PARTICLE-SIZE ANALYSIS OF ENGINE OILS

A SUPPLEMENT TO SPECTROMETRIC ANALYSIS

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Introduction — Section 1

In order to monitor the condition of each aircraft engine in its fleet, the Air Force periodically samples the lubricating oil and makes a spectrometric analysis of the metal content. These measurements serve as a guide to identify abnormal wear of parts and to schedule inspections or overhauls. As presently operated, the Spectrometric Oil Analysis Program (SOAP) prescribes alert levels for the concentration of critical metals for each engine type, and mandates particular actions in the field when such levels are detected. Pre-emptive time scheduled maintenance is performed at long intervals on engines not flagged in the interim by SOAP.

The efficiency of the SOAP system is assessed by means of an after-the-fact classification of each sample analyzed. Four categories are defined:

a. Failure. An oil-wetted part failed although the immediately preceding spectrometric analysis was within prescribed limits.
b. Hit. The spectrometric analysis fell outside prescribed limits and the immediately subsequent inspection of the engine revealed damage to a part.
c. Routine. The spectrometric analysis fell within limits and no engine malfunction occurred prior to the next spectrometric analysis.
d. Miss. The spectrometric analysis fell outside limits but no damage was found upon inspection.

Some two million samples are analyzed each year at more than a hundred laboratories world-wide. Of these, the vast bulk is routine; all other categories are comparatively rare. Failures run about 100-200 annually, hits 1200-1300, and misses 50-60. Yet the SOAP program pays for its considerable cost (estimated at round $10 per analysis) by the detection of the relatively small fraction of hits, each of which represents the averting of a possible failure that could result in the loss of an engine, an airplane, or the lives of aircrew. Prevention of failure is the central purpose of the program, and the goal of research and development in SOAP technology is to decrease the ratio of failures to hits. Even small improvements in this ratio exert a large favorable leverage on the cost-effectiveness of SOAP.

Various supplementary methods of analysis are under investigation with the aim of characterizing oil samples more completely to fine-tune the capability of SOAP with respect to identifying incipient failure. One such technique is particle counting, which defines the size distribution of wear metals and other particulate debris if present. This report develops a rationale whereby the measured total volume of particulates in a sample is compared with an expected value inferred from spectrometric analysis of the same sample. Experiments on authentic oil specimens, using this method of screening, indicate that the effectiveness of SOAP in preventing engine failure can be increased about six fold by supplementing each spectrometric analysis with a particle count.

Experimental Procedure — Section 2

Equipment

The particle counter used in this work is a commercially available light scattering laser-beam instrument (Spectrex ILI-1000). A helium neon laser beam (wavelength 0.6328 micron) scans the sample in a circular path for a measured period of time, and a photo detector collects pulses scattered forward by suspended particles. The intensity of each pulse is proportional to the square of the diameter of the scatterer, which is assumed spherical. The optics is designed to focus only pulses which originate within a zone of limited length (about 2 centimeters), the boundaries of which lie within the sample. This length, together with the diameter of the beam and the fixed circular rate of beam travel, determines the volumetric scan rate, which amounts to 0.6165 cm^3 per second for our particular instrument. The counter is coupled to a 15-channel pulse-height discriminator which sorts and stores counts according to their intensity – thus, according to the size of the scatterer generating the pulse. An additional summation channel counts all pulses received by the 15 sorting channels. Particles smaller than 1-2 microns, do not scatter light at the laser wavelength and cannot be detected.

In order to avoid multiple scattering of pulses and also keep the rate of arrival of pulses within the resolving power of the detector, it is required that the total concentration of particles do not exceed about 1,500 per cm^3. Further, the pulse intensity received at the detector from a particle of a given size is dependent upon the attenuation (if any) of the laser beam due to absorption by the liquid under examination; a correction for this effect can be made if the opacity of the specimen is independently measured, and this must be done as a part of the counting experiment. Opacity of 35% is about the limit for convenient operation; above this limit, the detector rapidly and progressively goes blind, except to strong pulses (from large particles). For these reasons it is necessary to dilute oil samples before counting, since both the particle concentration and the opacity of most used engine oils are well beyond the bounds mentioned.

Our particular assembly of equipment was calibrated before use against a standard polydisperse suspension of polystyrene spheres in water, the total concentration and size distribution of which were traceable to NBS determinations.

