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# PROGRESS REPORT

Determination of Engine Condition

by

Spectrographic Analysis of Engine

Oil Samples

ASTIA

DEC 31 1961

11:00 AM

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5 APRIL 1961

Progress Report  
Determination of Engine Condition

by

Spectrographic Analysis of

Engine Oil Samples

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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.

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.

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.

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.



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.

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 #14 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

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:

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.

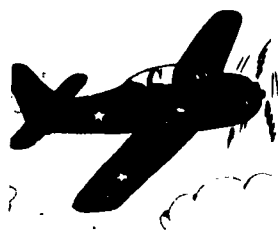
We have learned that the metallic content in engines in normal condition remains relatively constant. Apparently the loss of oil together with the wear metals in suspension, coupled with the addition of oil between flights results in establishment of a condition of equilibrium. We know that engines of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

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.

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.

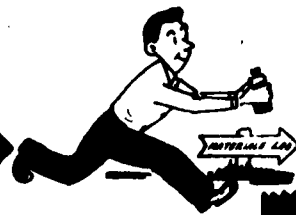


1. ENGINE OPERATING IN AIRCRAFT FOR DETERMINED PERIOD OF TIME.



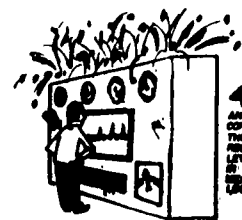
2

OIL SAMPLE TAKEN FROM OIL TANK PERIODICALLY AT SHORTER INTERVALS. SPECIAL SAMPLE TAKEN IF ANYTIME IF MALFUNCTION OR DISCREPANCY SUSPECTED.



3

OIL SAMPLE SENT BY POST TO OIL MATERIALS LAB.



4. SPECTROGRAPHIC ANALYSIS OF SAMPLE CONDUCTED BY LAB. THE PROCEDURE DETERMINES THE PRESENT LEVEL OF WEAR AND THE LEVEL OF WEAR IN RELATION TO THE OIL IN USE. RESULTS IN REPORT TO OIL MATERIALS LAB.

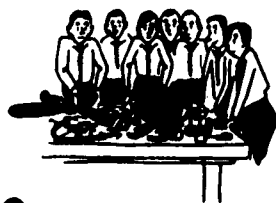
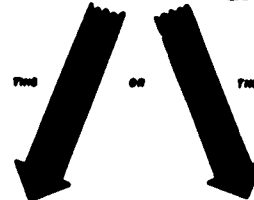


5. THE INFORMATION FURNISHED TO HEAD OILS DIV AND FOR COPY TO OILS DIV.

THIS

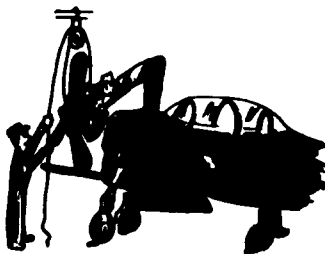
OR

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9

ENGINE DISASSEMBLED AND RESULTS FURNISHED TO ALL CONCERNED.

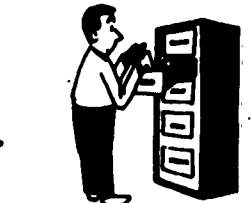


8

IF OILS SAMPLE ALSO SHOWS DISCREPANCY, ACTIVITY RETURNED TO FULL ENGINE AND SEND TO OILS DIV. ACTIVITY FOR PRESENT OILS.

7

IF DISCREPANCY IS SUSPECTED, OPERATING ACTIVITY IMMEDIATELY RESUMED BY PLACING OIL IN ENGINE TO OILS DIV. AND SEND OILS SAMPLE.



6

IF CONTAMINATION LEVELS OF OIL ARE CONSIDERED NORMAL, NO FOR ACTION. OILS FILED.

