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BEARING AND LUBRICANT PROBLEMS

Final Report  
for the period  
1 September 1962 to 31 August 1963

prepared by

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Contract AF 34(601)-14089  
University of Oklahoma Research Institute  
Project No. 1384-4

February 3, 1964

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## INTRODUCTION

The OU Research Institute, during the contract year 1963, worked on three general problems and eight specific problems under the above project. The general or continuing problems were (A) the development of a petroleum base lubricant for KC-97 and B-50 aircraft turbosuperchargers with improved viscosity-volatility and viscosity-temperature characteristics, (B) development of improved turbosuperchargers storage preservatives, (C) testing of synthetic lubricant (principally MIL-L-7878 currently being used in the constant speed drive system.)

The specific problems which were successfully completed and on which final reports were submitted were (A) suitability of grade 1100 aviation oil after contamination with aviation gasoline, (B) determination of a suitable lubricant for use in ram air turbines, (C) determination of a suitable lubricant for lead screws of missile attitude stands, (D) inspection of J79/F104 Toloflex box bearings, (E) engineering study of ball bearings P/N VI-224248, (F) inspection of bearings from air turbine assembly P/N 202280 and 202290, (G) investigation of pour point of refrigerator compressor oils, (H) prevention of freezing in an evaporative heat exchanger by using constant boiling mixtures, (I) determination of a suitable high temperature lubricant for swivel joints in the hot air bleed line of KC-97 superchargers.

The progress made in each of these areas is summarized in the main body of the report and a complete discussion is included in a suitable appendix, either as a final report or as a year end summary of the progress to date.

## STATUS REPORT ON GENERAL PROBLEMS

A. The development of a petroleum base lubricant for KC-97 and B-50 aircraft turbosuperchargers with improved viscosity-volatility and viscosity-temperature characteristics.

This problem was a continuation of a specific problem worked on during FY 1962 and arose from the fact that Grade 1065 aircraft engine oil was required to furnish satisfactory lubrication to the anti-friction bearings and pump drive gears at the operating temperature of 300 F. The use of lower viscosity oils tends to decrease the life of the turbosupercharger bearings markedly. However, this heavy Grade 1065 oil will not permit the turbosupercharger to start without external heating at subzero temperatures. Therefore a lighter Grade 1010 oil is required for cold starting with a consequent loss in bearing life of these units during winter months. It was therefore decided to develop a petroleum base lubricating oil which would have shear stability enough to maintain its viscosity during service and a viscosity index sufficiently high to enable it to match the viscosity of 1065 at the 300 F operating temperature while still approaching the viscosity of Grade 1010 material at 0 to -10 F.

An additional problem in this area is with the MIL-5606 hydraulic fluid used in 3000 psi hydraulic systems which shows excessive shear breakdown reducing the base oil viscosity by 30 to 40 per cent and allowing excessive wear of hydraulic pumps and valves. A hydraulic fluid of the equivalent viscosity-temperature characteristics but not subject to shear breakdown is expected from this program.

While conventional refining procedures will not produce petroleum base lubricants of these characteristics, the Standard Oil Company (Ohio) has a pilot plant utilizing a process known as thermal diffusion which

has produced experimental lubricants from paraffinic base stocks which are of 140 viscosity index. A contract was entered into with Standard Oil (Ohio) Research Department to renovate their test column and operate it so as to produce moderate quantities of test lubricants of various viscosity and volatility characteristics utilizing base stocks and producing finished viscosities as specified by our needs. (See Appendix I for listing of oils procured.) Meanwhile, another lubricant supplier furnished a material of Grade 1010 viscosity but included an EP ingredient of high thermal stability. Bench evaluation of this material indicated that it showed no improvement over base petroleum oils in increasing the load carrying ability of bearing races. Therefore, this lubricant was not recommended for service evaluation.

Using the thermal diffusion oils furnished by Sohio, a mixture was compounded which meets the Grade 1065 aircraft engine oil specification at 300 F and has a 10,000 centistoke rating at -30 F. This compounded oil was then tested for shear stability at 5,000 psi for 100 hours. No significant breakdown in the viscosity was noted at the end of this period. This oil then will be recommended for further cold weather testing. Details regarding this development are included in Appendix I.

As a related part of this general problem a hydraulic fluid not subject to shear breakdown was expected to be developed as mentioned previously. The problem in this area arose during the current year as a result of relatively short life being experienced by Vickers rotary cam operated piston type hydraulic pumps. Several reports furnished by Dr. Cushman of OURI pointed out deficiencies in the bearing design on the main shaft of this pump. In discussion with the manufacturer, Vickers admitted that the pump was critical with regard to these bearings and



stated that bearing distress would be expected if the viscosity of the hydraulic oil was less than that specified by the MIL-5606 specification, i. e., 10 centistokes at 130 F. Since MIL-5606 is admittedly not a shear stable lubricant, some field samples of lubricating oil were obtained from operating aircraft and showed materially reduced viscosity, ranging from 6.8 to 8 centistokes.

It was therefore arranged to utilize a hydraulic ground cart at OCAMA and have the engineering test section run a sample of new MIL-5606 lubricant for a period of time in order to determine the equivalent shear breakdown in service. The hydraulic circuit for this experiment consisted of a 3,000 psi pump, a relief valve which dissipated the 3,000 pound pressure to atmospheric, a heat exchanger to absorb the energy input and maintain the oil at 130 F with return to the suction of the hydraulic pump. Utilizing this test circuit, new MIL-5606 oil, having a viscosity of 10.3 centistokes, showed a decrease to 7 centistokes in 36 operating hours.

To determine whether this was an inherent characteristic of the lubricating oil or was due to the viscosity index improving polymeric thickener, straight mineral lubricating oil was obtained from Mid-Continent stocks possessing a viscosity index of 97. Although this material possessed too high a viscosity at sub-zero temperatures for use in aircraft service, the lubricant was matched in viscosity at the operating point, being 10 centistokes at 130 F. The circulation of this test oil for 36 hours produced a nominal viscosity decrease to about 9.5 centistokes. It is believed that most of this viscosity decrease was due to polymeric material left in the test stand from previous runs, since it is impossible to completely clean one of these stands before switching to a new test material.

Therefore, it was concluded that the difficulty was due to the use of the polymeric VI improver necessary to obtain viscosity temperature characteristics required by the MIL-5606 specification while using normally refined base stocks. It is therefore considered desirable to obtain an oil having a high natural viscosity index and it is expected that some of the stocks to be obtained from Sohio under the development program mentioned under Specific Problem 3 will be materials which have viscosities in the same range as present hydraulic oils.

Meanwhile a smaller shear breakdown apparatus was developed by the Engineering Test Laboratories OCAMA so that additional materials could be evaluated. A test rig was also built by the OURI Lubrication Laboratory. The OURI test rig consists of a hydraulic pump with built in heat exchanger suitable for circulating oils through a restrictor valve at pressures up to 10,000 psi and at controlled temperatures. This pressure is substantially above that currently used in USAF aircraft so that it should be able to evaluate materials under more severe conditions than imposed by current or prospective aircraft requirements.

To date several tests have been accomplished utilizing the test rig, both in calibrating its performance versus MIL-5606 type material, and in evaluating the improvement to be expected from thermally diffused natural high VI products.

Detailed results are included as Appendix II of this report. In summary, these are:

1. The OURI test stand duplicates the breakdown history of the OCAMA field-stand when the results are compared on a basis of equal energy added per pound of system fluid.

2. The rate of breakdown is controlled not only by the total amount of energy absorbed by the oil, but also by the rate of energy absorption. Thus, the smaller oil system storage capacities and higher system pressures are still further approaching into MIL-5606's already marginal capability.

3. Under test conditions of equal severity, thermally diffused oils showed negligible shear breakdown. When blended to equal viscosity at maximum system operating temperatures of 300 F, the untreated oils showed slightly inferior low temperature properties. Means of alleviating these characteristics are discussed in Appendix II.

B. Development of improved turbosupercharger storage preservatives.

This project is a continuation of work done during the FY 1962 contract where it was found that corrosion of the anti-friction bearings was occurring during long time storage of turbosuperchargers. This corrosion was acidic corrosion rather than rusting and the damage was attributed by the OURI group to acidic corrosion from oxidation of the rust preventive lubricant compounds. Although this was originally doubted by other investigators, it was found to be the correct conclusion by the end of the 1962 project. A suggestion was made by the supplier of the corrosion protective compound that the addition of an anti-oxidant additive known as Parabar 441 obtained from the Enjay Division of Humble Oil and Refining Company, would prevent the oxidation and eliminate or minimize the resulting corrosion. The addition of 0.2% of this material was therefore recommended to the turbine overhaul contractors, General Electric Company, Ontario, California.

Base stock lubricating oil and rust preventive compound used in the material furnished GE were obtained by OURI, and a series of sample oils were prepared. These included untreated lubricant base, pure corrosion

preventive compound, untreated corrosion preventive blend and corrosion preventive blend utilizing various percentages of the anti-oxidant material. In addition, an oxidation resistant corrosion preventive compound, MIL-L-21260, was obtained for comparison purposes. Samples of each of these lubricants were used to coat a full-scale turbine bearing such as those used in the turbosuperchargers. These bearings were units which had been rejected for mechanical defects by the Bearing Inspection Company, but which were not corroded. After being coated with the various lubricating materials, the bearings were half immersed in the test lubricant and were then stored in an atmospheric pressure oven at 160 F. After thirty days of this test, the following observations were made:

The oxidation sensitive material is the corrosion preventive compound rather than the base oil. Little change in lubricant characteristics and no corrosion are observed in the base lubricating oil even though no anti-oxidant has been used. Heavy deposits including corrosion pits have been observed in both the pure corrosion preventive material and in the 75/25 blend. The use of Parabar 441 as of thirty accelerated test service minimized oxidation and deposits and essentially eliminated the corrosion pits shown in the untreated specimen.

After fifty-eight days of this test the following observations were made:

1. Previous conclusions were confirmed in that the rust inhibiting compound is the oxidation sensitive material which furnishes acidic corrosion in the blend. Although material oxidation was observed in the base lubricating oil without anti-oxidant, no corrosive substances were formed.

