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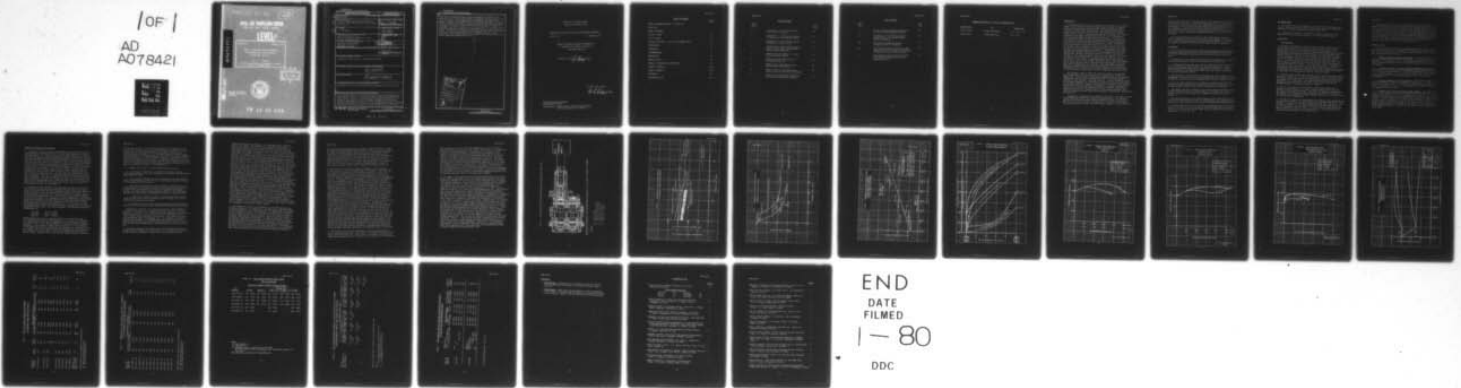
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NOVEMBER 1979

EFFECT OF ENGINE OPERATING ENVIRONMENTS
ON LUBRICANT LOAD CARRYING CAPACITY
OF HIGH GEAR LOAD OILS

By: P. J. Mangione

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both engine and simulated engine bearing compartment environments. The percentage loss in load carrying capacity was greater with the high gear load oils, but neither oil was significantly influenced by the engine type sampled. However, the absolute rating of the degraded XAS-2354 oil remained above the degraded MIL-L-23699 oil absolute ratings. The lower load carrying capacity of used oils, attributed to additive depletion, appeared to be recoverable with new oil additions of a high gear load oil. However, this capability would not be realized in normal operation of an engine lubrication system. An effective pre-conditioning treatment of gear tooth surfaces with a high gear load oil was demonstrated and recommended for use in the "run-in" of new or overhauled helicopter gearboxes for improved resistance to surface damage and extended service life.

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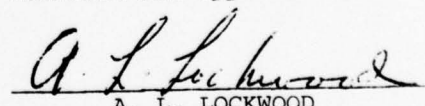
NOVEMBER 1979

EFFECT OF ENGINE OPERATING ENVIRONMENTS ON
LUBRICANT LOAD CARRYING CAPACITY OF
HIGH GEAR LOAD OILS

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Reviewed and approved


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CONVERSION FACTORS: SI TO U.S. CUSTOMARY UNITS

<u>Convert From</u>	<u>To</u>	<u>Multiply By</u>
Degree Celsius	Degree Fahrenheit	$t_f = 1.8 t_c + 32$
Newton/metre	Pound-force/inch	5.71×10^{-3}

INTRODUCTION

The progressive destruction of gears and gear systems due to surface damage by the scuffing or scoring failure mode is always a potential problem in high speed gas turbine engine gearing and heavily loaded helicopter transmissions and gearboxes. The projected technological growth of Navy aircraft propulsion and power transmissions systems toward heavier loads with corresponding emphasis on smaller and lighter components lends added significance to the role of the lubricant in these high speed/heavily loaded lubricated contacts. The ability of the lubricant to carry (prevent metal-to-metal contact) imposed gear tooth load is termed load carrying capacity and is nominally assessed by bench tests such as the Ryder Gear Machine. Current aircraft propulsion and power transmission systems in the Navy are lubricated by the general class of neopentyl polyol ester based fluids which, under the Navy's continuing efforts, are being further developed to provide improved load carrying capacity performance. Consequently, the current experimental, advanced lubricating oils (Specification XAS-2354) have demonstrated lubricant technology capable of providing a 50 percent increase in load carrying capacity over those oils presently in service. The success in the development of these high gear load oils can be attributed, in most cases, to increased amounts of existing additives and/or the use of new, more complex additive systems. While the extended use of these additives and/or additive systems may greatly enhance the load carrying capacity of the lubricant, these same additive packages may have a negative effect on other characteristics of the lubricant. Consequently, current efforts are directed toward a satisfactory balance of all performance characteristics prior to acceptance for service use.

The lubricant, working within the core of an engine, is surrounded by an environment which is conducive to its oxidative and thermal decomposition. Some preliminary evaluations indicated that engine operating environments may also have a detrimental effect on the load carrying capacity of these advanced, high gear load oils. Initial prognosis linked the observed degradation in load carrying capacity to possible instability of the complex additive systems in the high gear load oils. With increased emphasis on higher core operating temperatures, it appeared necessary to investigate the engine environmental effects on lubricant load carrying capacity and assess the relative effect on future weapon systems. The Naval Air Propulsion Center (NAPC) was authorized to perform the investigation by reference 1.

Subsequently, authorization was granted by reference 2 for NAPC to extend that investigation beyond the objectives described above. The extended program would determine whether additive depletion occurs in the used oil and, if so, can it be related to an adsorption or reactive process which can provide protection of the gear teeth active surfaces. In the event such

additive protection exists, the program would then determine the feasibility and benefits of applying, through run-in/pre-conditioning, a protective surface layer on new and reconditioned components in Navy weapons systems. Concurrently, the program was also directed toward the evaluation of used oil (depletion or loss of load carrying capacity) response to new oil additions in terms of recoverable load carrying capacity in an oil system which would reflect in-service maintenance practices, i.e., oil system "topping".

This report presents the results of these investigative and study efforts performed at NAPC for the Naval Air Systems Command. The report offers discussion and assessment of cause/effect of changes in load carrying capacity in current and advanced ester-based synthetic lubricants.

CONCLUSIONS

1. The load carrying capacity of current and advanced ester-based synthetic lubricants significantly decreases with time when operating in an engine environment and appears to approach a minimum absolute value within 300 hours.
2. Engine type did not significantly influence the degradation in lubricant load carrying capacity of either the MIL-L-23699 or XAS-2354 oil.
3. The advanced XAS-2354 high gear load oils experience higher percentage loss in load carrying capacity with time than MIL-L-23699 oils in both engine and simulated engine bearing compartment environments. However, absolute ratings of the degraded XAS-2354 oils remain above the degraded MIL-L-23699 oil absolute values.
4. The temperature of the operating environment can significantly effect degradation in lubricant load carrying capacity and at the higher temperatures, degradation occurs in less time (simulated engine bearing compartment tests).
5. At 5, 10, and 50 percent new oil addition to used oil, the XAS-2354 high gear load oil significantly increased lubricant load carrying capacity whereas the MIL-L-23699 new oil addition was relatively ineffective.
6. The benefits of new oil addition in an actual engine lubrication system would be minimized because the effectiveness of the high gear load oil is reduced based on the low average oil consumption estimates for service engines.
7. The pre-conditioning of gear tooth surfaces with an XAS-2354 high gear load oil can significantly increase the load at which gear scuffing/scoring occurs for a given lubricating oil of lower lubricant load carrying capacity.
8. The effectiveness of the pre-conditioning treatment varied and appeared dependent on additive/metal interactions through an adsorption or reactive process in the lubricated contacts under specific conditions of load/stress, temperature, and time at load.

RECOMMENDATIONS

1. The present "run-in" procedures on new or overhauled helicopter gear-boxes be accomplished with an XAS-2354 high gear load oil for improved resistance to surface damage and extended service life.
2. An analytical program be conducted to verify the existence of the additive/metal interaction at surfaces in rolling/sliding contact.

