NACA

RESEARCH MEMORANDUM

EVALUATION OF A SILICONE-DIESTER LUBRICANT IN BENCH STUDIES AND IN A TURBOPROPELLER ENGINE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A silicone-diester blend (SD-17) was investigated in various bench studies and in a turbopropeller engine to determine its suitability as a lubricant for aircraft engines.

The performance of the fluid was satisfactory during more than 17 hours of operation in a T-38 engine with power levels from 1745 to 2400 horsepower. The fluid has better viscometric properties than currently used lubricants and could eliminate low-temperature starting and pumpability problems for turbopropeller engines. The fluid has good boundary lubrication and other lubricant properties as measured with most bench devices. Especially good gear lubrication characteristics were established in bench studies and in the engine test.

Because of the superior combination of viscometric properties and load-carrying capacity of the silicone-diester blend over those of currently used lubricants and because of the satisfactory performance in an engine test, a complete evaluation of silicone-diester blends in extensive full-scale engine operation should be made.

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INTRODUCTION

Reference 1 shows that blends of silicones and diesters are capable of lubricating steel surfaces and that they have very good viscosity-temperature characteristics. A silicone-diester blend designated SD-17 has been formulated by NACA for possible use as a lubricant for turbopropeller engines.

The very good viscosity-temperature characteristics of this blend would allow it to be more viscous at engine operating temperatures and also to be more easily pumped at low temperatures than the synthetic fluids currently used as lubricants for turbopropeller engines and also the fluids meeting the viscosity requirements of specification MIL-L-7808. It is generally agreed that the load-carrying capacity of gears is increased by using lubricants of greater viscosity (refs. 2 to 4); therefore, a silicone-diester blend having high viscosity at operating temperatures and with favorable boundary lubrication characteristics (refs. 1, 5, and 6) might be well suited to lubrication of gears. Some of the present synthetic and petroleum lubricants which will provide adequate lubrication of turbopropeller engine reduction gearing are so viscous at low temperatures (-65° F) that the engines are apt to be inoperable because of inadequate low-temperature pumpability and the resulting high starting torque. The use of the silicone-diester blend could eliminate the low-temperature pumpability and starting problems.

It is the object of this report to present the results of various studies of lubrication characteristics and physical and chemical properties of the silicone-diester blend SD-17. Some of the information reported herein was obtained at the NACA Lewis laboratory in bench studies and in altitude wind tunnel tests of a turbopropeller engine. Data from other bench studies are reported which were obtained by Pratt & Whitney Aircraft, Esso Laboratories, Standard Oil Development Co., USAF Wright Air Development Center Materials Laboratory, Allison Division of General Motors Corp., Silicone Products Dept. of General Electric Co., and Southwest Research Institute. The excellent cooperation of these organizations and permission to use their data are gratefully acknowledged.

FORMULATION

Basic Silicone-Diester Blend

Reference 1 indicates that numerous solvents can be added to silicones to improve lubricating effectiveness for steel surfaces. The use of diesters as solvents was considered to have merit because the diesters were not volatile, had good thermal stability, and could be blended with various silicones. In further studies subsequent to those of reference 1, it was found that, in general, effective boundary lubrication of steel surfaces could be obtained if at least 27 percent (by volume) or preferably more diester was added to either methyl phenyl or methyl silicones of various viscosity grades. Increasing the amount of diester to 50 percent (by volume) gave slightly better lubrication at a sacrifice in viscometric properties. Also, the use of longer-chain-length silicones resulted in improved boundary lubrication. A blend of one third by volume of diester in silicone was selected as the best compromise on the basis of the following properties: lubricating effectiveness, viscosity-temperature (viscometric) properties, and low-temperature stability. Solubility of diesters and silicones was a problem because, as reported in reference 1, the blends became turbid at low temperatures. In general, solubility could be improved either by using less viscous diesters or less viscous silicones or by using methyl phenyl silicones rather than methyl silicones. To obtain the best possible lubricating effectiveness, it was considered advisable to work with the most viscous silicone and diester blend that would give adequate low-temperature fluidity and stability. It was found that methyl phenyl silicones of low phenyl content (Dow Corning 510 fluids) could be blended with diesters without encountering low-temperature turbidity and with little sacrifice in viscometric properties. An added advantage of using methyl phenyl silicones was that they have better thermal stability than methyl silicones.

The result of lubrication experiments and studies of physical and chemical properties for various silicone-diester blends resulted in the formulation of a blend designated SD-17 which was composed of one-third (by volume) di(2-ethylhexyl) sebacate (Rohm and Haas Corp., Plexol 201) and two-thirds methyl phenyl silicone (Dow Corning 510 fluid of 100-centistoke viscosity at 25° C). Table I and figure 1 show how the physical properties of SD-17 compare with those of other fluids used as lubricants. Comparative data and physical properties of other fluids were obtained from references 7 and 8 as indicated in table I. The viscosity-temperature characteristics of SD-17 are shown in table I and figure 1.

Additives

As indicated in table II, preliminary oxidation-corrosion runs at 347° F showed excessive metal attack when the SD-17 type fluid without an oxidation inhibitor was used. It was found that addition of 0.5 weight percent phenothiazine (PTZ) effectively reduced metallic corrosion in the 72-hour oxidation-corrosion runs at 347° F to within the requirements of specification MIL-L-7808. This result was confirmed by Pratt & Whitney Aircraft (appendix A) in oxidation-corrosion tests on SD-17 containing 0.5 percent phenothiazine.

Further checks of oxidation-corrosion and hydrolytic stability of SD-17 with and without 0.5 percent phenothiazine were made by the Air Force Wright Air Development Center Materials Laboratory, and are reported in appendix B. As shown in appendix B, the USAF recommended that a combination of phenothiazine (PTZ) and phenyl α-naphthylamine (PAN) would provide further improved oxidative stability.

Table II shows the preliminary oxidation-corrosion data obtained by the NACA with SD-17 fluid containing 0.25 percent PTZ and 0.25 percent PAN for oxidation inhibition. This formulation appeared to have satisfactory properties for engine operation and therefore was used in the T-38 turbopropeller engine run to be discussed later. Under some conditions the blends containing PAN became slightly turbid at low temperatures (< -40° F).

The final formulation of SD-17 was kept as simple as possible in order to minimize the influence of components other than the base materials (silicone and diester) on lubricating behavior. By the proper selection of additive materials, compensation can be made for many of the deficiencies of various types of lubricants; in all probability the same procedure can be used in the development of future silicone-diester blends. Data are available showing that additives can be used to reduce wear with silicone-diester blends as measured with the four-ball apparatus. Table 29 of reference 9 and some unreported NACA data indicate that the additives tricresyl phosphate or triethyl phosphate will reduce wear under both extreme loads and high bulk lubricant temperatures. Since information was lacking on possible undesirable side effects of the antiwear additives, they were not included in the formulation of the fluid for engine operation.

EXPERIMENTAL LUBRICATION RESULTS

Bench Studies

Table III presents a summary of experimental bench studies of the limiting conditions for effective lubrication of steel surfaces by SD-17 as compared with similar data for the other lubricants described in table I.

NACA data (table III) obtained with a high-sliding-velocity friction apparatus according to procedures described fully in reference 5, indicate comparative sliding velocities for incipient failure of surfaces lubricated with SD-17 and other lubricants. These runs were made at a load producing an initial Hertz surface stress (126,000 psi) that is representative of design values for gears. With SD-17, the sliding velocity at which incipient failure occurred was at least equivalent to that for any fluid except PRL-3313. The lubricating effectiveness of PRL-3313 is probably a function of both the increased amount of methacrylate polymer viscosity-index improver and the additive Ortholeum 162 (believed to be a lauryl acid phosphate, ref. 8). PRL-3313 is not a completely satisfactory lubricant, however; reference 9 states "Extensive laboratory tests have indicated border-line corrosion, foaming, and storage problems with PRL-3313 compositions."

The NACA has modified a SAE lubricant test machine so that the specimens operate in pure sliding by rotating in opposite directions at the same rotative speed (490 rpm). Needle bearings were installed for the lubricant cup specimen support bearings. The load was increased at a uniform rate (approximate scale reading, 8 lb/sec) according to the standard procedure, and the initial point of surface failure was reported. Increase in measured vibratory motion of the lubricant cup assembly, change in rate of increase of drive-motor power consumption, and inception of audible specimen chatter were used to indicate the point of failure. The incipient failure loads for SD-17 and the comparison fluid are reported in table III. The only synthetic fluid giving a higher failure load than the SD-17 was the PRL-3313. The petroleum oil, grade 1100, which also had higher SAE machine load capacity than the SD-17, is so viscous at low temperature (fig. 1) that it cannot be used in turbine engines for aircraft.

The bulk temperature limit for effective boundary lubrication by the various fluids was determined with the apparatus and according to the procedures fully described in reference 10. In general, friction specimens were run at a sliding velocity of 120 feet per minute with a load providing an initial Hertz stress of 149,000 pounds per square inch with the temperature increased gradually (from 75° to 500° F in 55 min) until incipient lubrication failure occurred. Incipient failure was indicated by increased or unstable friction and an abrupt increase in rate of wear.

