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The SPEX Speaker

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SPECTROMETRIC OIL ANALYSIS PROGRAM

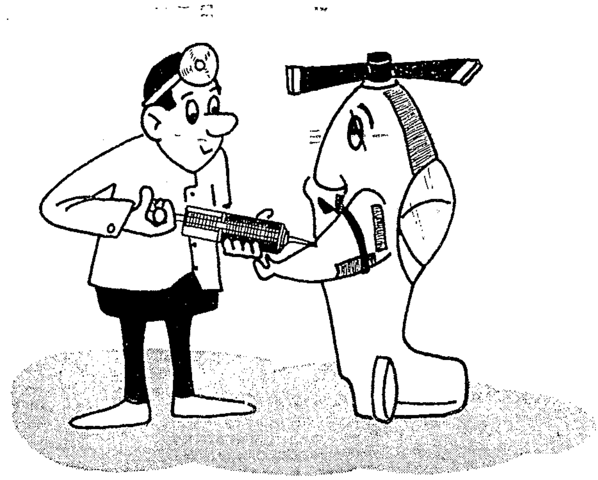
EARLY in 1964 anxious Air Force officers and mechanical engineers called an interservice meeting at Wright-Patterson Air Force Base in Dayton, Ohio, to discuss means of combatting a rash of crashes of its jet aircraft due to engine failure. As if to underscore the emergency, still another F-105 was lost during the conference; fortunately, its pilot like most of the others was able to eject himself beforehand. With costs well over $1 million per plane, however, some kind of early warning system and action were sorely needed.

A preventive maintenance program had already been well under way in the Navy. Taking its cue from the railroads, the Naval Air Rework Facility in Pensacola, Florida, had found that, by periodically analyzing the used lubricating oil of an engine spectrographically, they could establish a more or less normal wear level from the concentration of elements determined. Any unusual rise in the level of, say, iron might foreshadow failure of a vital moving part. Ironically, the very plane that had crashed during the 1964 conference had been under Navy spectrographic surveillance. A report of high iron was received too late to ground the plane before its failure.

What was decided at the meeting was to authorize Pensacola to increase its workload by taking Air Force planes into its spectrometric oil analysis program (SOAP) until the Air Force, which itself had a prototype analyzer on order, could do its own work.

Back in the Forties a similar lesson was learned by the railroads during the period when their steam engines were being phased out. First-generation diesel replacements were failing at an alarming rate, their load of freight or fidgety passengers forced to wait hours before a standby engine could be substituted. Ray McBrian of the Denver & Rio Grande Railroad is credited with the discovery that many such failures could be successfully predicted by monitoring the crankcase oil spectrographically. Soon locomotive manufacturers and railroads alike rushed to set up round-the-clock spectrographic control operations in order to sidetrack and overhaul engines before they broke down. The situation gradually improved not only through analytical diagnostics but through better design and material used in the construction of moving engine components. Although in recent years there has been a sharp drop in the number of analyses performed, many American and Canadian railroads continue to rely on the spectrograph instead of an arbitrary odometer as an overhaul timetable. Extension of time intervals between overhauls (TBOs) more than pays for the cost of running the lab.

In 1955, B. B. Bond, now head of the Materials Engineering Division and his supervisor, Harold Yesness, at the Pensacola Naval Rework Facility decided that what was good for diesel locomotives might very well be good for Navy aircraft. They sent J. C. Jennings, who now supervises one of the Pensacola SOAP shifts, on a visit to several railroad labs and



Courtesy Naval Air Rework Facility, Pensacola, Florida

within a few months they, too, were in business with a standard 2-meter ARL spectrograph. From that modest start has grown a program in which around 2500 samples are currently analyzed per week in Pensacola. A second facility has been established in San Diego, a simplified instrument installed aboard an aircraft carrier and two commercial labs have been called in to handle the snowballing backlog. That the effort took several years to get off the ground is quite understandable. Until all or a majority of plane engines are monitored, statistical evidence relating cause and effect is hard to establish.

In 1961 Pensacola found new evidence that was to convince other branches of the military that SOAP was indeed worthwhile. At Fort Walters, 350 H23 helicopters were taken out of service because of two crashes caused by needle bearing seizures in the main rotor transmission. Was this an unfortunate coincidence or was there something basically wrong with the bearing? Pensacola was called in to find out. Of the 350 oil samples analyzed six contained high concentrations of copper and iron. When the bearings in these transmissions were pulled, they were found dangerously near failure, blue from running at a temperature hot enough to destroy their film of protective lube oil. But the spectrographic analysis showed iron in addition to copper. Since the bearings were of bronze, iron could hardly have originated from this source. A little further sleuthing showed that the offender was not the bearing but a steel thrust washer holding it in place. Faulty design allowed it to become misaligned and press against the rotating bearing after several hours of running. The bearing naturally overheated and burned out. Now as obvious as the Columbus egg, the solution was to change the design of the penny washer not the expensive bearing. More important, no doubt any longer remained that spectrographic analysis of lubricating oil was potentially invaluable in forecasting problems involving oil-wetted aircraft parts.