DESCRIPTIONTest Equipment

1. The Ryder Gear Machine is basically used to assess the ability of a lubricant to prevent the destruction of gears by the scuffing/scoring failure mode. As such, it is one bench test presently used in the qualification testing of gas turbine lubricants for military specifications. An improved high speed/high temperature model, the Ryder Research Gear Machine (Figure 1), was used in this program. The gear machine operates on the four-square principle in that two parallel shafts are connected by two sets of gears; one set is the replaceable test spur gears and the other is a set of helical gears which are integral with the shafts. The load is applied hydraulically to the test gears by the axial movement of one shaft relative to the other. Gear tooth load, then, is a function of helix angle, shaft cross-sectional area (system constants), hydraulic pressure and gear tooth width. When specific failure criteria are incurred by test under fixed operating conditions, this value of gear tooth load is, by definition, the load carrying capacity of the test fluid.
2. The test gears are AISI 9310 aircraft quality steel, case hardened spur gears with 28 teeth at 22.5 degree pressure angle and eight diametral pitch. The mating (load) gears are the same configuration except for tooth width, and operate at 1:1 gear ratio. The gears meet both the metallurgical and dimensional specifications as set forth in Test Method D-1947 of the American Society for Testing and Materials (ASTM).
3. The test oil system is a closed-loop, recirculating system with a capacity of approximately 600 ml and a variable speed pressure pump for accurate control of test oil flow. The system is completely isolated from the support oil system and provides lubrication for only the test gears. The system is also designed to permit accurate control of the test oil inlet (to the gear mesh) temperature.
4. The test oils used in the program were all synthetic ester based lubricating oils which conformed to either lubricant specification MIL-L-23699 (oils currently in service) or XAS-2354 (experimental high gear load oils). Only the Navy's reference oil, a pentaerythritol ester basestock (Hercolube A), will be identified (code PE-5-L606). All other oils are coded and are not further identified except as "high gear load oils" or MIL-L-23699 oils to protect proprietary rights of the manufacturer.

5. The Erdco Bearing Rig is used to evaluate the thermal stability characteristics of gas turbine lubricants under varying levels of severity. It is one of the bench tests presently used in the qualification testing of lubricants for military specifications. The bearing "head" is divided into two main sections (support and test) with each having its own lubrication system. The test section houses an unshielded 100-mm roller bearing. This test bearing is operated under controlled environments which subject the test lubricants to specific severity levels for a predetermined number of hours. The test equipment and procedures were in accordance with Method 3410 of Federal Test Method Standard No. 791B.

METHOD OF TEST

1. The basic method, procedure and operating conditions set forth by the American Society for Testing and Materials (ASTM) in Test Method D-1947 were used in obtaining the load carrying capacity ratings of the lubricating oils evaluated in these programs.

a. Effects of Engine Operating Environment - Evaluate the load carrying capacity of lubricating oils both new and used, i.e., before and after operation in a gas turbine engine. The difference between these values was the estimated degradation in load carrying capacity due to the engine environment.

b. Effects of a Single, Simulated Bearing Compartment Environment - Evaluate the load carrying capacity of lubricating oils both new and used, i.e., before and after operation in a bearing compartment under simulated engine operating conditions. The difference between these values was the estimated degradation in load carrying capacity due to the simulated environment.

c. Used Oil Response to New Oil Addition - Evaluate any change in load carrying capacity of a used oil following the addition of 5, 10 and 50 percent (by volume) of new oil. An increase in load carrying capacity was taken as an estimate of the ability of a lubricant to "recover" load carrying capacity in an oil system.

d. Effects of Pre-Conditioning Gear Tooth Surfaces - The gears were "run-in" with a high gear load oil at selected operating conditions in an attempt to pre-condition the active surfaces of the gear teeth, i.e. provide a protective additive layer through an adsorption or reactive process at the surfaces. The pre-conditioning treatments were conducted at various load/stress levels, oil temperatures, and for selected intervals of time in an effort to induce the chemical reaction. The effectiveness of the pre-conditioning treatments was measured by the change in load carrying capacity of the synthetic basestock reference oil (Hercolube A) when evaluated on these gears.

ANALYSIS OF RESULTS AND DISCUSSION

1. The effect of engine operating environments on high gear load oils was investigated by evaluation of used oil periodically sampled from engines operated at NAPC. The evaluation on used oil samples was made in terms of load carrying capacity ratings obtained on the Ryder Gear Machine in accordance with standard procedures normally performed on new oils. The absolute ratings of the used oils showed a measurable loss in load carrying capacity with time as shown in Table I and Figure 2. Most of the data were obtained on MIL-L-23699 qualified products which established (a) a baseline for comparison with the high gear load XAS-2354 candidate oils, and (b) the effect of various types of engines. The results in Figure 2 indicate that the degradation in load carrying capacity in the engines sampled occurs at a constant rate (slope) for the MIL-L-23699 oils and a slightly different rate for the high gear load oils. The data were then normalized by using new oil ratings as references to eliminate differences in magnitude of the absolute ratings. Thus, the degradation or loss in load carrying capacity with time is shown in Figure 3 as a percent change in new oil rating. The curves clearly demonstrate that the high gear load oils lose load carrying capacity more rapidly than MIL-L-23699 oils and the engine type does not significantly influence the degradation.

2. The amount of data compiled on the lubricants in engine tests at NAPC was limited by the availability of XAS-2354 type oils and a test engine. In fact, the engine test data were essentially obtained from most laboratory engine programs in which only qualified MIL-L-23699 oils could be used because of basic test objectives. Concurrent with the lubricant evaluation in engine test programs, the effect of a simulated engine bearing compartment on the lubricating oil performance was also investigated. This approach permitted the evaluation of more experimental lubricants and utilization of normal test operation of the NAPC Bearing Test Rig, a bench test used in the qualification of synthetic lubricating oils. In this test, the oils are stressed under rigidly controlled operating conditions and at a lubricant temperature greater than in the engines sampled. The Bearing Rig operating temperatures are:

Oil Sump	198.9°C (390°F)
Oil Inlet	176.7°C (350°F)
Bearing	260°C (500°F)

Bearing rig operating time is normally 100 hours, although some oils were tested for 200 hours at these conditions. The rig oil-in temperature is significantly higher than the maximum oil inlet temperature, nominal range 185 - 250°F, of the engines sampled. In Figure 4, the loss (percent decrease) in load carrying capacity ratings (Table II) of oils subjected to the Bearing Rig operating environment are presented as a function of new oil ratings. The results appear as a linear degradation in load capability with increasing new oil ratings. However, the engine data indicated in Figure 3 that a constant loss in load carrying capacity should be realized

for each oil type (i.e. MIL-L-23699 and XAS-2354) as a function of time. As such, the 100 hour test time in the Bearing Rig should have produced percent loss in load carrying capacity as a nearly constant value (horizontal line in Figure 4). It is theorized that the severe environment in the Bearing test may degrade the oil beyond normal engine operation and other factors (i.e. viscosity change, TAN, etc.) are causing scatter in the load carrying capacity results. Subsequent evaluation of the oils exposed to the Bearing Rig environment for 200 hours of operation indicated little or no further decrease in load carrying capacity than noted for the same oils following 100 hours in the Bearing Rig.

3. In summary, the results of these investigations show that:

a. In an engine environment, lubricant load carrying capacity significantly decreases with time and appears to approach a minimum absolute value within 300 hours.

b. Of the engines sampled, the type of engine did not significantly effect the characteristic degradation in load carrying capacity of either the MIL-L-23699 or XAS-2354 oils.

c. The high gear load XAS-2354 oils experience significantly higher percentage loss in load carrying capacity with time than MIL-L-23699 oils in both engine and simulated engine bearing compartment environments. However, the load carrying capacity absolute ratings of used (degraded) XAS-2354 oils remain above the degraded MIL-L-23699 oil absolute values.

d. A significant temperature effect on the lubricant load carrying capacity exists in going from a nominal 185-250°F (engines) to a 390°F (Bearing Rig) operating environment.

e. The effect of time on lubricant load carrying capacity degradation diminishes with increased operating temperature based on bearing rig data.

Based on these results, the program was directed toward determining the mechanism of load carrying capacity loss and the effect on gearbox operation. Essentially, it is suspected that the additives and/or additive systems become unstable or reactive in the engine environment and are "lost" from the fully formulated, blended oils. This premise is based on two observations made in the program, i.e., (a) lubricant load carrying capacity can decrease to a minimum absolute value within 300 hours or less; and (b) the high gear load XAS type oils exhibit a higher percentage loss in load carrying capability in less operating time than MIL-L-23699 oils.