2. Heavy corrosion and marked lubricant deterioration were found both in bearings treated with the pure corrosion preventive and in bearings treated with the 75/25 blend of oil and corrosion preventive.

3. The 75/25 blend treated with various quantities of Parabar 441 showed materially reduced oxidation rates. In neither case was any acidic corrosion observed on the bearings.

4. An oxidation inhibited corrosion preventive oil available under Military Specification, MIL-21260, also prevented acidic corrosion of the parts and presumably would also be suitable as a rust preventive compound. It is not known whether this material would be suitable for use in aircraft reciprocating engines as well as in turbosuperchargers.

A test, utilizing 52100 steel coupons in place of the full-scale bearings and with still lower amounts of Parabar 441, to determine the minimum treatment level at which protection is obtained was also made. As a result of these preliminary tests, Parabar 441 was recommended as an anti-oxidant for use in preventing storage acidic corrosion in the use of MIL-6529C preservative oils. Simultaneously, a modified bench test was commenced to determine whether anti-oxidants more effective than Parabar 441 were available. Details of testing procedure and complete results are shown as Appendix III. They may be summarized as stating that the use of either Ethyl Corporation Anti-oxidant 702 at 0.2% concentration or the use of EI duPont Ortholeum 304 at 0.2% concentration plus the use of 0.1% duPont Metal Suppressor, will give protection for approximately double the life of that shown by Parabar 441. The use of Ethyl 702 seems indicated since it has already been extensively field tested by AF for use as an anti-oxidant in MIL-7808 lubricants.

Test superchargers with the Parabar 441 anti-oxidant were stored at Ontario, California, for field testing. These units were to be inspected after four to six months and every two months thereafter until such time as corrosion pits and oxidized oil deposits are observed to occur. An inspection after five months time revealed no evidence of acidic corrosion. Neither from appearance nor odor did the lubricating oil give any evidence of oxidation having occurred. It was concluded that the current treatment level of 0.2 % Parabar 441 could be considered as suitable for a minimum of five months storage at bases in the Los Angeles area. The next time interval for examination of a field stored unit will be after termination of this contract.

C. Testing of synthetic lubricant (principally MIL-L-7808 currently being used in the constant speed drive system.

The work on this general problem was concentrated on (1) determining the desirability of single source procurement for MIL-L-7808E lubricant for use in CSD units and (2) the testing of candidate lubricants on the OURI wear tester. Each of these will be discussed below.

A single source procurement was originally suggested by SAC and was discussed at length by representatives from ASD, OCAMA and the OU Research Institute at two meetings held at Wright-Patterson Air Force Base. The conclusion arrived at by the two conferences were as follows:

1. There is no indication from field service that any lubricant currently on the MIL-L-7808E approved list is better than any other lubricant for use in constant speed drives.
2. It is impossible at the present time to interpret differences in physical properties shown in the inspection tests in terms of variable performance in the constant speed drives.

3. The variation between two batches of MIL-L-7808E oil from a single manufacturer is at least as great as the variation between products obtained from different manufacturers.

4. Field experiences from the Sundstrand Company's test stand has been developed using chiefly a single source of supply; therefore, these total test hours do not lend themselves to interpretation as regards to the effect of lubricating oil quality.

5. Therefore, it is impossible at the present time to recommend a single source procurement of MIL-L-7808E on the basis of physical tests.

6. It was, therefore, recommended that the test program be designed to evaluate the effect of changing physical specifications on performance in constant speed drive units. This test program would require correlation of various physical test results on a variety of proposed candidate lubricants and their actual test results in CSD units in order to determine a unit rating on the lubricant for comparison with a rating determined from physical inspection data. It was recommended that this drive testing be done at ASD.

7. In view of the narrow range of variability set by the MIL-L-7808E specification, it was recommended that the attempt to procure a satisfactory CSD lubricant not be restricted to require conformity with the MIL-7808E specification.

The OU Research Institute concurs with the recommendations made at the meeting. As a result of this, ASD has circulated to various engineering groups a questionnaire on quality of MIL-L-7808E lubricants. The OURI comments on this questionnaire are included as Appendix IV.

Progress in testing of candidate lubricants on the OURI wear tester has proceeded along two avenues. Initially, testing was suspended in order to investigate better means of determining the useful life of the test pieces on a basis other than friction and noise levels. Since torque meter readings did not prove sensitive enough, an attempt was made to utilize vibration measurements. Due to the fact that the test rig is operated at 300 F, it has so far proven impossible to find a vibration pickup which will give an adequate electronic output continuously at temperatures of 300 F and above. Because of the difficulties with the torque meter readings and vibration pickup readings, the testing was continued basing useful life on noise and friction energy measurements. Information collected regarding these candidate lubricants led to the conclusion that the test machine did have value in predicting the load carrying ability of the lubricant. It was noted that the same lubricant tested under the same conditions repeated its results with reasonable accuracy considering the many variables that are involved. It is emphasized that this test machine should be used only to differentiate the load carrying abilities of lubricants undergoing the same standard test under identical conditions. This is a valuable test in that it is economical to operate and it gives conclusive results of the wear properties of the lubricants being tested.

In the initial testing with the Ethyl Corporation additive AWA 29, an increase was found in the antiwear properties of bearings tested on the OURI tester. Subsequent test with different MIL-L-7808 oils and the AWA 29 additive gave antiwear properties which were worse than the lubricant without any additive. It was therefore decided to discontinue testing with the AWA 29 additive.



Of the candidate lubricants evaluated on the OURI wear tester, the Socony Mobil XRM-139A type II oil proved to be of superior quality in load carrying ability. Its rating on the tester was very significantly higher than the standard MIL-7808 oil. On this basis, the Socony Mobil type II oil was placed in the CSD test stand at Tinker and a special drive evaluated using this lubricant. This special drive had had the bearing races coated with Molybdenum Disulfide and was run in conjunction with type II oil. The test drive ran approximately 34 hours at loads up to 81 kilowatts at which time it was disassembled and inspected. The bearings which were coated with the Molybdenum Disulfide showed very little scuffing. The drive was subsequently reassembled and run for approximately six more hours at loads of 130 KW at which time the drive failed due to mechanical deformation in the drive due to the overload. On the basis of this test, it was recommended that the Socony Mobil type II oil be used in the CSD test stands because of its superior performance as a lubricant.

In addition to the testing of lubricants, an analysis was made by Dr. Cushman of OURI on the design and finishing of the several raceways and pistons. Specifically, three quality and design deficiencies were found which will minimize raceway life: (1) Inadequate bearing contact surface, (2) poor raceway finish and polishing pits, and (3) the black oxide coating intended to prevent scuffing on the run-in but which constitutes a dirt contamination of the lubricant. The complete report is included as Appendix IV.

### SPECIFIC PROBLEMS

In addition to the previous problems which represent continuing areas of responsibility to the Air Force, the OURI group worked on several specific problems which were successfully concluded during the fiscal year and on which final reports made to the Air Force are included as appendices to this final report on the project. Summaries of these are given below:

A. Investigation of the suitability of Grade 1100 aviation oil after contamination with aviation gasoline.

This specific problem arose from the desire of the Strategic Air Command to extend the life of reciprocating aircraft lubricating oil. It is the policy of SAC in winter to dilute the oil in the lubricating system with approximately 12% of aviation gasoline. These engines are then ground run after being started for a sufficient length of time to evaporate the gasoline. Tech orders require that at least every third such engine start should be accompanied by flight to operating altitude 30,000 feet so as to fully warm the engine and evaporate the gasoline. At the present time the orders require discarding the lubricant after three such flights. It was requested that we determine if the remaining traces of gasoline dilution were causing deleterious effects or whether possibly four such operations could be considered.

A laboratory bench test was set up for a sample of new Grade 1100 aviation oil diluted with 12% gasoline. The results show that none of the changes in the physical specifications are considered to be harmful to the function of the lubricating oil and the comparison of results between one cycle and the three cycles indicates that continued deterioration is not to be feared. On the basis of these results,

a fourth operational cycle was recommended. The complete report including the recommendations are included as Appendix V.

B. Determination of the proper lubricant for use in ram air turbines.

This problem arose as a result of sticking of the pitch control mechanism in blades of ram air turbines. This pitch control is maintained by a set of interlocking gears held in place by ball bearings. The bearings stuck from rust corrosion due to condensation and ambient moisture. A review of the operating conditions and the requirements which the lubricant should meet was made. As a result a military approved lubricant, MIL-G-10924B, automotive and artillery grease, was recommended as a satisfactory lubricant for the purpose. The final report on this specific problem is included as Appendix VI.

C. Determination of a suitable lubricant for load screws of missile attitude stands.

This problem arose when the North American Aviation Company specified a proprietary lubricant for lubrication of load screws which control the attitude of the missile check out stand built by them and which had shown excessive wear when lubricated with conventional lubricants.

Their recommendation was that a material referred to as Torco Grade SAE 50 motor oil, supplemented with an additive known as Torco Red-top or Torco Blue-top additive. Procurement of these materials represents a supply problem in many parts of the United States.

Samples of Torco motor oil were obtained and analyzed for physical and chemical properties. From the results of the test, two Military Specification lubricants were recommended. The same or improved characteristics should be obtained by the use of Military Specification lubricant MIL-L-18486 or by the Federal Specification WV-L-768. With

this recommendation, the initial project on this specific problem was closed.

The same problem was reopened at a later date to have OURI furnish consulting services for the testing of the recommended alternate lubricants. At the end of the project year the testing of the proposed alternate lubricants had not been completed.

The final report on the first phase of this specific problem is included as Appendix VII.

D. Investigation of the serviceability of the J79/F104 Teleflex box bearings.

This problem arose when it became necessary to determine the serviceability of the J79/F104 Teleflex box bearing. After analysis of the bearing assembly the recommendation was made that the bearings be machine tested on the Tinker bearing test machine before installation into the Teleflex box. This bearing test, together with the washer lubrication were the only recommendations made in changing the assembly of this unit. The complete engineering report is included as Appendix VIII.