The data of table III show that with SD-17 as the lubricant, incipient surface failure occurred at a lower temperature than for any of the other fluids. While the reason for the relatively poor performance of SD-17 in this type of experiment is not known, if the silicone-diester fluids lubricate by physical adsorption as suggested in the hypothesis of reference 1, they might be expected to fail at lower temperatures than fluids that form chemisorbed lubricant films.

Unreported data on high-temperature bearing runs indicate that some of these fluids will lubricate bearings at temperatures at least 200° F higher than the bulk lubricant failure temperatures reported in table III. Lubrication failure in bearings is believed subject to several variables such as fluid residence time, heat-absorbing characteristics of the fluid, oil supply temperature, the formation of lubricant decomposition films (ref. 11), and the ability of the lubricated surfaces to reform the surface oxide films as they are worn away during sliding. The influence of these variables is minimized, and in some cases eliminated, in bulk lubricant runs; their importance is emphasized, however, by the higher operating limits for effective lubrication that have been obtained in jet- or drop-lubricated bearing experiments.

Preliminary NACA data have been obtained (in a manner somewhat similar to that described in ref. 12) with SD-17 used to lubricate a 20-millimeter-bore tool-steel ball bearing operating at high temperatures under light load and low rotative speed (2500 rpm). The SD-17 lubricant supplied at room temperature and at a rate of a few drops per minute provided effective lubrication at temperatures above 800° F. The PRL 3161 did not provide effective lubrication at bearing temperatures as high as were used with the SD-17.

The data obtained by Pratt & Whitney Aircraft and presented as appendix A provide an extensive evaluation of SD-17 in accordance with their current lubricant specification, PWA 521A. They also commented:

"This oil exhibited very good viscosity properties, corrosion tendencies, and panel coking tendencies. The load-carrying ability or resistance to scuffing gears as measured with the Ryder Gear Test was good; however, the wear tendencies as indicated by wear spot diameters at various loads until weld occurs on the Shell Four Ball E. P. Tester were definitely poorer than synthetic oil currently being used." Southwest Research Institute obtained Ryder gear rig test data for SD-17 (table III) that are in good agreement with values reported by Pratt & Whitney.

Pratt & Whitney also commented on the very high ash content (shown in appendix A) of SD-17, although they pointed out this high ash content was not reflected in the panel coking test (appendix A). In view of these results, Pratt & Whitney indicated that this property would require thorough investigation before SD-17 could be recommended as an engine lubricant.

The high ash content reported by Pratt & Whitney must be expected with fluids that are partly inorganic. The ash content (A.S.T.M. D482-38T) is determined by heating 20 cubic centimeters of fluid to a temperature at which the fluid will ignite at the surface and continue to burn to dryness. The residue is then heated with a flame or in a furnace until all free carbon has disappeared and a constant weight of residue is obtained. In the case of silicones, it could be expected that the ash might be an abrasive material. X-ray examination failed to produce any characteristic diffraction pattern for the ash; this could result from lack of crystalline structure or from extremely small crystal size. The thermal and oxidation decomposition characteristics of methyl phenyl silicones are reported in reference 13.

Comparative wear data were obtained between SD-17 and SD-17 containing 5 percent by weight ash. The runs were made with an apparatus similar to that reported in reference 1 except that the hemispherical specimen contacted the top of the lubricated disk. These data indicated that the ash did not have any effect on wear. An additional experiment with the solid lubricant friction apparatus described in reference 14 indicated that the ash by itself had high shear strength and therefore would not function as a solid lubricant and might be harmful when run dry or in high concentrations.

The Wright Air Development Center Materials Laboratory reported lubrication data obtained with the use of SD-17 in a Shell Four-Ball E. P. test apparatus (appendix B). The values of incipient seizure (40 kg) and weld point (115 kg) for SD-17 containing 0.5 weight percent PTZ are in good agreement with similar data reported by Pratt & Whitney in appendix A.

The Esso Laboratories, Standard Oil Development Company arranged for the Esso European Laboratories in England to obtain IAE gear failure data on several synthetic fluids supplied by the NACA. These fluids included the compounded diester PRL 3313 as well as the silicone-diester blend SD-17 containing 0.5 weight percent PTZ. The data obtained for NACA as well as comparative data for other compounded synthetic lubricants reported in reference 7 are presented in appendix C.

These IAE gear failure loads indicate that the SD-17 fluid compares favorably with other lubricants with respect to gear lubrication capabilities. As previously mentioned, the Pratt & Whitney data (appendix A) and data from Southwest Research Institute (table III) also indicated that SD-17 was an effective lubricant for highly loaded high-speed gearing.

The data obtained by Silicone Products Dept. of General Electric Corp. and reported in appendix D would indicate that SD-17 is not a particularly good boundary lubricant. The Shell four-ball apparatus, the Falex apparatus, and the Navy Gear Wear Test (stainless steel against brass) were used by General Electric to obtain these data.

The NACA high bulk temperature lubricant studies, the results of various Shell four-ball wear studies and the additional data obtained by General Electric indicated that SD-17 had certain deficiencies in boundary lubricating abilities as measured by these different devices. Other NACA data as well as the gear test results of Pratt & Whitney, Southwest Research Institute, and Esso indicated that SD-17 had very good lubrication properties as compared with several fully compounded lubricants (table III). Evaluation of the significance of these various results with respect to possible effective use of SD-17 in engines was based on how closely the various devices simulate limiting lubrication conditions for engines. This approach may be questioned, but was necessary because no quantitative engine correlation data are available for any of the bench devices for lubrication studies. References 3 and 7 imply that gear tests provide the best simulation of complex engine lubrication conditions. Also, gear failure loads are more generally accepted by engine manufacturers and military services as an indication of probable lubricating effectiveness in engine operation than any other laboratory data; the gear test data available indicated that SD-17 was a good lubricant. NACA studies under closely controlled lubrication conditions that were in the range common to engine operation indicated SD-17 to be an effective lubricant. The four-ball wear data at loads greater than the incipient seizure point formed the bulk of unfavorable data. Those wear data were obtained under pure sliding conditions with very high surface stresses (40 kg load at incipient seizure gives 460,000 psi initial Hertz stress). The practical significance of the four-ball data is not known.

These considerations led to the general conclusion that SD-17 had favorable lubrication characteristics under conditions of significance to engine operation as well as good physical and chemical properties for lubrication and therefore would merit further evaluation by means of engine operation.

Turbopropeller Engine Study

On the basis of data previously presented herein, the Bureau of Aeronautics, Dept. of Navy, and the Allison Division of General Motors agreed to a functional check of NACA silicone-diester blend SD-17 lubricant. With their permission and program concurrence, an engine test was made in the Lewis Altitude Wind Tunnel with an Allison T-38 turbopropeller engine which had been in use for extensive controls studies.

The early development of this engine was seriously hampered by gear box lubrication problems. In the present state of development of the T-38 engine, no serious lubrication problems are normally encountered with the current T-38 lubricant which has properties indicating it to be oil A of table IV in reference 7. The present situation has been realized by careful selective matching of gear components and by using a viscous lubricant which makes low-temperature (-65° F) starting virtually impossible. A new high-load-capacity lubricant with good low-temperature viscometric properties would simplify production and operating problems.

The engine for this run was assembled with Navy model XT-38-A-2 (Allison model 501-A-6), serial number 97, power section and with Navy model XT-38-A-2, serial number 7 reduction gear box. Before the run described herein the gear box had been run for 271:40 hours; this included a run-in of approximately 9 hours with PRL 3313, $1\frac{1}{2}$ hours with PRL 3161, a short preservative run (with PRL 3161 plus a preservative mixture), and approximately 261 hours with the current T-38 lubricant. All service operation prior to the tests with SD-17 was obtained in altitude wind tunnel control tests, which included 20 minutes operation with PRL 3313 and 260:50 hours with the current T-38 lubricant. It is not believed that the current T-38 lubricant contains any chemically active lubrication additives; therefore, it is probable that any reaction films formed during operation with PRL oils containing active additives would have been worn off the gear teeth during the extensive subsequent operation with the lubricant that did not contain active additives.

With the cooperation of Allison representatives, the gear box was dissassembled and inspected immediately before the SD-17 run. Highly loaded gears in the planetary gear system were photographed (figs. 2 and 3). The oil system was flushed twice with specification MIL-0-6081 grade 1005 petroleum oil, drained as completely as possible, and 51 gallons of SD-17 was put in the oil system. (It was previously determined that SD-17 was compatible in all proportions with 1005 oil.)

The engine operation experienced with SD-17 totaled 19:18 hours at 14,300 rpm, including 8:41 hours at 2050 shaft horsepower, 6:30 hours at 1745 shaft horsepower, 0:30 hours at 2400 shaft horsepower with -10° F engine intake air, and 0:30 hours at 2060 shaft horsepower with -10° F engine intake air; 1:07 hours operation was obtained during foaming checks at varied altitudes, and 2:00 hours power running time was obtained during warm-up, trouble-shooting, and miscellaneous operation. Typical values of operating temperatures and other performance variables during periods of stable operation are presented in table IV. In general, endurance operation consisted of alternate 30-minute periods with turbine-inlet temperatures of 1600° and 1500° F. The altitude foaming checks were made with a turbine-inlet temperature of 1550° F.