4. An area of concern is the effect of the lower load carrying capacity in normal service operation of the engines. In most cases, service engines operate without a mandatory oil drain interval and normally follow a

"topping" procedure with "make-up" oil to maintain proper lubricant level in the system. Consequently, an investigation was made to evaluate the effectiveness of new oil additions in regenerating the load carrying capability of the used oil. The "topping" procedure was simulated by preparing samples of used oils which contained various percentages (by volume) of new oil, i.e., 5, 10 and 50 percent new oil addition. The samples were prepared with both MIL-L-23699 and XAS-2354 used oils plus new oil additions of the respective oil type. The load carrying capacity ratings of the samples were subsequently obtained in the Ryder Gear Machine. These data are presented in Table III and are shown in Figure 5 with the curves extrapolated to the new oil value (100 percent new oil) above 50 percent new oil addition. The results indicate that: (a) a significant change in load carrying capacity does not occur with MIL-L-23699 used oils up to 50 percent new oil addition; and (b) load carrying capacity increases significantly with XAS-2354 used oil even at low (5-10) percentages of new oil addition. The difference in the regenerative characteristics between the two oils may be attributed solely to the quantity and/or type of additives in the XAS-2354 oils which give these oils their extremely high load carrying capability. The effectiveness of the XAS type oils in improving load carrying capacity was further evaluated by adding an XAS oil to a non-additive synthetic base oil. These results are also shown in Figure 5 and substantiate the load carrying capacity improvement qualities of these high gear load oils. However, in actual service operation, the recoverable load carrying capacity is never fully realized since additions of 50 percent new oil, for example, at one "topping" of the system would not occur. Instead, a small quantity (normally under 5 percent) is added during servicing which is then subjected to continued engine operation. In this manner, an engine lubrication system would never have a "true" percentage mix (above 5 percent) as simulated in the laboratory prepared samples. Thus, the load carrying capacity decreases with time in an actual lubrication system (Figures 2 and 3) because the effectiveness of the high gear load oils is reduced in the normal range of oil quantity added based on average oil consumption estimates for service engines.

5. The degradation and rate of degradation in load carrying capacity apparently depends on the stability of the additives/or additive systems in fully-formulated oils, particularly with the complex additive systems in the high gear load oils. This stability, or instability, evidently results in additive depletion in the used oils which manifests itself by the lower load carrying capacity ratings. Thus, the overall program included an investigation to determine if additive depletion in the used oil could be related to an absorption or reactive process which could provide protection of the gear teeth active surfaces. The investigation was directed toward evolving an effective "run-in"/pre-conditioning treatment of the test gears with the high gear load oils. The high gear load oils were selected for the investigation because of their extremely high initial load carrying capacity and suspected greater instability.

The investigation involved studies at various load/stress levels (in the gear mesh), oil temperatures, and intervals of time at load in an attempt to induce an additive/metal reaction at the gear teeth active surfaces. Essentially, the pre-conditioning procedure was accomplished by (a) "run-in" of test gears with a high gear load oil at selected load/stress level and oil temperature for specified time intervals; (b) complete flushing/cleaning of the test oil system; and (c) evaluation of a non-additive synthetic base oil on the pre-conditioned gears. The effectiveness of the pre-conditioning treatment was measured by the change in load carrying capacity rating of the reference non-additive base oil.

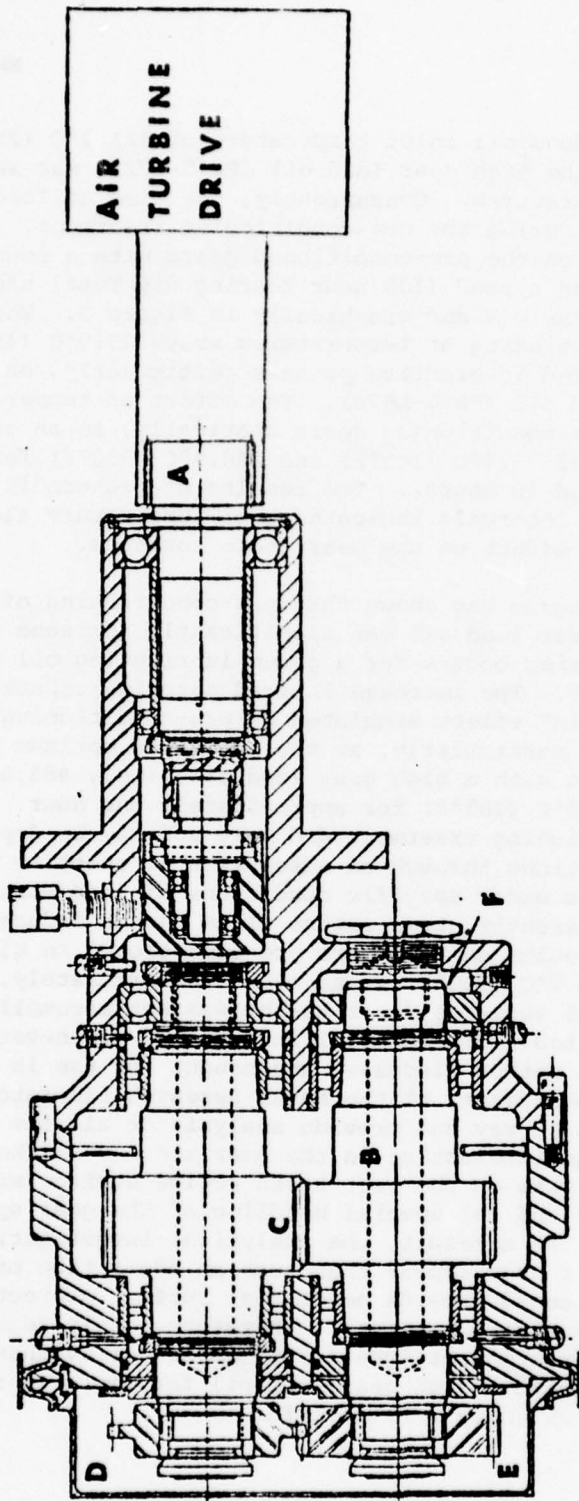
6. The benefits of a "run-in" period on surfaces in rolling and/or sliding contact is widely recognized and the technique is routinely used as a "break-in" procedure on most mechanical components. Since the pre-conditioning treatment with high gear load oils will, in effect, be influenced by "run-in" periods, the program attempted to isolate the "run-in" effect by evaluation of gears pre-conditioned with a non-additive base oil. Consequently, pre-conditioning of test gears was accomplished with the non-additive base oil (PE-5-L606) at tooth loads of 80,000, 322,000 and 483,000 N/m (460, 1840 and 2760 ppi) and time intervals, at load, of one and five hours. The results are presented in Table IV and graphically in Figure 6. The curves show the effect of "run-in" on load carrying capacity of the non-additive base oil (PE-5-L606) as determined in the Ryder Gear Machine. It appears that a significant increase in load carrying capacity can be attained by "run-in" for one hour at tooth loads up to approximately 315,000 N/m (1800 ppi) after which the effect diminishes as the pre-conditioning load approaches the load carrying capacity rating of the pre-conditioning fluid. Although an increase in load carrying capacity is also realized by "run-in" for five hours at light loads the benefits of "run-in" diminish rapidly when pre-conditioning at the higher loads for extended time intervals. Concurrently, an evaluation of test gears pre-conditioned with an XAS-2354 type high gear load oil (PE-5-L721) was conducted. The pre-conditioning treatment was again accomplished at tooth loads of 80,000, 322,000 and 483,000 N/m (460, 1840 and 2760 ppi) and time intervals, at load, of one and five hours with one ten hour interval at the 483,000 N/m (2760 ppi) load. The results are presented in Table IV and graphically in Figure 7 for the one and five hour time intervals. The curves not only reflect the effect of "run-in" but also indicate that pre-conditioning with the high gear load oil can provide increased load carrying capability, particularly at the 483,000 N/m (2760 ppi) load for both intervals of time evaluated. The effect of time at load was also demonstrated by pre-conditioning at the 483,000 N/m (2760 ppi) load for ten hours. The results are graphically shown in Figure 8 and basically suggest that optimum treatment time at the 483,000 N/m (2760 ppi) load lies in the interval of one to five hours.