E. Engineering study of ball bearings P/N VI-224248.

This problem arose when the ball bearings P/N VI-224248 used in the Vickers hydraulic motor model NR EA 1010-145-2A developed a roughness after a few hours of operation. It was suspected that this is one of the major causes of the motor failures. Assistance was requested to make a full analysis of the subject bearing and recommend corrective action. Of the five bearings submitted for inspection, four were found to be defective using the McKnight Analyzer and DuMont 403 oscilloscope test machine. The problem here seems to be one of manufacturing quality which can only be cured by quality testing at the factory. The complete Engineering report on this specific problem is included as Appendix IX.

F. Inspection of new bearings from air turbine repair kits S/N 1660-571-9158.

This problem arose when the Air Accessories Repair section experienced difficulty in passing an air turbine assembly P/N 202280 and 202290 due to excessive vibration. A number of new bearings were routed to the bearing shop for inspection and were found to be defective for various reasons. It was requested that OURI make an engineering analysis of several bearings to determine if they met manufacturing tolerances. Of the four New Departure JOLO20 bearings submitted, three were found satisfactory and one was rejected as being marginal. The complete report on this specific problem is included as Appendix X.

G. Investigation of pour point of refrigeration compressor oils.

This problem arose from the desire to utilize a conventional vapor compression refrigeration system in place of air heat exchanger cooling for electronic gear in certain special airplanes. In view of the fact that the refrigeration would not be continuously required, it was believed that an operational requirement on the refrigeration compressor would be that it be required to start at an ambient temperature of 40 to 45 below zero F, as a consequence of having been cold soaked at altitude for 2 to 5 hours prior to being called on to furnish a cooling load.

Since the equipment was to be procured from Dunham-Bush Company of Hartford, Connecticut, inquiry was made to their Engineering Department regarding the cold soak starting characteristics of their compressor. They informed that they could not guarantee the operation of their unit below -10 F ambient unless proprietary compressor oils were utilized. Those included Suniso Oil from Sun Oil Company, and Capella A Oil from

Texaco, Inc. With those oils they were able to operate at -35 F, but were not certain of the ability to start at any lower temperature since they had never utilized the unit at such temperatures. The compressors had been operated at -55 F, but this was done by cooling the ambient temperature with the unit operating, and with the use of Suniso Oil.

This information was furnished to OCAMA. At this point, the Cuban emergency alert occurred and the project was suspended. To date, no resumption of the project has been given us. It is, therefore, believed that the special problem is concluded and this constitutes a final report on the problem.

H. Prevention of freezing in an evaporative heat exchanger by the use of constant boiling mixtures.

This problem involved a heat exchanger which cooled bleed air by boiling of water. The heat exchanger is in the B-58 aircraft and trouble occurs in cold weather when the water in the heat exchanger freezes. The trouble arises when 400 F bleed air from the engine melts ice next to the heat exchanger tube and then vaporizes it before the main body of ice melts. This develops sufficient pressure to collapse the heat exchanger tubes and destroy the exchanger.

The analysis of the problem led to the recommendation that a mixture of Cellosolve/water and Methyl Cellosolve/water mixture be evaluated for inflammability hazards. The final report on this specific problem is included as Appendix XI.

I. Determination of a suitable high temperature lubricant for the swivel joint in the hot air bleed line of KC-97 supercharger.

This problem arose when the swivel joint in the hot air bleed line to the KC-97 supercharger would become corroded by the action of the hot

exhaust gases passing through the duct, resulting in freezing of the joint and subsequent breakage of the supercharger housing. It was requested that OURI participate in the solution of this problem by specifying a suitable high temperature lubricant.

By the very nature of the swivel joint, and the fact that high temperatures up to 1700 F are involved, a coating of some sort which would possess lubricating qualities seemed to be the answer. Investigations by NASA have shown that some inorganic compounds possess lubricating properties when introduced at the interface between sliding metal surfaces. In testing these compounds at temperature to 2,000 F the compounds were considered in the range for effective boundary lubrication under extreme conditions if these friction coefficients were below 0.2. Coatings which have shown considerable promise are lead monoxide bonded to stainless steels with lead silicate (good to 1,250 F) and calcium fluoride coatings bonded to nickel base alloys with a cobalt oxide, barium oxide, or boric oxide binder (good to 1,900 F).

The necessary materials for mixing and applying the lead monoxide base coating to the supercharger swivel joint were procured and a joint was coated. The end of the fiscal year contract period occurred before further experimenting and testing could be made with this coated swivel joint.

The search for the high temperature lubricant revealed that in addition to the NASA developments, there were two commercially available compounds which reportedly would be sufficient to prevent seizing. One compound is made by the Texaco Company, Dallas, Texas, and is qualified under Pratt and Whitney specifications. Another high temperature lubricant is sold by Felt Products Manufacturing Company, Skokie, Illinois.

Testing of these candidate compounds could not be accomplished in this contract year.



## APPENDIX I

### The Development of a Turbosupercharger Lubricant from Thermally Diffused Stocks

As mentioned in the first part of this report, special refining methods known as thermal diffusion make it possible to produce pure petroleum stocks of higher than normally obtainable viscosity index, with the volatility and shear stability of the base materials.

In view of the need of improved low and high temperature characteristics in turbosupercharger lubricants, the Sohio research laboratories were commissioned to produce a series of thermally diffused materials, the resulting test lubricants being listed in the attached table.

As can be seen from the attached viscosity temperature curves, Grade 1010 material has excellent viscosity characteristics at -30 F. However, its viscosity at full operating temperature is of the order of 1 cs (approximately that of water), thereby being ineffective in preventing excessive bearing wear.

Meanwhile, Grade 1065 material, which has an effective viscosity of 4 cs at 300 F, is much too viscous at low temperatures. General opinion of lubrication engineers is that effective bearing lubrication and suitable oil pumping characteristics ceases at viscosities above 10,000 cs (about 50,000 SUS), a condition which is attained at 5 F.

The thermally diffused SEB 78 material obtained from Sohio is seen to be essentially identical to Grade 1065 at high temperatures, but decreases the minimum operating point to -13 F.

A blend of a 40% mixture of SEN-100 (a lighter grade of thermally diffused material) with 60% of SEB-78 produced a material which still had a viscosity of 3 cs at the operating temperature of 300 F. This is

satisfactory for bearing lubrication since ASD has successfully completed high temperature bearing operating tests using thermally stable lubricants whose viscosity at the test temperature was between 2 and 2.5 cs. The low limit of 10,000 cs is -30 F, with borderline operation perhaps as low as -40 F.

The viscosity index of this product is approximately 129, and is obtained purely by refining and blending. Shear stability of the product is excellent as is shown by a test conducted on the OURI shear stability stand at 5,000 psi for a duration of 50 hours. This test involved an energy dissipation to the oil of approximately 10,000,000 ft. lb. of work per pound of oil in the system, and resulted in a decrease in viscosity of 0.56%. This slight decrease is less than can be plotted graphically on this V-T curve.

Therefore, it is recommended that a sample of lubricating oil made to these specifications be tested in full scale equipment either in flight or in an environmental hanger to determine if the preliminary evaluation is accomplished in actual service.

PROPERTIES OF THERMAL DIFFUSION OILS

Citcon 90106

Top fraction from thermal diffusion column.

Sohio Number 2132-37C

Vis. at 100 F = 84.41 cs  
at 210 F = 10.40

V.I. = 113

R.I. = 1.4766 at 20 C

SEB-78

Top fraction from thermal diffusion column.

Sohio number 2132-37D

Vis. at 100 F = 76.72 cs  
at 210 F = 10.25

V.I. = 120.5

R.I. = 1.4745 at 20 C

5/22/63

**THERMAL DIFFUSION OILS - PHYSICAL PROPERTIES**

(Produced for Oklahoma Research Institute)

Feed Stock	Run Number	Vol. %	R. I. at 20°C	Viscosity Centistokes		Viscosity SSU		V. I.	Pour Point		
				100°F	130°F	100°F	130°F				
HVI-100			1.4708	20.60	11.7	4.11	100.0	64.9	39.8	114	
SEN-100			1.4745	22.17	12.5	4.20	106.7	67.9	40.1	103	
SEB-78			1.4835	165.77	70.5	14.81	765.9	326.3	77.0	96	
CIICO			1.4830	143.75	65.0	13.42	664.1	303.3	71.7	95.5	

Thermal Diffusion Overhead Products

HVI-100	2132-15A	50.5	1.4635	15.01	9.0	3.55	77.2	55.5	38.1	135	+ 5°F
SEN-100	2132-16A	50.0	1.4674	16.89	9.9	3.71	84.7	58.6	38.5	123	+10°F
SEB-78	2132-27A	33.0	1.4742	74.35	36.8	10.41	343.5	171.6	60.6	125.5	
HVI-100 (Urea Treated)	2132-21A	50.0	1.4667	82.40	10.3	3.80	88.6	59.9	38.8	118	-15°F
HVI-100 (Urea Treated) +Enjay 628 + Acryloid 700 Added	2132-32C	50.0	1.4662	17.15	10.1	3.75	85.8	59.3	38.7	123.5	-40°F

Thermal Diffusion Bottom Products

HVI-100	2132-15B	49.5	1.4763	25.15	13.8	4.51	119.6	72.7	41.0	100	
SEN-100	2132-17B	49.1	1.4812	30.45	15.8	4.80	142.9	80.5	42.0	76	
SEB-78	2132-23B	66.0	1.4874	221.6	90	16.86	102.3	417	85.1	86.5	

RESEARCH DEPARTMENT  
The Standard Oil Company (Ohio)  
May 6, 1963

PHYSICAL PROPERTIES

2132-45B -- Urea Treated. 1% Enjay 628 and 0.4% Acryloid 710 added.

Vis. at 100 F = 18.14 cs  
at 210 F = 3.97

V.I. = 135

Refractive Index at 20 C = 1.4668

Pour Point = -35 F

2132-49B -- 1.0% Enjay 628 and 0.4% Acryloid 710 added.

Vis. at 100 F = 14.68 cs  
at 210 F = 3.47

V.I. = 131

Refractive Index at 20 C = 1.4682

Pour Point = -30 F

2132-50A -- 0.5% Enjay 628 and 0.2% Acryloid 710 added.