When the railroads first embarked on spectrochemical control, two methods emerged. One group of chemists favored ashing, followed by mixing of the ash with a common matrix such as graphite powder and finally arcing in a cratered electrode. The other chose to spark the sample directly through an intermediary rotating disc electrode dipping continuously into the shaken but otherwise undoctored sample. A third system—almost a hybrid between the two—was advocated by a small, dedicated group and now seems to have been relegated to the archives. The so-called rotating platform technique, it prescribed that the sample first be ashed on the face of the same graphite disc which later was to become the electrode.

The two main methods differ conceptually to an even greater extent than spectrographically. The rotating electrode technique is at best semiquantitative and its disciples openly admit the fact. Changes in the compositon of the oil base, viscosity, dilution with fuel, presence of heavy concentrations of sludge—all seriously affect measured intensity ratios which, in turn, alter the reported percentages of the trace elements. Perhaps the greatest source of error is the oil itself. Purchasing lubricants locally from different producers, railroads find that one product will contain a calcium-based additive, another phosphorus. So strongly do these elements shift the working curves that quantitative analysis becomes virtually impossible. Diluting with enough of a common matrix to quantitize the results reduces the sensitivity below values where the wear metals need to be measured.

Ashing techniques, on the other hand, can be both quantitative and adequately sensitive. Since a factor of around 100 is gained in sample size by the ashing step, dilution by an equal amount is perfectly acceptable. Ashing is, however, painfully long and involved and the cost is easily double that of the analysis proper. If ashing were essential to the success of the SOAP program, the total cost would possibly weigh decisively against its adoption. The more or less standard technique today is therefore that based on the rotating electrode or rotrode and a typical spark procedure.

Standards are available from at least two sources. Starting with National Spectrographic Laboratories' stock metallo-organic concentrates in which the individual element is carefully determined (ranging from 5 to 10%), the Navy prefers to dilute with ASTM No. 1 oil themselves so that standards wind up with 10, 20, 30, 50, 100, 200, 300 and 500 ppm of Al, Fe, Cr, Ag, Cu, Sn, Mg, Ti, Ni and Si. NSL also supplies premixed standards. Its 630-40 Series consists of five standards containing Si, Al, Cu, Pb, Fe, Cr, B, Sn and Ag in staggered concentrations from 3-100 ppm in a diesel oil base. NSL's 630-41 Series are similar but in a synthetic oil, Grade 105, favored by the Air Force. The National Bureau of Standards also provides standards but they are in powder form. To render them soluble in oil it is necessary to add complex and frequently expensive organic compounds as well as heat although early complaints about some elements not remaining in solution have largely been overcome.

What the control lab strives for instead of quantitative accuracy is relative precision for an individual engine oil. As long as the lab can provide figures proportional to the actual concentration of wear metals in that crankcase oil, the compelling argument goes, it is not important that the values themselves be correct or, for that matter, that they bear any relationship whatever with oil taken from any other engine. Needed is a continual profile record of an oil's trace elements so build-up trends can be quickly spotted and diagnosis just as quickly reported for corrective measures to be taken.

Carrying this argument to its logical conclusion, no two labs can be or should be expected to report the same values for the same sample oil. And, indeed, repeated round-robin tests of identical samples have demonstrated this convincingly. It also means that sampling instructions, record keeping, interpretation and recommendations must originate in the laboratory. The lab must offer a routinely efficient production facility.

The Navy lab at Pensacola has become just that. Its procedural aspects have been reduced to as much of a science as the actual analytical work. About 2500 samples per week are handled on a 3-shift basis. Oils from jet engines are sampled every 10 running hours by field maintenance personnel following strict routines. The engine must be warm, a preliminary amount is drained off and discarded; next the sample itself is withdrawn and transferred to a glass bottle, the cap of which will ultimately become the sparking container. Even the labeling procedure and the type of mailing bag have been standardized.

The Navy strives for an elapsed time of no greater than one week between sampling and reporting and, naturally, mailing consumes the greatest time. Once received, the sample is first logged in and its engine record card pulled from a Lectrotriever file, a rotating drum file cabinet permitting any one of thousands of cards to be located within seconds. Poured into the bottle cap, a portion of the well-shaken oil is taken to a Baird direct reader and sparked. In a little over one minute, analytical results appear on clock faces. These are next digitized then automatically transferred first to IBM card punch and typing equipment and finally to the permanent record card for the particular engine represented by the oil sample.