7. The influence of oil inlet temperature on the pre-conditioning of gears was also investigated in the program. The standard operating temperature of the Ryder Gear test, 73.9°C (165°F), was used in all prior pre-conditioning treatments and was continued in this part of the investigation.

Upon selection of a second oil inlet temperature of 121.1°C (250°F), pre-conditioning with the high gear load oil (PE-5-L721) was accomplished at both oil inlet temperatures. Concurrently, the time at load was reduced to ten minutes during the pre-conditioning treatment. The results of evaluations on the pre-conditioned gears with a non-additive base oil (PE-5-L606) and a used (100 hour Bearing Rig Test) high gear load oil are shown in Table V and graphically in Figure 9. The curves indicate that pre-conditioning at temperatures above 73.9°C (165°F) does not enhance the suspected interactive process particularly, as seen with the results on the used oil (PE-5-L678). The effect of temperature was also investigated by pre-conditioning gears statically, in an oven at oil bath temperatures of 73.9°C (165°F) and 148.9°C (300°F) for comparable time intervals (1, 5 and 10 hours). The results of pre-conditioning gears in glassware for these intervals indicated that temperature alone did not provide any beneficial effect on the gear tooth surfaces.

8. In summary, the program has shown that pre-conditioning of gear tooth surfaces with a high gear load oil can significantly increase the load at which gear scuffing/scoring occurs for a given lubricating oil (lubricant load carrying capacity). The increase in load carrying capacity appeared to be beyond the "run-in" effect simulated by pre-conditioning with the non-additive base oil, particularly, at the indicated optimum pre-conditioning conditions with a high gear load oil, i.e., 483,000 N/m (2760 ppi) load at 73.9°C (165°F) for approximately one hour. The effectiveness of the pre-conditioning treatment did vary and may be dependent on additive/metal interactions through an adsorption or reactive process in the lubricated contacts under specific conditions of load/stress, temperature, and time at load. Apparently, temperature alone cannot induce the interaction based on the results on the gears pre-conditioned in glassware to 93.9°C (165°F) and 148.9°C (300°F) in an oven. Unfortunately, an analytical evaluation of the metal surfaces (gear teeth) was not accomplished in the program and the suspected additive/metal interaction was never confirmed. The primary analytical method discussed and sought for use in the program was the Auger Spectrophotometer at the Naval Research Laboratory. It was determined that the Auger may not provide analysis on all the elements which may enter into an interaction on the gear teeth. Further problems involved were: (a) analysis on the gear tooth active surface without sectioning of the gear and (b) special handling of the gear specimens between laboratories. As a result, the analytical investigation was never initiated. However, it does appear that such an adsorption or reactive process may occur and could provide beneficial surface protection to the gears in power drive system components. Therefore, it is recommended that present "run-in" procedures (green run) on new or overhauled gear-boxes be accomplished with a high gear load oil for improved resistance to surface damage and extended service life.

FIGURE 1: CROSS-SECTION OF THE RYDER RESEARCH GEAR MACHINE TEST HEAD



LEGEND:

- A - Drive Shaft
- B - Driven (Load) Shaft
- C - Helical "Slave" Gears
- D - Test Gear - Narrow
- E - Load Gear - Wide
- F - Load (Oil) Chamber