Vis. at 100 F = 14.42 cs  
at 210 F = 3.19

V.I. = 90

Refractive Index at 20 C = 1.4771

Pour Point = Oil still fluid at -65 F

2092-71 -- Synthetic Oil -- Trans-didecyl Andimerata (didecyl-1,2-cyclobutane  
carboxylate)

Vis. at 100 F = 12.24 cs  
at 210 F = 3.25

V.I. = 153

Freezing Point = -40 F

Specific Gravity = 0.929<sup>20</sup>

Boiling Point = 428 F (1mm)

Flash Point (Pensky-Martins closed cup) = 405 F

Sohio Research - 6/14/63

HERMAL DIFFUSION OILS - PHYSICAL PROPERTIES

(Produced for Oklahoma Research Institute)

Pennsylvania Constant Temperature Bath Oil No. 90 (Top Fraction)

Sample Number 2132-52A

Vis. at 100 F = 12.33 cs  
at 210 F = 3.05

V.I. = 119

R.I. at 20 C = 1.4591

Pour Point = 20 F

Contains 0.5% Enjay 628 and 0.2% Acryloid 710

HVI-60 (Bottom Fraction)

Sample Number 2132-17A

Vis. at 100 F = 14.54 cs  
at 130 F = 8.5  
at 210 F = 3.19

V.I. = 88.5

R.I. at 20 C = 1.4772

Pour Point = -65 F

Contains 0.5% Enjay 628 and 0.2% Acryloid 710

SEN-100 (Top Fraction)

Sample Number 2132-17A

Vis. at 100 F = 14.09 cs  
at 210 F = 3.73

V.I. = 122

R.I. at 20 C = 1.4680

Pour Point = 10 F

6/24/63

**THERMAL DIFFUSION OILS - PHYSICAL PROPERTIES**

(Produced for Oklahoma Research Institute)

<u>Feed Stock</u>	<u>Run Number</u>	<u>Vol. %</u>	<u>R. I. at 20°C</u>	<u>Viscosity Centistokes</u>		<u>Viscosity SSU</u>		<u>V. I.</u>	<u>Pour Point</u>
				<u>100°F</u>	<u>130°F</u>	<u>100°F</u>	<u>210°F</u>		
HVI-60			1.4661	10.33	6.5	60.0	47.2	109	
Pennsylvania CTB Oil No. 90			1.4680	17.69	10.1	87.9	59.3	102.5	
<u>Thermal Diffusion Overhead Products</u>									
HVI-60	2132-42A	50.0	1.4552	8.08	5.3	52.3	43.4	129	
CTB Oil No. 90	2132-52A	50.0	1.4591	12.33	7.6	67.1	50.8	119	
<u>Thermal Diffusion Bottom Products</u>									
HVI-60	2132-42B	50.0	1.4771	13.83	8.1	72.8	52.4	78.5	-25°F Still fluid at -60°F
HVI-60 (Enjay 628 & Acryloid 710 Added)	2132-43A		1.4776	14.67	8.5	75.9	53.8	88.5	
CTB Oil No. 90	2132-52B	50.0	1.4769	28.75	15.0	135.4	77.3	77.5	

RESEARCH DEPARTMENT  
The Standard Oil Company (Ohio)  
June 18, 1963

PHYSICAL PROPERTIES

Section 37 (Top Fraction)  
Sample No. 2132-64A

Vis. at 100 F = 9.035 cs  
at 210 F = 2.466

V.I. = 107.5

R.I. at 20 C = 1.4621

Pour Point = -40 F

Humble Hydraulic Oil (Mail Fraction)  
Sample No. 2132-60B

Vis. at 100 F = 14.62 cs  
at 210 F = 3.228

V.I. = 93.6

R.I. = 20 C = 1.4653

Pour Point = -30 F

Humble Hydraulic Oil (Top Fraction)  
Sample No. 2132-55A

Vis. at 100 F = 8.72 cs  
at 210 F = 2.58

V.I. = 143.5

R.I. at 20 C = 1.4520

Pour Point = 25 F

Humble Hydraulic Oil (Bottom Fraction)  
Sample No. 2132-56B

Vis. at 100 F = 26.56 cs  
at 210 F = 4.201

V.I. = 40.5

R.I. at 20 C = 1.4784

Pour Point = still flowing at -55 F



Humble Hydraulic Oil (Top Fraction -- Feed ratio for this run one part  
through top to sixteen parts  
through bottom)

Sample No. 2132-60A

Vis. at 100 F = 8.934 cs  
at 210 F = 2.649

V.I. = 149

R.I. at 20 C = 1.4521

Pour Point = 20 F

Humble Hydraulic Oil (Drained from the column after the run was completed)  
Sample No. 2132-61B

Vis. at 100 F = 10.66 cs  
at 120 F = 2.818

V.I. = 124.5

R.I. at 20 C = 1.4572

Sohio Research - 8/16/63

## APPENDIX II

### The Interaction of Base Stocks and Polymeric Materials on Viscosity, Viscosity Index and Volatility.

In general, aircraft lubricant and hydraulic systems require the material to be fluid enough that cold starting is permissible without special equipment under arctic conditions, while retaining sufficient viscosity to be of lubricating value at elevated temperatures ranging from 300 F. At these temperatures, most petroleum base materials possess an appreciable vapor pressure, so that the relative volatility of the lubricant is important. This is especially important in aircraft operation where low ambient atmospheric pressures accentuate the evaporation problem.

MIL-H-5606 and similar lubricating type hydraulic fluids obtain their final characteristics by employing a blend consisting of a relatively small percentage of oil-soluble synthetic polymer in a base blend of conventionally refined petroleum base lubricants.

These polymers are usually of the acrylic type, and of very high apparent molecular weight as compared to the petroleum product, having molecular weights of 15,000 to 80,000 as compared to 350-800 for the base oil. They are therefore of extremely high viscosity. The blend therefore consists of an extremely high percentage of the petroleum material, which contributes relatively slightly to the total viscosity, together with a small percentage of polymer which contributes half or more of the blended viscosity. Thus typically a 5606 blend is required to be 10 cs at 130 F. It will be blended of about 95% petroleum oil having a viscosity of 2.5 to 3.5 cs at this same temperature, the remaining viscosity being due to the 5% or less of dissolved polymer.

The advantage to this scheme is that the polymer adds only slightly to the viscosity at sub-zero temperatures, thus allowing the blend to approach (although not attain) the low viscosity of the lighter base stock, while contributing strongly to the viscosity at elevated temperatures. This property is measured normally by the Viscosity Index, and the addition of the polymer typically increases the VI from 95 to 200 or over.

The disadvantages are two in number. First, the volatility is materially decreased, the flash point being reduced to 230 F, as compared to 350 or above for a straight hydrocarbon material of equivalent 130 F viscosity, and an evaporation loss of over 90% in 6 hours at 350 F, whereas the equivalent hydrocarbon would show less than 10%.

An even more serious disadvantage occurs in that the very high molecularweight of the polymers are attained by an essentially linear molecular structure. Such molecules are extremely sensitive to size degradation through mechanical shearing or internal vibration either from pressure waves or thermal agitation. This decrease in molecular size causes a decrease in the viscosity of the polymer thereby materially reducing its lubricating value.

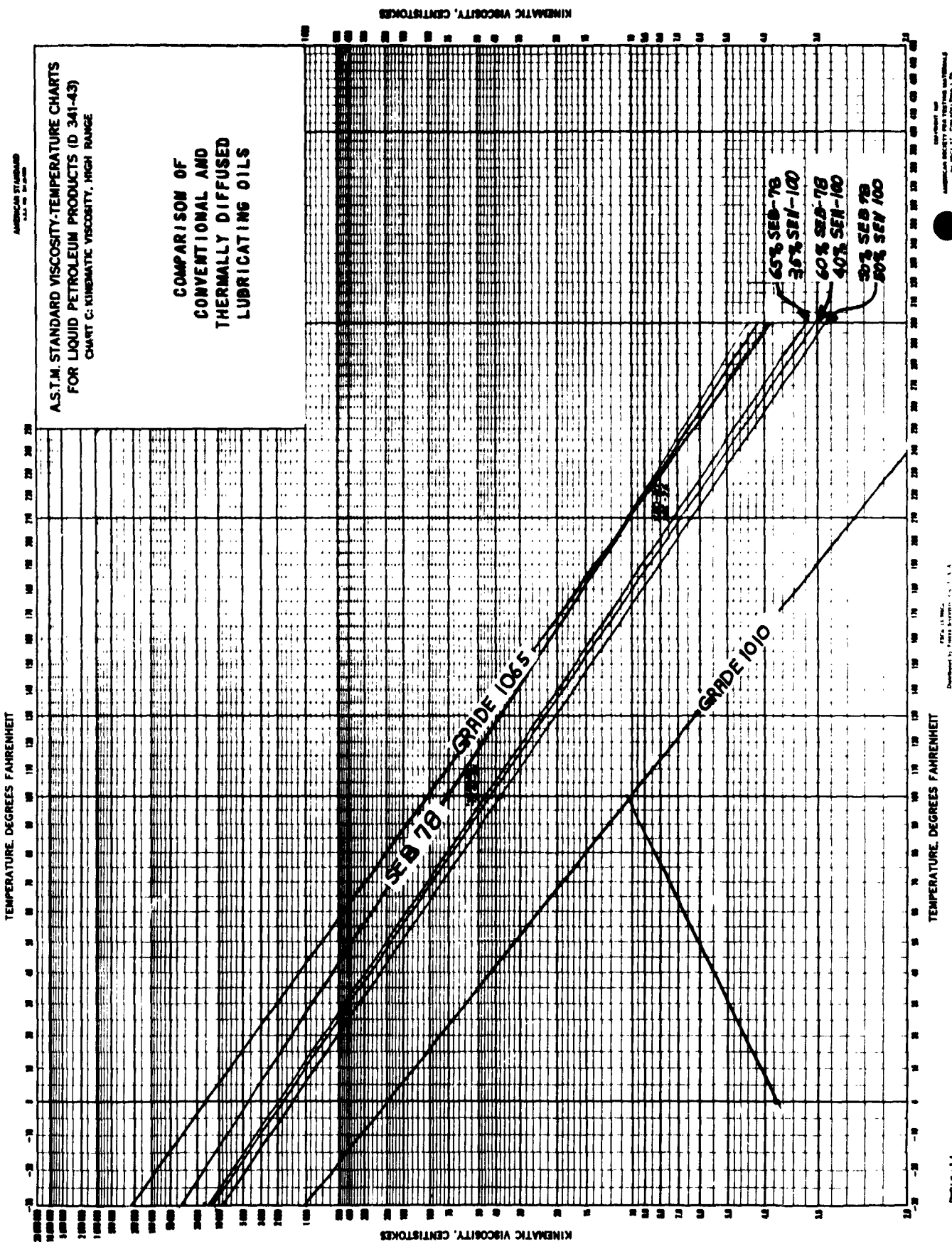
Thus, a standard shear stability test may show a 46% reduction in viscosity as compared with a 2-3% reduction in viscosity with conventional petroleum stocks of the same viscosity at 130 F. This same type of degradation occurs in aircraft hydraulic systems to the extent of 30-35% viscosity reduction during normal service life.