All endurance running was obtained at 5000 feet altitude with a tunnel air speed of Mach number 0.2. These conditions were selected as the optimum for continuous high-power operation in the altitude tunnel. The low-temperature (high-power) runs were made under conditions that could not be maintained for long endurance periods because the required tunnel refrigeration capacity was not available at all times. The general operating characteristics of this engine with the SD-17 lubricant was essentially the same as was experienced with the current T-38 lubricant .

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Special thermocouples were installed at approximately the pitch line on the side of the ring gear of the planet system and on the oil shield surrounding the planet system at locations approximately 40° from the bottom of the gear box.

After the runs with SD-17 it was planned to obtain comparative temperature data with the current T-38 lubricant. This was impossible because a mechanical failure of the engine was encountered before the desired data could be obtained. The failure was experienced during operation with the current T-38 lubricant but could not have been caused by the lubricant. Isolated and not directly comparable temperature data are available that were obtained with the current T-38 lubricant during final control studies. With the regular T-38 lubricant, at 3500 feet altitude and Mach number 0.3 tunnel air speed, the temperature rise of the oil in the gear box was 21° F; this temperature difference was that between the point of oil supply to the gear case and after it had passed through the reduction-gear oil supply pump and over the planet gears to the planet gear oil shield. Under similar power conditions with SD-17 as the lubricant operating at 5000 feet altitude and Mach number 0.2, the temperature rise was 28° F. The difference in temperature rise may have been the result of increased churning of the more viscous (at high temperatures) SD-17.

In normal operation the oil to the gear case was allowed to by-pass a venturi used to measure oil flow. When periodic oil-flow data were taken, the by-pass was closed by means of a solenoid valve. The gear-case oil flow was approximately 82 pounds per minute, which is normal for the engine.

The approximate total oil used during the entire running with SD-17 was 6 gallons, of which perhaps 3 gallons was lost through the gear case breather (during windmilling) and by minor losses from leaks, oil samples, and from opening the oil system periodically to inspect pump screens. Usage of oil at this rate (approximately 3 gal in 19:18 hr) is considered normal for this engine in this type of test. No lubricant was added during the run, and at the end of the running the neutralization number was the same as before operation.

The oil system installation in the altitude wind tunnel for the T-38 engine had flow characteristics different from those of an airplane installation. The peculiarities of the oil system led to more severe lubricant foaming troubles than have been encountered in operating aircraft. At various times, foaming trouble was encountered in the altitude tunnel set-up at altitudes from 26,000 to 34,000 feet with the current T-38 lubricant. To eliminate this problem during controls studies, the propeller reduction-gear box was pressurized at altitudes above 25,000 feet.

To check the foaming tendencies of SD-17, special runs were made at gradually increasing altitudes (without pressurizing the gear box) until increasing gear box oil-out temperature and spewing of oil through the breather sight glass indicated that the gear box oil was not being adequately scavenged. With SD-17, this condition occurred in the altitude range between 29,000 and 31,000 feet, as compared to values of 26,000 to 34,000 feet for the current T-38 lubricant. These data indicate that the altitude oil-scavenging characteristics for the system were not changed significantly by the use of SD-17 as compared with the current T-38 lubricant.

Allison Division of General Motors Corp. has made bench studies of the foaming characteristics of SD-17 and report that its behavior is comparable with the current T-38 lubricant. They also have indicated that no foaming problem has been encountered in the use of the current lubricant in aircraft installations of the T-38 engine. In addition, reference 15, which reports experience with T-38 engines in a B-17G and the Allison Turbo-Liner does not mention any lubricant foaming problems during flight tests at altitudes up to 35,000 feet with the currently used diester lubricant.

The gear box was disassembled for inspection immediately after being run with SD-17 and the highly loaded gear surfaces of the sun gear and a planet gear were subjected to very careful examination. The surfaces of the gear teeth were unchanged by operation with SD-17. Photographs of the surfaces of two planet gear teeth taken before and after the SD-17 run are shown in figure 2; the same surface marks were visible on the running surface.

Photographs of the same tooth surface of the sun gear before and after operation with SD-17 are shown in figure 3. The appearance of the sun gear tooth surfaces was different from the planet gear teeth because the sun gear had originally been given a "Granodizing" surface treatment. There was no evidence of any surface disturbance on the tooth of the sun gear that could have resulted from operation with SD-17. In these engine runs the SD-17 was completely effective as a gear lubricant since there was no evidence of surface failure or wear. The condition of the gears from the run can be compared with the condition of a failed gear from a T-38 engine shown photographically in reference 16. In view of the previously discussed high wear obtained with SD-17 in the four-ball apparatus, particular attention was given to elements which could indicate wear. No evidence of any detectable wear could be found.

Prior to the runs with SD-17, the sun gear spline was found to have fretted areas on both the loaded and unloaded surfaces. Photographs of tooth surfaces of the sun gear spline on both the loaded and unloaded sides of a spline tooth before and after operation with SD-17 are presented in figure 4. It was found that fretting debris had been displaced from the spline during operation with SD-17 and there was no evidence of additional fretting.

The rolling contact bearings for the planetary gears in the reduction gear box and the turbine bearing from the power section were examined after operation with SD-17. No evidence of any lubrication difficulty could be detected. The usual coating of decomposition products from the current T-38 lubricant on the hot turbine bearing was not disturbed by operation with SD-17.

No evidence of any corrosion of engine metals could be found during the partial disassembly of the gear box and power sections. Several elastomer O-ring seals were examined and no swelling or change in resiliency was noted. A gear box graphite-oil seal had some extremely fine particles of loose graphite on the surface of the seal. It is not known whether this is a usual condition or if the SD-17 oil had an adverse effect on the bonding media for the graphite seal. There was nothing to suggest, however, that the condition of the seal was not satisfactory.

No unusual deposits could be found in the engine after operation with SD-17. The tail cone of the engine had a fine light dust over surfaces exposed to heat and gases as shown in figure 5. The dust physically resembled the ash formed from the silicone-diester fluid but was not identified. Because no previous experience had been obtained with continuous high-output operation, it was impossible to determine whether such deposits were characteristic of SD-17 lubricant or of the engine. Independent combustion studies have indicated that very small concentrations of silicones in fuel would result in similar deposits on combustor surfaces.

SUMMARY OF RESULTS

Experimental study of NACA SD-17 silicone-diester fluid as a lubricant in bench studies and in a turbopropeller engine produced the following results:

1. The performance of SD-17 in a T-38 turbopropeller engine was satisfactory during more than 17 hours of operation at 1745 to 2400 shaft horsepower.

2. SD-17 had better viscometric properties than other lubricants that provide satisfactory lubrication in a turbopropeller engine and would allow low-temperature starting and operation under conditions such that present lubricants would prevent engine operation.

3. SD-17 has good lubrication characteristics as measured by most bench apparatus except the Four-Ball E. P. tester; good gear lubrication characteristics and high load-carrying capacity were observed.

CONCLUDING REMARKS

Because laboratory studies show that the silicone-diester blend SD-17 was satisfactory in an engine test and was superior to currently used lubricants with regard to the combined effects of both gear-load capacity and viscometric properties, a complete evaluation of silicone-diester blends in extensive full-scale engine operation should be made.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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APPENDIX A

RESULTS OF PRELIMINARY PRATT & WHITNEY TESTS ON NACA SD-17 LUBRICANT

	Results of NACA Oil SD-17[a]	Specification requirements PWA 521A
Lubrication		
Viscosity, centistokes, at:		
-65° F	4242	13,000 max.
-40° F	1175	3000 max.
100° F	42.59	11 min.
210° F	14.29	3 min.
Viscosity index	171	--
Pour point, °F	-85	-75 max.
Gear scuffing, lb/in.	3700, 2675	1700 min.
Shell four-ball:		
Min. load for immediate seizing, kg	40	--
Weld point, kg	110	130 min.
Corrosion		
Sulfur, percent	0.05	--
Neutralization number	0.00	--
Reaction	Neutral	--
Copper-strip corrosion	Passed	No pitting
Corrosion-oxidation stability		No pitting; slight stain permitted
Corrosion, weight change, mg/cm^2		±0.2 max.
Copper - stained	0.10	
Steel - stained	0.06	
Aluminum - passed	0.02	
Magnesium - passed	0.09	
Silver plate - passed	0.05	
Viscosity at 100° F, centistokes	43.28	--
Change from original, percent	+1.6	-5 to +15
Neutralization number	1.5	--
Change from original	1.5	1.0 max.
Average lead weight loss, (MROC), g	0.0070	0.30 max.
Neutralization number (after MROC)	0.10	--
Corrosion:		
Mallory 100 (wt. loss, mg)	8, 7	10 max.
Silver (wt. loss, mg)	5, 3	10 max.
Deposition		
Precipitation number	0.05	--
Carbon residue, percent	2.29	--
Ash, mg/20 g	4597 (23 percent)	--
Additives, metals (spectroscopic)	Heavy Si; Low Cu, Ag	Corrosion inhibitors and pour-point depressants permitted
Panel coking (wt. inc., mg)	25	100 max.
Miscellaneous		
Gravity, °API, 60° F	13.9	--
Gravity, specific, 60/60° F	0.9732	--
Saponification number	74.3	--
Flash point, °F	455	365 min.
Fire point, °F	505	--
Low-temperature stability (72 hr at -65° F)	Passed	No separation, or gelling
Evaporation loss at 275° F, percent by weight	0.515	10 max.

