

**BALL-ON-CYLINDER (BOC)
AIRCRAFT TURBINE FUEL LUBRICITY TESTER**

1. SCOPE:

- 1.1 This metric Aerospace Information Report (AIR) details a ball-on-cylinder (BOC) test device and specifies a method of rating the relative lubricity of aviation turbine fuel samples. The BOC produces a wear scar on a stationary steel ball by forcing it with a fixed load against a fuel wetted steel test ring in a controlled atmosphere. The test ring is rotated at a fixed speed so its surface is wetted by a momentary exposure to the fluid under test. The size of the wear scar is a measure of the test fluid lubricity and provides a basis for predicting friction or wear problems.

This ARP is intended as a guide toward a standard practice, but may be subject to frequent change reflecting experience and technical advances. Use of this AIR is not recommended where flexibility of revision is impractical. Anyone interested in current information on BOC developments and technology should contact the Coordinating Research Council (CRC) Aviation Group on Aviation Fuel Lubricity.

1.2 Field of Application:

To rate the lubricity of turbine fuels for the low lubricity pump endurance test or to determine fuel lubricity.

NOTE: This document, SAE ARP1797, and AIR4027 are complementary documents on the subject of aircraft turbine fuel low lubricity.)

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1.3 Background:

In recent years an increasing amount of lower grade crude oil has been used in the production of aircraft turbine fuel. Hydrogen refining techniques remove the sulfur and polar constituents of the crude oil. Some high quality hydro-refined fuel products have very poor lubricating properties. These low lubricity fuels have caused friction and wear problems in aircraft components. The BOC tester will be increasingly essential to monitor fuel lubricity for fuel system component development tests, production screening tests and field use.

2. REFERENCES:

2.1 Applicable Documents:

Related SAE Documents:

ARP1797 Aircraft and Aircraft Engine Fuel Pump Low Lubricity
Fluid Endurance Test
AIR4027 Aircraft Turbine Engine Fuel Low Lubricity Information
Report
SAE 8720 Steel

The following documents form a part of this AIR:

MIL-I-25017 Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble
ASTM D 329 Acetone
ASTM D 770 Isopropyl Alcohol
ASTM D 1016 Iso-octane
ASTM D 4306 Practice for Sampling Aviation Fuel for Tests Affected by
Trace Contamination
ANSI B3.12 Metal Balls
AISI E52100 Chromium Alloy Steel

2.2 Definitions, Symbols, and Abbreviations:

LUBRICITY: Property of the fluid, measured by the wear scar in millimeters, produced on a stationary ball from contact with the fuel wetted rotating cylinder operating under closely controlled conditions.

CYLINDER: Falex ring and mandrel assembly.

BOC: Common acronym for versions of the Fuery ball-on-cylinder machine, is also known as BOCM, BOCLE (ball-on-cylinder lubricity evaluator) and more recently BORLE (ball-on-ring lubricity evaluator).

RH: Relative humidity of air.

WSD: Wear scar "diameter," in millimeters, which is the dimensional average of the major and minor axes of the ball wear scar ellipse.

WEAR TRACK: The width of the wear mark in millimeters on the test ring.

SAE AIR1794**3. TEST REQUIREMENTS:****3.1 Apparatus:**

(Reference Figures 1 and 2.)

3.1.1 Ball-On-Cylinder Fuel Lubricity Tester: The BOC fuel lubricity tester is shown in Figures 1 and 2. The original BOC tester was designed by Exxon Research and Engineering Company of Linden, NJ. It was based on the "Fuery Ball-On-Cylinder Test Machine". A derivative of the Exxon design was made by Woodward Governor Company, Aircraft Engineering Department, Rockford, IL. This version beefed up the ball vise, the beam and support, eliminated a problem ridden "friction" measuring feature, provided spring-loaded bearings and larger diameter mandrel axle. A number of BOC testers have been made from nonproprietary Woodward drawings. A version of this design is commercially available in a complete system as p/n BOC-100 from Inter-Av, San Antonio, TX. A recent configuration change has been the adoption of a case hardened steel test ring on a mandrel in place of the test "cylinder". This change has been made to provide better accuracy and repeatability.