Results and Discussion

The feasibility of the dual-screening principle is readily demonstrated. Figure 1 is an X-Y plot of the extant data, showing that spectrometric routines (open circles) fall predominantly below the curve X=Y, whereas most failures (filled circles lie above it; hits (crossed circles are almost evenly distributed. Table 4 summarizes the results in a compact form.

According to this evidence, supplementary particle counting, had it been a part of the SOAP screening process, would have identified 84% of the failure samples as defective and would have caused an inspection to be made before the failure occurred. In the case of hits, almost half of the samples had already surpassed the x/y limit by the time the spectrometric analysis gave an alarm; the source engines would have been flagged for inspection at some previous juncture. And if the spectrometric routine samples are indeed representative of their class, the 11% of all engines now in service contain oil of a suspicious character; these are the engines more likely to yield future spectroscopic hits or failures. Again, supplementary particle counting would have precipitated an inspection of each of these engines at some earlier time, resulting in either a hit or miss finding. A point to be emphasized is that this would have occurred the **first time** the X/Y ratio exceeded unity. There could be no accumulation of dirty oil in the fleet; it would be purged upon discovery.

Ultimately, if we are to make reliable costs effectiveness studies, we need to know how supplementary particle counting would affect both the annual number of failures and the annual number of inspections (hits plus misses). The actual magnitude of these parameters can be determined only by a program of real-time dual analysis. Our present experiments allow us to judge with fair confidence that the number of failures will be reduced to about 16% of the present level; on-line experiments will serve principally to enlarge the statistical data and refine the estimate a few percent either way.

Conclusion and Recommendations

Section 3

The exploratory phase of this work has been completed. Particle counting appears to be a promising candidate method of supplemental analysis from the standpoint of failure prevention. The question of cost effectiveness remains to be investigated, and this calls for a regime of testing different from what has been conducted thus far.

It is recommended that further work proceed along the following lines.

a. Modify equipment and procedure to accomplish rapid particle counting in the thin-film mode, incorporating data readout from a dedicated microcomputer.
b. Using this nimble capability, established in a central R&D laboratory, conduct a program of real time particle analysis on every spectrometric sample from a number of operational aircraft (perhaps 20.) These aircraft should be selected to provide a cross section of engine types and severity of service; the test period should be of sufficient duration (at least a year) to guarantee a variety of maintenance experience.
c. During the test period, issue inspection advice and receive inspection feedback in order to assess the reliability and cost effectiveness of supplemental particle counting. Continuously refine decision criteria insofar as possible to improve performance.
d. Assuming favorable findings, move well-automated equipment and necessary instructions out to one or more SOAP laboratories to demonstrate the system as a field method.

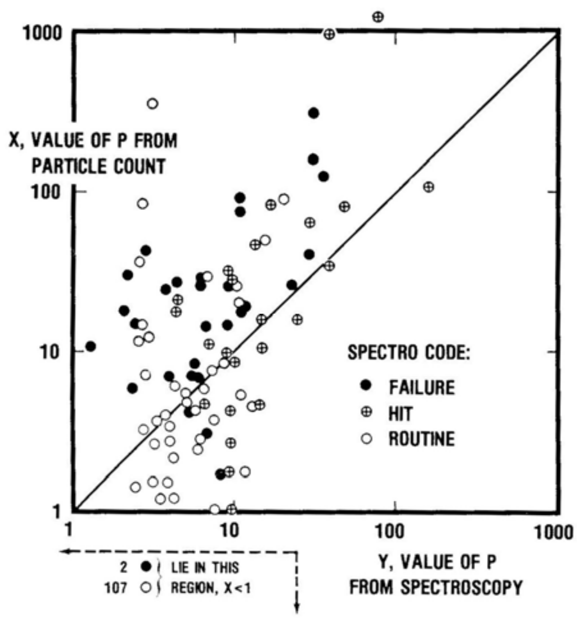

Figure 1. Failure Prediction based on comparison of two estimates for P, micro liters of particulates per liter of oil

Table 1 Effectiveness of Prediction

Spectro Class	Total Number	Number Defective	Fraction Defective	Limits of 80$ Confidence*
Failure	31	26	0.84	0.72 0.90
Hit	24	11	0.64	0.33 0.58
Routine	145	16	0.11	0.09 0.15
Total	200	53		

* Estimated from theory of sampling by attributes. Cf. Leslie E. Simon “Engineer’s Manual of Statistical Methods”, John Wiley and Sons, New York (1941,) Chapter 2.