FIGURE 2. DEGRADATION IN LOAD CARRYING CAPACITY OF LUBRICANTS IN GAS TURBINE ENGINES

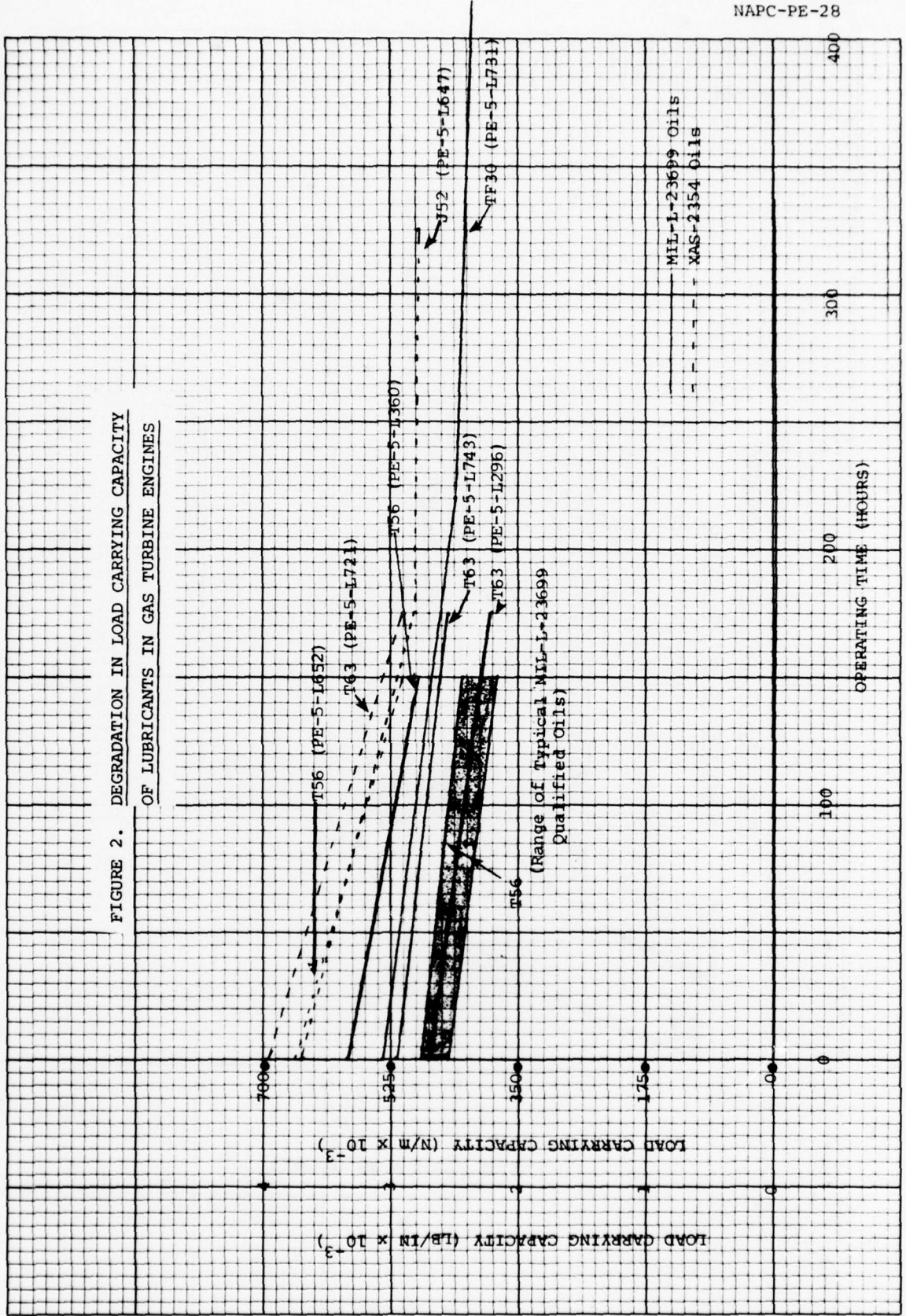


FIGURE 3: DEGRADATION IN LOAD CARRYING CAPACITY

NORMALIZED TO NEW OIL VALUES

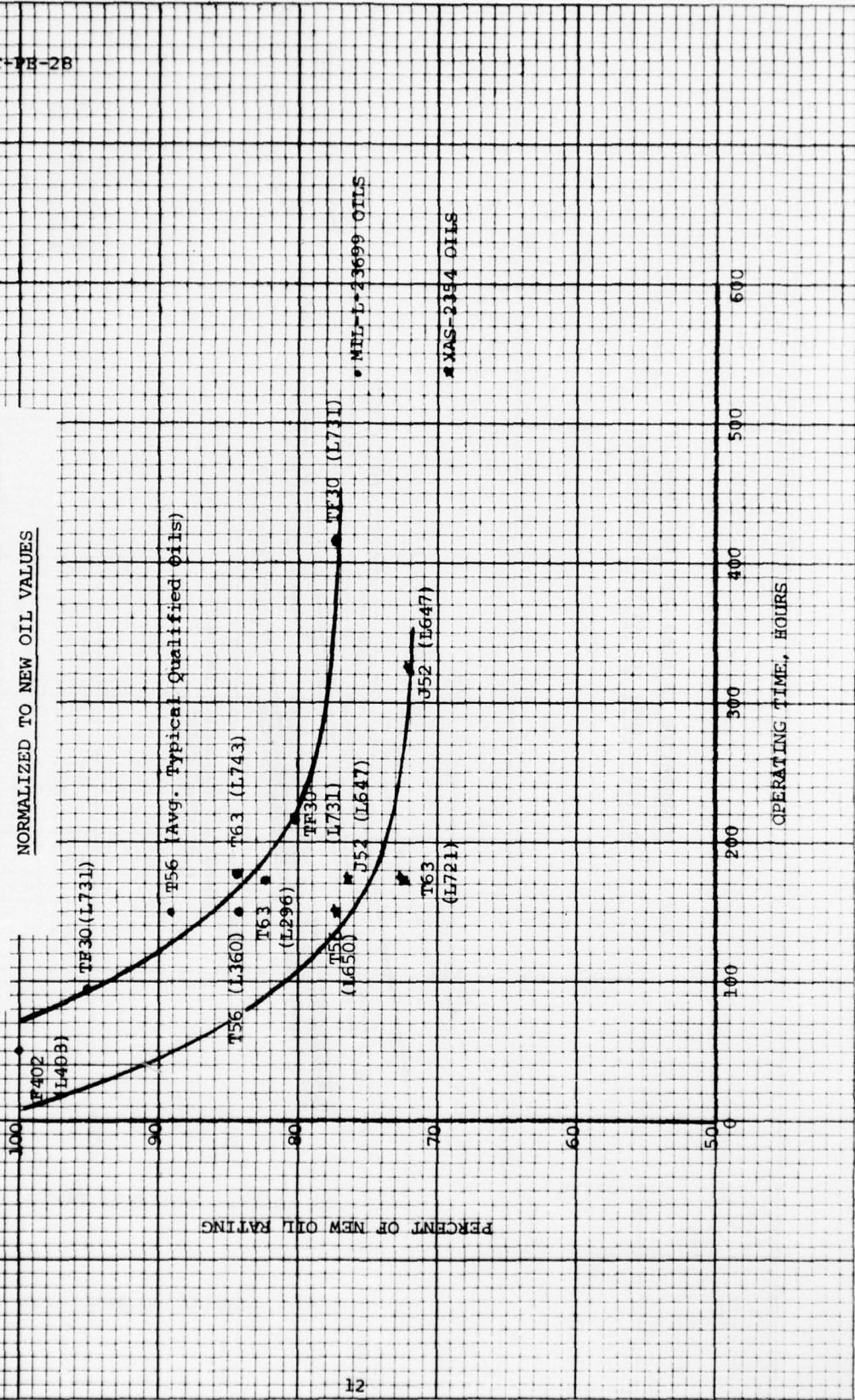
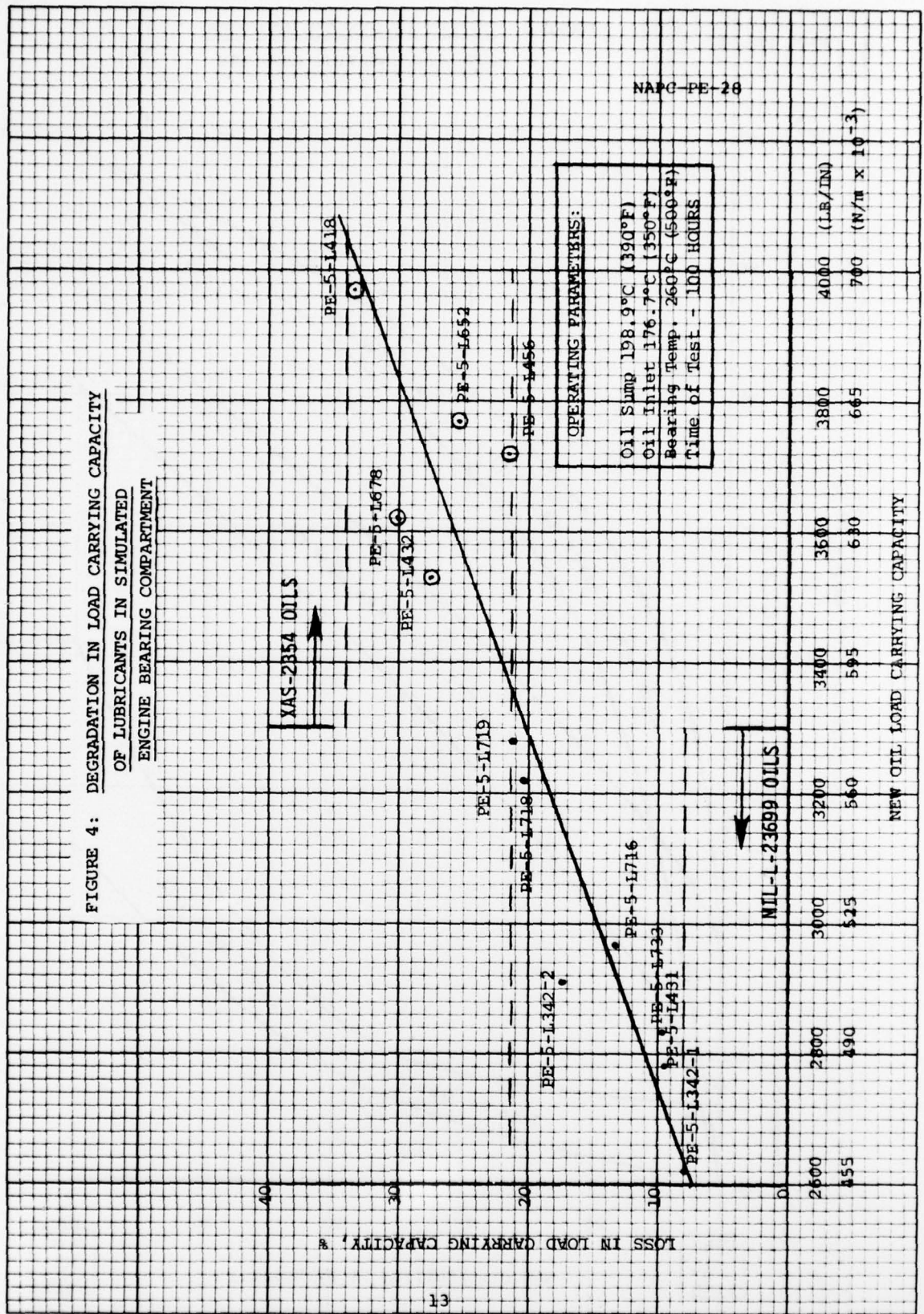