[a]Contains PTZ (0.5 percent) only.

APPENDIX B

PRELIMINARY DATA OBTAINED BY AIR FORCE MATERIALS LABORATORY ON NACA SD-17 BLEND

	Not inhibited	Inhibited
Viscosity, centistokes, at:		
210° F	14.35	14.25
130° F	29.58	29.78
-40° F	1106.6	-----
Neutralization number	0.02	0.03
Hydrolytic stability		
Weight loss of copper, mg/cm^2	0.0	0.0
Copper appearance	Red-brown stain	Light-brown stain
Insoluble residue, percent	0.004	0.015
Viscosity change at 130° F, centistokes	-.7	-.2
Water neutralization number	.02	.01
Oil neutralization number	.09	.09
Neutralization number change	+.07	+.06
Oxidation and corrosion at 347° F for 72 hours		
Weight change, mg/cm^2		
Cu	-0.2 (deposit and corrosion)	+0.1 (dark scaly deposit)
Al	.0 (light stain and corrosion)	0.0 (satisfactory)
Mg	-2.4 (corroded and deposits)	0.0 (satisfactory
Steel	-.1 (light stain)	0.0 (dark stain)
Viscosity change at 130° F, percent	+67.0	+2.9
Neutralization number change	+7.67	+.4
Four-ball E. P. test		
Incipient seizure	40	40
Weld point	120	115

Notation by NACA: The oxidation inhibitor was 0.5 percent by weight phenothiazine. This fluid was blended hastily and the oxidation inhibitor was not completely in solution; prior to Wright Air Development Center runs, the fluid was filtered to remove all solids, which took out a part of the oxidation inhibitor.

Wright Air Development Center Materials Laboratory recommended that the combination of phenothiazine and phenyl α-naphthylamine would be a more effective oxidation inhibitor.

APPENDIX C

IAE GEAR MACHINE FAILURE LOADS OF NACA TEST OILS (ESSO DATA)

[2000 rpm; 1/2 pint/min; 90° C; BS En. 39 gears.]

Oil	Kinematic viscosity, centistokes at 210° F	Acidity, mg KOH/g	Failure load, lb		Failure load as percent reference
			Test oil	EAO-100[a]	
United Kingdom di(2-ethylhexyl) sebacate	3.26	0.14	45	70	64
Compounded diester (PRL 3313)	10.41	2.17	115	65	170
Silicone-diester blend (SD-17) with 0.5 percent PTZ	[b]17.14	0.04	145; 150 no scuff	65	230

[a]Run on opposite side of corresponding gear with Esso Aviation oil 100 (grade 1100 mineral oil), ca. 21 centistokes at 210° F.

[b]Does not check viscosity measurement by NACA of 14.2 centistokes, or values given in appendixes A and B - possibly a typographical error.

Additional data from reference 7

	Viscosity centistokes at 210° F	Neutralization number			Scuffing load, percent of grade 1100 mineral oil
"Oil A" (believed to be the current T-38 lubricant)	7.9	0.2	--	--	105
"Oil B" (believed to be MIL-L-7808)	3.6	0.2	--	--	60

APPENDIX D

COPY OF REPORT BY SILICONE PRODUCTS DEPARTMENT OF GENERAL ELECTRIC

ON NACA SD-17 FLUID

November 23, 1953

Introduction:

A sample of a lubricating fluid designated SD-17, furnished by the National Advisory Committee for Aeronautics, has been evaluated on the Shell Four Ball, Falex and Navy Gear Wear testers in our laboratory. The fluid was compared to a commercial petroleum fluid, and a commercial diester fluid as well as a methyl polysiloxane. Our previous tests on fluids similar to SD-17 which is reported to be a silicone-diester mixture have not been too satisfactory when tested on the testers listed above. However, NACA, using a modified Bowden test rig, has shown this fluid to have particular merit under high slider velocities.

Experimental:

Each test was run under the exact same conditions for each fluid. The Navy gear wear test and the Falex wear test have been modified somewhat because of the poor lubricity of silicone fluids. As a result, the operation of the SD-17 is more easily compared under the test conditions.

Shell Four Ball Test

This is a standard type of test where one steel ball is run against 3 fixed steel balls immersed in the oil at 50 Kg. load, for 1 hour at 600 rpm. The three fixed balls are removed from the holder and the scar diameters resulting from the rotation of the fourth ball are measured. Two readings on each ball are taken and the average of the 6 values is recorded as the scar diameter measured in millimeters. The 50 kilogram load is used primarily as a screening test since lower loadings usually do not show as great a variation in scar diameter. Usually, if a lubricant looks good at the high loadings when testing steel on steel, it is equally as good at lower loads. However, when using other metal combinations, such as steel on bronze, the lower loadings become important.

Navy Gear Wear Test

The Navy Gear Wear tester is becoming an important test for many military grease lubricant specifications. The test method is to run a stainless steel gear with a reciprocating motion against a brass gear while the steel gear is partially immersed in the lubricant. The original test method calls for a test for 6000 cycles at a 5# load but when testing poor lubricants the gear teeth are usually destroyed before the completion of the test. To eliminate gear destruction the test modification used by us calls for a 2000 cycle test and the weight loss calculated in the same manner (reported in milligrams per 1000 cycles). However, when any lubricant gives a wear result of less than 2 mg/1000 cycles then the

Appendix D. - Continued.

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standard test method is used, namely, 6000 cycles at a 5# load and 3000 cycles at a 10# load. The results for the diester fluid in Table I are based on this standard test.

Falex Test

Two different testing methods are used on the Falex machine. In one test a steel pin is mounted between steel "Vee" blocks and a load applied through the jaws. The load is constantly increased until seizure occurs. This results either in shearing of the brass pin holding the steel pin in the chuck or shearing of the steel test pin. This is not a very reliable test but does indicate the ultimate load carrying ability of a test fluid.

A second test gives data more related to the gear wear test when the load is applied in 20 pound increments from 20 to 200 pounds and in 100 pound increments above 200#. The test is run for 10 minutes at each load and the wear is measured as the number of teeth on the rachet loading wheel required to bring the load back to its original loading after a ten minute run. By plotting load vs. wear, a wear curve is obtained, which for a good lubricant is quite flat and for a poor lubricant is very steep. By screen test fluids in this manner the gear wear testing is minimized, since a poor test on the Falex will usually result in a very poor test in the Navy Gear Wear tester. The results of the Falex tests are included in Table I and Graph I.

Conclusions:

The results of the above tests show the SD-17 to be comparable in properties to our early silicone-diester mixtures. It is essentially a compromise in properties between a diester fluid and a methyl silicone fluid. The Shell Four Ball and the low loads on the Falex tester indicates that it is a fairly good lubricant under these conditions. However, in applications when the lubrication approaches boundary conditions as in the Navy Gear Wear test and the higher loadings on the Falex tester, the lubrication is not much better than a methyl silicone fluid. The ultimate seizure loads during the Falex test illustrates that the SD-17 is not much better than straight silicone.

N. G. Holdstock
SILICONE PRODUCTS DEPT.
General Electric Company
Waterford, N. Y.

NGH:ARC

CF-3 back

Appendix D. - Continued.

TABLE I

Fluid	Shell Four Ball	Navy Gear Wear		Falex
	50 Kg	Stainless Steel on Brass		Gage load
	Steel on Steel	5#	10#	Ultimate Seizure
SD-17	.71	.62 mg.	failed	400#
Methyl Polysiloxane SF96-100	1.91	30.3	-	250#
Dioctyl Sebacate	.79	1.25	4.57	1500-1600#
SAE 20 Commercial Petroleum Oil	.50	1.40	-	850#

Appendix D. - Concluded.