The purpose of thermal diffusion methods is to attain these higher VI products by means of selecting the shape of the molecule without

appreciably affecting the size and molecular weight. Thus when an oil is thermally diffused, its viscosity (at the 100 to 210 F range) is decreased, and its Viscosity Index increased, without appreciably changing its volatility. The degree of success attained today is that Viscosity Index numbers of 130 to 140 have been obtained. This is not sufficient to obtain products whose viscosities at extremely high and low temperatures exactly match those nominally obtained with the polymer blends.

Two courses are then open. One is to relax the viscosity specifications either at high or low temperature to those obtainable by thermal diffusion, thus taking full advantage of the increased stability, and the decreased volatility so obtained.

Another course is to utilize the higher base VI and lower volatility in the TD oils as a base stock for polymer blends. Preliminary estimates are that a hydraulic fluid could be made which matched 5606 viscosity-temperature characteristics exactly, utilizing a base stock with approximately 5 cs at 130 F viscosity, and requiring only about half as much polymer in the blend. Such a base stock would have over 300 F flash point (possibly 330 F), thus reducing evaporation at 350 F to a point where at least some lubricating power would be retained over an appreciable time. The shear stability would be inferior to those attained by the base oils, but far superior to those of conventional 5606.



APPENDIX III

To: OCAMA

From: OURI

Final Report on Oven Test Utilizing Test Specimens to Determine Corrosivity of Treated MIL-C-6529.

Based on the success of preliminary tests on oven aging methods of predicting acidic corrosivity of MIL-C-6529 and similar rust preventive ICE lubricant and preservative compounds, it was decided to extend the scope of the testing. Since the relatively large number of full scale bearings required for the program were not obtainable, a bench type test was devised utilizing the following procedure.

Test specimens consisted of samples cut from 7/8" 52100 bar stock approximately 1/2" long. These samples were heat treated by oil quenching followed by tempering in accordance with standards for bearing race heat treatment in order to insure the metallurgical identity of the test specimens. Rockwell hardness tests indicated the finished specimens to be in the normal range for bearing raceways.

After heat treating, the test specimens were ground and hand polished, the final polishing being with 6/0 emery polishing paper, polishing being continued until all previous scratches from the 4/0 paper had been polished out. This striated surface made it easy to determine the onset of corrosive attack. The finished specimens were then cleaned in petroleum solvent, dried and stored in a desiccator until use.

The following oil samples were prepared for test

1. MIL-6529C concentrate
2. MIL-L021260 ICE rust preventive finished blend
3. MIL-L-6082 Grade 1065 base stock
4. 3/1 blend of base stock and concentrate
- 5, 6, and 7. 3/1 blend plus same ratios of Ethyl 702 antioxidant
- 8, 9, and 10. 3/1 blend plus same ratios of Ethyl 702 antioxidant

The first 3 samples consisted of material received from Bray Oil Company as representative of the product they were furnishing to GE, together with an oxidation inhibited rust preventive material for comparison. The remaining materials were prepared by weighing out a large batch of the 3/1 blend, heating to 200 F with stirring to insure adequate mixing, and then adding to portions of the blend the various additives as indicated. After adding the anti-oxidant, each small batch was reheated to 200 F with stirring to insure full solution of the antioxidant.

Each oil sample was placed in a non-catalytic aluminum cup, with a corrosion test specimen approximately half immersed in the oil, the remaining portion being oil coated and exposed to air. All test specimens were placed in a free convection atmospheric oven maintained at 180 F.

The following results were obtained. Corrosion followed the same corrosion mechanism as in the turbosupercharger storage cells, corrosion being associated with oil darkening, an oxidized odor and formation of a resinous coating. Sample No. 4 was the most sensitive to corrosion, being worse than either the base lubricating oil or the undiluted concentrate. First corrosion deposits were found between 25 and 30 days, indicating the safe protective life to be of the order of 20 days at these test conditions. Both the base oil, the MIL-21260, and all oxidation stabilized samples were untouched at 36 days test.

This test was concluded at 50 days, at which time the concentrate showed extensive deposits and corrosion, the base oil showed slight corrosion with no deposits, and MIL-21260 indicated some darkening although there was no corrosion or deposits.

The Parabar 441 treated specimens also had darkened appreciably

with the two lower concentrations of antioxidant also showing corrosion; the 0.125% concentration showed slight deposits. The 0.5% concentration showed protection on 2 of the 3 specimens with corrosion being indicated on the third. It is therefore believed that 50 days represents the borderline treatment for Parabar 441 at a somewhat advanced concentration over that used at GE. Since untreated oils showed deterioration and corrosion at the 7 to 8 month level, Parabar 441 treatment could be assumed to be adequate for approximately 1 year.

The Ethyl 702 additive showed much better color stability, the oil darkening being only about half as intense. At the 50 day termination of the test, the 0.2 and 0.25% treatment levels showed perfect protection, with the 0.125% level showing light corrosion with no deposits.

In view of the excellent corrosion protection obtained, it was felt worthwhile to investigate other types of antioxidant materials. Therefore a second set of test specimens were prepared, utilizing the following materials, Ethyl 702 and Parabar 441 for comparison purposes; "dilly-dap" from Carlisle Chemical Company, a sulfur containing organic alkane; Santonox from Monsanto, a hindered phenol similar in structure to 702 and 441, but containing sulfur; Ortholcum 304 from DuPont, an amine type (both with and without the addition of a metal deactivator); Butyl simate and Vanlube 76 from R. T. Vanderbilt, the former being a metal carbamate and the latter a proprietary antioxidant and rust inhibitor of unknown composition. All samples were tested at 0.2, 0.4 and 0.6% concentration. Failure by corrosion occurred at the following times.

Parabar 441, all samples between 35 and 40 days. This extension of time is attributed to the absence of oxidized oil fumes from the uninhibited specimens.



Santonox samples failed at 30-35 days, and dilly-dav at 40 to 45 days, being worse than Paraber or not significantly better. They are therefore eliminated from further consideration.

The test was concluded after 100 days. Materials showing no corrosion at this period are considered to be the equivalent of 18 months to 2 years container storage life. Test was discontinued at this time due to excessive evaporation of oil, so that there was essentially no material left to cover the test specimens.

The best material from an overall standpoint was Ethyl 702, which consistently maintained better color to the oil showing only about half as much darkening as did competitive materials. The Ortholeum 304 showed slight corrosion at 55 days on the 0.2% treatment level, but passed the 100 day test when reinforced with 0.1% metal deactivator. Oils were very dark in all cases.

Vanderbilt Butyl stimate also passed the test, with oil darkening intermediate between that of the Ethyl and duPont materials. However, the proprietary material showed corrosion at 30 to 35 days even when the treatment level was carried to 1.0%. Presumably these disappointing results are due to the material being present in solution rather than as 100% active ingredient as is the case with other test materials.

Test oils were analyzed for viscosity and acidity increase. All showed such increases but the amount of increase at point of first corrosion was quite varied, indicating that these tests could not be used for determining a danger point in the oil.

It is therefore concluded that the desired safe storage time could be obtained with a variety of oxidation inhibitor treatments at the 0.2% level, with Ethyl 702 being first choice due to its color maintenance

properties, and its previous successful use in Jet Engine oils where no operational difficulties were found when the oils were used in engine service. Since these same storage conditions prevail in reciprocating engine storage, it is further recommended that the Air Force investigate the possibility of adopting this treatment to all MIL-6529 lubricant grades.

APPENDIX IV

To: Commander  
Oklahoma City Air Material Area  
Tinker Air Force Base, Okla.  
Attention: OCNE

From: Paul A. Cushman  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
Order Number 34-601-63-4  
OURI Project No. 1384-4  
Re: OURI Problem Number 63-5  
Tinker Project Reference

This project was submitted by Walter Kline 7-25-63 and reported thus far on 8-14-63. It is a raceway study of the following two wobbler raceways. One race is Stock Number 1650 739-0825 of inner motor wobbler Part No. 689411, etched H-689411 between raceways. The other race is Stock Number 1650 739-1839 of roller pump wobbler, Part No. 689068, etched E-689068 between raceways. Both are made by Sunstrand. The first is about 6 11/16" OD and has two chamfered raceways 1/2" wide. The second is about 6 7/8" OD and has two chamfered raceways 9/16" wide.

Both chamfered raceways are perfectly straight across, with curvature only in the annular direction. These races are scheduled to last 1000 hours, None make better than 100 hours before fatigue develops in the raceways.

The path of contact is about .030" wide in each raceway of Part No. 689411 inner motor wobbler. This is found by measuring the width of the bright metallic line of the path of contact. This flat, straight line, contact forms a totally insufficient bearing area between the pin and raceway. The design utterly disregards the ball bearing law, that when a ball rolls in a raceway the diameter of the raceway must exceed the diameter of the ball by exactly 4% and never much more. The

computation must be made as follows.

The curvature of the rolling contact pins is approximately 1.75" diameter. This pin surface curvature must be held at exactly 1.75" in manufacture. Adding 1.75" plus  $.04 \times 1.75"$  gives 1.820", which must be the curvature in the raceway. This curvature can alone provide sufficient area of contact between pin surface and raceway surface according to the bearing manufacturers' rule. The pin surface curvature of 1.75" diameter provides the equivalent of a 1.75" diameter ball rotating on a chamfered surface as at present designed. The small contact area between pin surface and raceway provides insufficient curved area of contact for frictionless pin rotation. The small contact area between pin surface and raceway produces the narrow raceway path of .030", which should not be less than .160" to .130" of width. The surface in which the pins rotate must be an annular spherical seat instead of an annular chamfered surface.