FIGURE 4: DEGRADATION IN LOAD CARRYING CAPACITY OF LUBRICANTS IN SIMULATED ENGINE BEARING COMPARTMENT



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FIGURE 5: EFFECT OF NEW OIL ADDITION
ON LOAD CARRYING CAPACITY

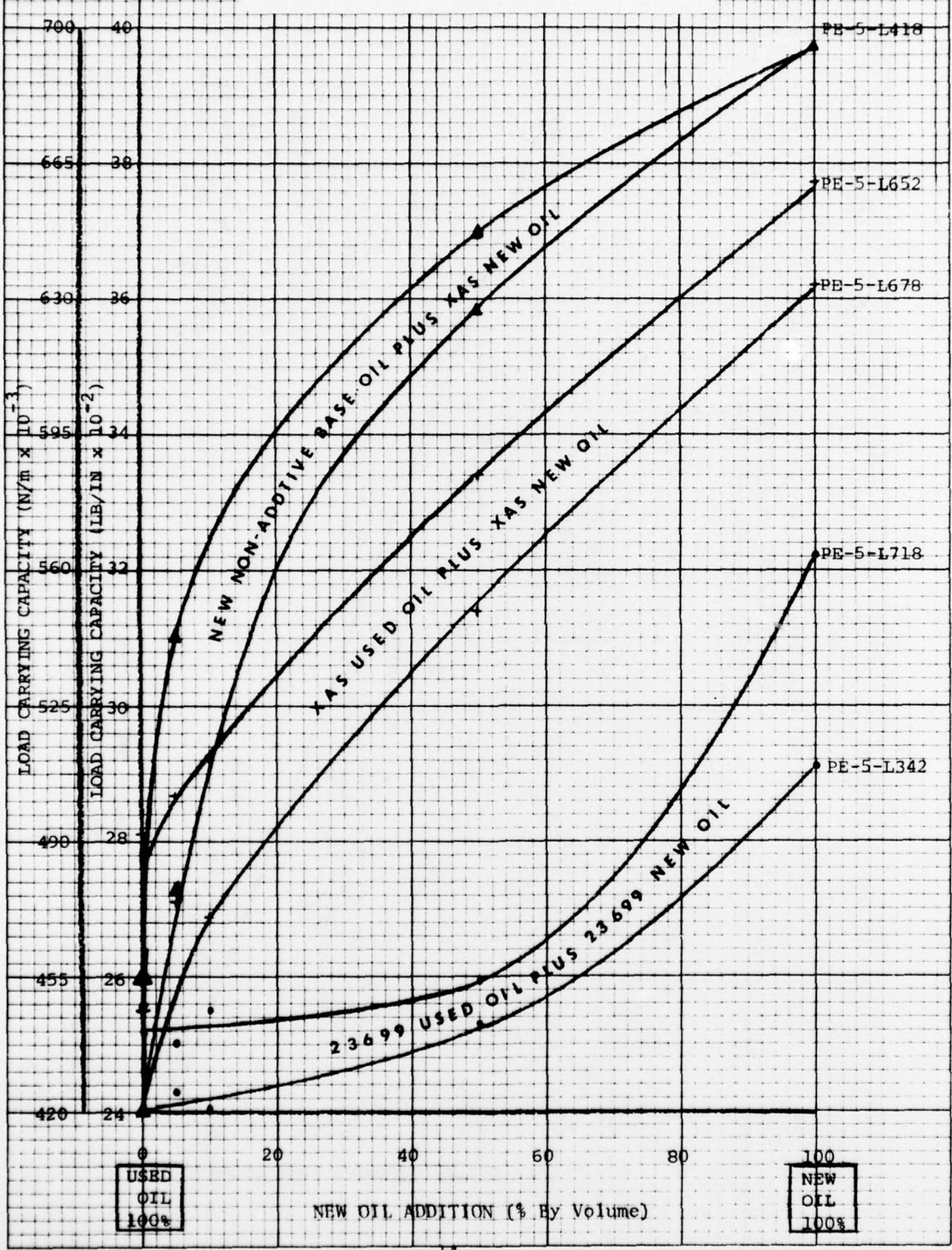


FIGURE 6: EFFECT OF PRE-CONDITIONING
WITH A NON-ADDITIVE
BASE OIL

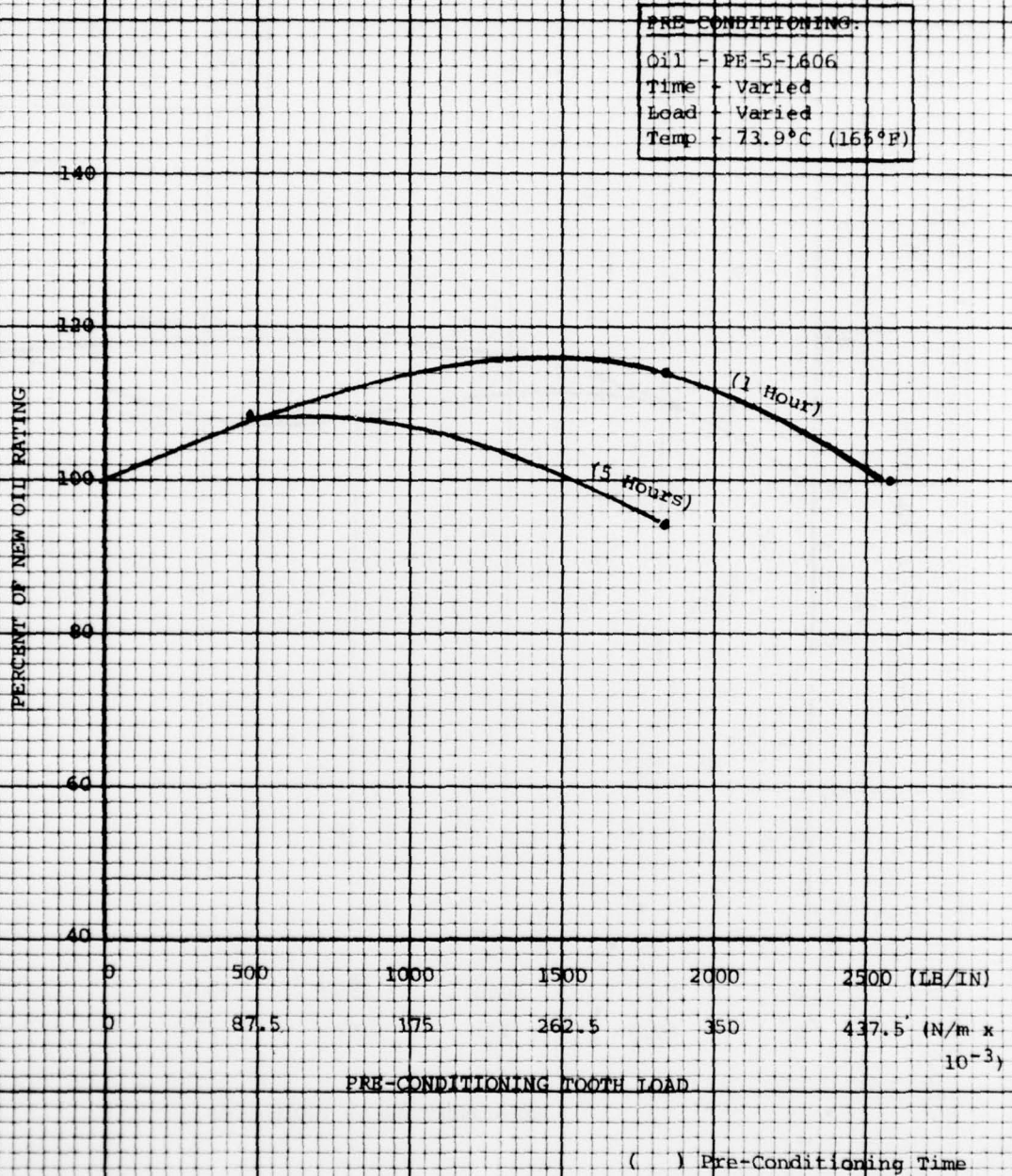