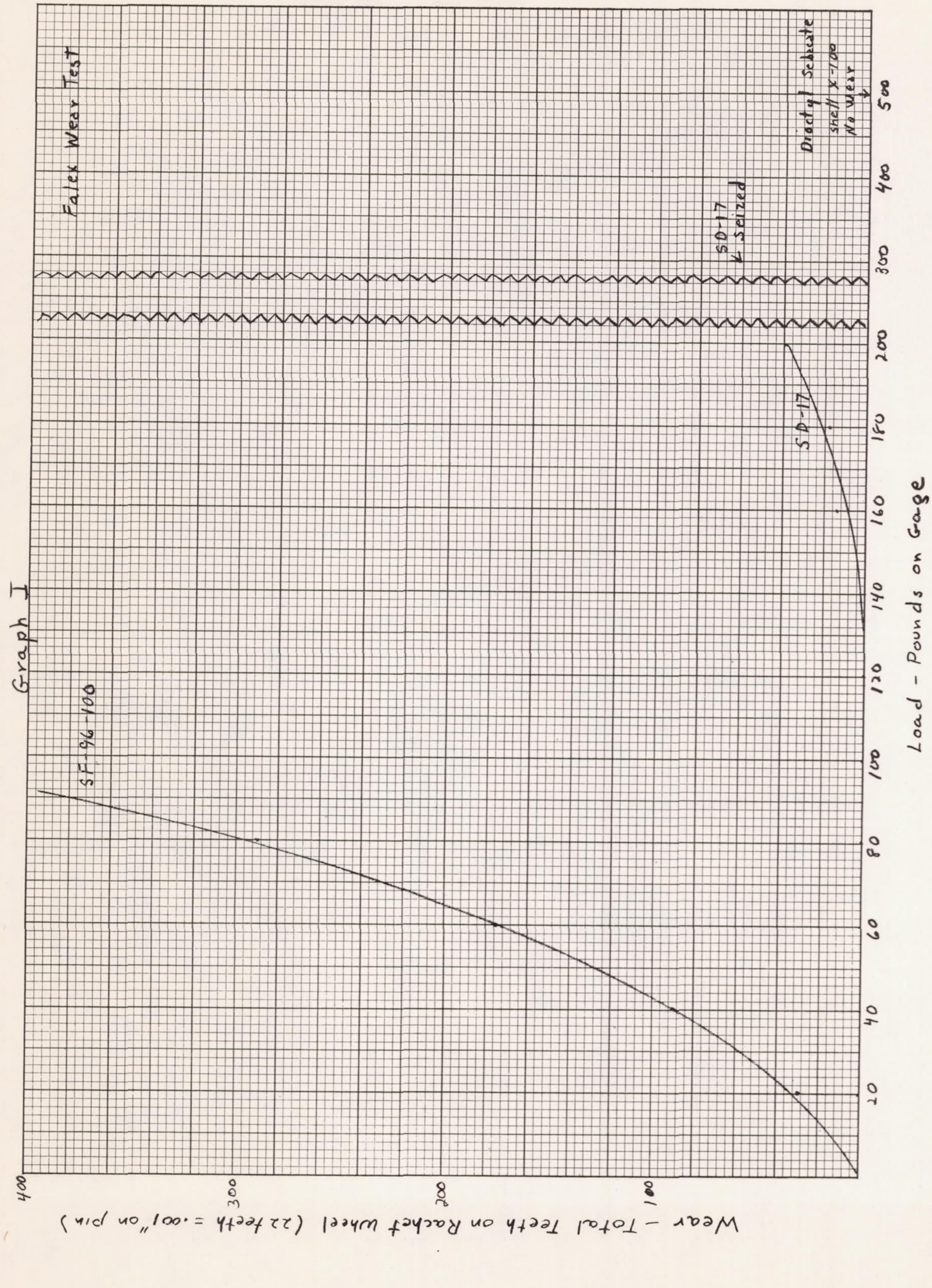

TABLE I. - PROPERTIES OF LUBRICANTS

Lubricant Designation	NACA SD-17	MIL-O-6082 grade 1100	MIL-L-7808[a]	Current T-38 lubricant[a]	PRL[b] 3161	PRL[b] 3313
Composition	1/3 By volume di(2-ethylhexyl) sebacate Plexol 201 in methyl phenyl poly-siloxane (100 centistokes at 25° C, Dow Corning 510) + 0.25 weight percent PTZ and 0.25 weight per-cent PAN[c]	Petroleum plus additives	Believed to be a compounded diester fluid	Believed to be a compounded diester fluid	90.6 Weight percent di(2-ethylhexyl) sebacate, 3.9 per-cent methacrylate polymer, 0.5 percent PTZ, 5 percent tri-cresyl phosphate, and 0.001 percent silicone antifoam[c]	85 Weight percent di(2-ethylhexyl) sebacate, 9 per-cent methacrylate polymer, 0.5 per-cent PTZ, 5 per-cent tricresyl phosphate, 0.5 percent Ortholeum 162, and 0.001 percent silicone antifoam[c]
Properties						
Viscosity, centistokes, at:						
210° F	14.5	20	3.6	7.9	5.3	10.2
100° F	42.6	250	14.2	38.0	20.8	43.1
-40° F	1104.0	---	1920.0	12,500.0	2700.0	----
-65° F	3885.0	---	13,000.0	Too high to measure	16,000.0	41,400.0
Pour point, °F	-100	0	<-75	-65	<-65	-62
Flash point, °F	445	500	430	450	450	435
Neutralization number	0.00	---	0.2	0.2	0.2	2.0
Temperature for 13,000-centistoke viscosity, °F	-85 (extrapolated)	+20	-65	-45 (extrapolated)	-63	-50

[a]Data from reference 7 (oils A and B).
[b]Data from reference 8.
[c]PTZ is phenothiazine.
PAN is phenyl α-naphthylamine.

TABLE II. - NACA OXIDATION-CORROSION MEASUREMENTS

[72 hours at 347° F.]

	SD-17 without oxidation-inhibitor	SD-17 + 0.5 weight percent phenothiazine	SD-17 + 0.25 weight percent phenothiazine + 0.25 weight percent phenyl α-naphthylamine	MIL-L-7808 maximum values
Metal catalysts, weight change, mg/cm²	(a)	(b)	(b)	
Copper	-0.77	+0.09	+0.04	±0.2
Aluminum	+.19	+.01	.00	±.2
Magnesium	-2.9	-.01	+.04	±.2
Steel	+.12	+.01	-.01	±.2
Neutralization number				
Original	.00	.00	.00	--
Final	6.5	.2	.1	--
Change	+6.5	+.2	+.1	+2.0
Viscosity at 100° F, centistokes				
Original	41.7	42.1	42.6	--
Final	65.2	43.5	44.8	--
Change, percent of original	+56.3	+3.3	+5.2	-5 to +15
Evaporation loss, percent by volume	15	9	9	--

[a]All specimens coated with heavy black residue.

[b]All specimens fairly clean; some have thin films.

TABLE III. - LIMITING LUBRICATION VALUES FOR VARIOUS FLUIDS

Property	NACA SD-17	MIL-0-6082 Grade 1100	MIL-L-7808	Current T-38 lubricant	PRL 3161	PRL 3313
Viscosity at 210° F, centistokes	14.5	20	3.6	7.9	5.3	10.2
Sliding velocity for incipient failure, ft/min	10,000	9000	8000	10,000	9000	13,000
Modified SAE incipient scuffing load, lb	116	140	105	90	105	153
Bulk temperature for incipient failure, °F	265	510	420	--	500	450
Ryder gear rig scuffing load, lb/in. tooth						
Pratt & Whitney	3700 and 2675	2600 to 3400	1450 to 2650	3300	1700 to 2000	3900 and 4450
Southwest Institute	3720 and 3380					
IAE gear rig failure load as percent of reference oil						
Esso	230	100	60	105	--	170
Shell four-ball incipient Seizure, kg						
Pratt & Whitney	40					
WADC	40		60		80	90
PRL					80	100
Esso		70	85	75		
Weld, kg						
Pratt & Whitney	110					
WADC	115		130		120	160
PRL					120	160
Esso		130	130	140		

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TABLE IV. - TYPICAL OPERATING CONDITIONS FOR ALLISON
T-38 TURBOPROPELLER ENGINE RUN WITH
NACA SD-17 LUBRICANT

[Altitude, 5000 ft; Mach number, 0.2.]

Operating time, hr	8:41	6:30	0:30	0:30
Shaft horsepower output	2050	1745	2400	2060
Rotative speed, rpm	14,305	14,270	14,310	14,345
Gear case oil flow, lb/min	82	82	---	---
Temperature, $^{\circ}F$				
Turbine inlet, gas	1600	1500	1600	1500
Engine intake air	45	45	-10	-10
Oil supply tank	141	136	89	90
Oil-in, power section	146	145	137	139
Oil-in, gear box	149	148	143	145
Oil-out, compressor section	159	159	140	143
Oil-out, turbine section	339	333	319	317
Oil-out, gear box	182	181	174	176
Ring gear edge, at pitch line	179	176	175	174
Planet oil throw-off on oil shield	177	175	174	173

