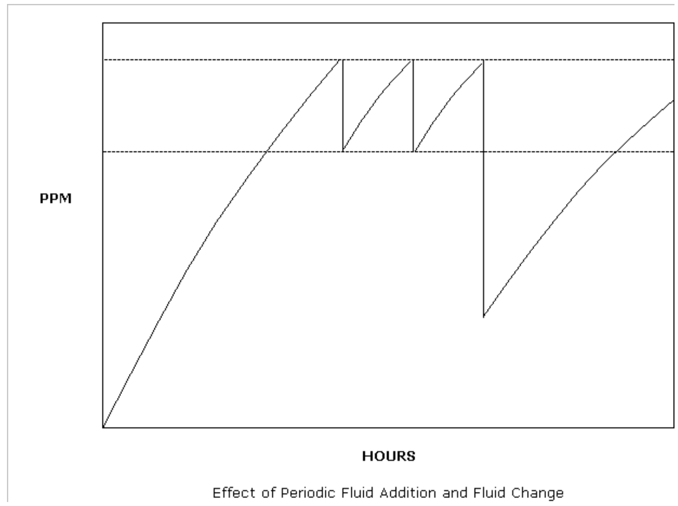

Fig 4. Effect of Periodic Fluid Addition and Fluid Change

D. Problem Solution

Given the scarce number of existing samples for engine and the intrinsic variability of the values of each engine:

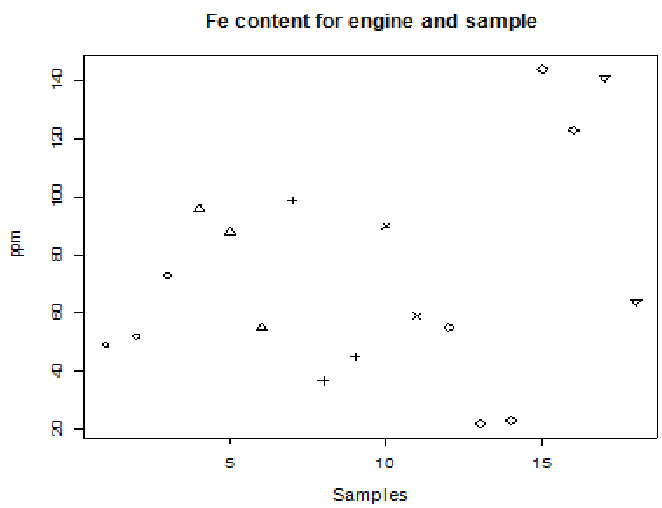

Fig 5. Variability in the levels of Fe for engine.

It seems reasonable to carry out a preliminary adjustment that eliminates the dependency of the flight hours with the same type of oil. This has the advantage that it allows to approach the posterior modeling with a mechanism of correction of the contaminant produced in the time of oil use, and to provide a mechanism of combination of contaminants produced in terms of total mass, so as to compare the criteria with the ones of the SOA [60]- [61]- [62]- [63]- [64].

For this, there will be accepted some hypothesis that will allow formulating the theory that is developed in this work:

When oil is replaced no metal remains in the engine and, for that reason, the metal concentration in the clean oil is 0. That is to say, it is supposed that the quantity of residual oil in the radiator is null.

The law of charge of metals in time in oil is not linear, but it follows an exponential law metal (t) = metalfinal* e-k1*t.

The pass of lubricating oil to the combustion chamber is constant in time. This supposes a linear lost of metals.

With this basic hypothesis, the objective will be to develop a formulation that allows estimating, in function of time, the mass production of metals in the engine's cylinders. It will be adopted an incremental formulation, evaluating the control values in the points of the engine's oil change.

This approximation has the assumed weakness that it doesn't tolerate absences in data of intermediate and not controlled oil changes, and also requires knowing the oil contribution during each period, to maintain the levels, as an indication of the velocity of the pass of oil to the cylinders.

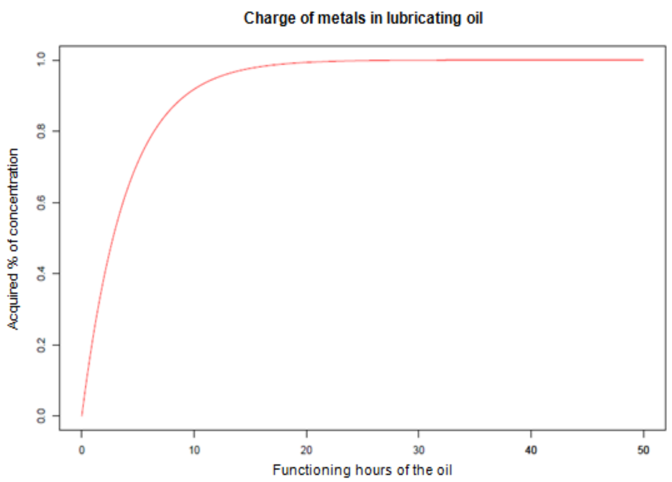

Fig 6. Law of transference of metals to oil.