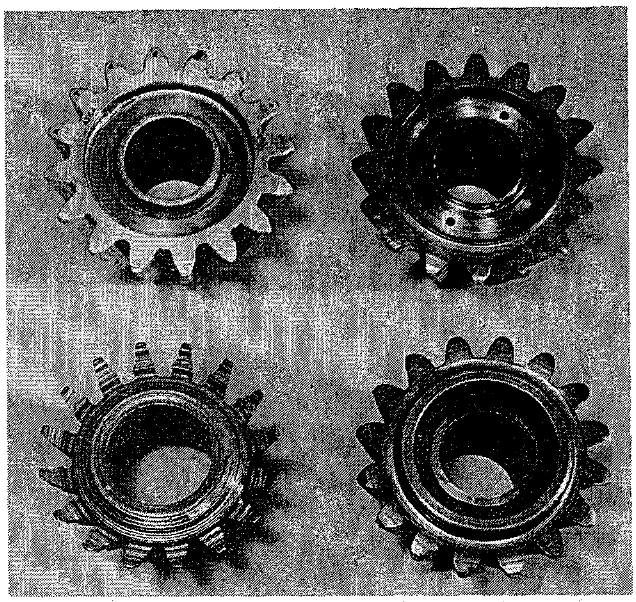
LAB	UNIT MODEL	UNIT SERIAL	OPERATING ACTIVITY	BASIC A/C MODEL	TYPE OIL	SAMPLING INTERVAL	NO. OF PREV. OVERHAULS	LAST DUP	HOURS AT LAST OVERHAUL	CROSS METAL	DATE FIRST SAMPLE
P	J60P5A	636933	FANDR	C140	9	3					D4

61-2492

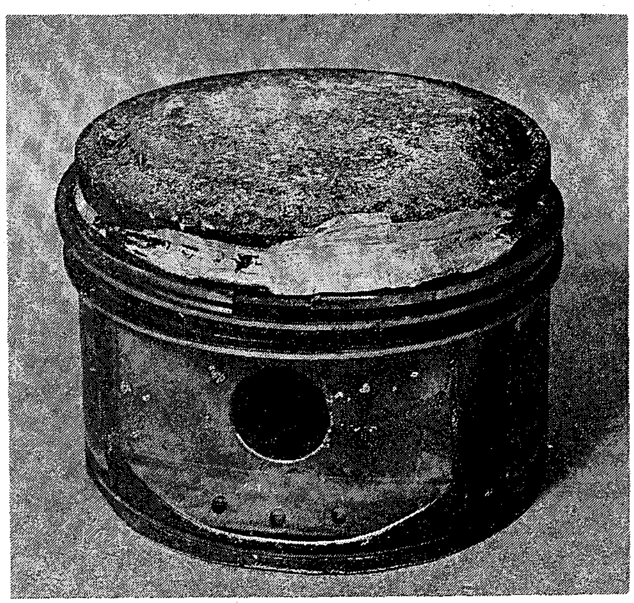
LAB REQ.	REASON FOR SAMPLE	DATE SAMPLE TAKEN	DAYS IN ROUTE	HOURS SINCE OVERHAUL	HOURS SINCE OIL CHANGE	CORRECTIVE MAINT. SINCE LAST SAMPLE	Al	Fe	Cr	Ag	Cu	Sn	Mo	Pb	Ni	Si
00	010	D154	03	0000	002	00000	002	005	002	000	001	003	001	011	001	000
00	100	D214	03	0011	011	00000	000	005	000	000	004	004	004	009	001	006
00	100	1025	03	0040	040	00000	001	009	000	001	005	008	005	016	002	006
00	100	1115	03	0090	090	00000	000	012	000	000	006	002	010	039	000	001
00	100	1265	02	0097	097	00000	001	016	001	000	004	004	009	029	000	002
00	100	2255	01	0121	121	00000	001	030	000	001	006	001	018	040	000	000
00	100	2255	01	0121	121	00000	002	033	000	002	006	002	020	043	001	000
00	100	3065	03	0153	153	00000	003	(040)	002	004	006	008	020	041	002	006
00	100	3065	03	0153	153	00000	002	(038)	001	001	006	004	020	036	000	005
J3	500	3125	04	0182	182	00000	000	(044)	000	003	006	002	019	038	001	003
J3	500	3125	04	0182	182	00000	000	(041)	000	003	005	000	017	035	001	002
J3	500	3225	01	0196	196	00000	003	(046)	001	002	006	007	022	038	001	005
J3	500	3225	01	0196	196	00000	002	(053)	001	002	006	012	022	040	001	003
S2	400	4045	04	0205	001	00006	000	009	004	000	000	003	001	008	001	005
A1	800	4065	01	0206	005	00000	000	004	001	000	001	005	000	006	001	003
A0	100	4225	01	0233	029	00000	002	007	001	000	002	005	002	000	000	008
00	100	4255	02	0254	046	00000	002	007	001	001	002	004	005	013	001	006

Figure 1: A typical oil analysis record card for a jet engine. As a result of laboratory warnings of high iron in the oil (circled values), a main component bevel drive gear bearing was found to be worn beyond limits. The return to normal of the metals content after the assembly change and oil change confirmed the correct maintenance action. (Courtesy NARF)

Fig. 1 shows the type of trend that only an experienced operator could detect. On Feb. 25, repeat determinations indicated that the iron content had doubled from 16 to around 30 ppm. Alerted but not overly concerned, laboratory personnel waited for the next sample from that engine. When the iron content again rose, this time to 40 ppm, a warning circle was immediately drawn around the value and maintenance men at the home base of the aircraft were notified by telegraph. The rise was not alarming, signalling no impending catastrophic failure but merely a worn part. For this reason the engine was not overhauled until late in March when, indeed, a main component bevel drive gear bearing was found scored and deformed. After the assembly change, the metals content returned to normal attesting to the correctness of maintenance action.