The wobbler action will possibly vary the design from 4% slightly but very little. Possibly 4.125% might prove a better figure than 4%. That would have to be proven by experiment.

Experimentation would be required to confirm any variation of the 4% law to such as 4.125% for this application to pin rolling contact. The angle of 8 degrees chamfer selected in this design makes complications which only experiment can determine. The angle of this raceway with the axis could require change to make the spherical seat work out correctly. The right combination will be that which gives raceway contact paths of around .160" to .180" widths. This contact width is the crucial factor which controls the design. The angle of the spherical seat must certainly be designed with respect to the axis so that the angle of contact is not much above 10 degrees. A large scale drafting

layout would prevent excessive angle of contact. The quoted per cent curvature rule may become 4.125%, 4%, or in between as found necessary when applied to wobbler design to attain the necessary width of contact pathway. In measuring the width of contact path, only the bright metal ring in the raceway must be scaled. It is not only .030" wide, which distinctly is the error as now layed out.

There is a thick black oxide coating giving an apparent width of over .030", but such additional width is not metal contact. It must not be considered as an area of support for the pins.

Another difficulty of the gravest importance is that the chamfered raceways contain polishing heat pits of .004" to .10" diameter. By scraping off a one inch length of the black oxide, we studied the original surface of H-682411. There are as many as twenty heat polishing pit holes in this one inch length, which are visible with an eyepiece at 6X magnification. This is exceptionally poor raceway grinding. Even one heat pit hole in this one inch length would be sufficient cause for rejection of this bearing.

There are areas with a scalloped, or speckled, appearance in the above mentioned one inch length. There are many valleys and many semi-polished ridges in this 1/2" wide by 1" long surface. Two polishing heat pit holes are .010" diameter. These are circled in ink. It is unusual to find two pit holes over .007" diameter in a one inch length. The twenty-odd in the one inch length can be clearly seen at 6X and 10X magnification with a microscope. The microscope greatly excels the eyepiece for this work.

The polishing heat pit holes are spots of metal weakness where fatigue holes begin to set up in two to twenty hours of operation. There is a discharge of steel powder from these polishing heat pit holes. This

powder sets up dirt not marks in the raceways, caused rapid wear and dynamic vibrations in these two wobblers. The holes in the raceways were made by the raceway polishers. They used the wrong kind of polishing material, excessive pressure on the polishing wheel or polishing cloth and excessive speed of rotation. Particularly, three to four pounds of pressure during polishing is a great plenty.

Where a strong flow of light No. 10 oil prevails during bearing rotation, the discharged dirt can be washed away from the bearing somewhat. This washing can prolong the life of a defective bearing slightly, and sometimes considerably. There is not such effective flow of oil in these wobblers. The polishing heat pit holes therefore completely destroy wobbler raceways in 100 hours. Wear begins in ten to twenty hours.

An oscilloscope will show very bad dynamic effects of progressively increasing violence in every ball bearing containing polishing heat pit holes. These holes will be observed to grow gradually larger and become fatigue spots when periodic checks of raceway wear are attempted. It is absolutely essential for every raceway to be visually studied. Rejection is required of every raceway which shows the least sign of such a defect as polishing heat pit holes, annular ridges in the raceway, annular valleys, scratches, corrosion, and impurities, any of which can be seen at 6X magnification. Of these raceway flaws polishing heat pit holes may be the most destructive of bearing life.

The wobbler raceway etched E689068 shows five polishing heat pit holes in an inked circle of 3/16" diameter, marked outside of the pathway. There are hundreds of heat polishing holes in this one raceway. On the opposite raceway a 2/16" x 5/16" parallelogram has been marked, also a 3/16" x 3/16" rhombus. The two scratches to the left of the rhombus were not made by us. Examination of these areas reveals a quantity of

heat pit holes, annular scars, annular valleys, and exceedingly poor raceway finish, which no bearing man of experience could tolerate,

A third, and serious, difficulty on the 6 11/16" OD race, H-689411, arises from the black oxide coating of .002" layer thickness. This coating constitutes a dirt contamination of the lubricant. It scratches off by knife rubbings. Even when the design and grinding-polishing errors are corrected, this dirt cannot be permitted. It is supposed to be a black oxide, but it has become gritty and constitutes a harmful dirt. The scars and scratches in the .030" pathway show that this grit and/or the discharged metallic dust has been rubbed between the piston surfaces and the raceways.

All three of these quality and design difficulties must be eliminated. Any one of these three flaws would be sufficient to cause very short raceway life.

To: Commander  
Oklahoma City Air Material Area  
Tinker AFB  
Oklahoma

From: W. J. Ewbank  
School of Mechanical Engineering  
University of Oklahoma  
Norman, Oklahoma

Subject: AF 34-(601)-14089  
OURI Project 1384-4  
Specific Problem 63-4  
Contamination of MIL-L-7808 Lubricating Oil in Sundstrand  
Drives.  
Comments on Letter from R. W. Wasserman

We would like to make the following comments on the request by R. W. Wasserman for suggestions as to specific physical properties required on a fluid to be used for constant speed drive applications.

1. The constant speed drive mechanism was originally developed under the concept that it would be a part of the engine lubricant system. The question of choice of lubricant was, therefore, not even considered, since the CSD was required to perform satisfactorily when utilizing the engine lubricant, this material having special properties designed to optimize its performance in a jet engine lubricating system.

3. The constant speed drive is, therefore, using MIL-7808 primarily for a reason which is no longer valid. This lubricant is designed to improve jet engine performance. Since, so far as we can determine, the CSD has consistently been lubricated only with MIL-7809 oil, there is no real basis for deciding whether any particular alteration in its properties would help or harm the operation of the lubricant as a CSD fluid. Although these comments apply to particular property values, it seems almost certain that such improvement in lubricant quality can be obtained once it is decided as to which properties affect the actual machine performance.



4. The comments regarding various physical properties which follow are, therefore, highly tentative, since it is not believed possible at the present time to set up any standards on physical properties which will guarantee that one lubricant will perform better than another. Rather, it is our feeling that a major goal of the proposed test program would be to determine which physical properties, if any have an important affect of the quality of lubrication of a GSD as measured by actual tests.

5. With regard to the physical tests, we would have the following comments:

- a. Kinematic viscosity - for theoretical reasons, we feel that materially greater scuff resistance in the pump plate and pump piston area would be obtained by using oils of higher viscosity. This is of the utmost importance in some newer installations. As a result, the effective viscosity in the pump is materially reduced. We would suggest that oils be tested having viscosity 50 to 100% greater than those specified in the MIL-7808 specifications in order to prove or disprove this theoretical idea.
- b. Flash point and pour point will both be increased when a more viscous oil is used. Since flash point is already safely high, the only purpose of this test is as a routine inspection to determine possible contamination. The pour point specification will need to be relaxed. Our information indicates that actual operation is not expected to occur at temperatures lower than -45 F. Therefore, a pour point below this value would appear to be safe.
- c. Although OCAMA has experienced difficulty with MIL-7808 oils of high lead corrosion number, it is well known that the corrosion results shown in these laboratory bench tests vary markedly from

field experience and correlation is only valid for a particular type of lubricant base stock. We would not, therefore, recommend that any potentially interesting lubricant be rejected as a test candidate on the basis of bench corrosion studies.

d. The same comments apply to synthetic rubber swell characteristics, since it seems absurd to reject an oil of excellent lubricating properties because of an adverse affect on the sealing gaskets. Rather, the gasket materials should be designed so as to permit the use of the most effective lubricant.

e. In view of the higher temperatures to which newer CSD units are being exposed, we would believe that the test requirements for evaporation loss, deposition number and oxidation stability should be held at the current values given in MIL-7808, but the tests should be run at a materially higher temperature (approximately 100 F). In view of the fact that the CSD is a hydraulic transmission, bulk modulus is an important design parameter. However, apparently the hydraulic characteristics of MIL-7808 are satisfactory. We would, therefore, suggest that candidate oils be at least equal to current MIL-7808 products. If possible, a candidate oil of materially better bulk modulus should be obtained and tested to determine whether improved drive performance is obtained with a material which is an improved hydraulic fluid.

f. With regard to load carrying capacity and lubricity which are the most important characteristics in view of current operating difficulties, we have not been able to correlate results obtained on various batches of MIL-7808 oil with field performance of these batches. Perhaps one reason for such lack of correlation is that

MIL-7808 oils cover a narrow range of these properties. In any event, there seems to be no way in which to choose either a test method or a range of values for any test method. We would, therefore, suggest that all candidate oils be tested utilizing the standard load and wear test methods such as Timken, SAE, Almen, Shell 4-ball (both seizure and wear test methods), etc., and that these results be compared with performance of the candidate oils as determined by actual tests in CSD units. With such results, it should be possible to determine which test method correlates best with service performance and what minimum values should be required in this test.

6. The heart of this evaluation program, therefore, resides in suitably testing a variety of candidate lubricants in full scale CSD units, since no evidence whatever exists showing that any screening test is able to predict that a given oil will show actual performance either better or worse than any other oil.

APPENDIX V

To: Commander, Oklahoma City Air Material Area  
Tinker Air Force Base, Oklahoma  
Attention: OCNE

From: W. J. Ewbank  
Project Director  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
Order Number 34-601-63-4  
OURI Project Number 1394-4  
Special Problem 63-7  
Suitability of Grade 1100 Aviation Oil after Contamination  
with Aviation Gasoline.

STATEMENT OF PROBLEM

This problem arose from the desire of Strategic Air Command to extend the life of reciprocating aircraft lubricating oil. It is the policy of SAC in winter to dilute the oil in the lubricating system with approximately 12% of aviation gasoline. These engines are then ground run after being started for a sufficient length of time to evaporate the gasoline. In many cases the engines are started and ground run without the aircraft being taken off; however, Tech Orders require that at least every third such engine start should be accompanied by flight to operating altitude of 30,000 feet so as to fully warm the engine and evaporate the lubricant. At the present time the orders require discarding the lubricant after three such flights. It was requested that we determine if the remaining traces of gasoline dilution were causing any deleterious effects or whether possibly four such operations could be considered.