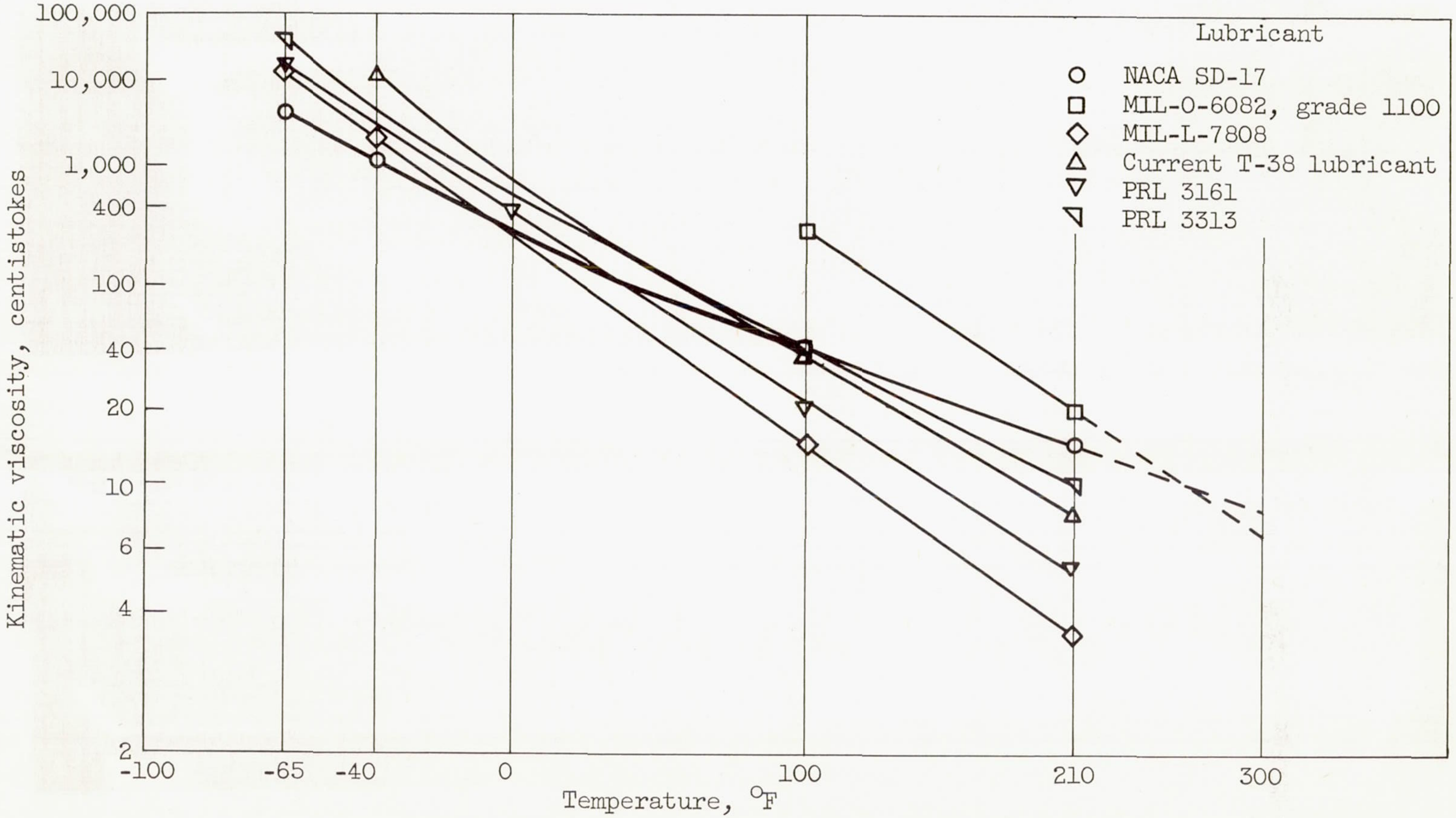
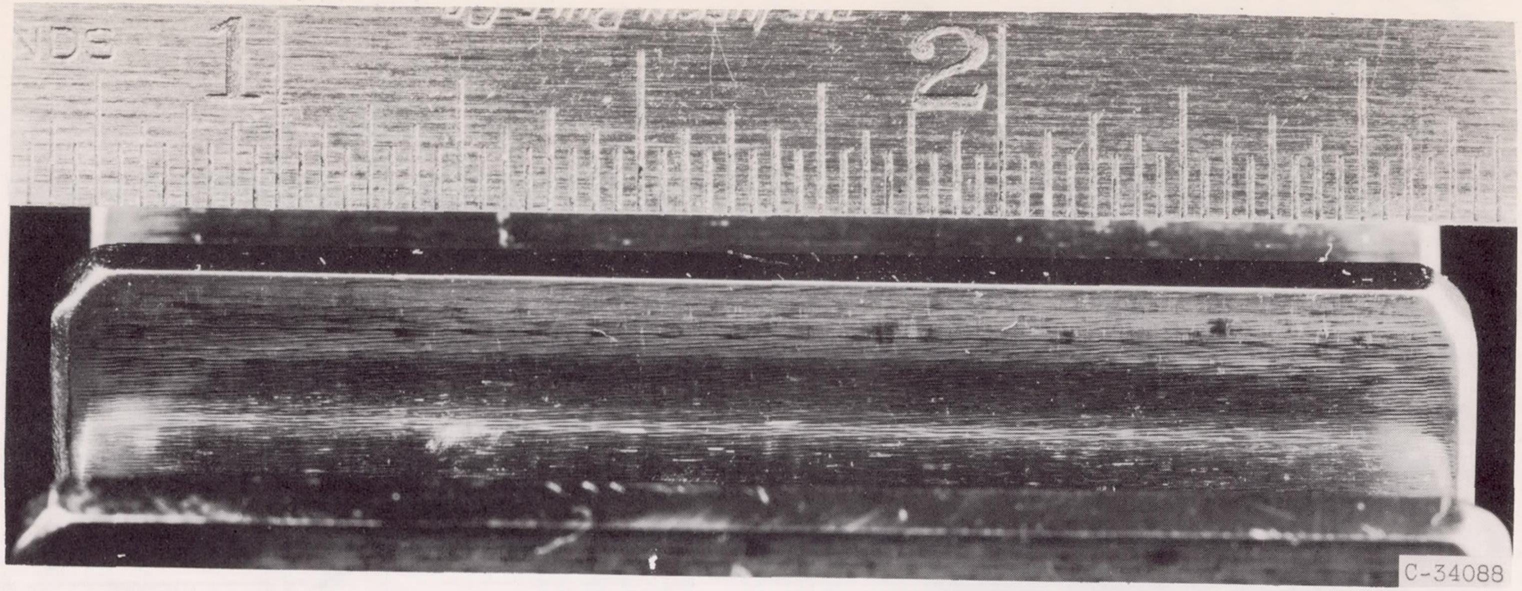
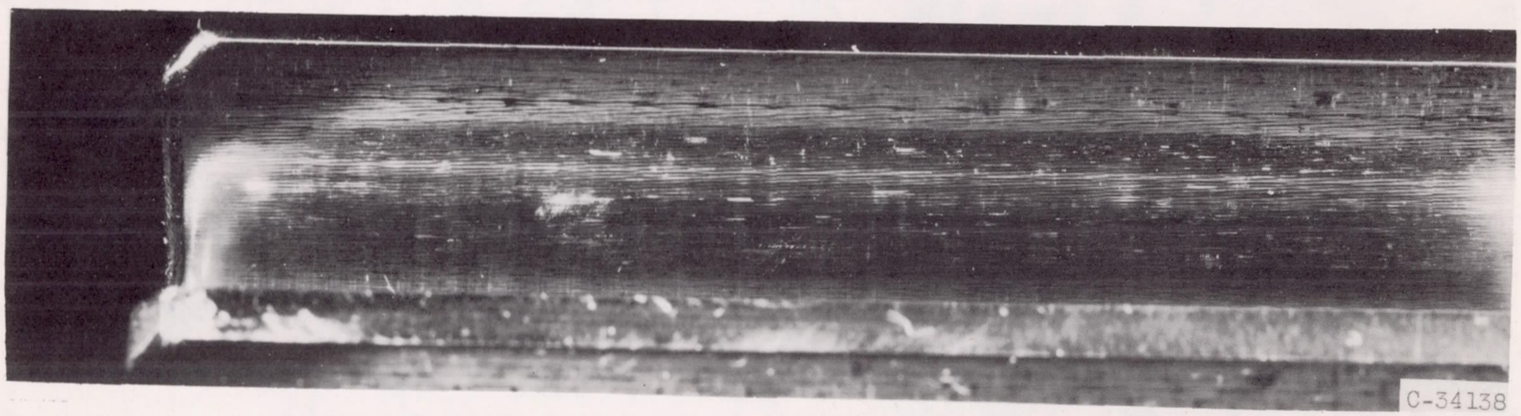


Figure 1. - Viscometric properties of fluid lubricants.