Reduction drive pinions: (A) was in satisfactory condition, (B) severely worn, (C) and (D) show scoring on faces of gear teeth. Oil analysis showed high iron, chromium and copper. (Courtesy NARF)



Piston with damaged upper ring land caused by broken ring. Oil analysis indicated high aluminum and iron. (Courtesy NARF)

While the Navy has placed its resources behind central laboratories with direct reading emission spectrometers, the Air Force has opted for base-level atomic absorption spectrophotometers. The Navy has but two fixed operating labs of its own plus one aboard the carrier, U.S.S. Constellation while the Air Force has at least 35 Perkin-Elmer Model 303 AA instruments at as many locations throughout the world. June 1967 was the target date for every Tactical Air Command to be AA operational and eventually all 180 AF bases are scheduled to be equipped with either AA or emission equipment. At that time every Government-owned engine will be kept under routine SOAP scrutiny.

There are two separate aspects to the friendly rivalry between AA and emission. Not only does instrumentation differ but the basic concepts of analytical control differ sharply in the two services. The Navy believes that SOAP control requires highly trained, specialized personnel brimming with extensive interpretive experience. On the other hand, the Air Force believes that the work and interpretations are considerations secondary to the speed of analysis even if the analyses must be performed by technicians with the equivalent of a high school diploma.

In a sense, the Air Force and Navy are simply weighing reporting time against reporting quality, each service thinking that the one is more important than the other. With the objective of rapid processing of information back to the plane maintenance staff, the Air Force favors AA. It is considerably less expensive than emission equipment, typically $10,000 **vs.** $50,000. Further, AA is less sensitive to the rigors of adverse climate, simpler to operate and, because it is less complex, less subject to breakdown.

With one exception, the reliability of AA is every bit as good as that of emission spectroscopy. Segregated clumps tend to pass through the AA flame without being detected. In general, emission techniques offer an integrated picture of the sample; AA, an instantaneous picture. Because most of the energy is funneled into a single spectral line, the sensitivity of AA is likely to be somewhat higher than that of emission.

Aside from their technically fundamental differences, the principal difference between AA and emission is operational: with the former, elements are determined sequentially; the latter, simultaneously. To operate an AA spectrophotometer efficiently, the day's batch of samples must be analyzed for one element at a time. The hollow cathode tube is then changed, the wavelength drum reset and the next element determined. The pro-rated analytical time is moderately greater in AA but the elapsed time to complete the analysis of a given sample is considerably greater. Weighed against the fact that the sample represents an aircraft "next door" and not half way around the world, however, the extra analysis time loses much of its significance. The strengths and shortcomings of AA and emission seem to balance one another especially if AA equipment is housed close to the aircraft themselves.

Interpretation of numbers and recommendation of action surface as the real points at issue. In an attempt to show that the first step—analysis—does not pose a problem, the Air Force has instituted a round-robin program in which a sample is sent each month to each of the cooperating laboratories. Both AA and emission labs are involved in the program but results thus far appear to be distressingly disappointing. On the same sample, each lab reports a different set of concentration values. The condition of the oil—its fuel dilution, sludge content, state of oxidation—severely limit the accuracy. Further, even with identical instrumentation and supposedly identical methodology a built-in bias inevitably appears from lab to lab. The Navy feels that the hurdles are insurmountable; the Air Force believe that progress can be and is being made towards the day when each of its labs will report essentially identical values for the same samples.

TWO private testing laboratories have found a proliferating market for their services in commercial as well as military applications. One, Spectron, Inc., located near San Juan, Puerto Rico, numbers among its customers a shipping firm, two Portland cement distributors and several sugar refineries in the Caribbean. The other, Analysts, Inc., with similarly equipped labs on the east and west coast, does work for trucking firms, sugar plantations, and commercial airlines.

Commercial applications for spectrometric analysis hinge on but one question: can a businessman be convinced that he will save money by switching from a time-based to a need-based maintenance program? In other words can TBOs be increased to the point where spectrometric costs are more than offset by maintenance savings.

Traditional preventive maintenance of machinery bears a striking resemblance to the queen who took a bath once a month whether she needed it or not. Every fixed number of hours of operation, filters and oil are methodically changed and grease squirted into appropriate fittings. On a strict schedule, heavy engines are torn down, inspected, worn and broken parts replaced and then reassembled. An overhaul is both costly and worrisome. Instead of trained workmen working with special tools and inspection equipment in a clean factory built for the expressed purpose of engine assembly, men lacking the skill, experience and tools necessary to do a first-rate job conduct overhauls in grimy garages. Before instituting spectrometric control, one sugar plantation in Puerto Rico found that an upsetting 30% of its **overhauled** engines failed during the harvesting season.

