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AEROSPACE INFORMATION REPORT

SAE AIR4978 REV. B

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Superseding AIR4978A

Temporary Methods for Assessing the Load Carrying Capacity of Aircraft Propulsion System Lubricating Oils

FOREWORD

All modern aviation propulsion system lubricant specifications contain some type of a gear scuffing/ scoring test to measure the lubricant's load carrying capacity, i.e., Ryder, IAE, and FZG. These tests are costly and recently have exhibited questionable reliability and availability and, in the case of the Ryder Test, complete unavailability because of a lack of a test gear source.

There are very large databases (from the past 30 plus years) for these tests and they form the basis for judging on the effectiveness of various products in controlling scuffing or scoring. For this reason, there are some strong ties to these devices. However, because of the expense of running these tests and because of the limited utility of the data generated regarding hardware design, there is little support to reestablish these tests to their former role. Although limited efforts may restore some capacity to perform these tests, the long-term perspective is to develop new methods based on the abundance of tribology research that has and is being done.

The continued use of the these gear type tests is considered at best tenuous and the development of new methods to completely replace the old methods is far term. Thus, there is a need to have test methods for the interim and that is the purpose of this document.

INTRODUCTION

This SAE Aerospace Information Report (AIR) is intended as a guide toward standard practices during a period when the ability to perform previously used lubricant load carrying test methods, such as Ryder and IAE, is severely limited. The methods presented herein are the result of communication among lubricant formulators, hardware designers, lubricant specialists, tribologists, lubricant specification writers, and lubricant users. These methods do not necessarily have a definitive correlation with the previously used test devices but rather provide a ranking relationship for oils of different load carrying classes as defined by those devices. As such, they can be used to generate data to assist in making judgments regarding qualification and batch approval of lubricants formulated with current state-of-the-art basestocks and additives which have a long service history. They should not be used for making judgments or decisions of any kind for oil formulation chemistry with no or little previous load carrying data and service experience.

INTRODUCTION (Continued)

The methods contained in this document consist of those which have been submitted to SAE Committee E-34 and which have been agreed by the committee to be consistent with the intended purpose.

1. SCOPE:

1.1 Purpose:

To present methods which, according to the consensus of the aviation propulsion community represented by SAE Committee E-34, allow the continued assessment of load carrying capacity of current chemistry products during periods of limited or nonavailability of previously used standardized methods.

1.2 Field of Application:

The methods listed in this document are intended to provide a means of generating data which can be used as a guide for making decisions against the backdrop of load capacity databases (Ryder, IAE, FZG) and experiences available on chemically similar oils used for lubrication of aircraft propulsion and power drive systems.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 ASTM Publications: Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 5001	Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-Cylinder Lubricity Evaluator (BOCLE)
ASTM D 5182-91	Standard Test Method for Evaluating the Scuffing (Scoring) Load Capacity of Oils

3. METHOD SELECTION:

3.1 Process for Approving Test Methods:

Methods will be submitted to Committee E-34 with data showing their relationship to a standardized load capacity test previously used for aviation propulsion system lubricants. The method should: a) Be affordable, i.e., cost no more than the currently used methods; b) Have adequate sources of test specimens; c) Separate oil performance according to the currently accepted load carrying classes as determined by databases for standardized load carrying test methods.

The Committee will review a method and supporting data and a) give tentative approval, b) give guidance for changes or for additional data to make a method acceptable, or c) reject a method as outside the scope of this document.

Use of a tentatively approved method will generate a broader database for the particular method and the committee will review the data and experience on this method at each meeting. Full approval for inclusion in the document, suggestions to improve the method or rejection of the method could result from these reviews.

This document and process will remain in effect until the committee decides there is no longer a need for alternate methods of assessing load carrying capacity of aviation propulsion system lubricants.

3.2 Methods:

The methods listed below received tentative approval for use under the terms of this document by SAE Committee E-34 on July 17, 2001.

a. Modified ASTM D 5182-91 Standard Test Method for Evaluating the Scuffing (Scoring) Load Capacity of Oils (Appendix A)
b. Rolls Royce Tribology Evaluator to Determine the Lubricating Quality of Aviation Turbine Oils (Appendix B)
c. Test Method for Prediction of Scuffing Load Capacity by the Gear Oil Scuff Test (GOST) Apparatus (Appendix C)
d. WAM Economical Load Capacity Screening Test (Appendix D)
e. WAM High Speed Load Capacity Test Method (Appendix E)

The methods listed in this AIR may involve hazardous materials, operations, and equipment. The AIR does not pupport to address all of the safety issues associated with the use of the methods. It is the responsibility of the user of this AIR and methods to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

PREPARED UNDER THE JURISDICTION OF
SAE COMMITTEE E-34, PROPULSION LUBRICANTS

APPENDIX A
MODIFIED ASTM D 5182-91 STANDARD METHOD
FOR EVALUATING SCUFFING/SCORING LOAD CAPACITY
OF AVIATION PROPULSION SYSTEM OILS

The gear load-carrying capacity test will be conducted in accordance with ASTM D 5182-91 modified as follows:

The FZG test speed shall be 1760 rpm rather than 1450 rpm.

The failure criteria is reached when the summed total width of scuffing/scoring/adhesive wear damage from all 16 teeth is estimated to equal or exceed two gear tooth widths (40 mm) rather than one gear tooth width (20 mm).

APPENDIX B
ROLLS ROYCE TRIBOLOGY EVALUATOR METHOD TO DETERMINE THE LUBRICATING QUALITY OF AVIATION TURBINE OILS

B.1 SCOPE/BACKGROUND:

Lubricant load carrying performance is an important parameter when considering evaluation/approval of a lubricant type for a specific application. The test methods currently in use within the aviation propulsion industry for assessing compliance with specification requirements are the Ryder and the IAE gear tests.

The Rolls-Royce tribology evaluator is a device used to rate the relative lubricating quality of aviation turbine oils. Employing ball-on-cylinder philosophy, a nonrotating steel ball is held in a vertically mounted chuck and forced against an axially mounted steel cylinder with an applied load. The test cylinder is rotated at a fixed speed while being partially immersed in the fluid reservoir. This maintains the cylinder in a wet condition and continuously transports a film of test fluid to the ball/cylinder interface. The wear scar generated on the test ball is a measure of the fluid lubricating properties.

B.2 TYPES OF WEAR:

Using this apparatus, the two distinct types of wear mechanisms most commonly seen in oil system components, namely mild and scuffing wear, can be reproduced and studied. Only a scuffing wear test method is included in this document.

B.2.1 Mild Wear:

As the test cylinder rotates, the lubricant is continuously transported to the ball/cylinder interface. At this interface under mild wear conditions, there is an elastohydrodynamic boundary layer of lubricant which prevents contact of anything other than the surface asperities of the ball and cylinder. However, due to the difference in hardness of these asperities, abrasion and, hence, mild wear occurs. Any wear debris carried from the cylinder to the wear scar area can also be a contributory factor.

B.2.2 Scuffing Wear:

At a specific applied ball load, a transition from mild to scuffing wear can be observed. At this transition, a reduction and ultimate breakdown of boundary lubrication and film thickness occurs. This results in full metal-to-metal contact of the sliding surfaces, leading to severe adhesive wear and a large wear scar. Loadings beyond this transition will result in localized welding of the surfaces and eventual seizure. It must be noted that scuffing wear is an entirely different tribological and physical phenomenon compared to mild wear. This method is concerned with the determination of the maximum load a particular lubricant can withstand prior to the onset of scuffing type wear.

B.3 PRIMARY TEST EQUIPMENT (See Figure B1):

B.3.1 Test Ball Specification:

Material : Chrome alloy AISI 52100 steel
Hardness : 64 to 66 Rc
Surface Finish : Grade 5-10 EP (extra polish)
Dimensions : 12.7 mm diameter

B.3.2 Cylinder Specification (See Figure B2):

Material : SAE 8720 steel
Hardness : 58 to 62 Rc
Surface Finish : 0.56 to 0.71 µm rms
Dimensions : 49.25 +0.00/-0.15 mm diameter

The ball and cylinder specifications described above are identical to those listed in ASTM D 5001.

B.3.3 Cleaning Solvents:

B.3.3.1 Isooctane (2,2,4 - trimethylpentane), analar, spectro, or better grade.

B.3.3.2 Isopropyl alcohol, reagent grade or better.

B.3.3.3 Acetone, reagent grade or better.

B.4 DESCRIPTION OF APPARATUS:

Figures B3 and B4 show the system components.

A speed controlled motor (0.25 kW), coupled directly to a reduction gearbox, provides the rotational drive to the test cylinder. The gearbox reduces the maximum shaft speed from 1850 to 440 rpm producing a maximum sliding speed of 44 in/s. A flexible drive coupling is incorporated between the motor and the test section to minimize the effect of any shaft misalignment.

The load arm and support are arranged with a moment such that the ball load is three times that applied to the arm.

Oil heating is provided via two 110 V/500 W cartridge heaters inserted into the reservoir. A Eurotherm controller is utilized to allow bulk oil temperatures of up to 200 °C ± 2 °C.

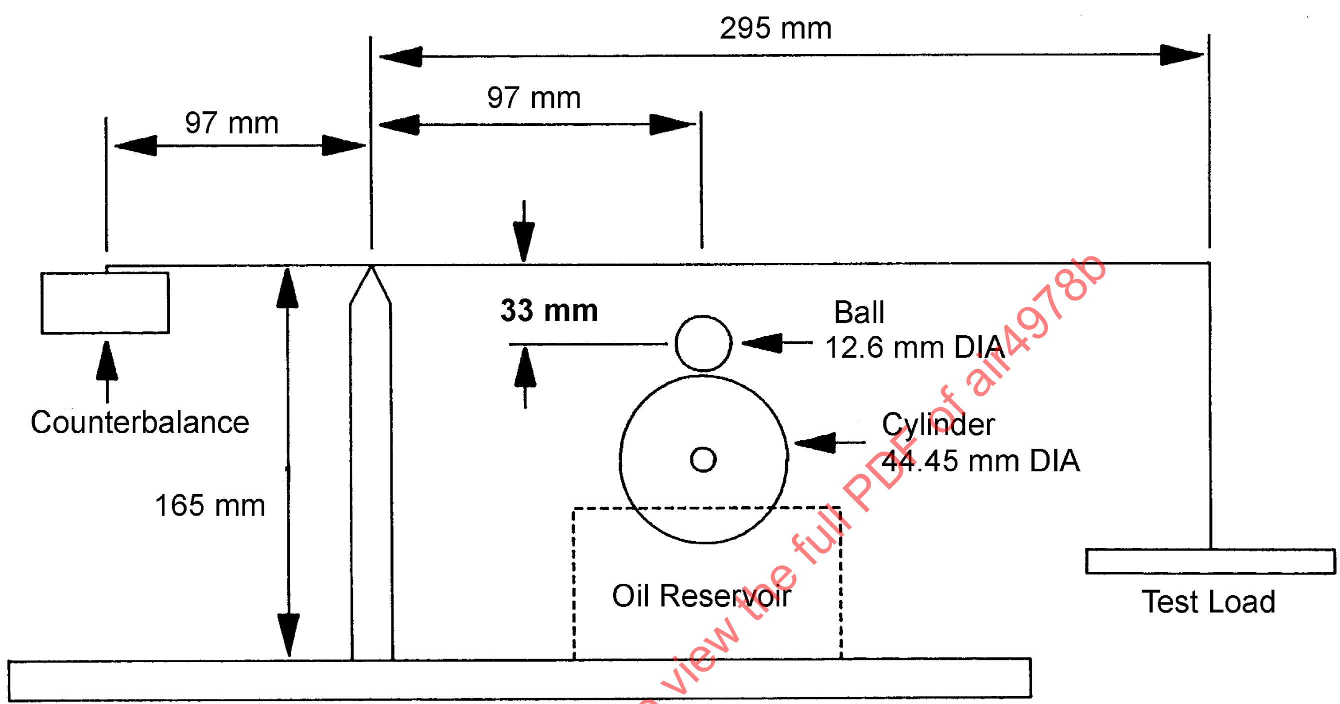
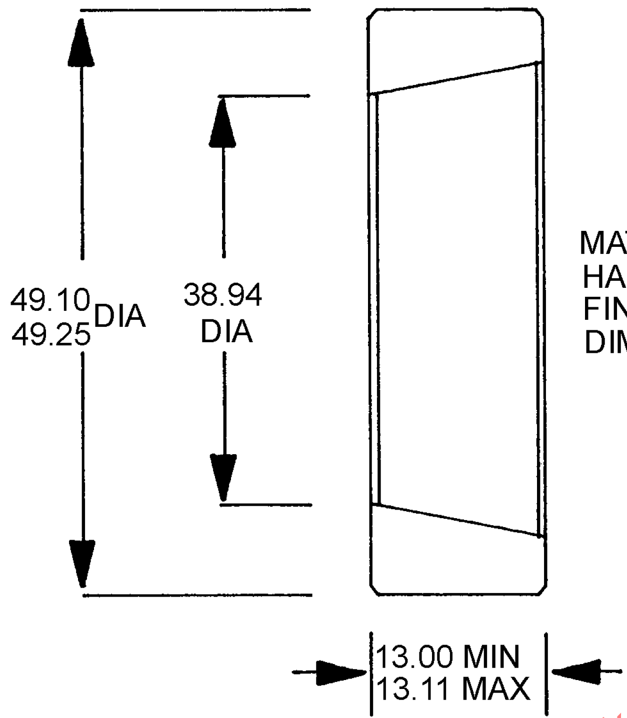