# 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

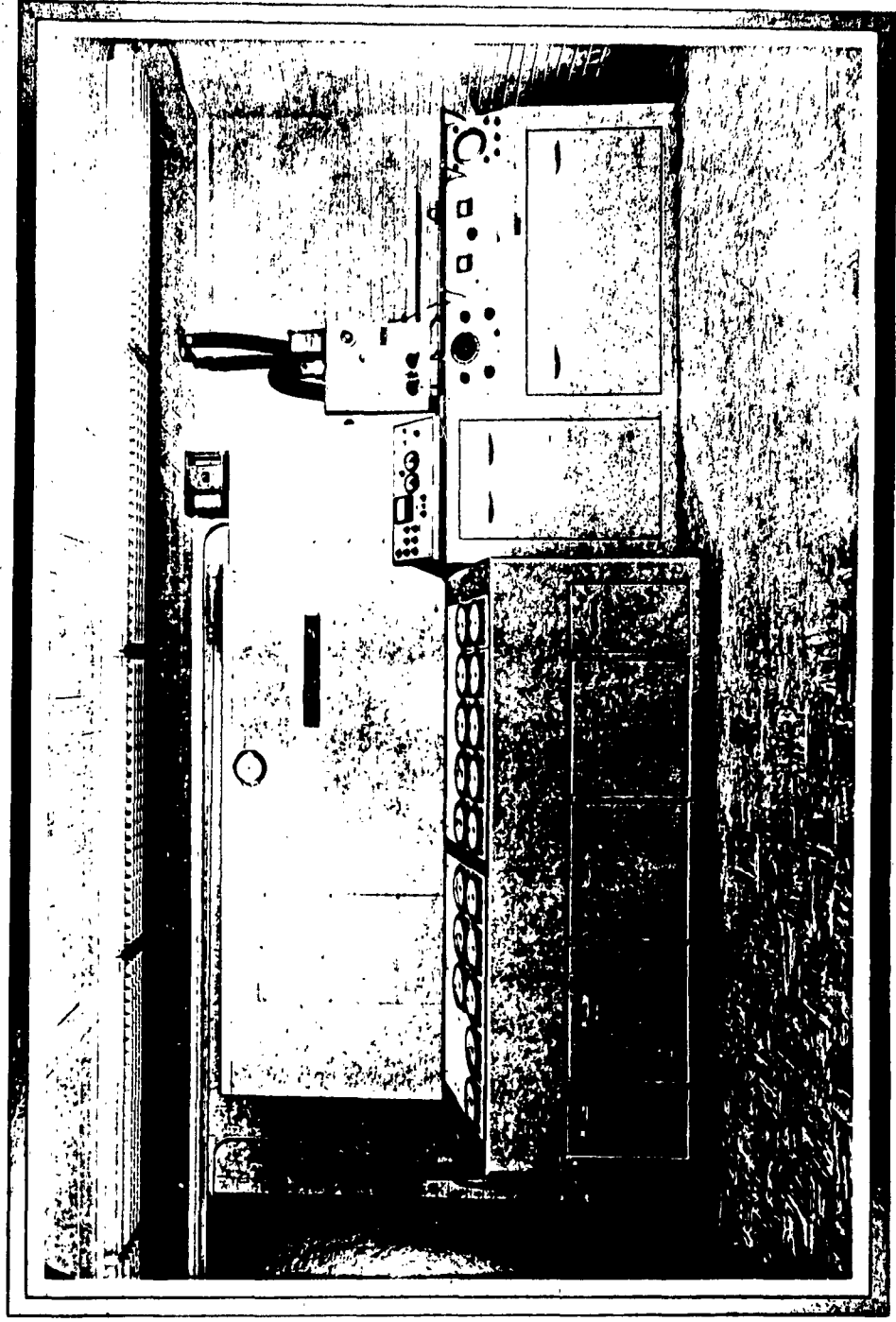


# **CHART SHOWING PROBABLE SOURCES OF WEAR