FIGURE 7: EFFECT OF PRE-CONDITIONING
WITH AN XAS-2354
HIGH GEAR LOAD OIL

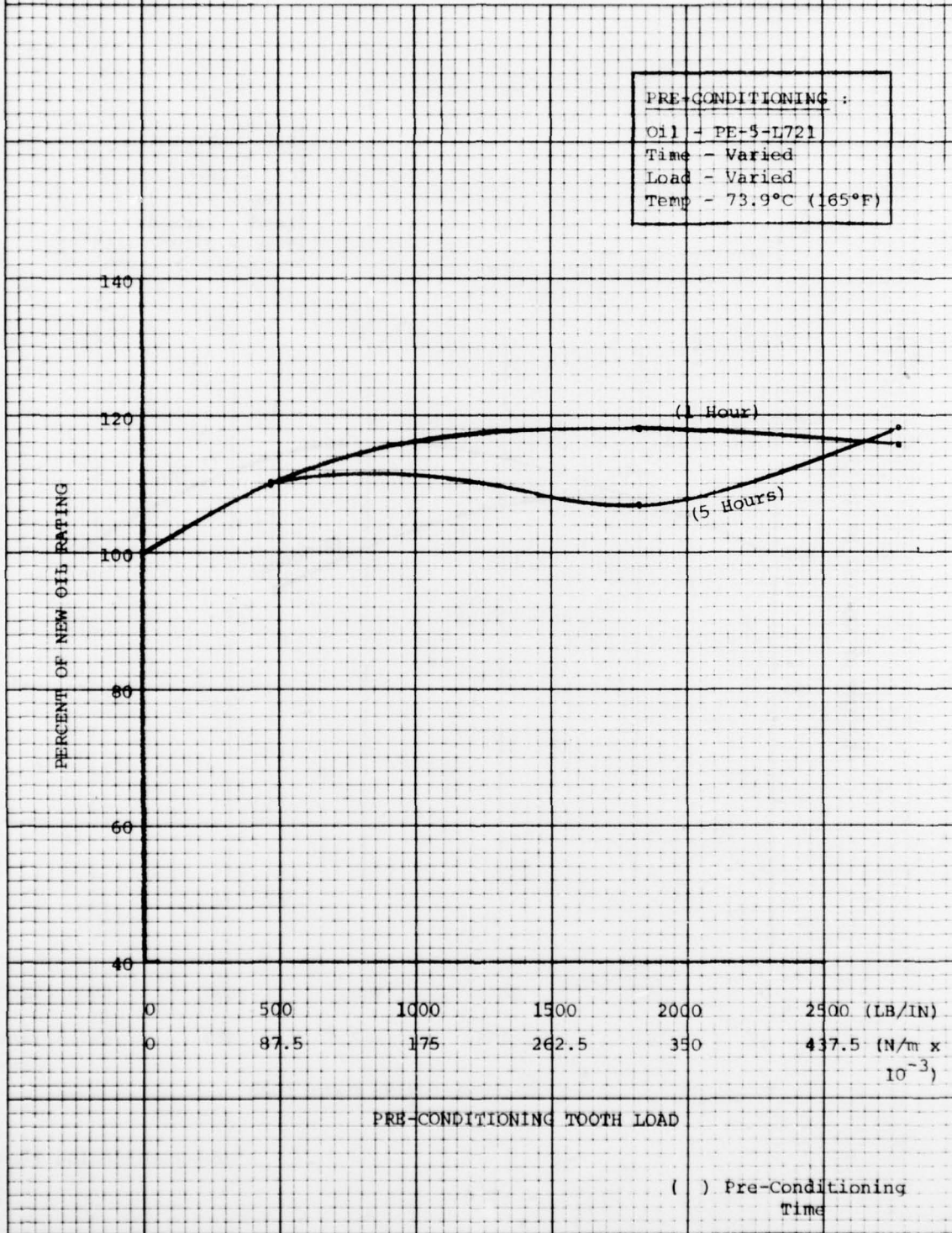
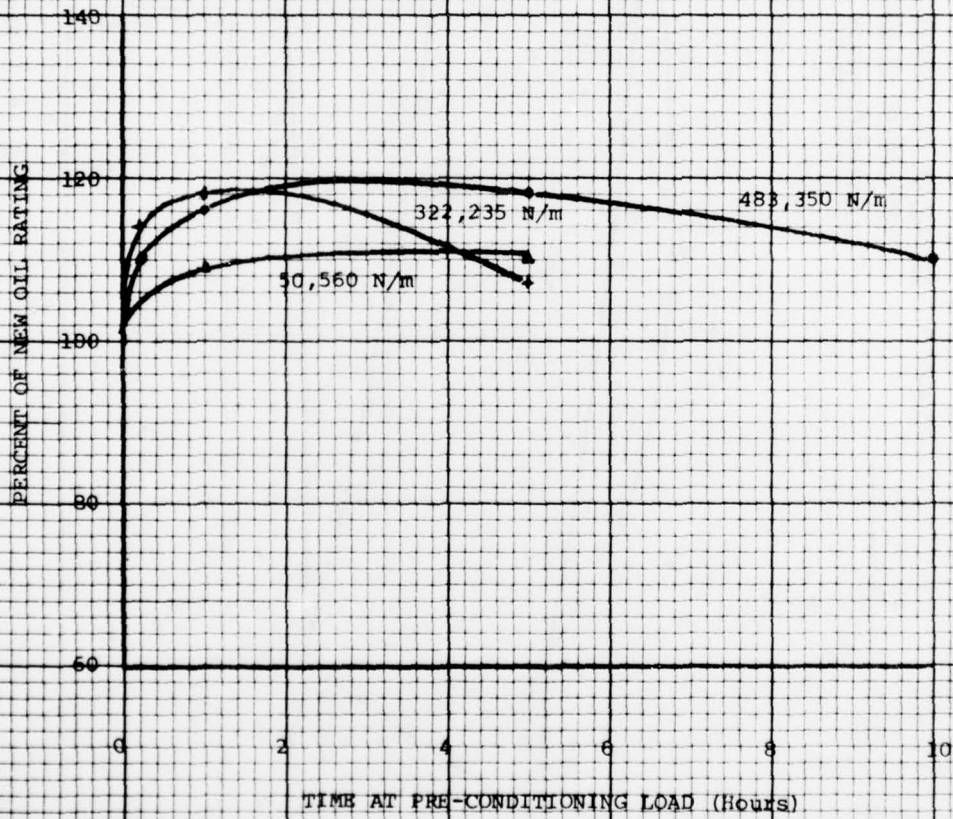


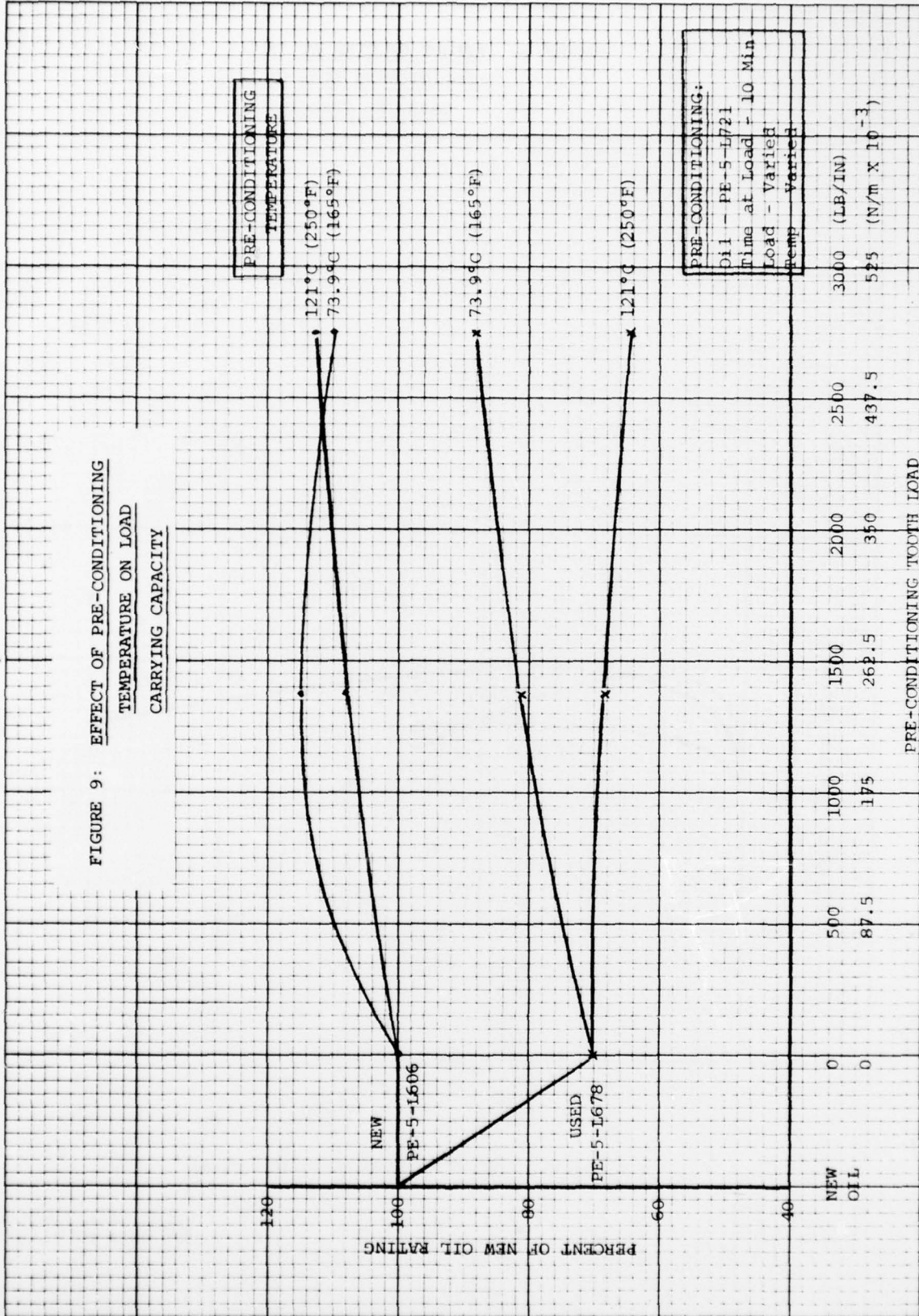
FIGURE 8: EFFECT OF TIME AT PRE-CONDITIONING LOAD ON LOAD CARRYING CAPACITY

PRE-CONDITIONING:
 Oil - PE+5-L721
 Time - Varied
 Load - Varied
 Temp. - 73.9°C (165°F)



Note: Ref. Table V for Data at 0.2 Hrs.