FIGURE B1 - Rolls-Royce Tribology Evaluator



MATERIAL: STEEL SAE *8270 SPECIAL MODIFIED
HARDNESS: 58 - 62 Rc
FINISH: 22 - 28 RMS
DIMENSIONS: mm

FIGURE B2 - RRTE Test Cylinder

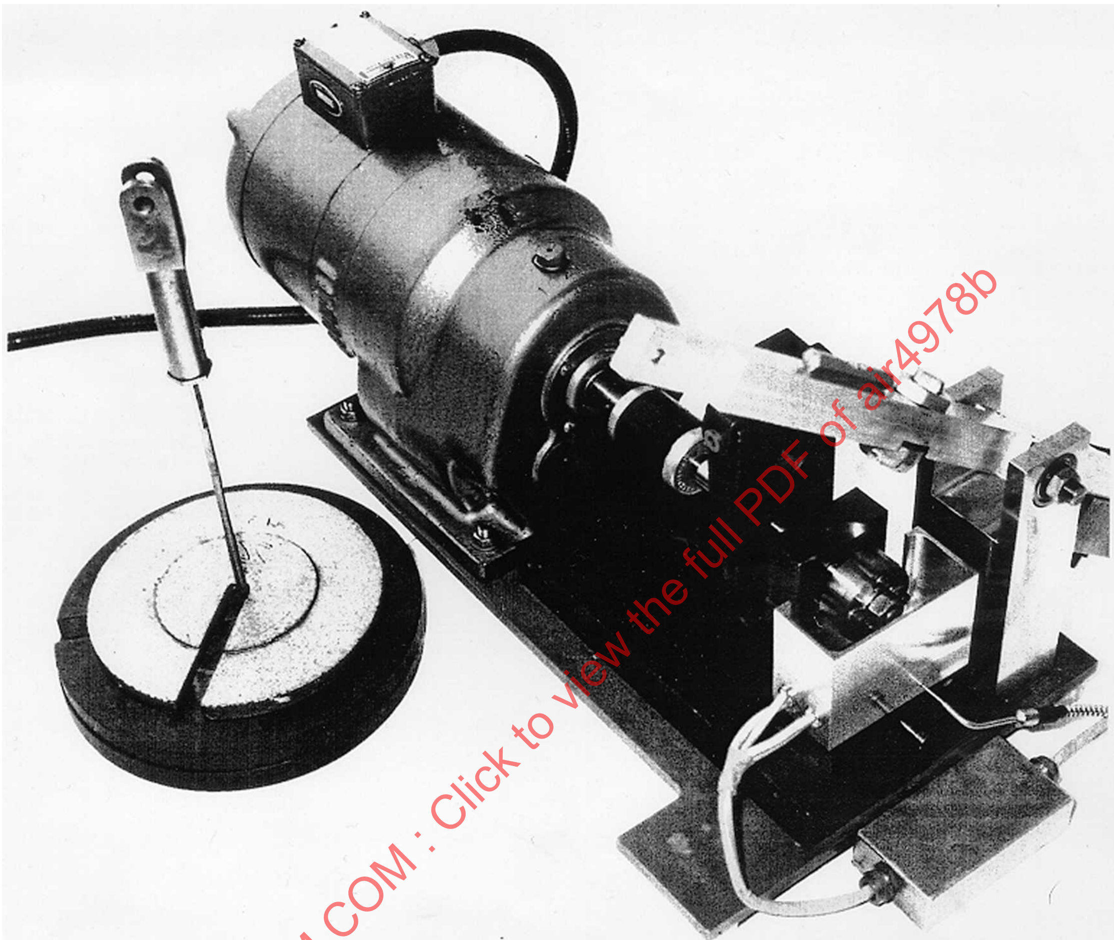


FIGURE B3

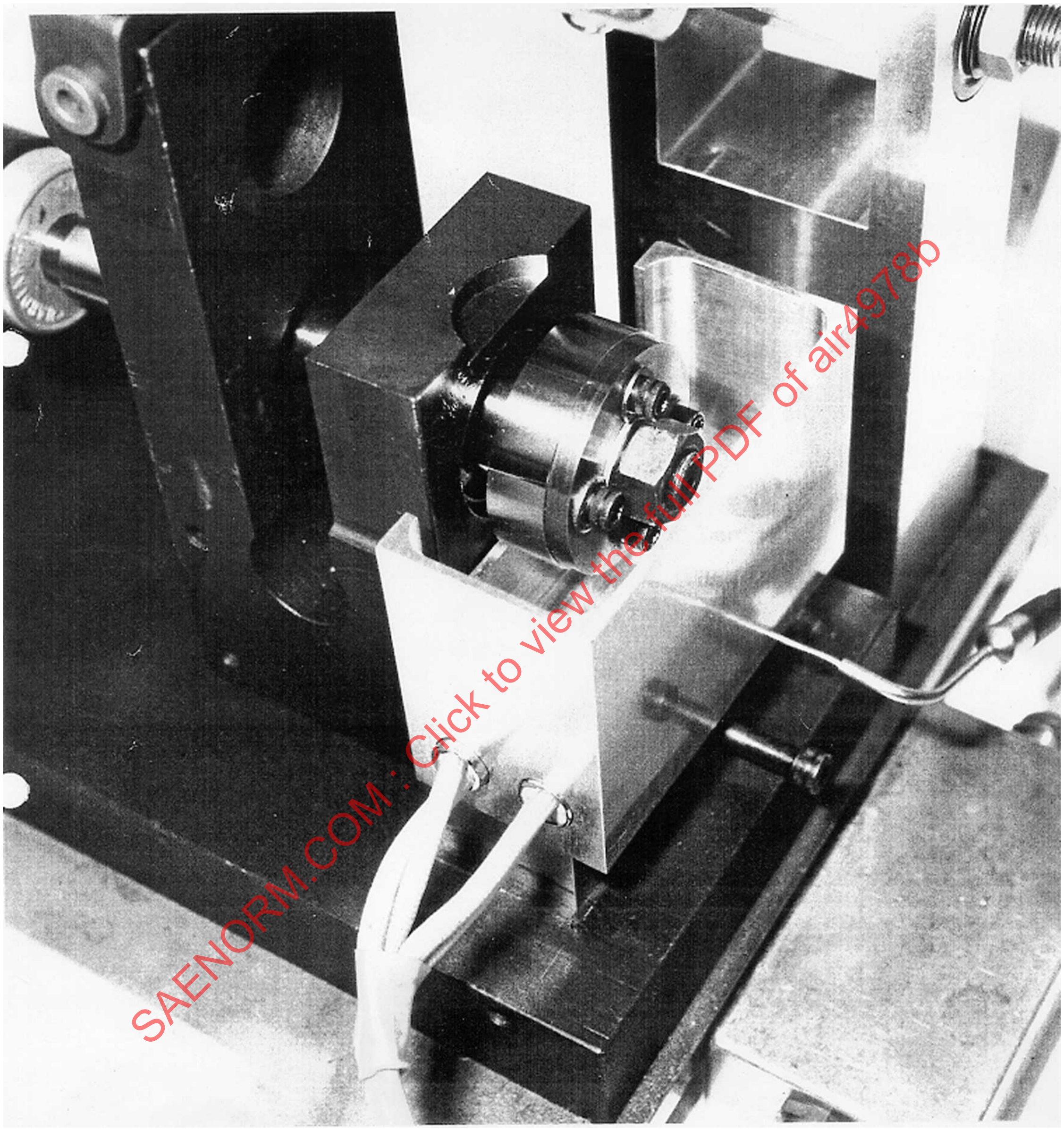


FIGURE B4

B.5 SUMMARY OF OPERATING CONDITIONS:

TABLE B1

Parameter	Scuffing Wear Mode	Mild Wear Mode
Test duration	1 min ± 0.05 min	30 min ± 0.1 min
Test temperature	150 °C ± 2 °C	100 to 200 °C ± 2 °C
Ball load	24 to 60 kg	3 to 39 kg
Cylinder speed	220 rpm ± 5 rpm	220 rpm ± 5 rpm
Sliding speed	22 in/s ± 0.5 in/s	22 in/s ± 0.5 in/s
Sample volume	48 ml ± 1 ml	48 ml ± 1 ml

B.6 PREPARATION OF APPARATUS:

Great care must be taken to adhere strictly to cleanliness requirements and to the specified cleaning procedures. During handling and installation procedures, protect cleaned test parts (cylinder, balls, reservoir, etc.) from contamination by wearing clean cotton gloves.

B.7 CLEANING OF APPARATUS AND TEST COMPONENTS:

B.7.1 Test Rings, As Received:

B.7.1.1 Strip the wax protective coating from the test rings by manually wiping them with a lint-free cloth soaked in acetone.

B.7.1.2 Using a steam bath, boil the test rings in acetone for a period of 20 min.

B.7.1.3 Drain off any remaining liquid and top up with fresh acetone. Boil for a further 20 min period.

B.7.1.4 Remove test rings from vessel and rinse thoroughly with acetone. Dry with a lint-free cloth and store in a desiccator.

B.7.2 Test Balls, As Received:

B.7.2.1 Remove the oil coating from each ball by wiping with an acetone soaked lint-free cloth.

B.7.2.2 Follow steps 7.1.2 through 7.1.4.

B.7.3 Oil Tank, Ball Chuck, and Ring Mandrel Assembly Components:

B.7.3.1 Rinse each component with isooctane.

B.7.3.2 Clean in an ultrasonic bath for 15 min in isopropyl alcohol.

B.7.3.3 Remove and rinse with isooctane.

B.7.3.4 Dry and store in a desiccator prior to use.

B.8 SCUFFING TEST:

B.8.1 Assembly and Test Procedure:

B.8.1.1 Rinse motor output shaft with isooctane and wipe with disposable wiper.

B.8.1.2 Assemble mandrel/cylinder components as shown in Figure B5. Finger tighten the four allen headed bolts, ensuring the keyway on the lockplate is aligned with the keyway on the mandrel.

B.8.1.3 Slide mandrel spacer and motor shaft and insert keyway.

B.8.1.4 Locate mandrel/cylinder assembly on the motor shaft keyway and attach outer washer and main locknut (see Figure B5).

B.8.1.5 Torque mandrel allen bolts in a progressive diagonal manner to a setting of 25 in/lb ± 3 in/lb.

B.8.1.6 By inserting the locking bar into the hole in the motor shaft, torque the main locknut to a setting of 50 in/lb ± 5 in/lb.

B.8.1.7 Rotate the motor shaft at test speed to check for satisfactory smooth running (periodically check the eccentricity of the assembly using a dial test indicator).

B.8.1.8 Install a clean test ball by first placing the ball in the retaining nut. Screw the retaining nut onto the threaded chuck located on the load arm and tighten securely.

B.8.1.9 Lower the load arm by sliding the counterbalance forward. With the test ball firmly in contact with the test cylinder check the load arm horizontal via the attached spirit level. The indicator bubble shall be centered in the middle of the two lines. If necessary, adjust the retaining nut screw to achieve a level load arm.

B.8.1.10 Having installed a fresh cylinder, it is necessary to adjust the relative lateral position of the load arm.

B.8.1.11 For subsequent tests, reset the cylinder position a distance of approximately 2 mm across from the edge of the previous wear track. When testing lubricants of known low load carrying greater than 2 mm between tracks is recommended.

B.8.1.12 Install the clean reservoir and support with spacing platform. Using a clean graduated 50 ml measuring cylinder, transfer 48 ml ± 1 ml of test lubricant to the reservoir.

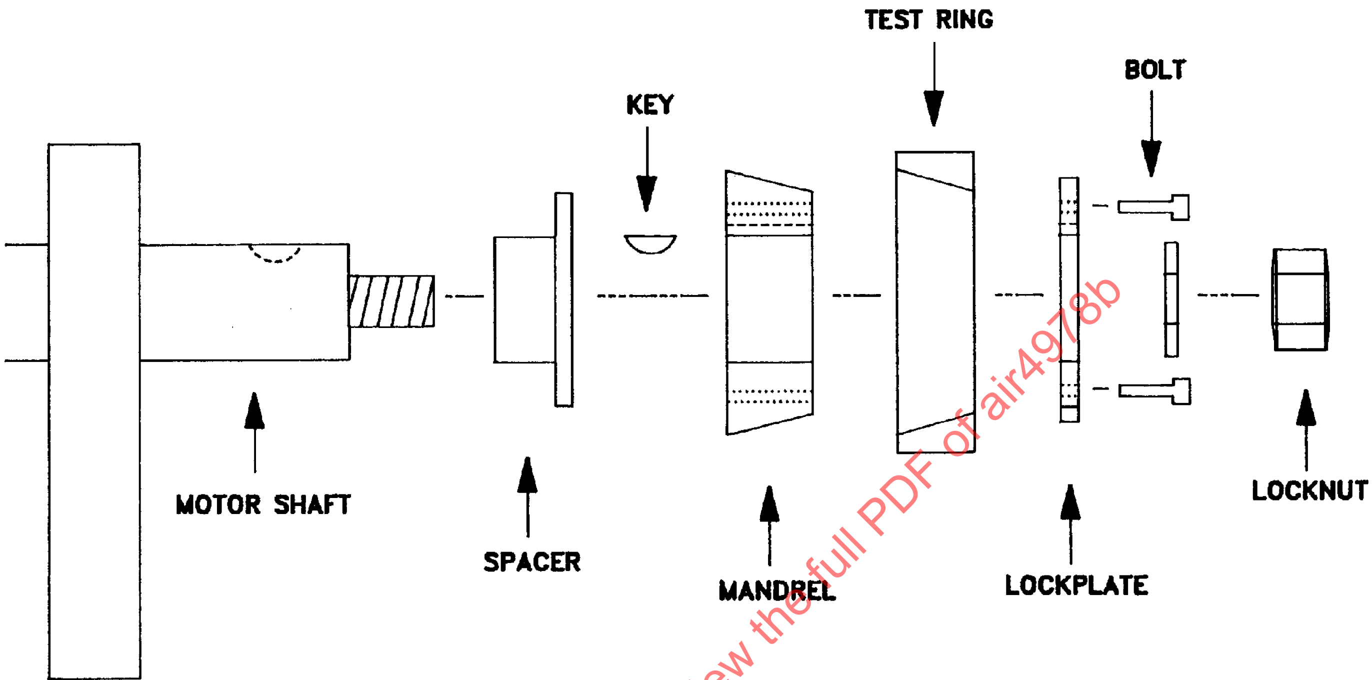


FIGURE B5 - Test Ring and Mandrel Assembly

B.8.1.13 Place thermocouple in lubricant immediately behind the cylinder. Ensure thermocouple tip is fully submerged.

B.8.1.14 Start rotation of cylinder by switching motor drive to ON. Set potentiometer on speed control unit to maintain 220 rpm ± 5 rpm.

B.8.1.15 Insert cartridge heaters into holes in oil bath and select desired oil test temperature on Eurotherm controller. Adjust controller setting until control within ±3 °C of the desired temperature is achieved.

B.8.1.16 After a minimum of 10 min, apply the required test load to the arm (see 8.2). Slide the counterbalance weight forward and lower the assembly onto the rotating cylinder. Care must be taken to ensure the arm assembly is lowered gently as failure to observe this fact will lead to erroneous and unreliable results. Set a timer to run for 1 min.

B.8.1.17 At the end of 1 min run time, immediately remove the load and raise the load arm by moving the counterbalance weight rearward.

B.8.1.18 Switch motor to OFF on speed control unit. Switch off the Eurotherm temperature controller.

B.8.1.19 Having allowed the apparatus to cool sufficiently, remove the test ball from the locking nut. Wipe ball clean with a disposable wiper prior to microscopic examination.

B.8.2 Selection of Test Load:

B.8.2.1 When evaluating the load carrying capability of a lubricant, the apparatus shall initially be run with a ball load of 24 kg.

This is equivalent to an actual load on the arm of 7.5 kg (the loading jig for the test weights weighs 500 g and there is a 3 times moment on the load arm).

B.8.2.2 In each subsequent test, the ball load should be raised by 3 kg incrementally until scuffing occurs during the test run. The onset of scuffing can be recognized by a significant increase in contact noise between the ball and the cylinder and a large, distorted wear scar on the ball. Once the wear scar diameter on the ball from a particular test exceeds 3.5 mm, no further tests shall be carried out.

B.9 MEASUREMENT OF THE WEAR SCAR:

B.9.1 Switch on microscope light and position test ball under traveling microscope at I00X magnification.

B.9.2 Focus microscope and adjust stage such that wear scar is centered within the field of view.

B.9.3 Align the left hand edge of the wear scar major axis with the graticule and traverse across the scar, measuring it to the nearest 0.01 mm.

B.9.4 Rotating the test ball through 90°, measure the minor axis to the nearest 0.01 mm.

NOTE: When taking measurements from scars with distorted edges, the graticule should be aligned to coincide with the approximate centerline of the peaks and troughs.

Any deviation from an elliptical shape should be recorded in the test results.

B.10 CALCULATIONS:

B.10.1 Calculate the wear scar diameter as follows in Equation B1:

$$WSD = (x + y)/2 \quad \text{(Eq. B1)}$$

where:

WSD = wear scar diameter, mm
x = major axis, mm
y = minor axis, mm

B.11 REPORT:

Report the following information:

B.11.1 Wear scar diameter to the nearest 0.01 mm.

B.11.2 Description of any abnormality in the wear scar area, i.e., anomalous wear pattern, unusual particles present.

B.12 DEFINING LOAD CARRYING CAPABILITY OF TEST LUBRICANT:

The ball load (kgs) required to achieve a wear scar of 1.5 mm shall be reported as the relative load carrying capability of the test lubricant. See Figure B6.