METALS IN AIRCRAFT ENGINE OIL**

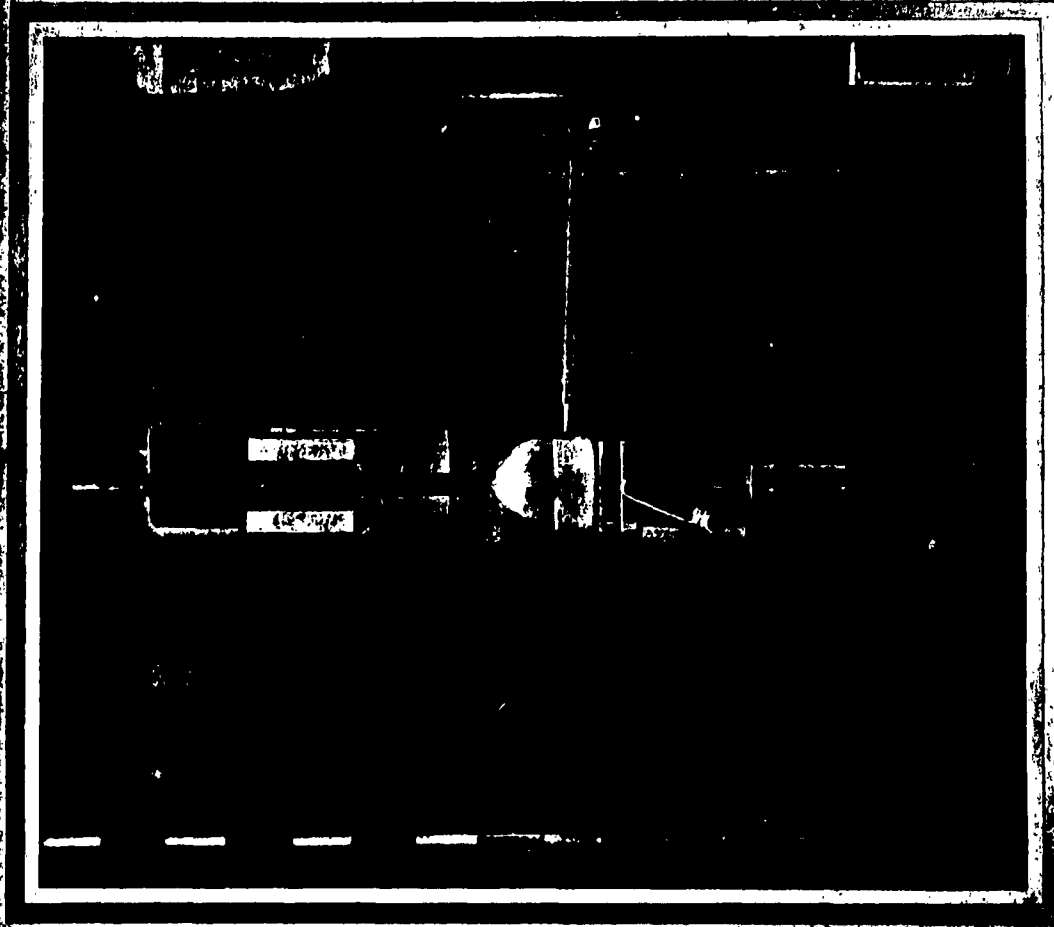
**R-1820-86**

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