FIGURE 9: EFFECT OF PRE-CONDITIONING TEMPERATURE ON LOAD CARRYING CAPACITY



PRE-CONDITIONING:
 Oil - PE-5-L721
 Time at Load - 10 Min.
 Load - Varied
 Temp - Varied

TABLE I: EFFECT OF ENGINE OPERATING ENVIRONMENT

ON LUBRICANT LOAD CARRYING CAPACITY

Lubricant Code No.	Engine	No. of Hours	*Load Carrying Capacity		Loss, %	New Oil, % of
			New, N/m x 10 ⁻³ (ppi)	Used, N/m x 10 ⁻³ (ppi)		
PE-5-I647(1)	J52	175	650 (3713)	495 (2825)	24	76
		325	652 (3725)	471 (2690)	28	72
PE-5-L360(2)	T56	150	580 (3312)	488 (2788)	15.5	84.5
PE-5-L731(2)	TF30	90	525 (3000)	498 (2846)	5	95
		218	538 (3075)	432 (2467)	20	80
PE-5-L296(2)	T63	433	525 (3000)	408 (2333)	22.2	77.8
		175	472 (2698)	388 (2218)	17.5	82.5
PE-5-L721(1)	T63	175	700 (3998)	507 (2897)	27.5	72.5
		175	519 (2966)	450 (2568)	15.5	84.5
PE-5-I652(1)	T56	150	660 (3770)	510 (2910)	22.7	77.3
PE-5-LA03(2)	F402	51	504 (2887)	519 (2962)	-	-
Range of MIL-L-23699 Qual. Oils	T56	150	446 (2550)	382 (2180)	11	89
			482 (2750)	425 (2430)		

*Each rating is an average of 4 determinations

- (1) XAS-2354 High Gear Load Oils
- (2) MIL-L-23699 Qualified Oils

TABLE II: DEGRADATION IN LOAD CARRYING CAPACITY OF LUBRICANTS
IN A SIMULATED ENGINE BEARING COMPARTMENT

Lubricant Code No.	Load Carrying Capacity*		No. of Hours	Loss, %
	New, $N/m \times 10^{-3}$ (ppi)	Used, $N/m \times 10^{-3}$ (ppi)		
PE-5-L342 (2)	458 (2618)	420 (2397)	100	8.3
PE-5-L431 (2)	487 (2780)	441 (2520)	100	9.4
PE-5-L342-2 (2)	509 (2907)	420 (2400)	100	17.5
PE-5-L456 (1)	650 (3715)	510 (2915)	100	21.5
PE-5-L432 (1)	617 (3525)	450 (2570)	100	27.1
PE-5-L418 (1)	696 (3975)	463 (2642)	100	33.5
PE-5-L718 (2)	540 (3220)	448 (2556)	100	20.6
PE-5-L719 (2)	574 (3280)	451 (2575)	100	21.5
PE-5-L678 (1)	634 (3620)	445 (2540)	100	30.0
PE-5-L652 (1)	660 (3770)	491 (2805)	100	25.5
PE-5-L733 (2)	495 (2830)	446 (2550)	100	9.8
PE-5-L716 (2)	519 (2965)	448 (2560)	100	13.6

*Each Rating is an average of 4 determinations

- (1) XAS-2354 High Gear Load Oils
- (2) MIL-L-23699 Qualified Oils

TABLE III: LOAD CARRYING CAPACITY RATINGS WITH
NEW OIL ADDITIONS

Oil Code No.	<u>*Load Carry Capacity Rating, N/m x 10⁻³ (ppi)</u>									
	New Oil		Used Oil		Used Oil Plus % of New Oil					
					5%		10%		50%	
PE-5-L718 (1)	540	(3220)	448	(2556)	440	(2511)	447	(2554)	453	(2589)
PE-5-L342-2(1)	509	(2907)	420	(2397)	425	(2430)	420	(2400)	444	(2537)
PE-5-L652 (2)	660	(3770)	491	(2805)	502	(2864)	512	(2923)	550	(3140)
PE-5-L678 (2)	634	(3620)	445	(2540)	474	(2705)	471	(2688)	585	(3339)
PE-5-L317 (3)	420	(2400)	-		478	(2730)	-		627	(3580)
PE-5-L417 (3)	455	(2600)	-		542	(3097)	-		649	(3707)

Notes:

(1) MIL-L-23699 Oil

(2) XAS-2354 Oil

(3) Synthetic Base Oil (plus XAS Oil PE-5-L418)

PE-5-L317 and PE-5-L417 are different lots (production batches) of PE-5-L606.

*Each Rating is an average of 4 determinations

TABLE IV: LOAD CARRYING CAPACITY RATINGS OF A NON-ADDITIVE BASE OIL ON GEARS
PRE-CONDITIONED AT VARIOUS LOAD LEVELS/TIME INTERVALS

Time at Pre-Conditioning Load (Hours)	PRE-CONDITIONING FLUID					
	PE-5-L606			PE-5-L721		
	Pre-Conditioning Load N/m x 10 ⁻³ (ppi)	Pre-Conditioning Load N/m x 10 ⁻³ (ppi)	Pre-Conditioning Load N/m x 10 ⁻³ (ppi)	Pre-Conditioning Load N/m x 10 ⁻³ (ppi)	Pre-Conditioning Load N/m x 10 ⁻³ (ppi)	Pre-Conditioning Load N/m x 10 ⁻³ (ppi)
	80 (460)	322 (1840)	483 (2760)	80 (460)	322 (1840)	483 (2760)
1	477 (2724) [108]	503 (2875) [114]	441 (2520)* [100]	481 (2746) [109]	519 (2966) [118]	495 (2928) [116]
5	475 (2712) [108]	416 (2377) [94]	-	483 (2760) [110]	471 (2691) [107]	520 (2973) [118]
10	-	-	-	-	-	482 (2750) [110]
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*Failure occurs prior to attaining pre-conditioning load

Notes:

1. All values are average of 4 determinations
2. [] percent of new oil rating
3. Oil temperature was 73.9°C (165°F)

TABLE V: LOAD CARRYING CAPACITY RATINGS ON GEARS PRE-CONDITIONED
AT VARIOUS LOAD AND TEMPERATURE LEVELS

Test Oil Code No.	Condition of Oil	LCC Rating N/m x 10 ⁻³ (ppi)	*Pre-Conditioning		Load Carrying Capacity Rating N/m x 10 ⁻³ (ppi)	Percent of New Oil Rating %
			Load N/m 10 ⁻³ (ppi)	Temp. °C (°F)		
PE-5-L606	New	441 (2520)	242 (1380)	73.9 (165)	509 (2906)	115
			483 (2760)	73.9 (165)	486 (2777)	110
			242 (1380)	121.1 (250)	478 (2729)	108
			483 (2760)	121.1 (250)	497 (2839)	113
PE-5-L678	Used in Bearing Rig Test (100 Hrs.)	445 (2540)	242 (1380)	73.9 (165)	917 (2950)	81
			483 (2760)	73.9 (165)	561 (3204)	88
			242 (1380)	121.1 (250)	432 (2467)	68
			483 (2760)	121.1 (250)	405 (2314)	64
	New	634 (3620)				

*Pre-Conditioning Fluid - PE-5-L721

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REFERENCES:

1. AUTHORIZATION: NAVAIR Work Unit Assignment No. NAPC-136; "Effect of Engine Operating Environments on High Gear Load Oils", dated July 1974
2. AUTHORIZATION: NAVAIR Work Unit Assignment No. NAPC-136 Amendments A & B; "Effect of Lubricant Additive Adsorption or Reactive Processes on Gear Scuffing", dated 15 July 1975 and 17 July 1976, respectively

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