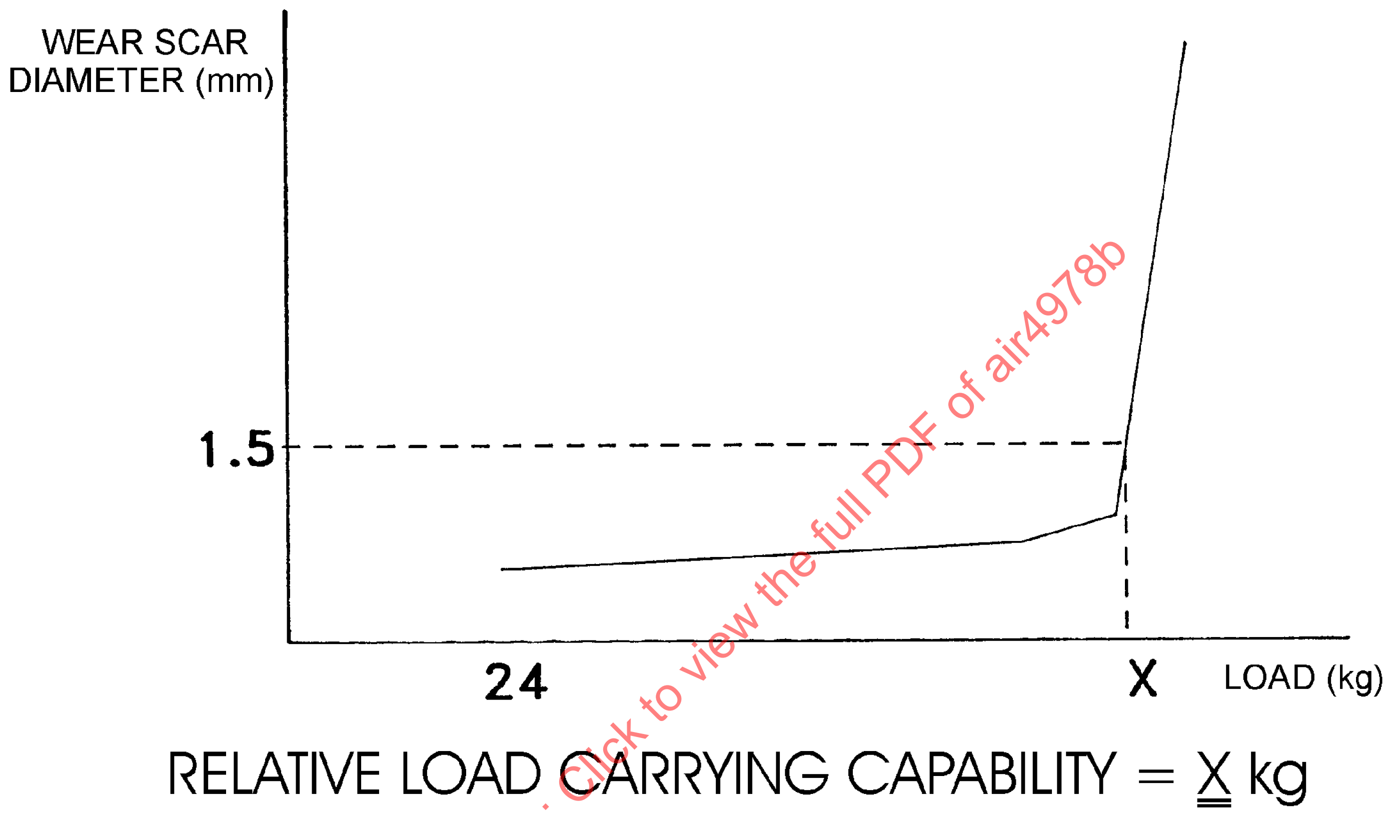


FIGURE B6 - Defining Load Carrying Capability

APPENDIX C
TEST METHOD FOR PREDICTION OF SCUFFING LOAD CAPACITY BY THE
GEAR OIL SCUFF TEST (GOST) APPARAUS

C.1 SCOPE:

C.1.1 This test method predicts the load carrying capacity of lubricating oils prior to the onset of scuffing using a Gear Oil Scuff Test (GOST) apparatus.

C.1.2 This test method is applicable to formulated oils intended for use in highly loaded applications such as gearboxes.

C.1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

C.2 APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

C.2.1 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 5001 Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-Cylinder Lubricity Evaluator (BOCLE)[1]

C.3 TERMINOLOGY:

C.3.1 Descriptions of Terms Specific to This Standard:

C.3.1.1 APPLIED LOAD: The weight in grams added to the load arm of the GOST unit.

[1] Annual Book of ASTM Standards, Vol. 05.03.

C.3.1.2 CONTACT LOAD: The force in grams with which the ball contacts the test ring.

C.3.1.2.1 DISCUSSION: For the GOST cantilever system, the contact load is two times the applied load.

C.3.1.3 SCUFFING: In lubrication, damage caused by instantaneous localized welding between surfaces in relative motion which does not result in immobilization of the parts.

C.3.1.4 SCUFFING LOAD CAPACITY (SLC): The minimum load required to produce scuffing of surfaces under controlled conditions.

C.3.1.4.1 DISCUSSION: In this test method, the SLC of a fluid is evaluated by the minimum applied load in grams that, at any time during the test, will produce a friction coefficient greater than 0.175 between a stationary ball and a fluid wetted rotating ring operating under defined conditions.

C.3.1.5 CORRECTED SCUFFING LOAD CAPACITY (CSLC): The SLC adjusted to account for the effects of viscosity on the onset of severe adhesive wear in the Ryder gear test.

C.3.1.5.1 DISCUSSION:: Hydrodynamic and elastohydrodynamic lift in many applications are sensitive to both oil viscosity and contact geometry. The GOST test is designed to minimize viscosity effects.

C.3.1.6 FRICTION TRACE: A recorded trace of the tangential friction force in grams.

C.3.1.7 FRICTION COEFFICIENT: Tangential friction force divided by the contact load.

C.4 SUMMARY OF TEST METHOD:

C.4.1 A 50-mL test specimen of oil is placed in the test reservoir of a GOST apparatus and adjusted to the standard temperature of 80 °C.

C.4.2 A load arm holding a 6.35-mm diameter non-rotating steel ball and loaded with a 500-g mass is lowered until it contacts a polished steel test ring partially immersed in oil rotating at 700 r/min. The ball is forced to rub against the test ring for a 30-s break-in period before beginning an incremental load test.

C.4.3 Wear tests are conducted by maintaining contact between the ball and the partially immersed 700-r/min test ring for 60 s. A new portion of the test ring and a new ball are used for each incremental load test.

C.4.4 The tangential friction force is recorded while the ball is in contact with the test ring. The friction coefficient is calculated from the tangential friction force.

C.4.5 The minimum applied load required to produce a friction coefficient greater than 0.175 is an evaluation of the lubricating properties of the oil.

C.5 SIGNIFICANCE AND USE:

C.5.1 The applied load required to produce severe adhesive wear and failure has some reliance on lubricating properties of the oil. Shortened life of components such as gears and cam followers has sometimes been ascribed to lack of ultimate load carrying ability.

C.5.2 The relationship of GOST results to gear tooth distress due to severe adhesive wear has been demonstrated using the Ryder gear test apparatus. Figure C1 shows the correlation achieved with the Ryder apparatus.

C.5.3 The GOST procedure may be used to evaluate the relative effectiveness of oils for preventing wear under the prescribed test conditions.

C.5.4 This test method is designed to evaluate boundary lubrication properties. While viscosity effects on the contact are not totally eliminated, they are minimized. An equation to predict the effects of viscosity on the correlation achieved with the Ryder gear test is provided in C.12.2.

C.6 APPARATUS:

C.6.1 Gear Oil Scuff Test (GOST) Apparatus:

C.6.1.1 The GOST apparatus, illustrated in Figure C2, is a modification of the Ball-on-Cylinder Lubricity Evaluator (BOCLE) specified in Test Method D 5001. Complete operating conditions are given in Table C1.

C.6.1.1.1 The GOST consists of a fluid reservoir, a load arm, a hanger, and a load cell.

C.6.1.2 If a standard BOCLE machine is modified, a device to measure and record tangential friction force is necessary.

C.6.1.3 If a standard BOCLE machine is modified, a redesigned reservoir cover or splash guards is necessary to prevent loss of fluid from the joint between the reservoir cover and reservoir.

C.6.1.4 If a standard BOCLE machine is modified, an adaptor capable of holding a 6.35-mm diameter test ball is required.

C.6.1.5 If a standard BOCLE machine is modified, an electric heater apparatus is required, capable of achieving a test oil temperature of 80 C.[2]

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[2] Heater element, Part No. BOC-219H from Inter-Av, Inc., P.O. Box 792228, San Antonio, TX 78279, has been found satisfactory.

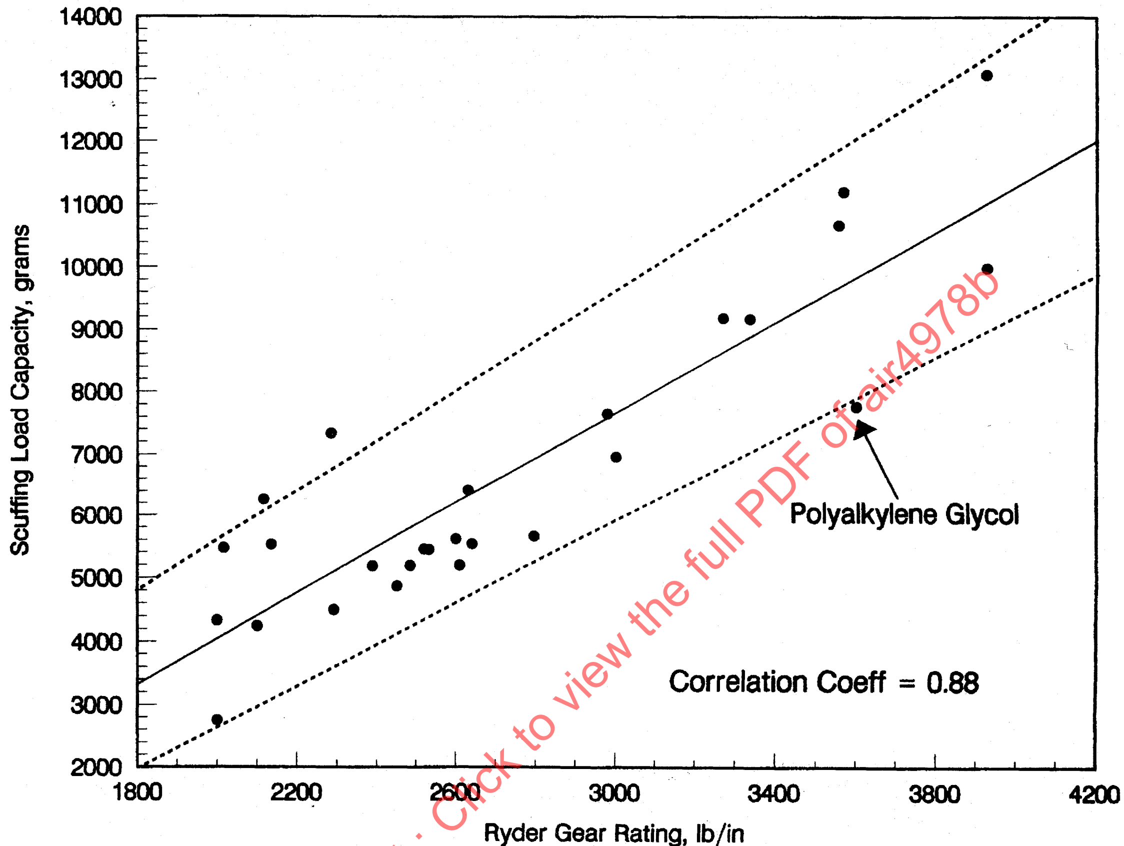


FIGURE C1 - Correlation Between the Ryder Gear Test and Results Obtained Using the GOST Procedure with Polyolester-Based Oils

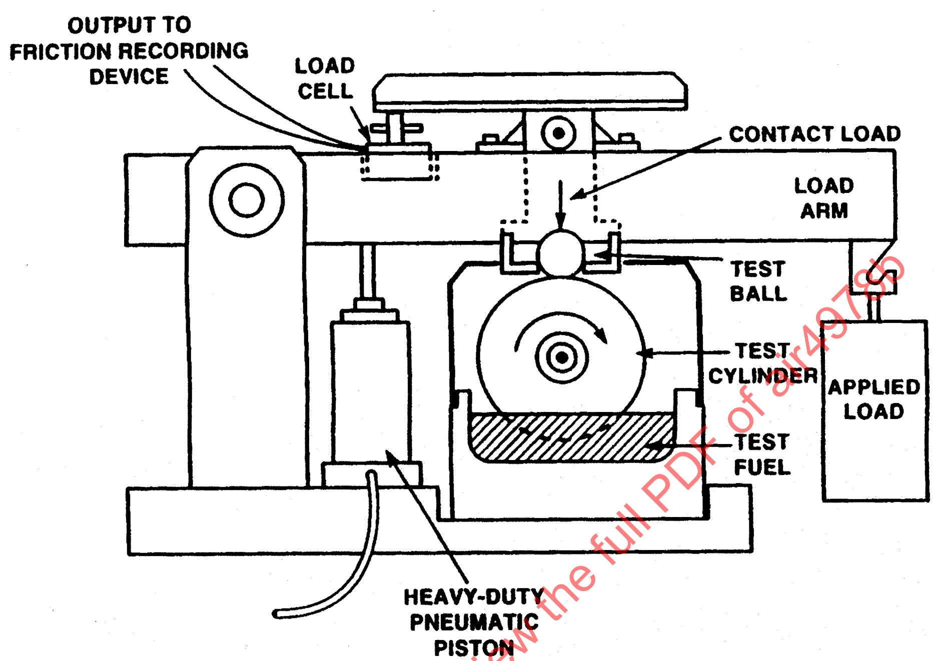


FIGURE C2 - Schematic Diagram of the Gear Oil Scuff Test (GOST) Apparatus, Not Including Instrumentation

TABLE C1 - Standard Operating Conditions

Fluid Volume	50 mL ± 1.0 mL
Fluid Temperature	80 °C ± 2 °C
Cylinder Rotational Speed	700 r/min ± 5 r/min
Applied Load	
Break-In Period	500 g
Incremental Load Test	500 to 12,000 g
Test Duration	
Break-In Period	30 s
Wear Tests	60 s

C.6.2 Cylinder, the polished test ring and mandrel assembly. See Figure C3.

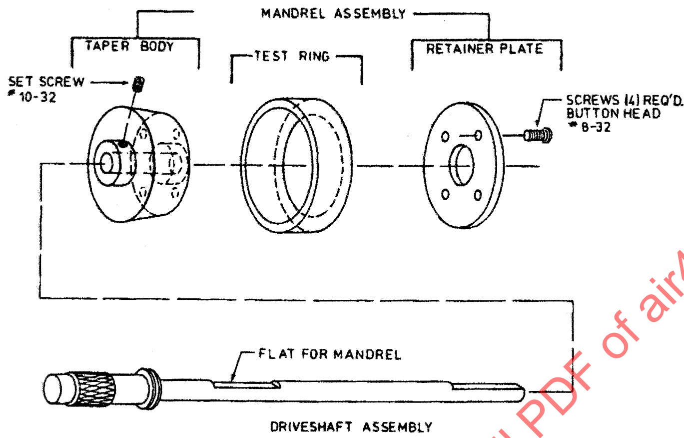


FIGURE C3 - Ring and Mandrel Assembly (Cylinder)

C.6.3 Mandrel, a 10° tapered short cylindrical section used to hold test ring.[3] See Figure C3.

C.6.4 Cleaning Bath, ultrasonic seamless stainless steel tank with adequate capacity and a cleaning power of 40 W or greater.

C.6.5 Desiccator, containing a non-indicating drying agent, capable of storing test rings, balls, and hardware.

C.7 REAGENTS AND MATERIALS:

C.7.1 Acetone, (Warning - see Note 1) conforming to Specification D 329.

NOTE 1: WARNING: Extremely flammable. Vapors may cause flash fire.

C.7.2 Compressed air, (Warning - see Note 2) containing less than 0.1 parts per million by volume (ppmv) hydrocarbons and 50 ppmv water.

NOTE 2: WARNING: Compressed gas under high pressure. Use with extreme caution in the presence of combustible material.

C.7.3 Gloves, clean, lint-free, cotton, disposable.

[3] Mandrel, Part No. M-O from Falex Corp., or P/N BOC-2101 from Inter-Av, Inc., P.O. Box 792228, San Antonio, TX 78279, has been found satisfactory.

C.7.4 Isooctane, (Warning - see Note 3) conforming to Test Method D 1016, 95% purity minimum, 2,2,4-trimethylpentane.