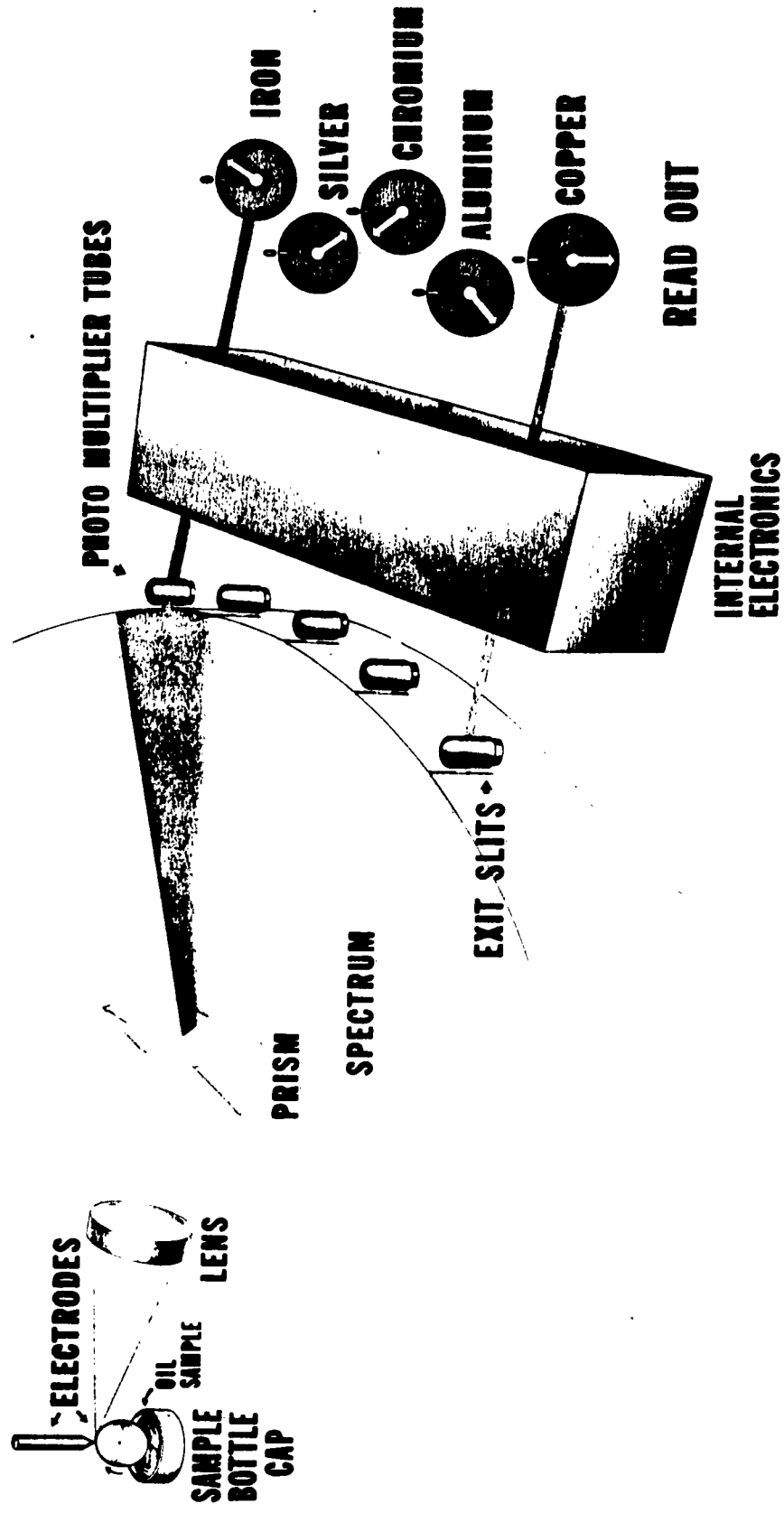
**GENERAL VIEW OF DIRECT READING SPECTROMETER**  
**USED FOR ANALYSIS OF AIRCRAFT ENGINE OIL SAMPLES**



