



AEROSPACE RECOMMENDED PRACTICE

ARP6156™

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WAM High Speed Load Capacity Test Method

RATIONALE

ARP6156 serves to document the conditions and procedures required for the user of a WAM ball-on-disc test machine to run a standard protocol scuffing load capacity test. The continuous measurement of the traction coefficient provides insight into the anti-wear and extreme pressure properties of the lubricant. The WAM scuffing load stage is a report item in AS5780 and the measurement method is currently described in the appendix to determine if limits can be assigned for aviation turbine oil qualification. The SAE E-34 committee has made a recommendation for the test method to be documented as recommended practice.

ARP6156 has been reaffirmed to comply with the SAE Five-Year Review policy.

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Documents

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1. SCOPE

The lubricant performance capability for aero propulsion drive systems is derived from the physical properties of the oil and the chemical attributes associated with the oil formulation. All properties, such as viscosity, pressure-viscosity coefficient and full-film traction coefficient are inherent properties of the lubricating fluid. Chemical attributes are critical for the formation of protective boundary lubricating films on the surfaces to prevent wear and scuffing. To assure performance and to provide needed information for engineering design, test methodologies for at least five oil properties or attributes are being addressed: (1) pressure-viscosity coefficient, (2) full-film traction coefficient, (3) scuffing resistance, (4) wear resistance, and (5) micropitting propensity. While viscosity versus temperature data are readily available, the above five properties or attributes must be measured under relevant conditions for aero propulsion hardware systems. This document (ARP6156) describes the test method for scuffing and wear resistance. It should be noted that the test method results are limited to the selected test conditions, which may not be representative of the broad scope of conditions encountered in service.

1.1 Purpose

The purpose of this test method is to provide the scuffing performance of aviation oil formulations under a defined set of engineering parameters and with gear materials (AISI 9310) and surface processing representative of that used in aero propulsion. The test method also provides anti-wear (AW) behavior. Anti-wear is associated with the polishing or wear protection of roughness features similar to what is experienced in critical aviation bearing and gear hardware. The degree of wear experienced by roughness features is reflected in the measured traction (friction) coefficient during a scuffing load capacity test. ARP6156 serves to document the conditions and procedures required for the user of a WAM ball-on-disc test machine to run a standard protocol scuffing load capacity test. The document also serves to support a "modified" test protocol which operates under more severe conditions for high scuffing performance oils. The original test conditions used in the standard protocol were derived from the Ryder Gear Test Method and described in Appendix D of AIR4978 "Temporary Methods for Assessing the Load Carrying Capacity of Aircraft Propulsion System Lubricating Oils". While these test conditions and loading protocol do not actually simulate the Ryder Gear Test, the test conditions and materials have linkage to Ryder Gear and its tribology mechanisms leading to scuffing failures. The continuous measurement of traction coefficient and specimen temperatures that reflect the wear behavior of roughness features throughout the test protocol provide both scientific insight and engineering usefulness. They allow the calculation of the total contact temperature for additive activation and scuffing limit.

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.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR4978	Temporary Methods for Assessing the Load Carrying Capacity of Aircraft Propulsion System Lubricating Oils
AIR5433	Lubricating Characteristics and Typical Properties of Lubricants Used in Aviation Propulsion and Drive Systems
AS5780	Specification for Aero and Aero-Derived Gas Turbine Engine Lubricants

3. APPROACH

The historical challenge to develop a meaningful and yet cost effective test for oil lubricating performance is associated with the large range of lubricated contacts and operating conditions that the oil must serve. The original association of this test method with the Ryder Gear Test Method provides some degree of continuity and linkage to historical data. The Ryder Gear Test Method also represents one of the most severe lubricated contacts that the oil must serve. Five key tribology parameters control the severity of the contact: (1) entraining velocity (U_e); (2) sliding velocity (U_s); (3) elastohydrodynamic (EHD) oil film thickness-to-surface roughness ratio (h/σ); (4) total contact temperature (T_c); and (5) contact stress (both Hertzian stress and qualitative local asperity stress). To further engineering usefulness and to provide scientific insight for the formulator the WAM High Speed Load Capacity Test Method provides continuous measurement of specimen temperatures and traction coefficient. These measurements can be used to calculate the total contact temperature (T_c) for gear scuffing prediction and for additive activation.