NOTE 3: WARNING: Extremely flammable. Harmful if inhaled. Vapors may cause flash fires.

C.7.5 Isopropyl Alcohol, (Warning - see Note 4) conforming to Specification D 770.

NOTE 4: WARNING: Flammable.

C.7.6 Reference Fluids:

C.7.6.1 Fluid A: Hercolube-A reference basestock. Store in clean, borosilicate glass with an aluminum foil-lined insert cap. Store in dark area.

C.7.6.2 Fluid B: ETO-25 Gear Box oil. Store in clean, borosilicate glass with an aluminum foil-lined insert cap. Store in dark area.

C.7.7 Test Ball, chrome alloy steel, made from AISI standard steel No. E-52100, with a diameter of 6.35 mm, grade 5 to 10 EP finish. The HRC shall be 64 to 66.

C.7.8 Test Ring, of SAE 8720 steel, having an HRC of 58 to 62 and a surface roughness between 0.04 and 0.15 μm after polishing.[4]

C.7.9 Wiper, wiping tissue, light-duty, lint-free, hydrocarbon-free, disposable.[5]

C.8 PREPARATION OF APPARATUS:

C.8.1 Cleaning of Apparatus and Test Components:

C.8.1.1 Test Rings, as Received:

C.8.1.1.1 If test rings are covered with a wax-like protective coating or with grease, remove the coating by rubbing the rings with a clean paper towel saturated with isooctane.

C.8.1.1.2 Place rings in a clean, 500-mL beaker. Transfer a sufficient volume of a 1-to-1 mixture of isooctane and isopropyl alcohol to the beaker so that the test rings are completely covered.

C.8.1.1.3 Place beaker in ultrasonic cleaner and turn on for 15 min.

C.8.1.1.4 Remove test rings and repeat ultrasonic cleaning cycle of C.8.1.1.1 and C.8.1.1.2 with a clean beaker and fresh solvents.

[4] Test rings, defined in ASTM D 6078 “Test Method for Evaluating the Lubricity of Diesel Fuels by the SLBOCLE,” have been found satisfactory. Other specimens will provide significantly different results.

[5] Blue Wipe, Catalog No. C6415-31 from Baxter Healthcare Corp., 210 Great Southwest Parkway, Grand Prairie, TX 75050, has been found satisfactory.

C.8.1.1.5 Handle all clean test rings with clean forceps. Remove test rings from beaker, rinse with isooctane, and dry. Rinse with acetone.

C.8.1.1.6 Dry and store in a desiccator.

NOTE 5: The parts can dry by sitting until the acetone has evaporated. The drying process can be accelerated by using a compressed air (7.2) jet at 140 to 210 kPa pressure.

C.8.1.2 Test Balls, as Received:

C.8.1.2.1 Place balls in 300-mL beaker. Transfer a sufficient volume of a 1-to-1 mixture of isooctane and isopropyl alcohol to the beaker so that the test balls are completely covered by the cleaning solvent.

NOTE 6: Approximately a 5-day supply can be processed at one time.

C.8.1.2.2 Place beaker in ultrasonic cleaner and turn on for 15 min.

C.8.1.2.3 Repeat the cleaning cycle of C.8.1.2.1 and C.8.1.2.2 with a clean beaker and fresh solvent.

C.8.1.2.4 Remove and rinse with isooctane and dry. Rinse with acetone.

C.8.1.2.5 Dry and store in a desiccator.

C.8.1.3 Reservoir, Reservoir Cover, Ball Chuck, and Ring Mandrel Assembly Components:

C.8.1.3.1 Rinse with isooctane.

C.8.1.3.2 Clean for 5 min in an ultrasonic cleaner with a 1-to-1 mixture of isooctane and isopropyl alcohol.

C.8.1.3.3 Remove and rinse with isooctane and dry. Rinse with acetone.

C.8.1.3.4 Dry and store in a desiccator.

C.8.1.4 Hardware:

C.8.1.4.1 The hardware and utensils (drive shaft, wrenches, and tweezers) that come in contact with the test fluid shall be cleaned by washing thoroughly with isooctane and wiping with a lint-free cloth.

C.8.1.4.2 Store parts in desiccator when not in use.

C.8.1.5 After Test:

C.8.1.5.1 Disassemble components and clean for 5 min in an ultrasonic cleaner using a 1-to-1 mixture of isooctane and isopropyl alcohol. Rinse with isooctane and dry. Rinse with acetone. Reassemble components.

C.8.1.5.2 Dry and store in a desiccator.

C.9 CALIBRATION AND STANDARDIZATION:

C.9.1 Visually inspect, with the naked eye, test balls and rings before each test. Discard specimens that exhibit pits, corrosion, or surface abnormalities.

C.9.2 Reference Fluids:

C.9.2.1 Test each new batch of the reference fluids in accordance with Section C.10.

C.9.2.2 Verify the calibration once every twelve oils.

C.9.2.3 Perform the calibration at the two loads defined in C.9.2.6 to verify test performance and accuracy with each fluid.

C.9.2.4 Additional tests are necessary if the applied load in grams using Reference Fluids A or B lies outside the acceptable range.

C.9.2.5 Calculate the maximum friction coefficient for each applied load in accordance with C.12.1.

C.9.2.6 The following reference fluid values are preliminary: The maximum friction coefficient should be less than or equal to 0.175 for applied loads of 4000 and 7250 g with Reference Fluids A and B, respectively. The maximum friction coefficient should be greater than 0.175 for applied loads of 5000 and 8250 g with Reference Fluids A and B, respectively.

C.9.3 Leveling of Load Arm:

C.9.3.1 The level of the load arm shall be inspected prior to each test. Level the motor platform by use of the circular bubble level and adjustable stainless steel legs.

C.9.3.2 Install a test ball in the holder and attach to load arm, as described in C.10.3.

C.9.3.3 Lower load arm by disengaging blue pull pin. Attach required weight to end of load beam. Lower ball onto ring manually.

C.9.3.4 Check level on top of load arm. The indicator bubble shall be centered in the middle of the two lines. If required, adjust the retaining nut screw to achieve a level load arm.

C.9.4 Assembly of Cylinder:

C.9.4.1 Place a clean test ring on the mandrel and bolt the back plate to the mandrel.

C.10 PROCEDURE:

C.10.1 Installation of Cleaned Test Cylinder:

C.10.1.1 Adhere strictly to cleanliness requirements and to the specified cleaning procedures. During handling and installation, protect cleaned test parts (cylinder, balls, reservoir, and reservoir cover) from contamination by wearing clean cotton gloves.

C.10.1.2 Secure the load beam in the UP position by inserting the blue pin.

C.10.1.3 Push the drive shaft through the left-hand bearing and support bracket.

C.10.1.4 Hold the cylinder with the set screw hub facing left. Push the drive shaft through the cylinder bore, through the right-hand bearing support bracket, and into the coupling as far as the drive shaft will go.

C.10.1.5 Align the coupling set screw with the flat keyway side of the cylinder drive shaft. Tighten set screw.

C.10.2 Position Cylinder:

C.10.2.1 For a new cylinder, set micrometer at 2.50 mm and slide cylinder to the left until it is firmly against micrometer probe. Ensure that cylinder set screw is directed toward the keyway (flat surface of drive shaft) and tighten set screw. This should position the first wear track on a ring approximately 1 mm in from the left side. If a cylinder used for a previous oil is being used, then position the new wear track at least 1.5 mm to the right of the last track on the ring.

C.10.2.2 Back micrometer probe away from the cylinder before drive motor is engaged.

C.10.2.3 Record on the data sheet the ring number, if assigned, and the position of the test cylinder as indicated by the micrometer. The first and last wear tracks on a ring shall be approximately 1 mm in from either side.

C.10.3 Installation of Clean Test Ball:

C.10.3.1 Clamp the ball in holder. Securely tighten allen screw.

C.10.3.2 Place ball holder in retaining nut.

C.10.3.3 Screw retaining nut onto the threaded chuck located on the load arm and hand tighten. Ensure that the allen screw holding the ball within the holder is toward the front of the load arm.

NOTE 7: If the allen screw is facing toward the side of the load arm, the test ball will turn in the holder and the test must be repeated.

C.10.3.4 Install the clean reservoir. Install the blue spacing platform by raising the reservoir. Slide blue spacer platform into position under the reservoir. Place thermocouple in the hole provided at the rear left side of the reservoir.

C.10.3.5 Transfer 50 mL ± 1 mL of the test fluid to the reservoir. Place cleaned reservoir cover in position.

C.10.3.6 Move power switch to ON position.

C.10.3.7 Adjust reservoir temperature as required until temperature stabilizes at 80 °C ± 1 °C.

C.10.3.8 Place lift actuator switch in the UP position.

C.10.4 Break-In:

C.10.4.1 Place 500-g load on load arm.

C.10.4.2 Start rotation of cylinder by switching motor drive to ON. Set rotation to 700 r/min.

C.10.4.3 Remove blue pin and gently lower load arm until the complete load is supported by the test specimens.

C.10.4.4 Switch timer on for 30 s.

C.10.4.5 When the timer sounds at the end of 30 s, immediately remove the test load, manually raise the load arm, and insert the blue pin.

C.10.5 Incremental Loading:

C.10.5.1 Start rotation of cylinder by switching motor drive to ON. Set rotation to 700 r/min ± 1 r/min.

C.10.5.2 Switch on recording device for friction trace output.

C.10.5.3 Check all test condition readouts and adjust as necessary. Record all necessary information on data sheet.

C.10.5.4 Place 8000-g load on load arm.

C.10.5.5 Remove blue pin and gently lower load arm until the complete load is supported by the test specimens.

C.10.5.6 Switch timer on for 60 s.

C.10.5.7 When the timer sounds at the end of 60 s, immediately remove the test load, manually raise the load arm, and insert the blue pin. If severe vibration or severe changes in sounds are evident, terminate the test prior to completion of the 60 s.

C.10.5.8 Turn motor drive switch to off and switch off recording device. Manually rotate motor shaft and wipe the revolving ring with an unused, disposable, lint-free cloth to remove residue from the test ring.

C.10.5.9 Remove test ball and ball holder from locking nut. Wipe ball clean with disposable wipe. Replace with new ball as described in C.8.7.4.

C.10.5.10 Calculate the MAXIMUM friction coefficient as described in Section C.13. Typical plots of friction coefficient versus time, where the maximum friction coefficient does and does not exceed 0.175, are shown in Figure C4.

C.10.5.11 Loosen the coupling set screw, NOT the mandrel set screw, and reset the cylinder to a new test position at least 1.5 mm from the last track by adjusting the micrometer. A spacing of 0.75 mm may be used if severe scuffing was not observed in the preceeding test.

C.10.5.12 Based on the maximum friction coefficient and Figure C5, choose the next load increment and repeat the testing sequence from C.10.4 through C.10.5.11 except for substituting the new load for the 8000 g load in C.10.5.4.

C.10.5.13 Terminate the incremental load tests when the applied load for a maximum friction coefficient exceeding and not exceeding 0.175 differs by 250 g.

C.10.5.14 Repeat the test procedure from C.10.1 with a different, precleaned test ring to obtain a second result with the same oil sample. This does not constitute a duplicate result.

C.10.5.14.1 For the repeat test procedure more rapid convergence may be obtained by using load increments near to the previously obtained result.

C.10.5.15 If the two test results differ by 1000 g or more, the results are not reliable and should be discarded. The complete test procedure detailed in Section C.10 should be repeated.

C.10.5.16 If the results of the repeated test again vary by 1000 g or more, an average value for the four data points (two from the first test and two from the second test) should be reported.

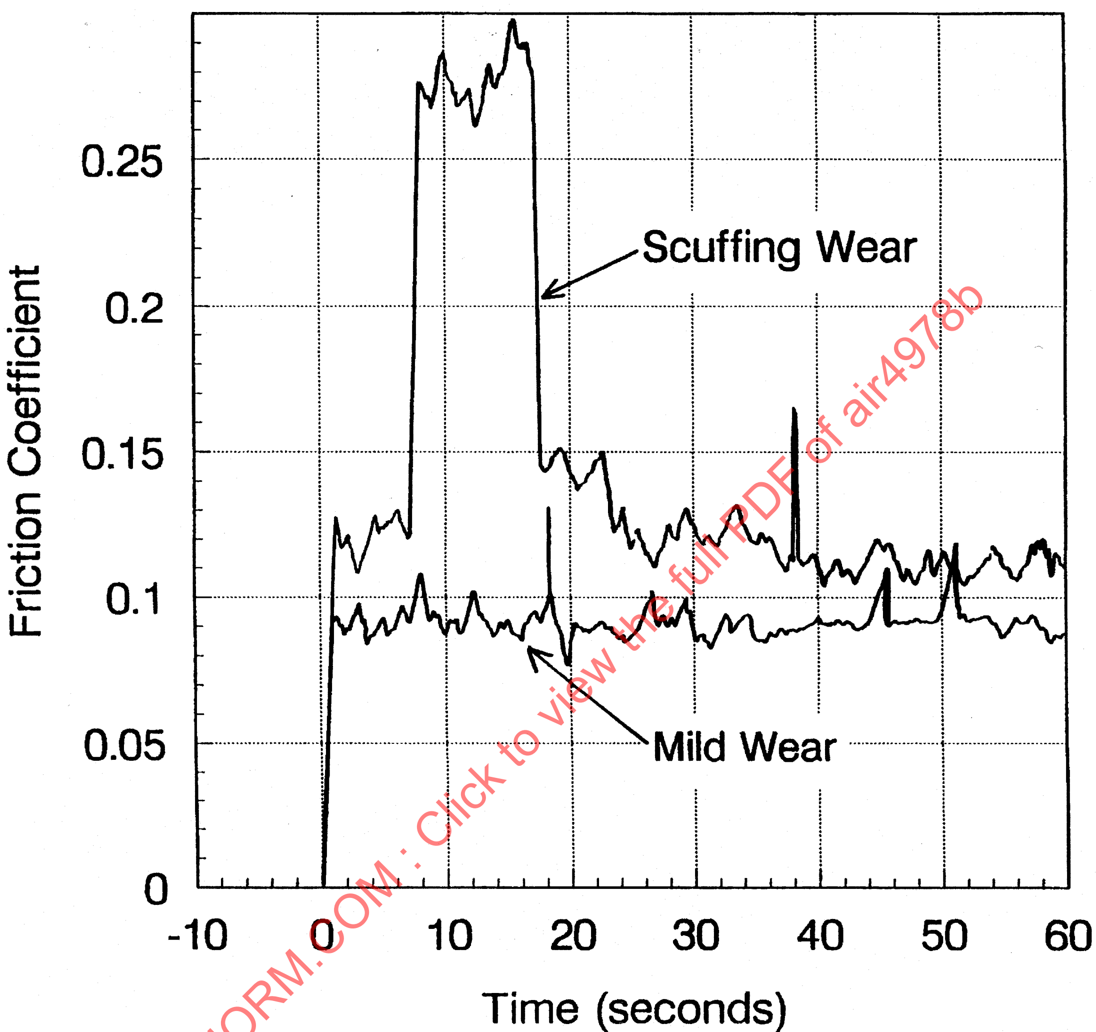
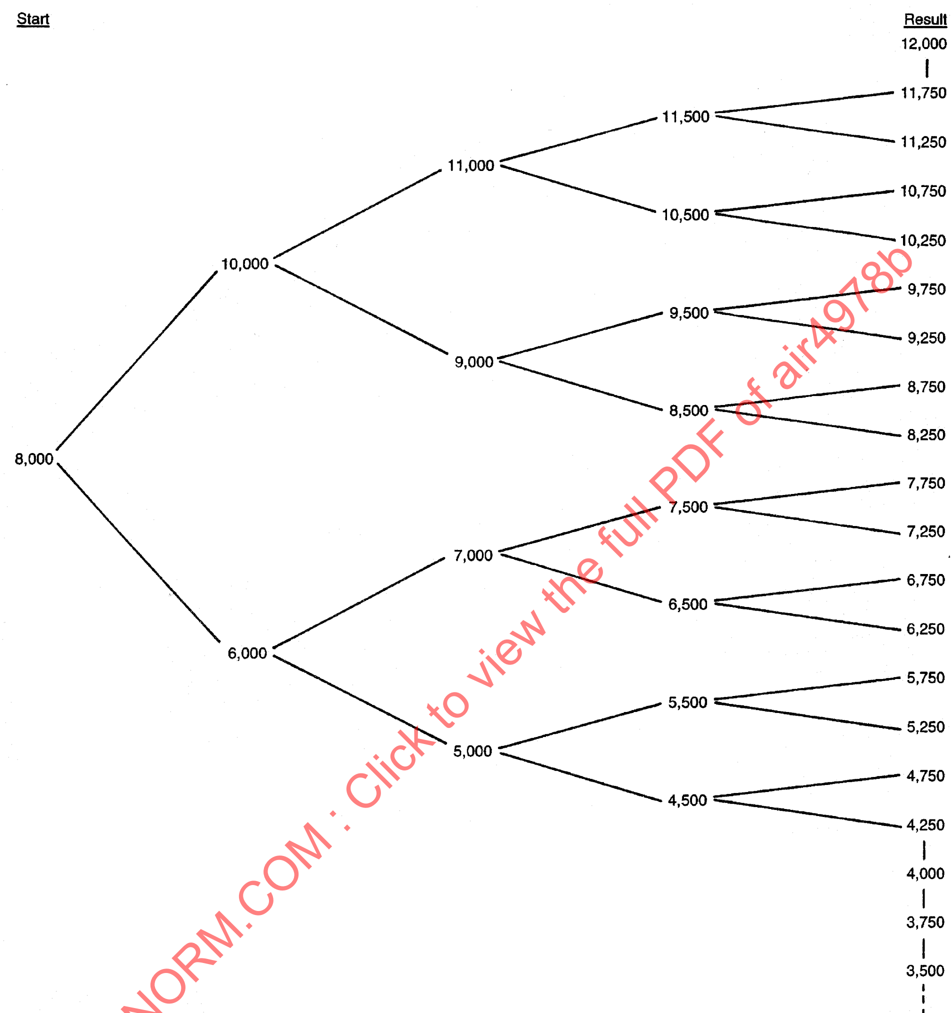