TEST PROGRAM AND RESULTS

A laboratory bench test was set up where a sample of new Grade 1100 aviation oil was diluted with 12% gasoline. The resulting diluted material was then evaporated at 190 to 200 F over a steam bath at

atmospheric pressure. After two such operations, the third evaporation took place in a vacuum flask at 190 F, the pressure in the vacuum flask being maintained equivalent to that at 30,000 feet altitude. These three dilutions ended by a vacuum re-evaporation hereafter referred to as a cycle. Samples from the new oil from one cycle and from three cycles of operation were analyzed by the Chemical Laboratory, OCAMA, using an infrared spectro-photometer and were subjected to physical tests and analysis by the OU Research Institute.

The infrared spectro-photometer test was included because this engine uses Grade 1100 lubrication oil to which 2% cyclohexanone has been added for the purpose of acting as a carbon solvent and softener. Preliminary work utilizing samples of Grade 1100 aviation oil diluted with various percentages of cyclohexanone indicated a good absorption peak for this material which showed a quantitative correlation with the percentage of cyclohexanone known to have been put into the sample.

Briefly, the results of this test showed that even after one cycle, no trace of cyclohexanone was left. Naturally, the same result was obtained from the sample after three cycles of operation. A special test sample of cyclohexanone-treated oil without dilution was exposed to the same 190 F test temperature for the same length of time and showed less than 50% removal of cyclohexanone. It is therefore believed that the complete removal of cyclohexanone is due to the rather vigorous boiling action of the gasoline diluent on such heating, this action causing the stripping of the cyclohexanone similar to the effects of steam distillation.

Physical tests of the new oil, the one cycle treated oil and the three cycle treated oil are given below:

<u>Test Procedure</u>	<u>New Oil</u>	<u>One Cycle Oil</u>	<u>Three Cycle Oil</u>
Viscosity at 100 F, centistokes	245	216	229
Viscosity at 210 F, centistokes	20.06	18.9	18.9
Flash point, °F	525	500	440 (See note 1)
Ash content	0	0.05	0.05

Note 1. A small flash was obtained at 440 F. It was a very small blue flash typical of fuel dilution. The test was therefore continued; flash was not obtained at every 5° intervening temperature until 490 F from which time a flash was obtained at each 50 F. Therefore, the low flash is considered to be typical of fuel dilution with the 490 F being typical of the lubricating oil. This was confirmed by the fact that the fire point of 580 F is typical of undiluted lubricating oil of this grade.

#### CONCLUSIONS

None of the changes in the physical specification are considered to be harmful to the function of the lubricating oil and the comparison of results between the one cycle and the three cycle indicates that continued deterioration is not to be feared.

The worst point found in the investigation was the complete disappearance of the cyclohexanone additive after only one dilution cycle. If SAC believes that this material is furnishing a real service in preventing engine carbon deposit formation, some provision should be made for a continuous replenishment of the cyclohexanone content of the lubricating oil during winter service. Due to the fact that evaporation is slow in the absence of dilution boiloff, it is doubtful that cyclohexanone replacement is necessary unless dilution procedures are being followed.

In any event there seems to be no reason why a fourth operational cycle should not be performed by SAC assuming that engine operating conditions are normal and that the engine lubricant has not been contaminated from some outside source.

APPENDIX VI

To: Commander  
OCAMA  
Tinker Air Force Base, Oklahoma  
Attention: OCNE

From: W. J. Ewbank  
Project Director  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
Order Number 34-601-63-4  
OURI Project Number 1384-4  
Final Report on Special Problem 63-9 (62R76801)  
Determination of the Proper Lubricant for Use in Ram  
Turbines

1. This problem arose as a result of sticking of the pitch control mechanism in blades of ram air turbines. This pitch control is maintained by a set of interlocking gears held in place by ball bearings. The bearings stuck from rust corrosion due to condensation and ambient moisture.

2. Investigation of the problem indicated that the use of a rust-inhibiting lubricant should prevent this corrosion and alleviate the situation.

3. An analysis of the operating conditions of the bearings showed that the lubricant recommended should be able to meet the following requirements:

- a. It should permit operation of the bearings at low ambient temperatures.
- b. The maximum temperature in service will be under 200 F.
- c. It should have maximum corrosion (water) resistance.
- d. It should absorb water into the grease structure without excessive softening.



4. A military approved lubricant which meets these requirements is MIL-G-10924B, Automotive and Artillery Grease, which is hereby recommended as a satisfactory lubricant for the purpose.

APPENDIX VII

To: Commander  
Oklahoma City Air Materiel Area  
Tinker Air Force Base, Oklahoma  
Attention: OCNE

From: W. J. Ewbank  
Project Director  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
OURI Project Number 1384-4  
Specific Problem 63-11  
Determination of a Suitable Lubricant for Lead Screws of  
Missile Attitude Stands

STATEMENT OF PROBLEM

This problem arose when the North American Aviation Company specified a proprietary lubricant for lubrication of lead screws which control the attitude of the missile checkout stand built by them and which had shown excessive wear when lubricated with conventional lubricants.

Their recommendation was that a material referred to as Torco grade SAE 50 motor oil be used, supplemented with an additive known as Torco Red-Top or Torco Blue-Top additive. These materials are extensively sold to "hot rod" owners on the West Coast but represent a supply problem in other parts of the United States.

RESULTS

Samples of Torco motor oil and Torco Red-Top additives were obtained from Clinton-Sherman Air Force Base. Although a sample of Torco Blue-Top additive was not obtained, it is believed that the analytical comments apply to it since the instructions from North American Aviation indicates that the two additives are essentially identical and may be used interchangeably.

ratio, at which time, the vapor evolving is still over 90% water. Thus essentially only water evaporates. Assuming that the evaporation is stopped at this point, and that water only evaporates, the thermal capacity of the system would be of the order of 140,000 Btu, with a reserve of about 20,000 Btu obtainable by evaporating the glycol at temperatures between 250 and 270 F. The latter is the approximate boiling point of pure glycol at 30,000 feet. This system would also have the disadvantage that before it ran dry, it would undoubtedly be evaporating a combustible mixture, although only in the very final stages. If these occurred only in flight, it is doubtful that any flammability hazard would incur.

8. The use of methyl or ethyl alcohol or other low boiling miscible solvents as anti-freeze is not recommended. No suitable azeotropes are known, and due to the relative boiling points, concentration of the organic material occurs within the vapor phase, probably leading to an inflammability hazard, which would be most serious during the early ground run stages.

9. On the basis of the above survey it is recommended that the Chemical Laboratory OCAMA run tests to evaluate the inflammability hazard of the "Cellosolve"/water and the "Methyl Cellosolve"/water mixtures as well as the freezing characteristics.

Freezing point of the 30/70 mixture is between 10 and 15 F, which is a material improvement. Again, specific information on this material's freezing characteristics is lacking. However, typically concentration of the higher melting point material occurs in the solid phase, thus concentrating the anti-freeze effect. Thus the freezing point of a 50/50 mixture is -20 F. Organic fluid-water mixible solutions therefore tend to freeze to a slush of ice crystals in an unfrozen liquid solution. Such a material should melt completely without building up pressures due to premature boiling. Incidentally, typically such materials shrink on freezing thus eliminating pressure build-up due to freezing.

5. If the above system is found to furnish combustible vapors, a lower concentration version is "Methyl Cellosolve"/water in a 17/83 volume ratio. This also boils at 210 F, and other comments are pertinent.

6. Heat of solution data have not yet been found. However, for these systems it is believed small, so that a reasonable approximation of thermal capacity should be obtained by assuming latent heats to be a summation of individual values. On this basis, the "Cellosolve" solution has a capacity of about 170,000 Btu, and the "Methyl Cellosolve" solution about 184,000 Btu. These would seem to be reasonable compromises with capacity.

7. Straight anti-freeze treatment would seem to be inferior to the above suggestion, but some feasibility. No azeotropes are formed by any of the common glycols. Typically, a 30/70 mixture of ethylene glycol and water will have a freezing point of 5 above zero, and an atmospheric boiling point of 218 F. The first material to be evolved will be over 95% water, so that a continuous shift towards a higher glycol concentration will occur. The boiling temperature at atmospheric pressure remains below 250 F until the composition has shifted to an 80/20 glycol water

2. If the minimum required capacity is the full 200,000 Btu, the problem is insoluble, since water has by considerable the highest latent heat of vaporization of any material found which boils in the same range.

Water 970 Btu/lb

Ammonia 550 Btu/lb

Freon 70 Btu/lb

The variation is due to the high energy of the hydrogen-oxygen bond together with the untypically high boiling point for such a low molecular weight compound.

3. The only materials which meet both the combustibility and toxicity requirements and boil in the proper range are the Freons. Due to their large molecular weight, the latent heat per pound is very low. Unless the system is overbuilt to an absurd extent, the Freons will not be suitable. Even taking into account their density of about 1.4, the capacity of 24 gallons will furnish an energy availability of only about 25,000 Btu.

4. If a small decrease in capacity is permitted, the most promising solution seems to be the formation of a constant boiling mixture using a non-toxic volatile organic solution. First recommendation would be the use of 30 volume % "Cellosolve", a proprietary solvent of Union Carbide Chemicals Company, and 70 volume % water. This material boils at 99 C (or 210 F) at atmospheric pressure. It is non-toxic to high concentrations. Although I was not able so far to find combustibility information on water solutions, evidence on comparable materials, e. g., alcohol indicate that 30/70 mixtures are not combustible. No production of a more combustible material is anticipated at any time, since the particular material is an azeotrope and boils off completely at this composition. Combustibility of the mixture can easily be checked in the laboratory.

APPENDIX XI

To: Commander  
Oklahoma City Air Material Area  
Tinker AFB  
Oklahoma

From: W. J. Ewbank  
School of Mechanical Engineering  
University of Oklahoma  
Norman, Oklahoma

Subject: Contract AF 34(601)-14089  
OURI Project 1384-3  
Final Report Problem 63-8  
Special Coolants for Ebullition Cooling in B-58 Aircraft

This problem involves a heat exchanger which cools bleed air by ebullition of water. The heat exchanger is in the B-58 aircraft, and is charged with 24 gallons of water which must last during the flight with a satisfactory reserve. Trouble occurs in cold weather when the water in the heat exchanger freezes. So far as can be determined, expansion of water during freezing does not cause difficulty. However, when the engines are started, 400 F bleed air melts ice next to the heat exchanger tube and then vaporizes it before the main body of ice melts. This develops sufficient pressure to collapse the heat exchanger tubes and destroy the exchanger.