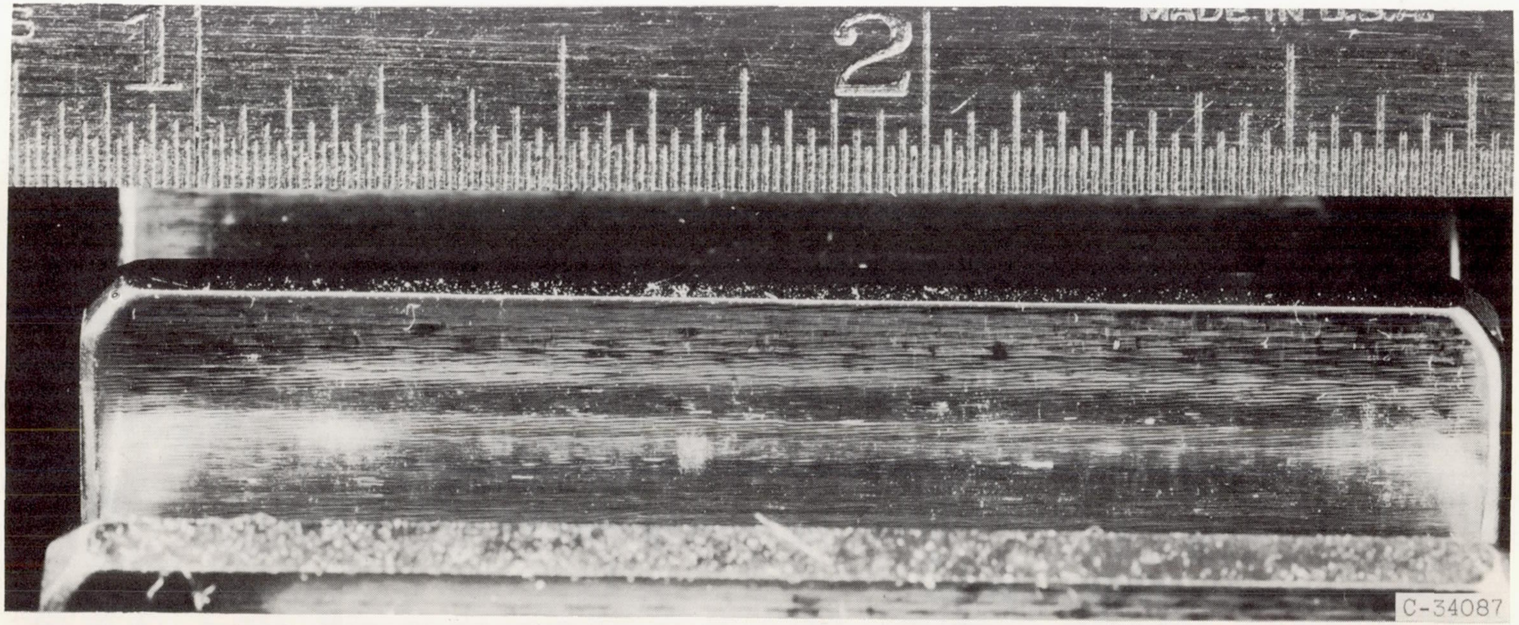


(a) Planet gear tooth before operation with SD-17.

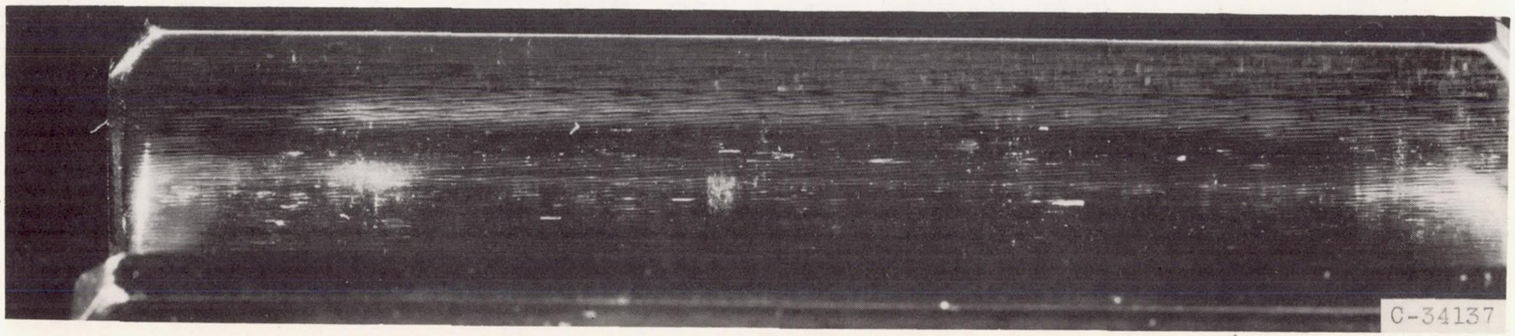


(b) Planet gear tooth after operation with SD-17 (same tooth as in part (a)).

Figure 2. - Photographs of planet gear tooth surfaces from reduction-gear box of T-38 engine.

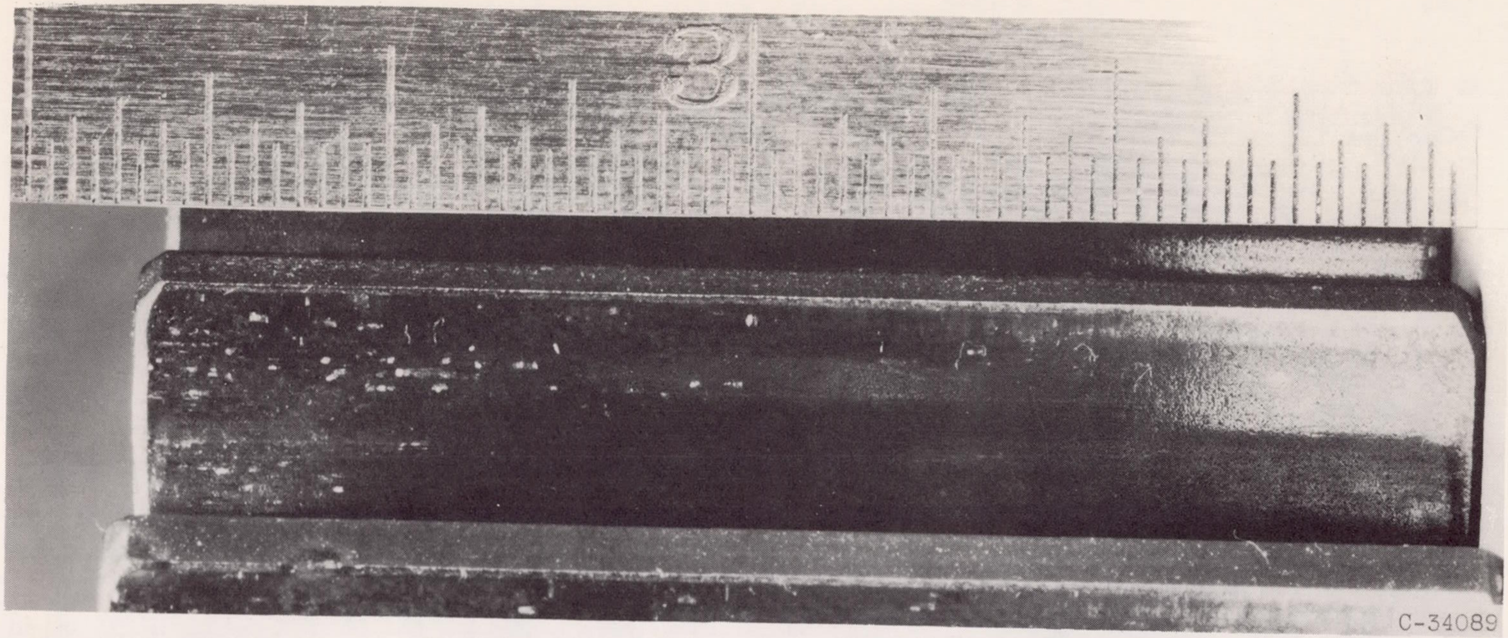


(c) Planet gear tooth before operation with SD-17.



(d) Planet gear tooth after operation with SD-17 (same tooth as in part (c)).

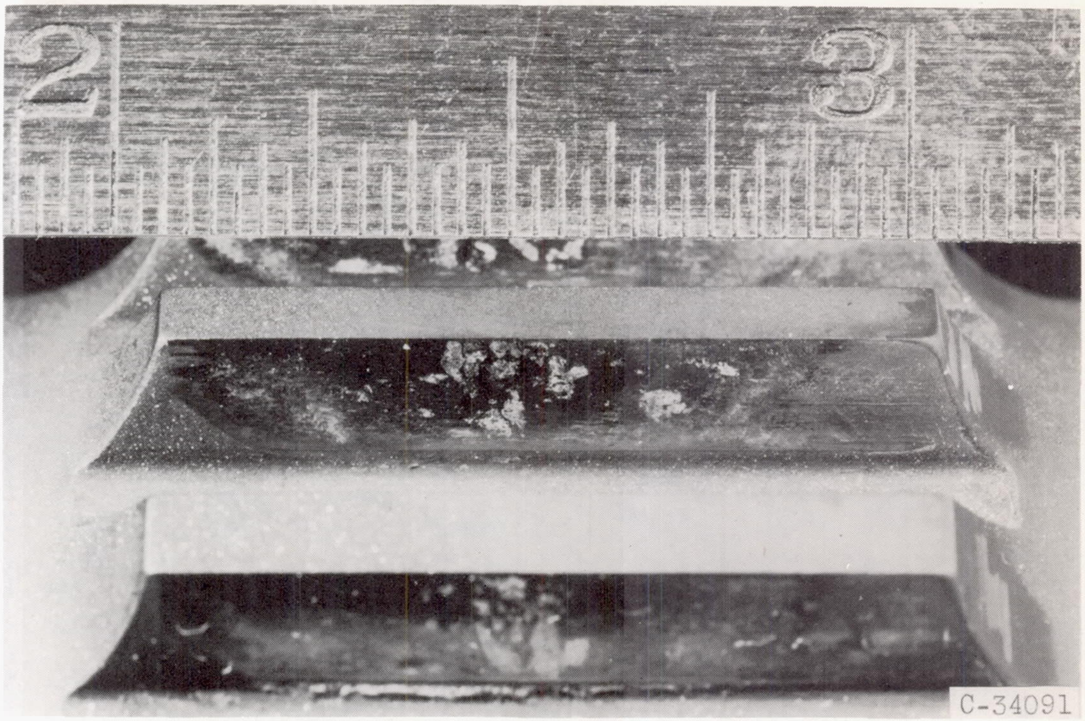
Figure 2. - Concluded. Photographs of planet gear tooth surfaces from reduction-gear box of T-38 engine.