FIGURE C4 - Typical Friction Coefficients Obtained During Load Wear Tests, Calculated from Friction Trace Recording



Rules

1. Move left to right when selecting load, start at 8,000 g.
2. If maximum friction coefficient exceeds 0.175, select the next lower load to the right (i.e., follow the downward arrow).
3. If maximum friction coefficient is less than 0.175, select the next higher load to the right (i.e., follow the upward arrow).
4. The result is the lowest load at which the maximum friction coefficient exceeds 0.175, reported to the nearest 250 g.
5. If necessary, additional tests may be performed to assess oils outside the range 4,000 to 12,000 g. However, few oils exceed the given range.

FIGURE C5 - Incremental Load Test Sequence

C.11 MEASUREMENT OF FRICTION:

C.11.1 Friction Measurement:

C.11.1.1 Read the maximum tangential friction force in grams from the friction trace recording.

C.11.1.2 Calculate friction coefficient as described in Section C.14.

C.11.1.3 Record applied load and maximum friction coefficient.

C.12 CALCULATION:

C.12.1 Calculate maximum friction coefficient as follows:

$$\mu_m = \frac{F_t}{2F_a} \qquad \text{(Eq. C1)}$$

where:

μ_m = maximum friction coefficient
F_t = maximum tangential friction force, g, from friction trace recording
F_a = applied load, g

C.12.2 Calculate corrected scuffing load capacity (CSLC), corrected for the effects of viscosity as follows:

$$CSLC = SLC + 2385\,(\ln \nu)^{1.333} - 4500 \qquad \text{(Eq. C2)}$$

where:

SLC = average of the applied loads in grams determined in C.10.5.14 and C.10.5.15 for which the maximum friction coefficient exceeds 0.175
CSLC = scuffing load capacity corrected for viscosity
υ = kinematic viscosity at 100 °C, as defined using Test Method D 445

C.12.3 If required, the Ryder gear test result for the oil may be predicted from Figure C1.

C.13 REPORT:

C.13.1 Report the following information:

C.13.1.1 Report the average of the applied loads in grams determined in C.10.5.14 and C.10.5.15 for which the maximum friction coefficient exceeds 0.175. This is commonly referred to as the scuffing load capacity (SLC).

C.13.1.2 Report the CSLC determined in C.12.2.

C.13.1.3 The kinematic viscosity (υ) used in calculating the CSLC.

C.13.1.4 The conditions of the test, oil temperature, etc.

C.13.1.5 Description of the test oil and date of sampling.

C.13.1.6 Date of testing.

C.14 PRECISION AND BIAS:

C.14.1 Precision:

The precision of this test method was developed for oils with GOST results between 4000 and 12,000 g.

C.14.1.1 Repeatability: The difference between successive test results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following value in only one case in twenty:

$$\text{Repeatability} = 1000 \text{ g (estimated)} \quad \text{(Eq. C3)}$$

C.14.1.2 Reproducibility: The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following value in only one case in twenty:

$$\text{Reproducibility} = \text{currently undefined} \quad \text{(Eq. C4)}$$

C.14.2 Bias:

The procedure in this test method has no bias because scuffing load carrying capacity is not a fundamental and measurable fluid property and thus is evaluated in terms of this test method.

C.15 KEYWORDS:

Wear, friction, scuffing, adhesive wear, boundary lubrication, lubricating oil

APPENDIX D
WAM ECONOMICAL LOAD CAPACITY SCREENING TEST

D.1 BACKGROUND:

The Ryder Gear Test Method provides a scuffing or load capacity rating for aviation oils. The load capacity rating is derived from a scuffing criteria, even though most bearing and gear deterioration mechanisms are associated with micro-pitting and other surface distress failure modes. Through its use over many years as a qualification test, the Ryder Gear Test Method has developed a large database. The database provides a historical record for oil lubricating performance.

The U.S. Navy and U.S. Air Force have supported efforts to replace, or at least supplement, Ryder Gear testing with other test methods. The U.S. Navy has supported efforts on the Wedeven Associates, Inc. test machines, WAM1 and WAM3, to provide Ryder-like load capacity data of gas turbine and gearbox oils. These efforts also expand the scope of oil characterization beyond the narrow perspective of a pass/fail or ranking of oils, with scuffing performance the only criteria. To provide a continuity between Ryder Gear load capacity data and future oil characterization methods, the following economical screening test can be used to give Ryder-like scuffing performance ranking.

D.2 SCOPE:

The purpose of this test method is to rank oils according to the Ryder Gear Test Method. The test method invokes a scuffing failure caused by the limits of EHD and boundary lubricating properties of the test oil. A scuffing failure, which occurs under high sliding conditions, is associated with a sudden loss of surface integrity, generally accompanied by a sharp rise in traction (friction) coefficient. Prior to a scuffing event, the surfaces undergo polishing wear and the formation of boundary lubricating surface films. The lubrication and surface deterioration events during a load capacity test follow the same sequence of events found on Ryder Gear teeth. As in the Ryder test, a scuffing event is detected by a visual judgment of surface condition for scuffing. Scuffing is simultaneously detected by a sudden rise in traction. A scuffing event is also clearly audible.

The scuffing load capacity test method has been correlated with Ryder data for oils representing the specifications of MIL-L-23699, DOD-L-85734 and 9 cSt aviation Gearbox Oils.

D.2 (Continued):

WARNING: This test method is a simulation of Ryder Gear Test ranking. The test conditions are carefully selected to make the results correlate with the Ryder Gear Test. While the Ryder Gear Test operating conditions, in terms of rolling/sliding speeds, temperatures and contact kinematics, are representative of helicopter gearbox hardware, slight operational changes are likely to cause different ranking. This is based on WAM load capacity tests conducted over a range of test conditions, which affect EHD film generation and contact temperature. Load capacity tests over a range of conditions are recommended. The conditions selected here are specific to Ryder ranking using a set of five reference oils supplied by the U.S. Navy. In addition, there is no confirmation that scuffing load capacity performance is in any way connected with other prominent life-limiting performance criteria, expressed as surface distress (wear and micro-pitting). Additional tests for surface distress, or a complete simulation of specific hardware, are recommended to supplement scuffing load capacity results.

D.3 APPROACH:

The development of a Ryder-like scuffing test focused on the following features:

1. Invoke the same surface features associated with the scuffing phenomenon observed in the Ryder.
2. Visually monitor the surface condition while the test is in process.
3. Provide good thermal control and temperature measurement of test specimens and oil.
4. Limit the surface area exposed to the test oil to reduce effects due to cleaning procedures.
5. Perform a scuffing test without interruption of load using computer-controlled test parameters.

The test specimen configuration, shown schematically in Figure D1, consists of a rotating ball loaded against a rotating disc. The ball and disc specimens are fabricated from AISI 9310 steel and case hardened to 60 Rc. The disc is submerged in a small lubricant reservoir, which requires 15 ml of test oil. The temperature of the disc and test oil are controlled with a resistance heater placed below the disc specimen. The ball is heated by the disc below it and to some degree by the oil in which it is in contact. The ball temperature is tuned to the desired level with a resistance heater placed below the mounting quill for the ball. Fine adjustments in temperature of both specimens are made with a heat lamp. Ball and disc specimen temperatures are measured with trailing thermocouples. All heating devices are connected to temperature controllers to maintain minimum temperature limits of the test specimens.

Load and contact kinematics between the specimens are controlled by the WAM3 test machine, shown in Figure D2. The test machine controls specimen position, contact load and motions of a single contact in space. Traction measurements can be made in both X and Y directions. All motions and temperatures are computer-controlled. The disc specimen is continuously monitored with a microscope and TV/VCR system. A titler is used to display the applied load and time on the TV screen. Video recordings are used for post test analysis, when necessary. The test parameters are recorded on video tape or saved on computer. They include the following:

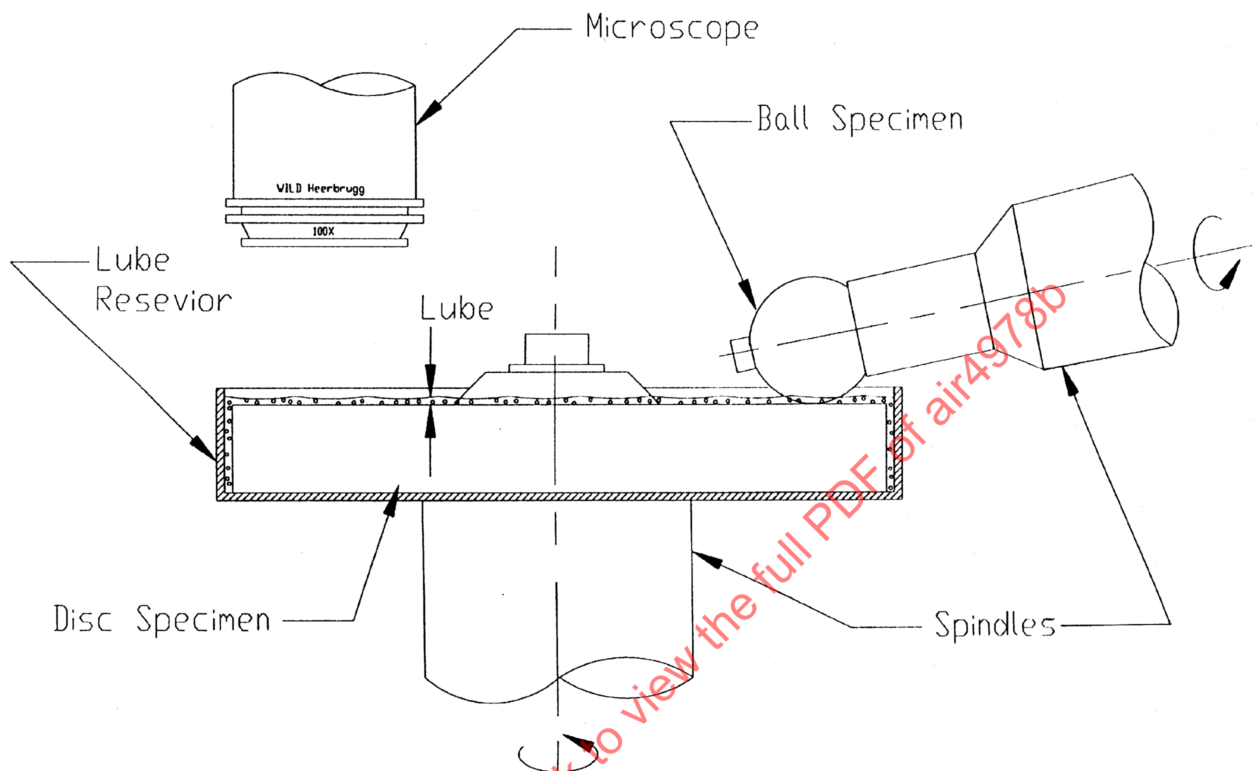


FIGURE D1 - WAM3 Test Specimens for Economical Load Screening Test

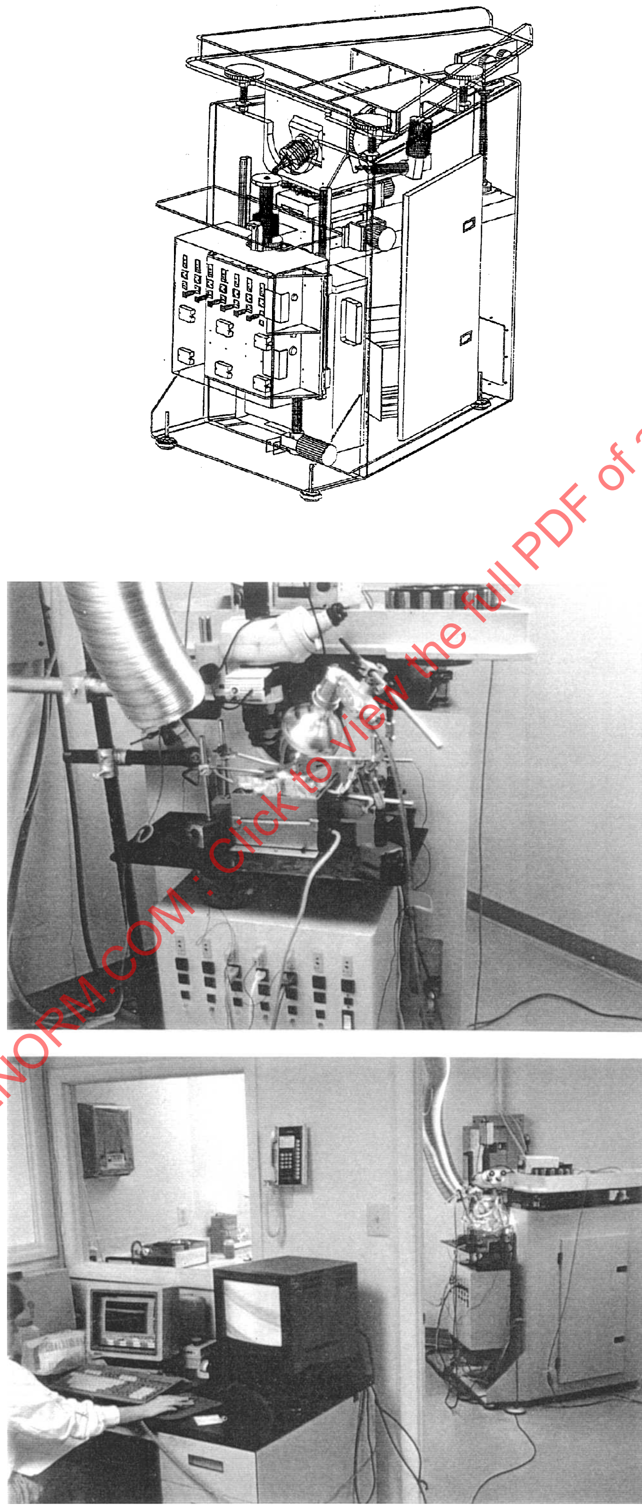


FIGURE D2 - WAM3 Rig Configuration for Economical Load Carrying Capacity Screening Test

D.3 (Continued):

Ball and disc temperatures
Traction coefficient
Ball and disc surface velocities
Contact load
Time
Video of running track on disc specimens

The test method utilizes the following features:

1. Slow application of load to avoid surface damage during test startup.
2. Exponential rather than linear increase in load so that a final scuffing event is reached, rather than a transition into a wear mode without scuffing.
3. A polished disc specimen finish to reveal scuff initiation and the formation of boundary lubricating surface films.
4. Incremental increase in ball speed with test stage to avoid test suspensions without a scuffing event.
5. Sufficiently high specimen temperatures to invoke oil chemistry similar to Ryder.
6. Inclusion of a run-in period, before load stages commence.
7. Continuous specimen contact rather than cyclic contact to avoid load/unload damage.
8. Small incremental load stages to increase resolution.
9. Non-collinear velocity vectors to prevent wear grooves and edge scuffing.