RESULTS OF INVESTIGATION TO DATE

1. The exhaust fumes from the heat exchanger are sufficiently near the engine exhaust that a definite fire hazard exists with the use of an inflammable solvent. Toxic materials also are not usable due to the poisoning hazard during ground run-up operations. The exact Btu capacity needed in the system has not yet been obtained from SAAMA or GD/FW, but it presumably is something under 200,000 Btu. The end results should also cause boiling within the same temperature range as water.

sensitivities. Distinct peaks appear in each wave. On disassembly  
we find the outer raceway has annular ridges which are too coarse.  
The inner raceway is satisfactory. Although we would reject this  
bearing it is not awfully bad. It is on the questionable point where  
rejection seems best.

APPENDIX X

To: Commander  
OC J1A  
Tinker AFB  
Attention: OCNE

From: Paul A. Cushman  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
OURI Project Number 138424  
OURI Problem Number 63-16

Four New Departure JOLO20 bearings were submitted for inspection.

There are two bearings in a piece of aluminum foil. Both are distinctly etched ZH5182J. These are perfect bearings by DuMont 403 Oscilloscope test on the two highest sensitivities. They are equal to our best bearing standards which we use for comparison.

Two bearings are in colophane packages numbered #2 and #12. These had been studied by the Bearing Branch by microscope at about 12X magnification. The etched letters on these are ZH5182J.

#2 bearing is not as good as the two bearings in aluminum foil. However it is a well made bearing. The vertical range of oscilloscope waves is slight and never fuzzy. There are many more ripples per inch of length of wave than on some of our best standard bearings. However these waves do not have sharp points at the top and bottom. We are sure that the bearing would give reasonably good life. We decided to study the raceways and have found them to be satisfactory, but not equal to the best which New Departure can manufacture.

#12 is not as good as #2. It is not as good as the bearings which we use as quality standards. We would reject #12. The vertical range of the oscilloscope lines is too great on both .001/X.1 and .001/x.5



developments after factory packaging must be found. There is a deep corrosion spot of two months accumulation on one of these four inner raceways.

It is impossible to cull bad bearings out of production in a factory, because the factory cannot afford to purchase and use all of the above equipment. They cannot build or buy sufficient test machines to adequately set up dynamic tests. The process of sorting out good and bad bearings is a job for people interested in aircraft bearings. It is a job for Tinker AFB and other air force bases, not a function of factories except to a minor extent. Only an air force base can gather the necessary information about what this VI-224248 bearing must accomplish.

Factories can attempt to make a first sorting and first rejection of bad bearings, but the work must be done again at some or each air force base immediately prior to the bearing use.

Practically none of the ball bearing companies are sufficiently adept in the use of microscopes and eyepiece magnifying glasses by which it is necessary to detect ball bearing raceway flaws that cause very early bearing wear and deterioration.

The bearing company representatives--over a dozen of them--who have come to Tinker AFB do not talk with experience about raceway flaws. They do not use high enough magnification to locate dynamic flaws in bearings. Secondly, none of these men are accustomed to use a suitable variety of dynamic test machines. Only one of the bearing representatives has ever used any dynamic test machine. To explain bearing flaws to men with such backgrounds, they must become familiar with the following procedure.

#### PROCEDURES OF TEST

Without both the McKnight Analyzer and DuMont 403 Oscilloscope with Rotator test machine, we would be unable to either detect the presence of the flaws of the VI-224248 bearings before disassembly or determine which flaws caused the dynamic impacts. The McKnight Analyzer slowly rotates the outer race. The inner race can be moved by hand until a flaw on the inner raceway makes a sound, dial record, and oscilloscope wave all of unsatisfactory magnitude. There is no mistaking the location this flaw. This location is marked by a scratch. The DuMont 403 Oscilloscope similarly locates each distinct flaw in the outer raceway. Both machines agreed on the rejection of four bearings.

Both machines depend upon good standard bearings for comparison. The agreement of both machines as to presence of serious flaws, and comparison of flaw magnitudes with the superior dynamic performance of good standard bearings is necessary on all supply bearings if these VI-224248 bearings are ever to be brought within reasonable and satisfactory life performance. Manufacturing flaws must be found. Corrosion

APPENDIX IX

To: Commander  
OCAMA  
Tinker AFB  
Attention: OCNE

From: Paul A. Gushman  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
OURI Project Number 138424  
OURI Problem Number 63-15

Five VI 224248 bearings made by Split Ball Bearing Company, Lebanon, N. H. were submitted for inspection.

There was one good bearing among the five. Four bearings show bad on both the McKnight Analyzer and DuMont 403 Oscilloscope Rotator test machine. These four bearings would have a very early failure on the oscillator service in which they are used.

The four bad bearings were disassembled. Three had been marked at one or more spots of the inner raceway, where flaws were indicated by the McKnight Analyzer. By visual inspection at 6X magnification it was readily possible to observe that the marked spots were a major cause of the dynamic defects shown by both ball bearing test machines. A second flaw in several of these bearings is the presence of coarse annular ridges extending throughout the circumference and width of each outer raceway. These two classes of raceway flaws can only be seen at 4X to 6X magnification. We have 4X on microscopes in the Bearing Branch at Tinker AFB. We use also a 6X magnification eyepiece from a discarded projector lantern. The 6X magnification is the better and simpler to manipulate of the two observations. I recommend that both be used on every inspection, never one alone. A jig is necessary for rotation of the inner race.

APPENDIX VIII

To: Commander  
OCAMA  
Tinker AFB  
Attention: OCNE

From: Paul A. Cushman  
OURI  
Norman, Oklahoma

Subject: Contract Number 34(601)-14089  
OURI Project Number 1384-4  
OURI Problem Number 63-13  
Tinker Project Reference MIP OC 63-5295R2K

It is desired to investigate the serviceability of the J79/F104 Teleflex Box Bearing (MIP OC 5295R2K).

The bearing is notch loaded, a full capacity ball bearing without a retainer, and grease sealed. It oscillates slowly in service. The bearing dimensions are .750 bore, 1.186 OD, .247 outer width.

A fitting was devised for use on the ball bearing test machine by which bearing dynamic flaws can be located with a DuMont 403 Oscilloscope. There were two unsatisfactory bearings among seven tested. This is a very common ratio of bad bearings in supply lots. It is not practical to test the bearings without removal from the housing of the Teleflex Box, because there is considerable friction between the housing and a washer when any rotation is attempted. It is important that grease or oil lubricant be used on this washer. This has been overlooked. Test of the whole assembly on the bearing test machine might also prove desirable when the washer is lubricated.

The bearings should always be machine tested with the DuMont 403 Oscilloscope before installation into the Teleflex Box. This bearing test, together with the washer lubrication, appear to be the only necessary changes in the assembly of this unit, and they should eliminate failures.

It is understood that a liquid lubricant is required for this lubricating system. If it could be adapted to the use of lubricating grease, two lead naphthenate base lubricating greases are available in military procurement as MIL-L-7645 and MIL-G-14470.

It is believed that any of the above specifications plus the commercial product mentioned above would give equal or better performance than the Torco lubricating oil plus additive currently recommended by North American Aviation, as well as being available without logistic problems.

## CONCLUSIONS

As was found in tests by North American Aviation, it is expected that a base lubricating oil of the Arkansas pale type fortified with the Torko Red-Top additive would show mild extreme pressure characteristics, since the base oil is known to possess a minor amount of such activity and both lead naphthenate and zinc dithiophosphate are known anti-wear agents. The major additive used in Torko Red-Top additive, i. e., the polybutene VI improver, serves no useful purpose.

The same or improved characteristics should be obtained by the use of Military Specification lubricant, MIL-L-18486, which is a worm gear lubricant developed by Naval Ordinance for use on heavy duty worms onboard ship.

While no composition requirements are placed on the material, approval is based both on an efficiency measurement of a test worm gear set utilizing the finished lubricant and on a wear inspection of the worm and worm wheel after the efficiency test.

No straight lead naphthenate gear oils have been found in the Military Lubricant Specifications. Such materials are available commercially, the most available probably being the Merona series of gear lubricants distributed by Texaco Inc. These materials are available in a variety of viscosity grades and the active agent is 7  $\frac{1}{2}$ % lead naphthenate soap.

Another Federal Specification lubricant which would probably be suitable for this purpose is the general purpose extreme pressure gear oil bought by government agencies under the Federal Specification VV-L-768. The military general purpose gear lubricant purchased under MIL-L-2105B would not be suitable since this material is extremely active and would probably corrode the bronze parts of this lubricated system.

Physical and chemical analyses were performed on the Torko motor oil and on the Torko Red-Top additive with the following results.

1. The Torko motor oil appears to be a typical non-additive straight mineral oil manufactured from South Arkansas crudes and containing the characteristic high natural sulfur content of these materials which are referred to in the lubricating oil industry as Arkansas pale oils. Such lubricant stocks show a minor amount of EP activity due to the natural sulfur content.

2. The Torko Red-Top additive appears to be a mixture of this base lubricating oil plus additives. A major additive constituent is a VI improver of the polybutene type. This material has no extreme pressure or anti-wear effect but is normally used in the lubricating oil industry as a Viscosity Index improver and as a means of increasing the viscosity of the oil at low shear rates so as to decrease leakage. A second additive is lead naphthenate soap and zinc dithiophosphate.

Evidence for the presence of these latter materials was found by spectroscopic analysis which showed major amounts of lead and zinc. Evidence for the polybutene additive was the physical appearance of the oil together with the tendency to precipitate a rubbery material on heating to a temperature of approximately 400 F.

Final confirmation of the presence of these additives was obtained by mixing a sample of base lubricating oil with additives of this type and running an infra-red spectrophotometer trace. The infra-red test of the synthetically prepared material was identical with that of Torko Red-Top additive except for one very small absorption band which is believed due to the red dye used in the Torko additive to color the finished material.