# AIRCRAFT ENGINE OIL SAMPLE BEING SPARKED IN DIRECT READING SPECTROMETER



# ANALYSIS • TECHNIQUE

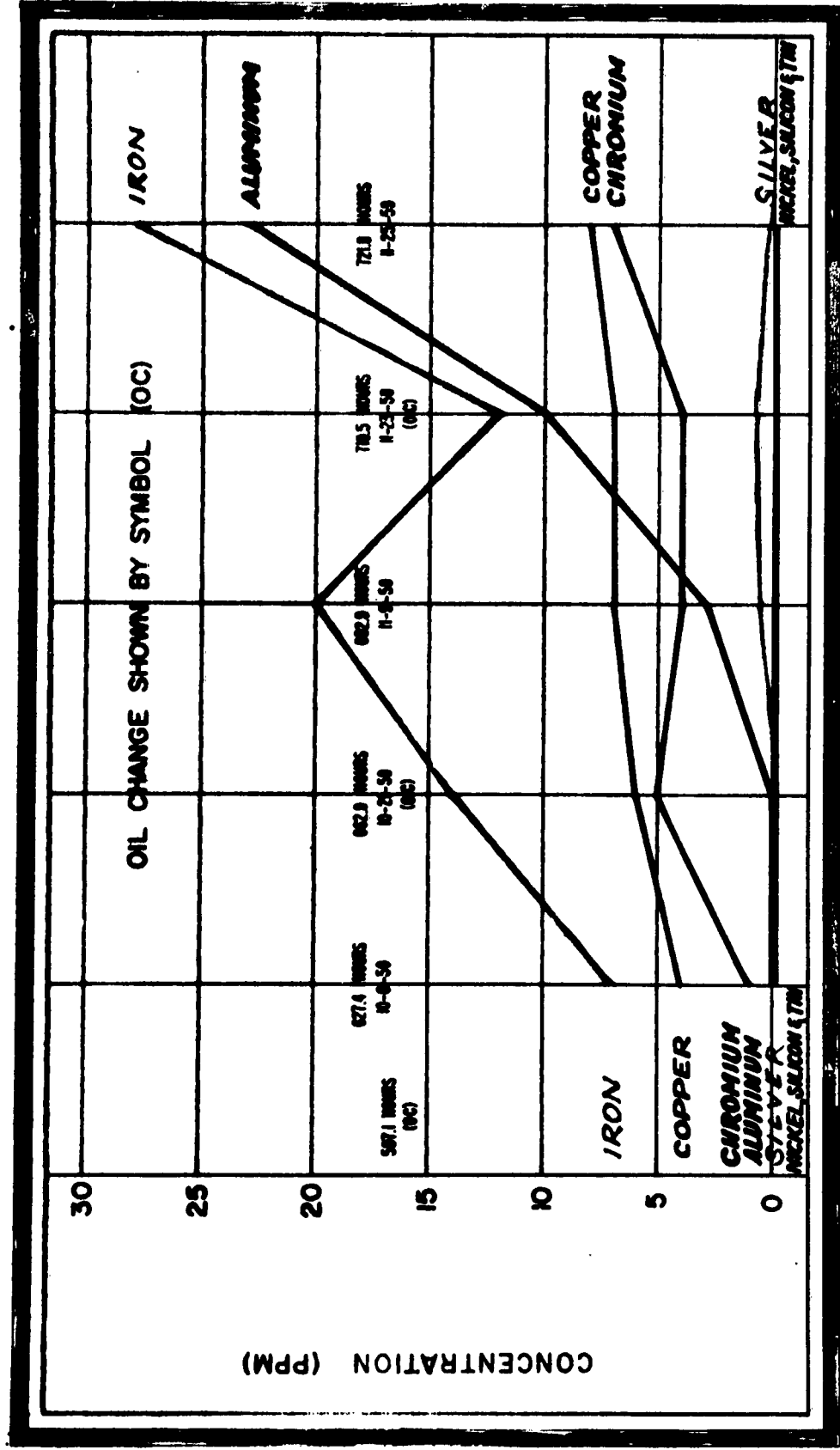


**RECORD CARD SHOWING ALL ANALYSES OF OIL SAMPLES**  
**TAKEN FROM ONE AIRCRAFT ENGINE UP TO TIME OF FAILURE**

[illegible]