The test protocol parameters focus on creating tribological conditions which activate the same type of chemical response as the Ryder gear test. The key parameters controlling these conditions are: (1) entraining velocity to control EHD film thickness, (2) sliding velocity, (3) surface topography and (4) specimen temperatures (including effects of frictional heating). If the ranking of oils by a scuffing event falls in line with the Ryder Gear Test, it is assumed that the key tribological conditions invoked must be similar to the Ryder. The progression of surface features (like abrasive scratches, polishing of grinding ridges and surface film formation) formed prior to a scuffing event also follow the same sequence generated in the Ryder.

D.4 TEST PROCEDURE:

The specifications for the test specimens and initial operating conditions for the test protocol are given below:

Ball	2.06375 cm (13/16 in) dia, AISI 9310, “hard grind,” Ra = 0.25 µm (10 µin)
Disc	10.16 cm (4 in) dia, AISI 9310, polished finish (~1 µin Ra)
Ball vel.	U_b = 1 m/s (39.37 in/s) to 2.44 m/s (95.92 in/s) over 61 stages
Disc vel	U_d = 0.01016 m/s (0.4 in/s), after the run-in stage
Orientation	Non-collinear velocity vectors (angle between velocity vectors = 30°)
Load	1 kg (2.2 lb) with exponential increase to 58.8 kg (127.4 lb)
Test duration	Until scuff, or suspension (61 stages, 1140 s)
Scuff criteria	Defined by loss of surface integrity and increase in traction
Temperature	Disc controlled at 180 °C; initial ball temperature 150 °C
Oil supply	Disc submerged in reservoir with 15 ml of lubricant

Prior to each test series, the ball and disc specimens are cleaned in an ultrasonic bath with petroleum ether, followed by acetone. The AISI 9310 “hard grind” ball specimens are processed through the hard grind stage of a ball manufacturing process. The “hard grind” ball specimens tend to have a consistent surface finish (Ra = 10-13 µin) for good repeatability. The test balls are from a single manufacturing batch consisting of approximately 8000 balls. A polished disc specimen is selected to provide a consistent surface for repeatability. The surface features on the disc specimen are one order of magnitude less than the ball specimen.

Before each test, the ball and disc specimens are heated to their desired temperatures. During the heat-up period, the ball and disc specimens are slowly rotated without load and with a small separation between their surfaces. The temperature of the disc is maintained at 180 °C with a resistance heater located below the disc. A disc temperature of 180 °C was found to give the best correlation with the Ryder Gear Test. The bottom portion of the ball, which is submerged in the oil reservoir, is partially heated by the oil. Additional heat is provided by a resistance heater located near the ball mounting adapter. The ball temperature, which is initially set at 150 °C, is allowed to increase during the loading protocol. Frictional heating causes the ball temperature to increase with testing stage in a similar fashion to the small test gear in the Ryder Gear Test. An initial temperature of 150 °C was found to give the best correlation with the Ryder Gear Test. The temperatures of the ball and disc specimens are measured with trailing thermocouples.

The details of the test protocol loads and speeds are given in Table D1. Figure D3 shows a plot of the load, ball velocity and disc velocity that covers 61 stages of operation. The first stage, which occurs over a period of 240 s, is designed to initiate the test with a run-in process to avoid premature surface damage. The run-in stage allows time for the most prominent surface roughness features on the ball to be polished before any serious loading is initiated.

The run-in stage is run with a higher disc velocity and lower ball velocity than used during the loading stages. The surface velocities used during the run-in stage provide a higher entraining velocity for the generation of a thicker elastohydrodynamic (EHD) film.

TABLE D1 - WAM Economical Load Capacity Screening Test

Time (s)	Testing Stage	Ball Speed (in/s)	Ball Speed (m/s)	Disc Speed (in/s)	Disc Speed (m/s)	Ent. Velocity (in/s)	Ent. Velocity (m/s)	Sliding Velocity (in/s)	Sliding Velocity (m/s)	Load (lb)	Load (kg)
0	1	9.84	0.25	4.00	0.10	6.73	0.17	6.68	0.17	2.20	1.00
30		9.84	0.25	4.00	0.10	6.73	0.17	6.68	0.17	2.20	1.00
30		9.84	0.25	2.00	0.05	5.81	0.15	8.17	0.21	2.20	1.00
60		9.84	0.25	2.00	0.05	5.81	0.15	8.17	0.21	2.20	1.00
60		9.84	0.25	1.50	0.04	5.58	0.14	8.57	0.22	2.20	1.00
90		9.84	0.25	1.50	0.04	5.58	0.14	8.57	0.22	2.20	1.00
90		9.84	0.25	0.40	0.01	5.09	0.13	9.50	0.24	2.20	1.00
120		9.84	0.25	0.40	0.01	5.09	0.13	9.50	0.24	2.20	1.00
120		14.06	0.36	0.40	0.01	7.20	0.18	13.72	0.35	2.20	1.00
135		14.06	0.36	0.40	0.01	7.20	0.18	13.72	0.35	2.20	1.00
135		18.28	0.46	0.40	0.01	9.31	0.24	17.93	0.46	2.20	1.00
150		18.28	0.46	0.40	0.01	9.31	0.24	17.93	0.46	2.20	1.00
150		22.50	0.57	0.40	0.01	11.42	0.29	22.15	0.56	2.20	1.00
165		22.50	0.57	0.40	0.01	11.42	0.29	22.15	0.56	2.20	1.00
165		26.72	0.68	0.40	0.01	13.53	0.34	26.37	0.67	2.20	1.00
180		26.72	0.68	0.40	0.01	13.53	0.34	26.37	0.67	2.20	1.00
180		30.93	0.79	0.40	0.01	15.64	0.40	30.58	0.78	2.20	1.00
195		30.93	0.79	0.40	0.01	15.64	0.40	30.58	0.78	2.20	1.00
195		35.15	0.89	0.40	0.01	17.75	0.45	34.80	0.88	2.20	1.00
210		35.15	0.89	0.40	0.01	17.75	0.45	34.80	0.88	2.20	1.00
210		39.37	1.00	0.40	0.01	19.86	0.50	39.02	0.99	2.20	1.00
240		39.37	1.00	0.40	0.01	19.86	0.50	39.02	0.99	2.20	1.00
240	2	39.37	1.00	0.40	0.01	19.86	0.50	39.02	0.99	3.30	1.50
255		39.37	1.00	0.40	0.01	19.86	0.50	39.02	0.99	3.30	1.50
255	3	39.92	1.01	0.40	0.01	20.13	0.51	39.57	1.01	3.30	1.50
270		39.92	1.01	0.40	0.01	20.13	0.51	39.57	1.01	3.30	1.50
270	4	39.92	1.01	0.40	0.01	20.13	0.51	39.57	1.01	4.40	2.00
285		39.92	1.01	0.40	0.01	20.13	0.51	39.57	1.01	4.40	2.00
285	5	40.47	1.03	0.40	0.01	20.41	0.52	40.12	1.02	4.40	2.00
300		40.47	1.03	0.40	0.01	20.41	0.52	40.12	1.02	4.40	2.00
300	6	40.47	1.03	0.40	0.01	20.41	0.52	40.12	1.02	6.05	2.74
315		40.47	1.03	0.40	0.01	20.41	0.52	40.12	1.02	6.05	2.74
315	7	41.02	1.04	0.40	0.01	20.68	0.53	40.67	1.03	6.05	2.74
330		41.02	1.04	0.40	0.01	20.68	0.53	40.67	1.03	6.05	2.74
330	8	41.02	1.04	0.40	0.01	20.68	0.53	40.67	1.03	7.70	3.49
345		41.02	1.04	0.40	0.01	20.68	0.53	40.67	1.03	7.70	3.49
345	9	41.57	1.06	0.40	0.01	20.96	0.53	41.22	1.05	7.70	3.49
360		41.57	1.06	0.40	0.01	20.96	0.53	41.22	1.05	7.70	3.49
360	10	41.57	1.06	0.40	0.01	20.96	0.53	41.22	1.05	9.35	4.24
375		41.57	1.06	0.40	0.01	20.96	0.53	41.22	1.05	9.35	4.24
375	11	42.12	1.07	0.40	0.01	21.23	0.54	41.77	1.06	9.35	4.24
390		42.12	1.07	0.40	0.01	21.23	0.54	41.77	1.06	9.35	4.24
390	12	42.12	1.07	0.40	0.01	21.23	0.54	41.77	1.06	11.00	4.99
405		42.12	1.07	0.40	0.01	21.23	0.54	41.77	1.06	11.00	4.99
405	13	42.67	1.08	0.40	0.01	21.51	0.55	42.32	1.07	11.00	4.99
420		42.67	1.08	0.40	0.01	21.51	0.55	42.32	1.07	11.00	4.99
420	14	42.67	1.08	0.40	0.01	21.51	0.55	42.32	1.07	13.20	5.99

TABLE D1 (Continued)

Time (s)	Testing Stage	Ball Speed (in/s)	Ball Speed (m/s)	Disc Speed (in/s)	Disc Speed (m/s)	Ent. Velocity (in/s)	Ent. Velocity (m/s)	Sliding Velocity (in/s)	Sliding Velocity (m/s)	Load (lb)	Load (kg)
435		42.67	1.08	0.40	0.01	21.51	0.55	42.32	1.07	13.20	5.99
435	15	43.22	1.10	0.40	0.01	21.78	0.55	42.87	1.09	13.20	5.99
450		43.22	1.10	0.40	0.01	21.78	0.55	42.87	1.09	13.20	5.99
450	16	43.22	1.10	0.40	0.01	21.78	0.55	42.87	1.09	15.40	6.99
465		43.22	1.10	0.40	0.01	21.78	0.55	42.87	1.09	15.40	6.99
465	17	43.77	1.11	0.40	0.01	22.06	0.56	43.42	1.10	15.40	6.99
480		43.77	1.11	0.40	0.01	22.06	0.56	43.42	1.10	15.40	6.99
480	18	43.77	1.11	0.40	0.01	22.06	0.56	43.42	1.10	17.60	7.98
495		43.77	1.11	0.40	0.01	22.06	0.56	43.42	1.10	17.60	7.98
495	19	44.32	1.13	0.40	0.01	22.33	0.57	43.97	1.12	17.60	7.98
510		44.32	1.13	0.40	0.01	22.33	0.57	43.97	1.12	17.60	7.98
510	20	44.32	1.13	0.40	0.01	22.33	0.57	43.97	1.12	19.80	8.98
525		44.32	1.13	0.40	0.01	22.33	0.57	43.97	1.12	19.80	8.98
525	21	44.87	1.14	0.40	0.01	22.61	0.57	44.52	1.13	19.80	8.98
540		44.87	1.14	0.40	0.01	22.61	0.57	44.52	1.13	19.80	8.98
540	22	44.87	1.14	0.40	0.01	22.61	0.57	44.52	1.13	22.55	10.23
555		44.87	1.14	0.40	0.01	22.61	0.57	44.52	1.13	22.55	10.23
555	23	45.52	1.16	0.40	0.01	22.93	0.58	45.17	1.15	22.55	10.23
570		45.52	1.16	0.40	0.01	22.93	0.58	45.17	1.15	22.55	10.23
570	24	45.52	1.16	0.40	0.01	22.93	0.58	45.17	1.15	25.30	11.48
585		45.52	1.16	0.40	0.01	22.93	0.58	45.17	1.15	25.30	11.48
585	25	45.97	1.17	0.40	0.01	23.16	0.59	45.62	1.16	25.30	11.48
600		45.97	1.17	0.40	0.01	23.16	0.59	45.62	1.16	25.30	11.48
600	26	45.97	1.17	0.40	0.01	23.16	0.59	45.62	1.16	28.05	12.72
615		45.97	1.17	0.40	0.01	23.16	0.59	45.62	1.16	28.05	12.72
615	27	46.52	1.18	0.40	0.01	23.43	0.60	46.17	1.17	28.05	12.72
630		46.52	1.18	0.40	0.01	23.43	0.60	46.17	1.17	28.05	12.72
630	28	46.52	1.18	0.40	0.01	23.43	0.60	46.17	1.17	30.80	13.97
645		46.52	1.18	0.40	0.01	23.43	0.60	46.17	1.17	30.80	13.97
645	29	47.07	1.20	0.40	0.01	23.71	0.60	46.72	1.19	30.80	13.97
650		47.07	1.20	0.40	0.01	23.71	0.60	46.72	1.19	30.80	13.97
650	30	47.07	1.20	0.40	0.01	23.71	0.60	46.72	1.19	34.10	15.47
675		47.07	1.20	0.40	0.01	23.71	0.60	46.72	1.19	34.10	15.47
675	31	47.62	1.21	0.40	0.01	23.98	0.61	47.27	1.20	34.10	15.47
690		47.62	1.21	0.40	0.01	23.98	0.61	47.27	1.20	34.10	15.47
690	32	47.62	1.21	0.40	0.01	23.98	0.61	47.27	1.20	37.40	16.96
705		47.62	1.21	0.40	0.01	23.98	0.61	47.27	1.20	37.40	16.96
705	33	48.17	1.22	0.40	0.01	24.26	0.62	47.82	1.21	37.40	16.96
720		48.17	1.22	0.40	0.01	24.26	0.62	47.82	1.21	37.40	16.96
720	34	48.17	1.22	0.40	0.01	24.26	0.62	47.82	1.21	40.70	18.46
735		48.17	1.22	0.40	0.01	24.26	0.62	47.82	1.21	40.70	18.46
735	35	48.72	1.24	0.40	0.01	24.26	0.62	47.82	1.21	40.70	18.46
750		48.72	1.24	0.40	0.01	24.26	0.62	47.82	1.21	40.70	18.46
750	36	48.72	1.24	0.40	0.01	24.26	0.62	47.82	1.21	44.00	19.96
765		48.72	1.24	0.40	0.01	24.26	0.62	47.82	1.21	44.00	19.96
765	37	49.27	1.25	0.40	0.01	24.81	0.63	48.92	1.24	44.00	19.96
780		49.27	1.25	0.40	0.01	24.81	0.63	48.92	1.24	44.00	19.96

TABLE D1 (Continued)