3.1.2 Constant Temperature Control: The temperature of flowing water through the BOC reservoir base shall be $25^{\circ}\text{C} \pm 1$.

3.1.3 Hygrometer: The hygrometer shall be capable of measuring the RH of purge air to $\pm 0.2\%$ at a flow rate of $0.03 \text{ m}^3/\text{h}$ to $0.22 \text{ m}^3/\text{h}$.

3.1.4 Microscope: The microscope shall have a capability up to 100X with an ocular containing a scaled reticule 0 to 1 mm in graduations of 0.1 and 0.01 mm or cross hairs and a mechanical stage with the same resolution.

3.1.5 Ultrasonic Cleaner: There shall be an ultrasonic cleaner with a timer and a minimum 2 L stainless steel tank.

3.1.6 Frequency (Speed) Counter: The frequency counter shall be capable of reading $\pm 1 \text{ Hz}$ (rpm).

3.2 Materials:

3.2.1 Test Ball: The test ball shall conform to ANSI specification B3.12:

Material - RB 12.7 AISI E52100 chrome alloy steel

Diameter - $12.7 \text{ mm} \pm 0.0127$

Grade - 5 to 10 EP (extra polish) finish. Note: This is not in ANSI specification

Hardness - 64 to 66 Rc. Note: This recommendation is not in ANSI specification

3.2.2 Test Rings: Test rings shall conform to the following:

Material - SAE 8720 Modified steel

Size - 49.10 to 49.25 mm diameter, 13.00 to 13.11 mm wide

Hardness - 58 to 62 Rc

Finish - $0.56 \text{ to } 0.71 \text{ } \mu\text{m}$ (22 to 28 μin) CLA

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3.2.3 Compressed Air: The compressed air shall contain less than 0.1 ppm hydrocarbons and 50 ppm water.

3.2.4 Acetone: The acetone shall conform to ASTM D 329.

CAUTION: Acetone is extremely flammable.

3.2.5 Iso-octane: The iso-octane shall be 2,2,4 trimethylpentane, conforming to ASTM D 1016, 95% purity minimum.

CAUTION: Iso-octane is extremely flammable.

3.2.6 Isopropyl Alcohol: The isopropyl alcohol shall conform to ASTM D 770.

CAUTION: Isopropyl alcohol is flammable.

3.2.7 Reference Fluid A: Reference fluid A shall be ISO Par M[®] and 30 ppm by weight of DCI-4A corrosion inhibitor.

3.2.8 Reference Fluid B: Reference fluid B shall be 100% ISO Par M[®].

3.3 Precautions:

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

3.4 Sample Test Units:

Suggested minimum fluid samples are 1 L for this testing. This will provide adequate sample reserve for retests if required to verify repeatability. Reference ASTM D 4306.

3.5 Preparation of Apparatus:

3.5.1 Identification of Test Rings and Balls: Test rings should be numbered consecutively. The number should appear on the wide side of the test ring and should be permanent. Track numbers should start at the end opposite the mandrel set screw. Balls shall be numbered and recorded along with the test ring and wear track number on the test data sheet. Used test balls may be stored in plastic bags.

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3.5.2 Cleaning Procedures:

CAUTION: Great care must be taken to adhere strictly to cleanliness requirements and to these cleaning procedures.

Contaminants containing surface active agents (soaps, oils) may not have any measurable effect on a good fuel but can make a really bad fuel look good. After cleaning, parts of the device must be protected from contamination by the operator wearing clean, lint-free throwaway cotton gloves. Use only the specified ASTM solvents for cleaning parts to aid in eliminating contamination problems. Protect the surfaces of the balls and test rings to prevent scratches or other damage even though they are extremely hard. Hardware, i.e., shaft, wrenches, tweezers, etc., that come into contact with test fluid shall be cleaned by washing with iso-octane and wiping with wiping tissue. Store parts in desiccator when not in use.