The sugar processing industry has over a seven year span learned to accept spectrometric control as enthusiastically as the military. Despite the dissimilarity in equipment, the two share one common fear: engine breakdown. For six months of the year, sugar cane is just left to grow. With the exception of equipment and plant maintenance, there is nothing to do but wait and pray for good weather. Starting in February in the Caribbean the race against devastating tropical storms begins. Yesterday's machete-wielding swarms of itinerant workers have been replaced by huge diesel-powered cutters drawn by diesel-powered tractors and followed by immense diesel-powered trucks which harvest the cane and unload it at nearby processing plants. Field work is scheduled by the hours of daylight; plants work a 24-hour day until mid-summer.

The practice at Aguirre Centrale Sugar Company in Puerto Rico had been to take advantage of the six-month waiting period by conducting a rigorously thorough preventive maintenance program. To make sure that they would withstand the strenuous harvest season without breakdown, all engines—fixed and stationary—were torn down and overhauled. A typical refinery costs about $10,000 a day to run; the loss of any link in the production chain can disrupt output disastrously. The preventive maintenance program was not entirely satisfactory, however. The 30% failure rate of overhauled engines left a considerable something to be desired.

That was the situation when Robert Kincaid of Spectron was invited into the picture. Aguirre Sugar decided to risk placing their engines on spectrometric monitoring; only those that showed tell-tale trace element buildup got the winter overhaul. It was a big gamble for both organizations. Spectron's very future in Puerto Rico depended on the success of the program. But the big bet paid off and to quote the now-confident Mr. Kincaid, "Spectrochemical oil analysis provides positive specific information to the maintenance superintendent as to which specific units require what specific attention and, equally important, which units require **no** attention."

So successful, in fact, has this sugar program grown that other large-scale operators of heavy diesel engines have followed the lead, expanding Spectron's clientele many fold. Ready Mix Concrete, Inc. a newer customer, operates 100 diesel trucks, 9 cranes and one front-end loader. Besides the manager, their maintenance staff consists of five mechanics, eight helpers, two foremen, eight lube men and two parts men. Employing one mechanic for every 22 engine units, their fleet availability has increased to an impressive 95% now that it is on spectrometric control. Oil and filter change interval has doubled. When tests with a less expensive grade of oil indicated no appreciable difference in performance between a selected group and the remainder of the fleet acting as a control the entire fleet was switched to the less expensive oil. Alone, this cost saving pays for the entire cost of SOAP.

According to Mr. Kincaid, Ready Mix has unexpectedly found spectrometric analysis important in its labor relations. On several occasions poor performance after maintenance has been traced to particular shop personnel; likewise abuse of equipment, has been traced to particular operators. Where disciplinary action has been found needed, management has been able to support its position so convincingly with oil analysis records, that, confronted with such evidence, unions have generally been acquiescent and cooperative.

Spectrometric analysis is not, of course, a cure-all. Spectron runs at least two other tests routinely as part of its maintenance package. One is oil viscosity. Should this drop, fuel dilution is indicated and a faulty seal or worn piston rings may be the cause. A second test is of naphtha precipitants, a measure of insolubles in the oil. This test determines the total amount of sludge, contaminants and oil breakdown products.

To round out their spectrometric analysis Analysts Inc. apply two different types of tests with essentially the same goals as Spectron. In place of viscosity, they prefer a boil-off method for appraising fuel dilution, claiming that this is a direct method free of interferences from other sources. Rather than a solubility test, they centrifuge out the suspended and non-suspended solids, thereby achieving an effective measure of filter efficiency and oil dispersancy.

The analytical package, ranging in cost from $5 to $10 depending on the number of monthly samples run, includes prompt reporting of the results usually by telephone. Analysts Inc. was awarded a contract with the Navy to monitor stationary engines aboard cruising ships at 100-hour intervals. Samples are picked up by interceptor ships and air-mailed to the Linden lab. In less than one week, Analysts can get a report of a discrepant engine back to the ship commander through an intermediate phone call to his base command in the United States.

Intervals between SOAP tests are determined by many factors. Military aircraft engines, pushed to the very limits of their endurance and performance, are rigorously sampled every 10 hours. On the other hand, it is recommended that commecial jet and reciprocating engines be checked only after 25 running hours. Lube oil from diesel-fired stationary engines ought to be analyzed every 100 hours while the same engines fired by cleaner natural gas can run 500 hours safely.

Jon Poley of Analysts' Linden, N. J. lab, cited a beautiful example of the value of SOAP to one of their clients, an organization that rents out small helicopters for such purposes as crop dusting and aerial surveys. Under regular 25-hour spectrometric surveillance for many months, oil from one main helicopter rotor engine showed an abrupt rise in the silicon content. This is generally caused by a perforated or torn air filter and, on finding the discrepancy, Poley immediately phoned his client to give him his opinion. During the phone conversation that cause was all but ruled out by the client. It was winter time, snow was on the ground; the helicopter had not been flying low over dry soil whipping a cloud of dust into the air intake manifold. Yet silicon was abnormally high and an explanation was still lacking.