# **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**



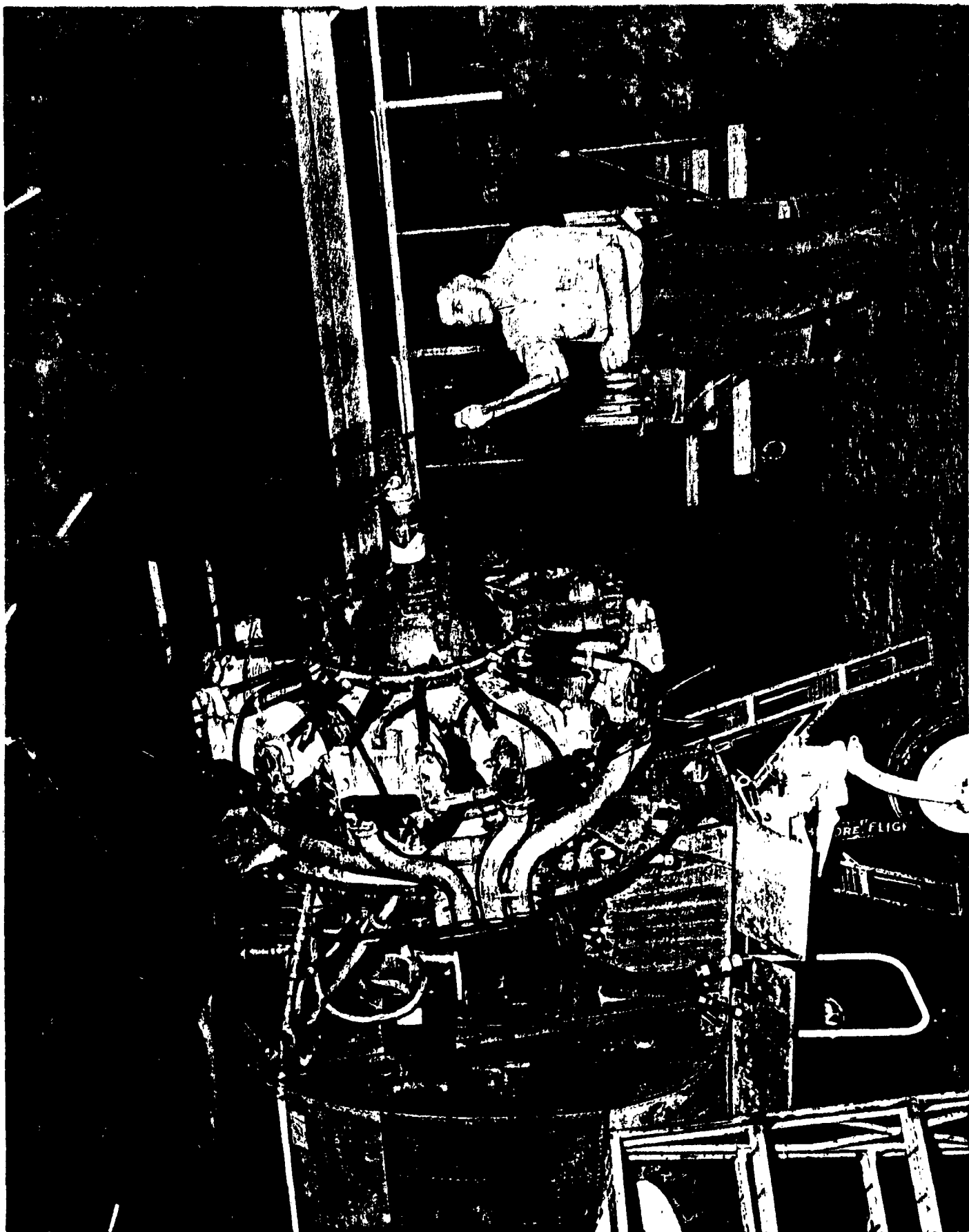


Exhibit 11

# **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.