Time (s)	Testing Stage	Ball Speed (in/s)	Ball Speed (m/s)	Disc Speed (in/s)	Disc Speed (m/s)	Ent. Velocity (in/s)	Ent. Velocity (m/s)	Sliding Velocity (in/s)	Sliding Velocity (m/s)	Load (lb)	Load (kg)
780	38	49.27	1.25	0.40	0.01	24.81	0.63	48.92	1.24	47.85	21.70
795		49.27	1.25	0.40	0.01	24.81	0.63	48.92	1.24	47.85	21.70
795	39	49.82	1.27	0.40	0.01	25.08	0.64	49.47	1.26	47.85	21.70
810		49.82	1.27	0.40	0.01	25.08	0.64	49.47	1.26	47.85	21.70
810	40	49.82	1.27	0.40	0.01	25.08	0.64	49.47	1.26	51.70	23.45
825		49.82	1.27	0.40	0.01	25.08	0.64	49.47	1.26	51.70	23.45
825	41	50.37	1.28	0.40	0.01	25.36	0.64	50.02	1.27	51.70	23.45
840		50.37	1.28	0.40	0.01	25.36	0.64	50.02	1.27	51.70	23.45
840	42	50.37	1.28	0.40	0.01	25.36	0.64	50.02	1.27	55.55	25.20
855		50.37	1.28	0.40	0.01	25.36	0.64	50.02	1.27	55.55	25.20
855	43	50.92	1.29	0.40	0.01	25.63	0.65	50.57	1.28	55.55	25.20
870		50.92	1.29	0.40	0.01	25.63	0.65	50.57	1.28	55.55	25.20
870	44	50.92	1.29	0.40	0.01	25.63	0.65	50.57	1.28	59.40	26.94
885		50.92	1.29	0.40	0.01	25.63	0.65	50.57	1.28	59.40	26.94
885	45	51.92	1.32	0.40	0.01	26.13	0.66	51.57	1.31	59.40	26.94
900		51.92	1.32	0.40	0.01	26.13	0.66	51.57	1.31	59.40	26.94
900	46	51.92	1.32	0.40	0.01	26.13	0.66	51.57	1.31	64.40	29.21
915		51.92	1.32	0.40	0.01	26.13	0.66	51.57	1.31	64.40	29.21
915	47	53.92	1.37	0.40	0.01	27.13	0.69	53.57	1.36	64.40	29.21
930		53.92	1.37	0.40	0.01	27.13	0.69	53.57	1.36	64.40	29.21
930	48	53.92	1.37	0.40	0.01	27.13	0.69	53.57	1.36	70.40	31.93
945		53.92	1.37	0.40	0.01	27.13	0.69	53.57	1.36	70.40	31.93
945	49	56.92	1.45	0.40	0.01	28.63	0.73	56.57	1.44	70.40	31.93
960		56.92	1.45	0.40	0.01	28.63	0.73	56.57	1.44	70.40	31.93
960	50	56.92	1.45	0.40	0.01	28.63	0.73	56.57	1.44	77.40	35.11
975		56.92	1.45	0.40	0.01	28.63	0.73	56.57	1.44	77.40	35.11
975	51	60.92	1.55	0.40	0.01	30.63	0.78	60.57	1.54	77.40	35.11
990		60.92	1.55	0.40	0.01	30.63	0.78	60.57	1.54	77.40	35.11
990	52	60.92	1.55	0.40	0.01	30.63	0.78	60.57	1.54	85.40	38.74
1005		60.92	1.55	0.40	0.01	30.63	0.78	60.57	1.54	85.40	38.74
1005	53	65.92	1.67	0.40	0.01	33.13	0.84	65.57	1.67	85.40	38.74
1020		65.92	1.67	0.40	0.01	33.13	0.84	65.57	1.67	85.40	38.74
1020	54	65.92	1.67	0.40	0.01	33.13	0.84	65.57	1.67	94.40	42.82
1035		65.92	1.67	0.40	0.01	33.13	0.84	65.57	1.67	94.40	42.82
1035	55	71.92	1.83	0.40	0.01	36.13	0.92	71.57	1.82	94.40	42.82
1050		71.92	1.83	0.40	0.01	36.13	0.92	71.57	1.82	94.40	42.82
1050	56	71.92	1.83	0.40	0.01	36.13	0.92	71.57	1.82	104.40	47.36
1065		71.92	1.83	0.40	0.01	36.13	0.92	71.57	1.82	104.40	47.36
1065	57	78.92	2.00	0.40	0.01	39.63	1.01	78.57	2.00	104.40	47.36
1080		78.92	2.00	0.40	0.01	39.63	1.01	78.57	2.00	104.40	47.36
1080	58	78.92	2.00	0.40	0.01	39.63	1.01	78.57	2.00	115.40	52.35
1095		78.92	2.00	0.40	0.01	39.63	1.01	78.57	2.00	115.40	52.35
1095	59	86.92	2.21	0.40	0.01	43.63	1.11	86.57	2.20	115.40	52.35
1110		86.92	2.21	0.40	0.01	43.63	1.11	86.57	2.20	115.40	52.35
1110	60	86.92	2.21	0.40	0.01	43.63	1.11	86.57	2.20	127.40	57.79
1125		86.92	2.21	0.40	0.01	43.63	1.11	86.57	2.20	127.40	57.79
1125	61	95.92	2.44	0.40	0.01	48.13	1.22	95.57	2.43	127.40	57.79
1140		95.92	2.44	0.40	0.01	48.13	1.22	95.57	2.43	127.40	57.79

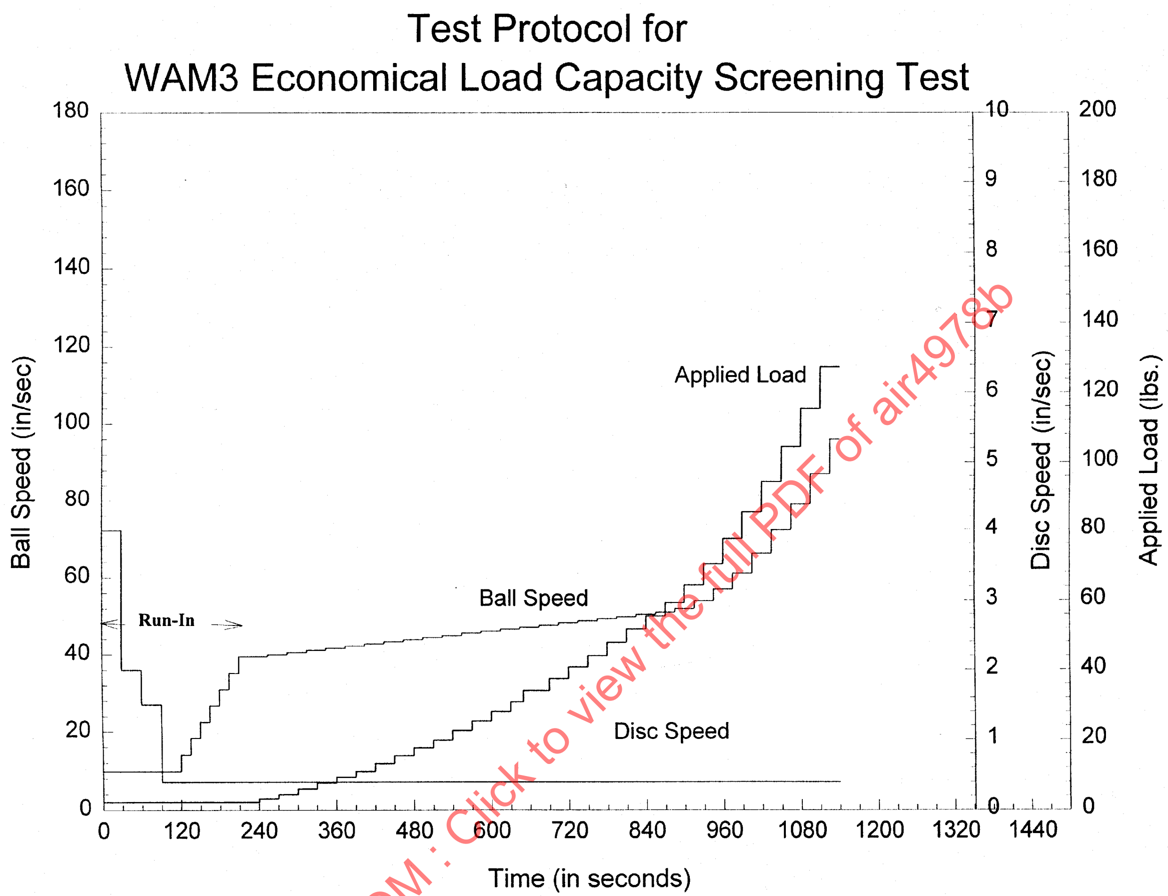


FIGURE D3 - Test Protocol for WAM3 Economical Load Capacity Screening Test

D.4 (Continued):

It also lowers the sliding velocity, which reduces the risk of surface damage due to abrasive wear or micro-scuffing. The entraining velocity (U_e) and sliding velocity (U_s) are defined below:

$$U_e = 1/2\,(U_b + U_d)$$
$$U_s = (U_b - U_d) \qquad \text{(Eq. D1)}$$

where:

U_b = surface velocity vector of the ball at the contact point
U_d = surface velocity vector of the disc at the contact point

The entraining velocity (U_e) and sliding velocity (U_s) are key parameters that control the degree of surface separation and the rate of surface tangential shear that the oil must accommodate. The entraining velocity and sliding velocity parameters are plotted in Figure D4. With the parameters selected, the initiation of a load capacity test is similar to the Ryder Gear Test in that there is generally little or no evidence of surface damage during the first load stage.

D.5 TRACTION AND TEMPERATURE DATA FOR TYPICAL LOAD CAPACITY TESTS:

The traction coefficients for load capacity tests of four oils is shown in Figure D5. The ball and disc temperatures displayed are for the 9 cSt oil PE-9-G0041. The traction coefficient during the initial part of the run-in stage frequently decreases, indicating that some of the surface features on the ball are becoming polished. During this polishing period, the track on the disc may sometimes become visible. If a good run-in has been achieved, there is little or no evidence of abrasive wear marks on the polished disc surface. Local abrasive wear marks are believed to be initiation sites for premature scuffing.

The run-in stage is completed by lowering the disc velocity and increasing the ball velocity in preparation for the initiation of a loading protocol. The traction coefficient sometimes rises during this period because the entraining velocity is less and the surfaces encounter more interaction. The ball temperature also increases. This is due to greater frictional heating with higher sliding velocity. It is also due to a greater amount of hot oil, which is picked up by the ball when it begins to rotate faster. The ball temperature increases at a moderate rate during the loading stages.

The traction data in Figure D5 show that the traction coefficient decreases with load. This can be explained by a lower limiting shear strength of the bulk oil as the contact temperature increases with load. A decrease in traction coefficient is also attributed to the polishing of the topographical features on the ball. This is frequently observed by small perturbations in traction between each load stage.

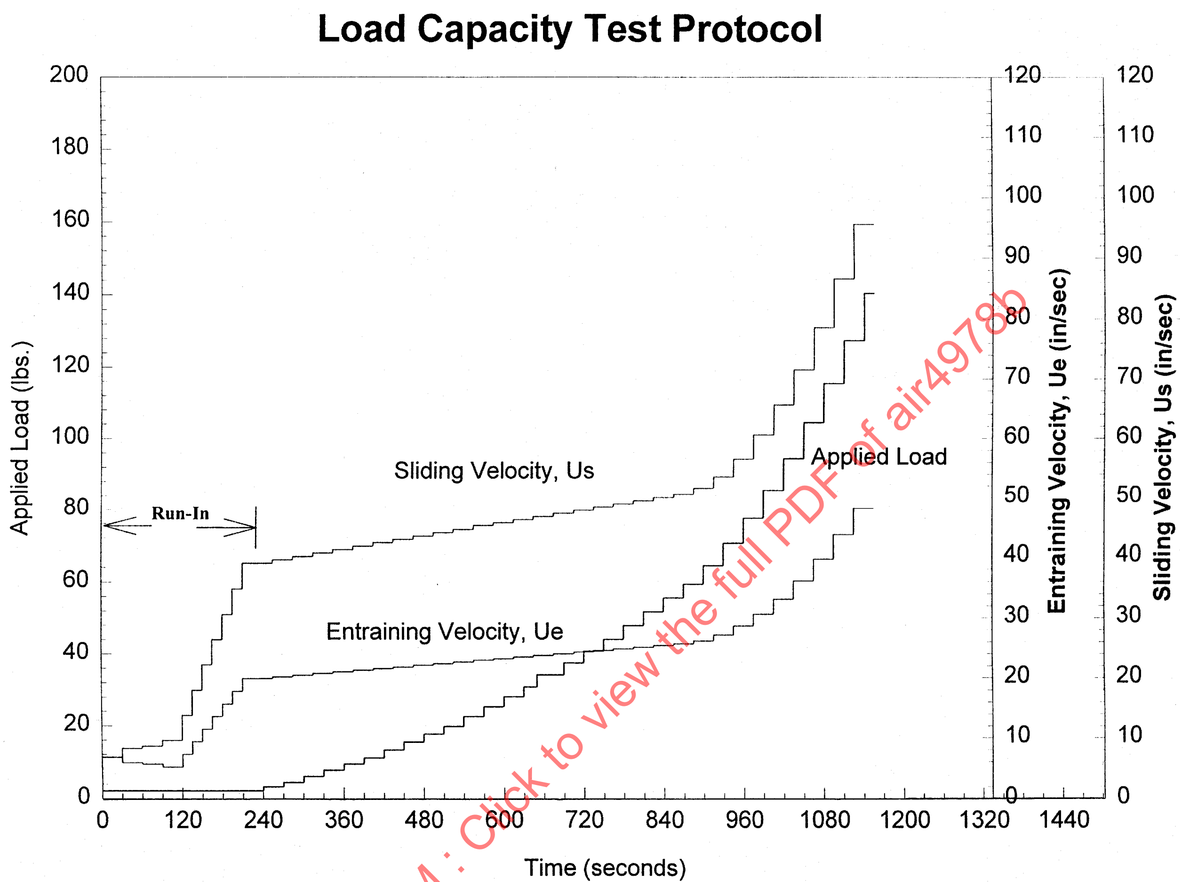


FIGURE D4 - Test Protocol for WAM3 Economical Load Capacity Screening Test

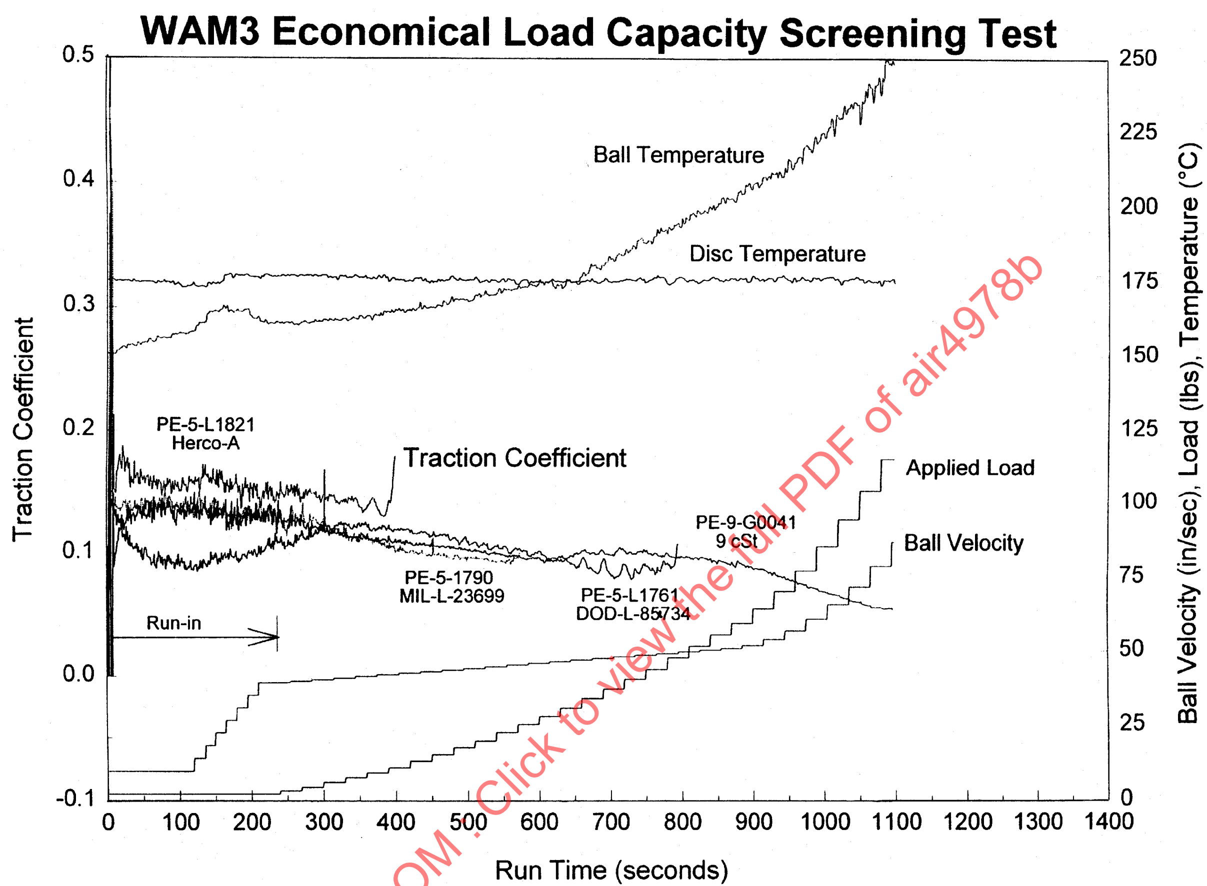


FIGURE D5 - Load Capacity Traction Data for Four Test Oils

D.5 (Continued):

The end point in a load capacity test is clearly defined by a sudden increase in traction coefficient and a complete loss of surface integrity. The onset of a scuffing failure can usually be detected by the removal of surface films, which accumulate on the running track during the loading protocol. Good load carrying oils can replenish these boundary lubricating films to allow the surfaces to continue to run to higher test stages without scuffing.