After hanging up, Mr. Poley pondered over the discrepant silicon and it occurred to him that the helicopter had a wet clutch, one sharing the crankcase oil with the engine. Could the trouble be in the asbestos face plates of the clutch? He phoned back and the answer, as soon found during teardown, was a resounding yes. "If we had operated that ship any longer," the customer wrote in an appreciative letter, "we would have had metal-to-metal contact and possible clutch failure." Oil analysis had very likely prevented not only damage to the engine, but to the aircraft and a nasty accident as well.

Both commercial laboratories favor emission to atomic absorption spectroscopy. The compelling factor appears to be analytical time which, in turn, is reflected in cost per analysis. For one thing, sequential determinations required by AA, does not lend itself readily to repeats. When a sudden change is noted lab personnel understandably find it advisable to rerun the sample to be sure of their results before reporting them. The analyst can do this within two minutes for all of the elements simultaneously by emission spectroscopy. In sharp contrast, a complete AA rerun, involving changing of settings and hollow cathode tubes, may take 30 minutes.

SOAP does have its limitations. Recurrent depletion and replenishment of crankcase oil tend to mask trace-element buildup. Time between sampling and analysis may be too long to catch an incipient failure. Catastrophic failures—snapping of a linkage arm because of metal failure, for example—cannot be predicted at all.

When a particular element or group of elements does rise above normal concentrations, it is the task of the lab to attempt to put its finger on the troublemaker. To do this intelligently, an intimate knowledge of composition of the oil-wetted innards of the engine is essential. Progress is so rapid that often two identically coded engines will be manufactured with a part or two the composition of which has been switched. The problem is compounded in a commercial laboratory where the variety of engines, gear boxes and types of oil is so much greater than in military aircraft.

Table 1 is a rough summary of probable causes of trace-element build up.

To quote General Electric's Flight Propulsion Division Service News of June 1967,

"Although SOAP alone may not isolate to less than two or three suspect areas, and other forms of trouble shooting may be required to pinpoint the contaminating part, SOAP labs can ALWAYS be certain that a component is NOT wearing abnormally when oil contamination is normal."

TABLE I

USUAL CAUSES OF TRACE-ELEMENT BUILDUP

Trace element detected	Evaluation
Fe	Defective gear—outer race scraping against its liner.
Fe, Ag	Ag-plated spline wearing excessively.
Fe, Cu, Ag	Appearing in this order, excessive bearing wear.
Mg	Oil from pump and gearbox housings. Steel gear may be abrading Mg-cast housing.
Cr	Worn parts frequently built up by Cr-plating and replaced. Normal.
Pb	In reciprocating engines, tetraethyl lead in gasoline interferes. In jet engines, Pb bearing surfaces are common.
Si	Silicone in synthetic oil interferes. Otherwise, defective air filter.
Al	Lube pump wear (General Electric T58 engine has Al-cast housing).
Na	Salt water leakage into engine aboard ship.

WHETHER from atomic absorption, emission spectroscopy or any other type of chemical method, analytical results can only furnish inferential information because the parameter measured is not the parameter desired. What is wanted is a means of predicting impending failure of a component and what the chemist does is to examine waste products. In other words, the composition of the used crankcase oil is one step—and sometimes more than one step—removed from a malfunctioning engine. Recognizing this, a number of organizations are at work on a means of inching closer to actual engine performance. Such a monitor might be as simple as a stethoscope with which the sound of a scraping journal often can be detected and isolated, too. Going one step further, a string of microphones might be placed over vital moving engine parts, their output fed to a computer programmed to ring a warning bell whenever the sound pattern departs from a plugged-in normal reference range.

American Airlines is actively pursuing this approach in its Astrolog, an airborne recorder/computer designed and built by the AiReseach Division of Garrett Corporation. At a cost of $100,000 per plane, AA is currently equipping its entire fleet of aircraft with the device.

Astrolog actually has a dual function: to monitor crew performance as well as engine health. Before takeoff, the crew record the flight number, segment number, day of the month, actual takeoff weight, fuel quantity and the number of the flight plan. Aloft, the flight performance recorder then continuously tapes such information as start of takeoff roll, gear retraction point, flap management, climb conditions, descent rate, engine thrust, time from 50 feet to landing, landing speed and reverse thrust management. It goes without saying that Astrolog can thereby provide indisputable evidence of poor flight management. But at the same time a second recorder—the engine performance monitor—provides a continuous record of engine condition. In this unit such parameters as engine pressure ratio, exhaust gas temperature, rotor speed, oil temperatue and pressure and turbine vibration are plotted.