A detailed study of the Ryder Gear Test Method revealed general operating conditions from which a test method was derived. The test method was designed to operate within the limits of the original prototype WAM (Wedeven Associates Machine) tribology test equipment. While the test method is not a true simulation of the Ryder Gear Test Method, the physical phenomena driven by stress, temperature and sliding velocity to invoke a scuffing event is similar to the conditions on the Ryder Gear active tooth profile where scuffing is initiated. The test configuration and some of the operating conditions are shown in Figure 1.

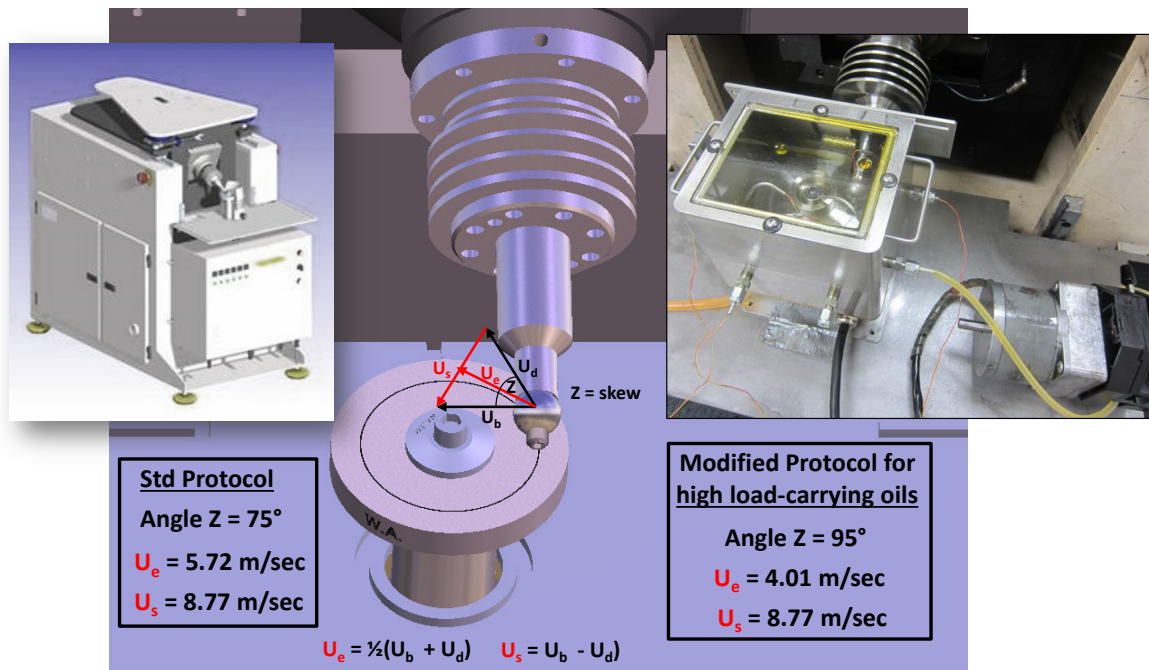


Figure 1 - WAM test machine

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 scuffing and wear test protocol uses AISI 9310 ball and disc specimens with specifications described in Section 4. A detailed test procedure is given in Section 5. The general operating conditions are given below:

Test Conditions:

Ball velocity, $U_b = 7.214$ m/s (284 in/s)

Disc velocity, $U_d = 7.214$ m/s (284 in/s)

Skew = 75° ; skew is the angle between U_b and U_d surface velocity vectors

Entraining velocity, $U_e = 5.723 \text{ m/s}$ (225 in/s), $U_e = 1/2(U_b + U_d)$

Sliding velocity, $U_s = 8.783 \text{ m/s}$ (346 in/s), $U_s = (U_b - U_d)$

Load: Exponential increase from 17.9 N (4 pounds) to 627.2 N (140 pounds) in 30 stages over 1800 seconds. Increase in load is accomplished with a computer controlled script file according to the values in Table 1.