Figure D6 shows a ball and disc running track at the onset of a macro-scuff. The center of the ball track shows smeared material, similar to that found on scuffed areas of Ryder Gear teeth. The sides of the ball track, which have become polished during the loading protocol, have not yet become scuffed at this point in the scuffing failure event. A macro-scuff failure event usually occurs within a few seconds of operation.

The disc track, shown in Figure D6, contains abrasive wear scratches and clearly defined areas of scuffing. A surface which has reached this degree of scuffing has little chance of recovery. Good load carrying oils can sometimes reach a micro-scuffing stage, which is followed by a healing of the surfaces and recovery. Recovery events are evident in the traction data for the DOD-L-85734 oil in Figure D5. These micro-scuff events, which are more common with chemically active oils, introduce a degree of scatter in the scuffing load capacity data.

D.6 OPTIONAL WEAR MEASUREMENT:

The scuffing resistance of high load capacity oils with active chemistry is associated with a sacrificial wear process, where the formation of chemical reaction films are sacrificially removed instead of a gross failure of the near-surface material. This is sometimes evident with oils that reach high load stages, where high temperatures and reactive chemistry exist. A wear failure criteria may be used in place of a scuffing criteria.

An example of the competition between scuffing and wear is shown in Figure D7, where the wear track width on the disc specimen is displayed for a load capacity test that did not encounter a macro-scuff event. The wear track width is measure from the video recording of the disc specimen. The track width is plotted along with the calculated Hertzian contact width. The departure of the track width from the Hertzian width during the initial part of the test is due to the surface roughness features on the ball. The track width and Hertzian width become nearly equal as the topographical features on the ball become polished. A transition in wear, or a significant departure in the wear track width beyond this point, could be used as an optional criteria for failure. A wear transition can be seen near the end of the test in Figure D7. This approach reflects the notion of a bifurcation phenomena, where the failure pathway may go toward a sacrificial wear mode instead of a macro-scuff. This seems to be the nature of the phenomena. A high load carrying oil may achieve its ranking by chemistry and a sacrificial wear process.

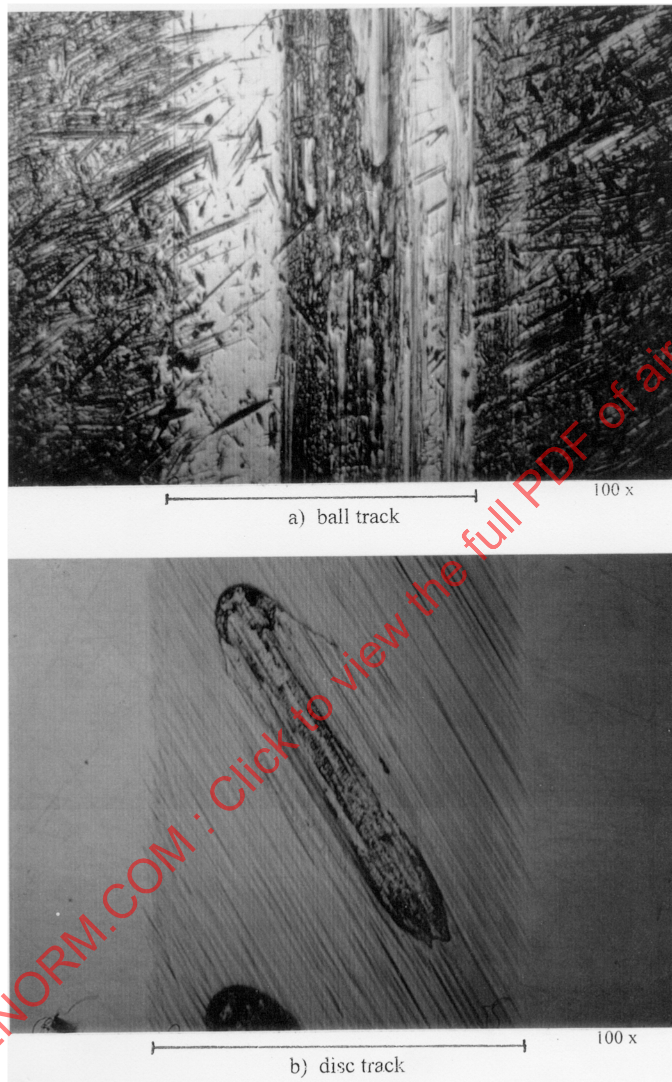


FIGURE D6 - Onset of Macro-Scuff

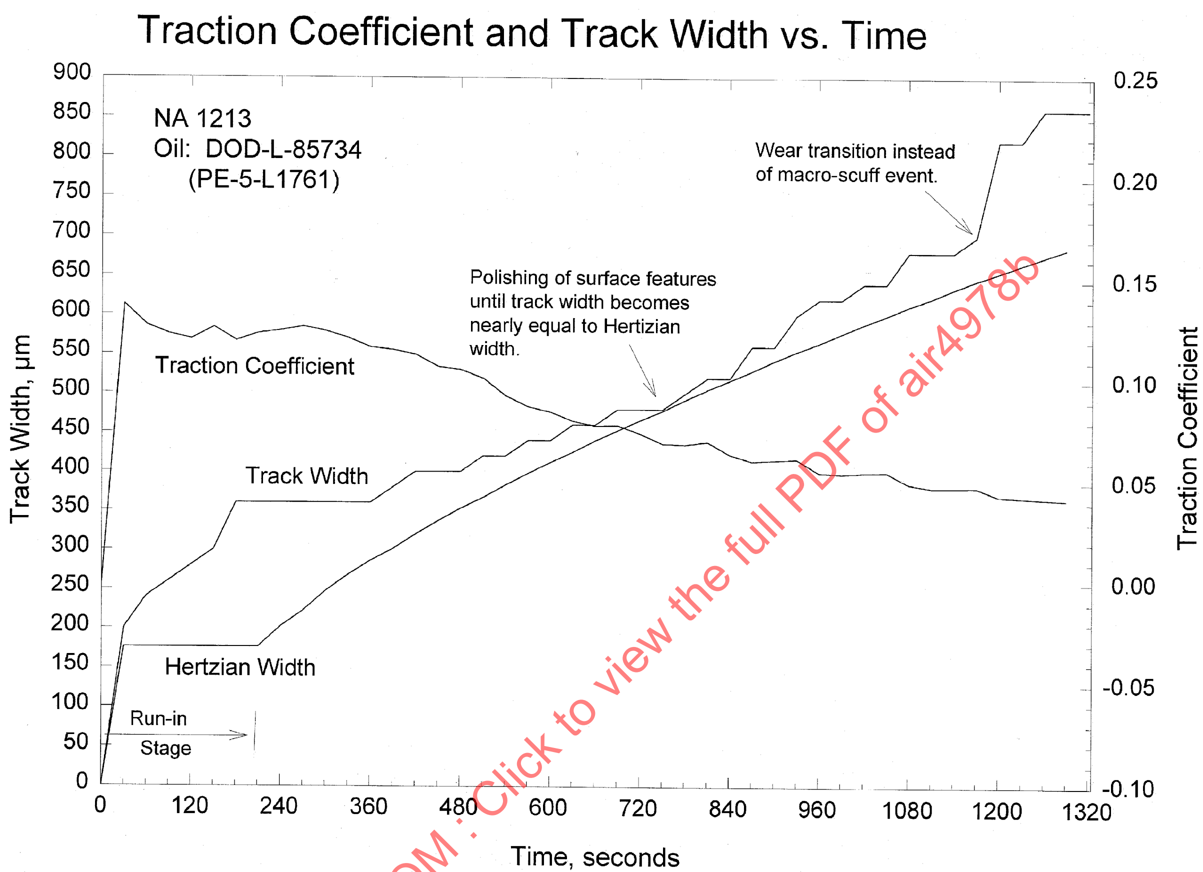


FIGURE D7 - Measurement of Wear Track Width for DOD Oil That Ran to a Test Suspension

APPENDIX E
WAM HIGH SPEED LOAD CAPACITY TEST METHOD

E.1 BACKGROUND:

The Ryder Gear Test Method provides a scuffing or load capacity rating for aviation oils. The load capacity rating is derived from scuffing criteria. Scuffing is one of several surface deterioration mechanisms controlling life and durability of aircraft bearing and gear hardware. Through its use over many years as a qualification test, the Ryder Gear Test Method has developed a large database. The database provides a historical record for oil lubricating performance.

The U.S. Navy has supported efforts on the Wedeven Associates, Inc. test machines, WAM1, WAM3 and WAM4 to provide Ryder-like load capacity data of gas turbine and gearbox oils. These efforts also expand the scope of oil characterization beyond the perspective of a pass/fail or ranking of oils, with scuffing performance the only criteria. To provide a continuity between Ryder Gear load capacity data and future oil characterization methods, a “WAM Economical Load Capacity Screeng Test” was developed to rank a wide range of engine and gearbox oils similar to the Ryder Gear Test Method (see AIR4978, Appendix D). This test method ranks oils with respect to a scuffing failure event. It also characterizes oils with respect to traction (friction) behavior.

The introduction of high thermal stability (HTS) oils, and particularly corrosion inhibited (CI) oils, has highlighted the need for greater testing sensitivity for oils exhibiting lower than average lubricating performance. Low lubricating performance, as evidenced in the Ryder test, reveals itself in the form of a superficial form of scuffing (“micro-scuffing”).

The test protocol described below was developed partially under U.S. Navy PO No. N00421-98-M-6001, June 24, 1998. The test conditions selected highlight the load capacity performance features of oils that are submitted for qualification under the MIL-PRF-23699 specification. Load capacity tests are conducted with ball and disc specimens, which are operated under tribological contact conditions similar to the U.S. Navy Ryder Gear Test Method.

E.2 SCOPE:

The purpose of this test method is to evaluate oils according to the Ryder Gear Test Method, with enhanced sensitivity for lower than average lubricating performance. It is important to recognize that the Ryder Gear performance criteria are based upon the visual observations of “scuffing” damage on Ryder gear teeth. Since some scuffing features found on Ryder gear teeth are superficial, a Ryder-like test method must also invoke the same type of surface deterioration mechanism. Micro-scuffing is a superficial form of scuffing, which is confined to the surface topographical features of the gear teeth. Micro-scuffing is generally associated with surface damage at low load stages where contact stresses are too low to cause “macro” scuffing. Scuffing, or “macro-scuffing”, is associated with the complete loss of surface integrity. Scuffing involves gross failure of near-surface material, in addition to surface roughness features. When traction (friction) is measured, micro-scuffing is generally detected by a rapid decline in traction coefficient. The decline in traction coefficient is associated with the removal of surface roughness features. While this action actually restores some of the EHD fluid film separation between the surfaces, the rapid removal of surface features by plastic flow and rapid polishing wear reflects a failure of the oil to provide adequate surface films for boundary lubrication. In contrast, macro-scuffing is associated with a sudden increase in traction coefficient resulting from massive adhesion and plastic flow of near surface material. A sudden and massive scuffing failure requires high contact stresses in the presence of high sliding velocities.

The observation of traction coefficient during a load capacity test is quite informative. High precision measurements of traction coefficient clearly identify “events” like scuffing and micro-scuffing, as discussed above. Traction behavior also reflects the continual interactive process between oil chemistry and the mating material pair within the contact. Subtle changes in topographical features due to wear are reflected in traction behavior.

WARNING: This test method is a simulation of Ryder Gear Test ranking. The test conditions are carefully selected to make the results correlate with the Ryder Gear Test. While the Ryder Gear Test operating conditions, in terms of rolling/sliding speeds, temperatures and contact kinematics, are representative of helicopter gearbox hardware, slight operational changes are likely to cause different ranking. This is based on WAM load capacity tests conducted over a range of test conditions, which affect EHD film generation and contact temperature. Load capacity tests over a range of conditions are recommended. The conditions selected here are specific to Ryder ranking using a set of five reference oils supplied by the U.S. Navy. In addition, there is no confirmation that scuffing load capacity performance is in any way connected with other prominent life-limiting performance criteria, expressed as surface distress (wear and micro-pitting). Additional tests for surface distress, or a complete simulation of specific hardware, are recommended to supplement scuffing load capacity results.

E.3 APPROACH:

The load capacity test protocol is conducted with a WAM test facility shown in Figure E1. The test machine controls specimen position, contact load and motions of a single contact in space. A computerized run file controls load and contact kinematics between the specimens. Specimen temperatures are recorded with trailing thermocouples. The high-speed test protocol uses AISI 9310 ball and disc specimens with tight specifications for surface finish and hardness. To capture Ryder-like oil performance features, the following test specimen specifications and test conditions have evolved.

Ball	2.0638 cm (13/16 in) dia, AISI 9310, “hard grind” surface roughness, Ra = 0.25 µm (10 µin), hardness HRC 62.5-63.5
Disc	10.16 cm (4 in) dia, AISI 9310, surface finish Ra = 0.15 µm (6 µin), hardness, HRC 62-64
Ball vel.	U_b = 7.21 m/s (284 in/s)
Disc vel.	U_d = 7.21 m/s (284 in/s)
Orientation	Non-collinear velocity vectors (angle between velocity vectors = 75°)
Entraining vel.	5.72 m/s (225 in/s)
Sliding vel.	8.78 m/s (346 in/s)
Load	Exponential increase from 1.8 kg (4 lb) to 63.6 kg (140 lb) in 30 stages
Test duration	Until scuff, or suspension (30 stages = 30 min)
Failure criteria	Scuff defined by loss of surface integrity and sudden increase in traction. Micro-scuff defined by rapid decline in traction coefficient.
Performance	Oil performance is judged by load stages causing micro/macro scuffing event(s) and traction behavior, which reflects wear of surface topography.
Temperature	Specimen temperatures controlled by frictional heating. Surface temperatures increase with load stage from ambient to ~200 °C.
Oil supply	Computer controlled peristaltic pump, approximately 1 drop/s. Oil flow rate is selected for adequate lubrication without significant cooling.

The entraining velocity (U_e) and sliding velocity (U_s) are defined below:

$$U_e = 1/2(U_b + U_d)$$
$$U_s = (U_b - U_d) \quad \text{(Eq. E1)}$$

where:

U_b = surface velocity vector of the ball at the contact point
U_d = surface velocity vector of the disc at the contact point

The entraining velocity (U_e) and sliding velocity (U_s) are key parameters that control the degree of surface separation and the rate of surface tangential shear that the oil must accommodate. With the parameters selected, the initiation of a load capacity test is similar to the Ryder Gear Test in that there is generally little or no evidence of surface damage during the first load stage.