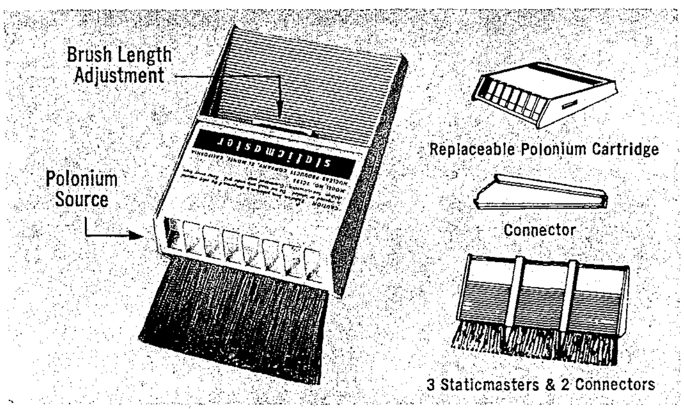
At the end of each day, tape magazines are removed from the aircraft, their data transmitted to an IBM 360 computer at American Airlines' Maintenance and Engineering Center in Tulsa where it is processed. The computer prints out 1) a list of the faulty engines identified during the day; 2) a description of their symptoms and probable causes; 3) an evaluation of the urgency. In addition, the computer keeps a daily record of the more important engine parameters on a separate sheet for each engine. Referring to these sheets, an inspector searches for trends. The actual operating temperature of the lubricating oil may vary somewhat from engine to engine. An upward trend, however, portends trouble ahead.

Whether the Astrolog approach will supplement or supplant spectrometric analysis is anyone's bet at this time but, quite clearly, Astrolog has only scraped the surface of its potential capability. Already, engine vibration as a whole is taken as an important monitoring parameter. This is but one trivial step removed from engine vibration at several vital points. When the vibration of a particular section is continuously compared with and judged against a pattern considered normal, a significant breakthrough will have been made.

Most likely, electronic computer technology will ultimately dovetail with spectrometric analysis to provide an even fuller and faster picture of engine performance than is being obtained currently. The spectacular results of SOAP weigh heavily in its favor today. SOAP is now applied to over 60,000 AF jets, turboprop and reciprocating engines. Correct predictions are very much the rule. When the SOAP lab recommends examination, they are right 90% of the time for jet engines, 80% of the time for recip engines, 92% of the time for transmission boxes. In 1966, the Air Force estimated a saving of $13,000,000 through SOAP. The Army is extending the program on an experimental basis to tracked vehicles in Alaska, heavy duty tractors in Missouri and generator sets at various missile sites.

Commercial and after that household applications are certain to develop. Jon Poley believes that in ten years spectrometric analysis will be a common, accepted routine for thrifty automobile owners. Perhaps they will even learn to spell spectrograph without deleting the central "r."

—AJM



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2—A retractable brush head providing adjustment for stiffness and/or closeness of the brush upon the surface being cleaned.

Fully retracted, the soft bristles are also afforded protection when the brush is not in use.

3—The new 3″ model has provision for joining several together when that is desirable.

All of the brushes are ideal for lint removal from such untouchables as gratings, mirrors, slits, and yes, also phonograph records.

3900 **Staticmaster Brush,** 1″ wide, model 1C50 (50 microcurie polonium element) ....each **$5.25**

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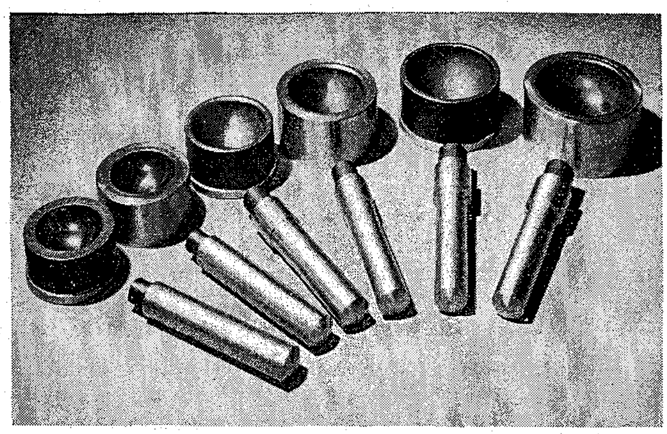
Replacement Polonium Cartridge for 3C500 each **$ 10.20**

3902 **Staticmaster Brush,** 1″ wide, model 1C200 (200 microcurie polonium element) ....each **$ 6.75**

3903 Connector for joining 3″ models ....each **$ 1.75**



SILICON CARBIDE MORTARS

Even a quick perusal of a Knoop Hardness chart will confirm that, next to diamond, boron carbide is the best material with which to construct mortars for hand grinding. At the two and three inch diameter sizes, however, economics becomes a significant factor and many labs have frugally been making do with not so hard, not so durable and not so expensive alumina mortars.

The rugged individualist, who for some years has been our (and just about the entire nation's) specialist in finishing and polishing boron carbide, has now come up with another helping hand: a silicon carbide mortar and pestle set costing less than half that of boron carbide. Again consulting Knoop we find silicon carbide hardness right up there double that of tungsten carbide and within the range of sapphire.