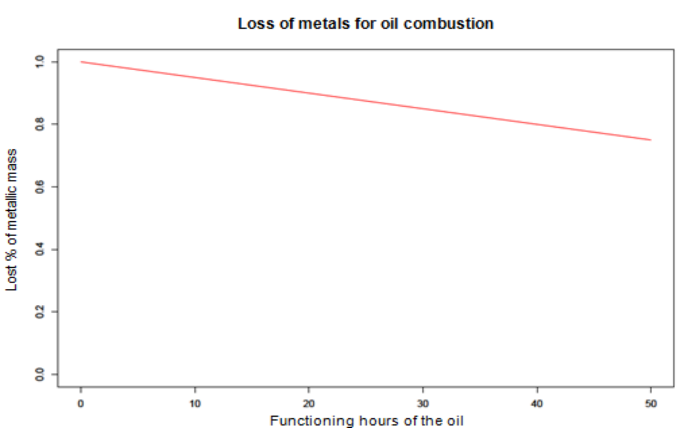

Fig 7. Law of transference of oil to the combustion chamber.

We will designate:

Symbol	Meaning
M(t)	Mass of the metal of interest in mg at the instant t
[M](t)	Concentration of the metal of interest, measured in mg/l at the instant t
MTANQUE(t)	Mass of the metal due to the oil in the tank at the instant t
VTANQUE	Volume of oil in the tank
V(t)	Effective volume of oil in the tank at the instant t
m(t)	Mass of the metal lost due to combustion of the oil since the last change until present time
ni	Instant of the i-th oil change
t	Present instant, with t > i
k1	Coefficient that marks the velocity of the charge of metals in the new oil
k2	Coefficient that marks the velocity of the pass of oil to the cylinders

In general and taking into account the notation previously defined, it can be written:

$$M(t) = M(n_i) + M^{TANQUE}(t) + m(t) \qquad n_i < t \leq n_{i+1} \quad (1)$$

Now, we know that:

$$M^{TANQUE}(t) = [M](t) * V^{TANQUE} \quad (2)$$

The value of m (t) will be determined by means of a mass balance:

$$m(t) = \int_0^t [V^{TANQUE} - V(s)] * [M](s) ds \quad (3)$$

Replacing the relations of lost volumes and of generation of metals in the oil, we will have:

$$m(t) = \int_0^t k_2 \cdot s \cdot (1 - e^{-k_1 \cdot s}) ds \quad (4)$$

Therefore, operating, we have:

$$m(t) = \frac{1}{2} \cdot k_2 \cdot t^2 + \frac{k_2}{k_1} \cdot e^{-k_1 \cdot t} \cdot (t + \frac{1}{k_1}) - \frac{k_2}{k_1^2} \quad (5)$$

I.e.:

$$M(n_{i+1}) = M(n_i) + [M](\Delta T) \cdot V^{TANQUE} + \frac{1}{2} \cdot k_2 \cdot \Delta T^2 + \frac{k_2}{k_1} \cdot e^{-k_1 \cdot \Delta T} \cdot (\Delta T + \frac{1}{k_1}) - \frac{k_2}{k_1^2} \quad (6)$$

Using the latter expression and applying it for successive oil changes, it is possible to obtain an estimation of the evolution of the metal's mass that has been pulled out of the cylinders and evacuated through the lubrication system.

Note, also, that constants k1 and k2 can be variables in each interval ni < t < ni+1, thus allowing a larger degree of flexibility in modeling reality.

III. Conclusion

In this work, it is justified the convenience of applying techniques for monitoring the contaminants in the oil of aircraft's engines, so to evaluate its potential contribution to predictive maintenance techniques. It is also identified the difficulty of the analysis with each sample, because of the variability of each airplane model and each equipment within a model, as well as the different frequency of the sampling.

For this reason, it has been formulated a constructive incremental model of production of metals dragged to the lubrication system, that allows to take into account the different age of the oil. From this formulation, there will be applied data mining techniques to estimate the coefficients through regressors and to adjust the estimation of the metals production along the functioning periods, as key elements to construct a law for the evolution of contaminants.

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