Table 1 - Load capacity test load stages and the corresponding contact stress

Load Stage (#)	Load		Stress	
	lbs	N	ksi	GPa
1	4.0	17.9	106	0.73
2	6.1	27.1	122	0.84
3	7.7	34.5	132	0.91
4	9.4	41.9	141	0.97
5	11.0	49.3	149	1.03
6	13.2	59.1	159	1.10
7	15.4	69.0	167	1.15
8	17.6	78.8	175	1.21
9	19.8	88.7	181	1.25
10	22.6	101.0	190	1.31
11	25.3	113.3	197	1.36
12	28.1	125.7	204	1.41
13	30.8	138.0	210	1.45
14	34.1	152.8	218	1.50
15	37.4	167.6	224	1.54
16	40.7	182.3	231	1.59
17	44.0	197.1	237	1.63
18	47.9	214.4	244	1.68
19	51.7	231.6	250	1.72
20	55.6	248.9	256	1.77
21	59.4	266.1	262	1.81
22	64.4	288.5	269	1.86
23	70.4	315.4	277	1.91
24	77.4	346.8	286	1.97
25	85.4	382.6	295	2.03
26	94.4	422.9	305	2.10
27	104.4	467.7	316	2.18
28	115.4	517.0	327	2.26
29	127.4	570.8	338	2.33
30	140.0	627.2	348	2.40

Test duration: Until a macro-scuffing event or test suspension (no macro-scuffing event). If no macro-scuff occurs, test time is 30 minutes.

Failure criteria: Macro-scuff defined by total loss of surface integrity and sudden increase in traction coefficient or a micro-scuff defined by rapid decline in traction coefficient due to local scuffing or smearing confined to the roughness features.

Performance: Oil performance is judged by the contact stress (or load stage) at which either a macro or micro scuff occurs. To accommodate test specimen or other operating environmental variations, scuffing performance can also be given relative to a reference oil. Additionally, traction coefficient behavior, which reflects wear of roughness features, is used to characterize anti-wear performance.

Temperature: The test method allows specimen temperatures to be driven by frictional heating. Surface temperatures increase with load stage from ambient to approximately 200 °C. Specimens are required to be at room temperature (23 to 27 °C) before the start of a test.

Oil supply: Computer controlled peristaltic pump, 15 mL/min. Oil flow rate is selected for adequate lubrication without significant cooling. The oil is wetted and distributed across the disc surface from a central oil slinger. The test oil is not recirculated.

Variables recorded during a test include the following:

Ball and disc temperatures
Traction coefficient
Ball and disc surface velocities
Contact load
Time

4. SPECIMEN SPECIFICATIONS

4.1 Ball Specification

- 4.1.1 Material: Carburized case hardened AISI 9310, AMS6265
- 4.1.2 Diameter: 20.64 mm (0.8125 inch)
- 4.1.3 ABMA Grade: 10 or better (for geometry)
- 4.1.4 Through-Hole: 6.48 mm (0.255 inch)
- 4.1.5 Case Depth: 0.762 to 1.02 mm (0.030 to 0.040 inch); 58 HRC at approximately 1.0 mm from surface
- 4.1.6 Hardness: Case hardened surface to be 63 HRC $\pm$ 1 HRC
- 4.1.7 Roughness: Ra = 0.274 micrometer $\pm$ 0.025 micrometer (11 microinches $\pm$ 1 microinch); "Hard Grind" isotropic finish
- 4.1.8 0.2 mm (0.008 inch) material removal for final grind after heat treatment
- 4.1.9 Regrinding is not permissible
- 4.1.10 Storage and Handling
 - 4.1.10.1 Ball specimen for test should be handled with clean gloves in a work zone free of contaminants that could contaminate or corrode the specimen surface.
 - 4.1.10.2 When not in use, ball specimen is to be coated with a rust preventative oil such as Ferrocote® 5856 BF T1 and stored in a sealed plastic bag.

4.2 Disc Specification

- 4.2.1 Material: Carburized case hardened AISI 9310, AMS6265; double vacuum melt (VIM VAR) per OEM spec; grain size 5 or finer
- 4.2.2 Diameter: 102 mm (4.0 inches)
- 4.2.3 Thickness: 12.7 mm (0.50 inch) nominal
- 4.2.4 Through-Hole: 19.05 mm (0.750 inch $\pm$ 0.0005 inch), perpendicular to either face 0.0005 inch; concentricity 0.001 inch
- 4.2.5 Parallelism of Faces: 0.0002 inch
- 4.2.6 Flatness: 0.0002 inch
- 4.2.7 Case Depth: 0.762 to 1.02 mm (0.030 to 0.040 inch); 58 HRC at approximately 1.0 mm from surface
- 4.2.8 Hardness: Case hardened surface to be HRC 63 $\pm$ 1