Our new Silicon Carbide Mortar and Pestle Sets are mounted just like those expensive sets and, but for the extreme grinding problems still requiring boron carbide, will be just as efficient and comparably contaminant-free. Silicon carbide is inert to most solvents and contains no binder.

3207 **Mortar and pestle,** silicon carbide. Mortar cavity 2″ d by 1″ deep; pestle 9/16″ d. ....set **$138.00**

3208 **Mortar and pestle,** silicon carbide. Mortar cavity 3″ d by 1-1/2″ deep; pestle 3/4″ d. ....set **$200.00**

tricks of the trade

Freezer/Mill Feats

The only time anyone challenges our new liquid-nitrogen-cooled 6700 Freezer/Mill is when all else fails. For reluctantly, we confess that our room-temperature grinders have two drawbacks. Substances are cooperative only to the extent that they are brittle at room temperature. Secondly, localized heating caused by the violent impact can change the composition of unstable organics.

In the course of grinding feasibility samples for customers we have come on two valuable tips we'd like to pass on. To make certain that samples are not locally overheated even under liquid nitrogen, we often cycle the grinding time: two minutes on, followed by one minute off. Usually two or three such cycles suffice. To grind particularly gooey materials such as a sticky oil-extended SBR rubber, we found the addition of a grinding aid to be necessary. Sand, KBr, household detergent are all suitable, the latter boasting the advantage of being unreactive and leachable with water.

A representative group of samples ground in the Freezer/Mill follows. Would you like to send us an evaluation sample or two? No obligation, naturally.

6700 Freezer/Mill Grinding Results

Material	Form	Weight, g	Time, min.	Final Mesh
Nylon (a)	1/8" beads	2	2x2 (b)	100-200
Teflon	2 mil tape	3	2x2	100
Polyethylene	10 mil sheet	1	2	200
Candle wax	chunk	1.5	2	100-200
Chewing gum	chunk	1.5	2	100-200
Hair	dog clipping	0.5	2	200
Sheep wool	wad	0.5	2	200
Rubber, oil-extended	shearings 3/16"	1.5 (c)	2	25-50
Rubber band	shearings 3/16"	1.5	2x2	100
Space food	stick	2	2	100
Aluminum foil	2 mil piece	1 (d)	3x2	100-200
Steel wool	wad	0.5	2	100
Permalloy 5	shot 1/16"	2	3	30
Mouse skin	Raw, 1/2 animal	2	3	200 (e)

(a) Three different types of nylon yielded similar results.

(b) Two 2-minute grinds with a one-minute cooling period between.

(c) Equal amount of sand added. Purpose: ethanol-toluene extraction.

(d) 0.5g of Tide detergent added.

(e) Equal weight of sodium sulfate as dehydrating agent.

6700 **Freezer/Mill,** 115 v, 50-60 Hz, can be used with or without LN_2 bath ....each **$620.00**

6701 **Grinding Vial,** including two end plugs, an impactor and four plastic center sections....each **$ 35.00**

Noted in the Literature

For the agronomists among us the Spex Mixer/Mills and Shatterbox are recommended for grinding soil prior to carbon determination in "Methods of Soil Analysis, Part 2," published by the American Society of Agronomy.

Also the Journal of the American Oil Chemists Society for October, 1967 found the Mixer/Mill suitable for wet grinding oil seeds.

Prettier Planchets

Our 3619 Spec-Caps fit rather loosely inside our 1-1/4" die and, if they are not properly centered beforehand, often a lopsided pellet will be formed. To prevent this, the cap should be flared slightly before filling so it slides snugly into the die cylinder. Simply press a 2" diameter ball against the open face of the cap. The ball handle of our C-30 Hydraulic Press is most convenient, otherwise suitable wooden cabinet pulls can be purchased for about 15¢ at most hardware stores. We've cleaned the local Sears store out of pulls so we can supply one at no charge with your next order for 1000 or more Spec-Caps. Yours for the asking but keep a mallet handy too unless you have a rather firm palm or just a cap or two to do.

Plastic Funnel Counterbore

On the underside of our plastic funnels, there is a double counterbore. The smaller, of course, receives standard graphite electrodes. The larger one is designed to fit over our 1/2" diameter plastic vials. In the event that you find your technicians' aim not wholly accurate, the added target area of the funnel should prove helpful.

Paper Dolls to the Rescue

Conventional microphotometry relates the transmittance of a photographed spectral line to the concentration of the emitting element. Assuming an emulsion contrast of around 1.5 and limiting transmittance of 5% and 85%, the concentration range is restricted to about 100. Covering a range of 1000, the entire four members of our ubiquitous semiquantitative G standards cannot be measured conventionally.

An established technique, recently rediscovered in our laboratory, provides the answer. It utilizes the direct relationship between the energy emitted and the total amount of silver in the developed photographic image. If your recorder is equipped with a disc integrator, the entire line is simply scanned, its integrated value plotted against concentration. In the absence of a disc integrator, "paper dolls" are handy, the area under the curve simply cut out and weighed. Either way, we have obtained nice smooth curves.

SPEX **INDUSTRIES INC.**
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Return Requested