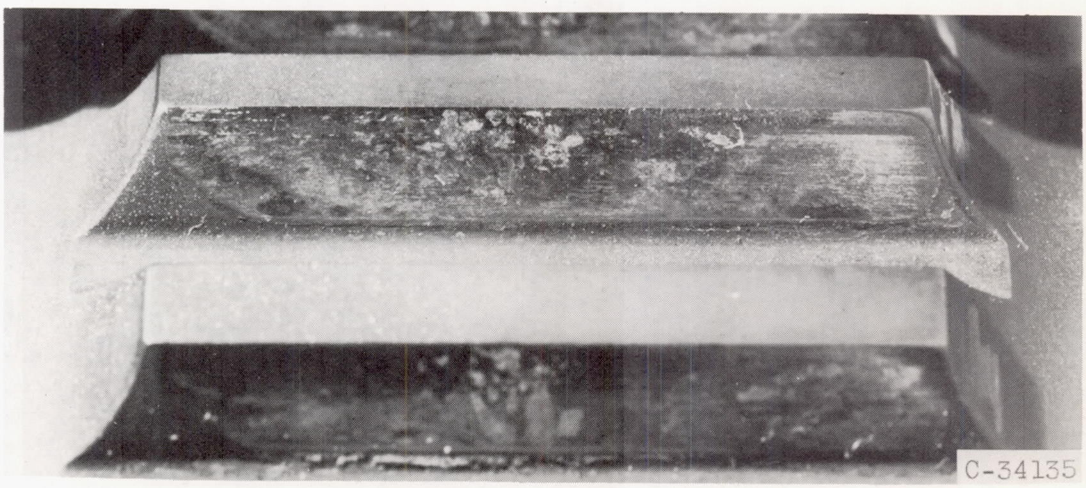
(a) Sun gear tooth before operation with SD-17.

(b) Sun gear tooth after operation with SD-17 (same tooth as in part (a)).

Figure 3. - Photographs of sun gear tooth surface from reduction-gear box of T-38 engine.

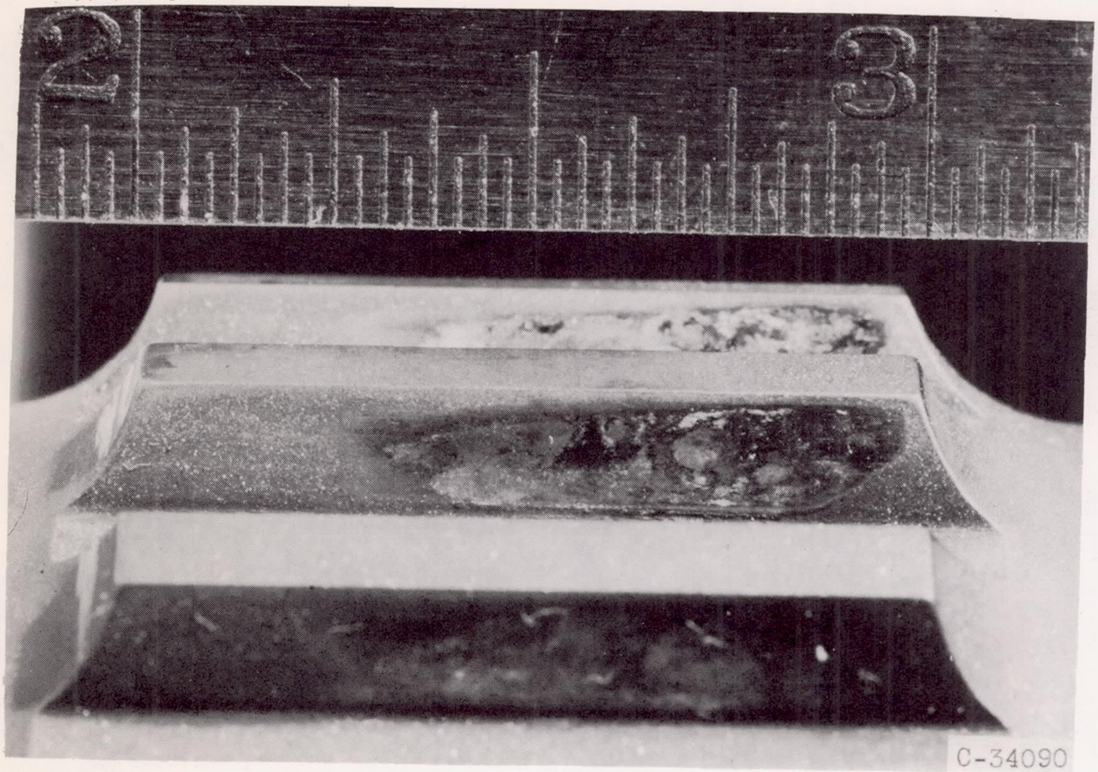


(a) Loaded side of spline tooth before operation with SD-17.



(b) Loaded spline tooth after operation with SD-17 (same tooth as in part (a)).

Figure 4. - Photographs of spline surfaces of sun gear from reduction-gear box of T-38 engine.



(c) Unloaded side of spline tooth before operation with SD-17.

(d) Unloaded side of spline tooth after operation with SD-17 (same tooth as (c)).

Figure 4. - Concluded. Photographs of spline surfaces of sun gear from reduction-gear box of T-38 engine.

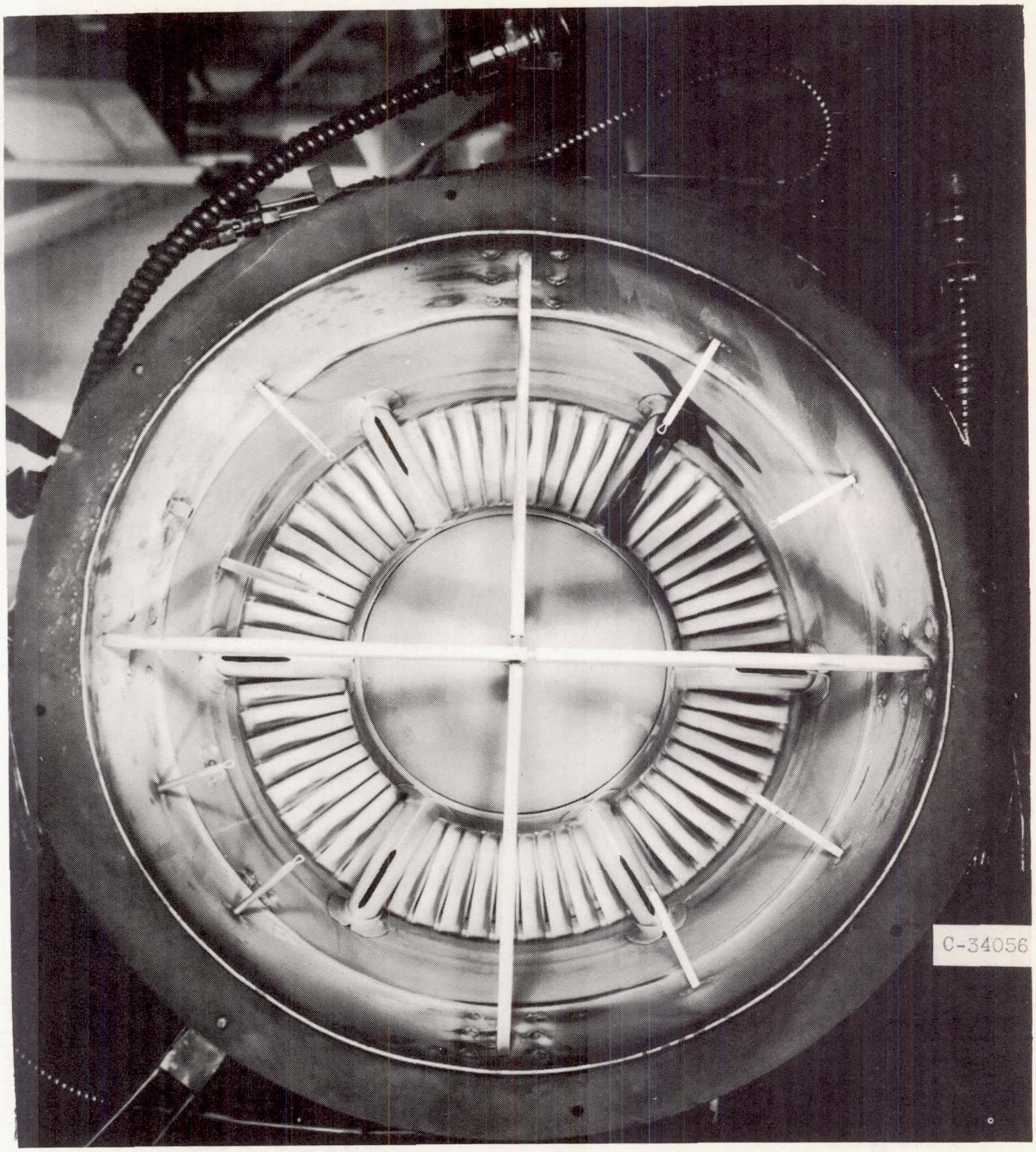


Figure 5. - Photograph of tail cone of T-38 engine after operation with SD-17.