3.5.2.1 Test Rings - Initial Cleanup: Test rings received from the supplier are coated with a film of preservative to prevent corrosion. Prior to use, this film must be completely removed using the following:

- a. Remove test rings from their protective covers. Place them in a clean 500 cc beaker. Cover them with a 50/50% volume mixture of iso-octane and isopropyl alcohol.
- b. Place the beaker in the ultrasonic cleaner, turn it on, and clean for 15 min. Test rings should be turned over several times. Remove the test rings and repeat the cycle using a clean beaker and fresh solvent mixture. At the end of the second cycle, remove the test rings from beaker, rinse with acetone, dry with clean compressed air, visually inspect, and store in desiccator.

3.5.2.2 Balls - Initial Cleanup: The initial cleaning of balls shall be according to the following:

- a. Remove a 5-day supply of balls from their storage container.
- b. Place them in a clean 500 cc beaker. Cover balls with a 50/50% volume mixture of iso-octane and isopropyl alcohol.
- c. Place the beaker in ultrasonic cleaner, turn it on, and clean for 15 min. Remove the balls and repeat the cycle using a clean beaker and fresh solvent mixture. At the end of the second cycle, remove the balls from beaker, rinse with acetone, dry with clean compressed air, visually inspect and store in desiccator.

SAE AIR1794**3.5.2.3 Reservoir, Reservoir Cover, Test Ring, Mandrel, Ball Chuck, Ball Lock Ring:**

- a. After completion of each test run, pour the used test fluid from the reservoir into a waste container.
- b. Remove reservoir, test ring, and mandrel.
- c. Disassemble components and clean in an ultrasonic cleaner using a 1 to 1 mixture of iso-octane and isopropyl alcohol for 5 min. Rinse with iso-octane. Dry. Rinse with acetone.
- d. Reassemble components.
- e. Dry and store in a desiccator.

3.6 Calibration With Standard Reference Fluids:

A calibration is recommended at least weekly during activity or whenever a new test ring is installed.

3.6.1 Reference Fluid A: A mixture of ISO Par M[®] and 30 ppm by weight of DCI-4A corrosion inhibitor (see appendix) shall be used for calibration and standardization of the BOC apparatus. This mixture should produce a wear scar of $0.57 \text{ mm} \pm 0.04$ with 10% RH purge air.

3.6.2 Reference Fluid B: Shall consist of 100% ISO Par M[®], a narrow cut isoparaffinic solvent (see Appendix A) shall be used for calibration and standardization of the BOC apparatus. This fluid should produce a wear scar of $0.85 \text{ mm} \pm 0.04$ with 10% RH purge air.

3.7 Conditioning - Control of Purge Air RH:

The water content or RH of a fuel sample has an effect on the WSD generated on the ball during a test. The RH of a fuel sample during testing is determined by the RH of the purge air bubbled through the fluid during conditioning. After conditioning is completed, this flow is redirected to cover the sample during the actual test run. RH of the purge air should be monitored by a precision hygrometer and controlled by mixing wet and dry air.

WARNING: A humidity level of 10% has been selected for classification of fuel for the SAE ARP1797 low lubricity fuel pump endurance test. The use of other humidity levels for endurance fuel classification may result in the endurance fuel being significantly different in lubricity than the requirements were intended to provide.

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3.8 Procedure:

Summary of operating conditions for BOC lubricity tester:

Ball load	1000 g normal load (500 g arm load)
Test ring speed	240 rpm $\pm$ 1
Test duration	30 min $\pm$ 1
Fuel volume	50 cc $\pm$ 1 (fuel should not contact the drive shaft)
Fuel temperature	25°C $\pm$ 1
Supply air	Should contain less than 0.1 PPM hydrocarbons and 50 ppm water
Purge air	RH = 10% $\pm$ 0.2 (see 3.7)
Pretreatment of fuel in reservoir	Bubble 0.5 L/min (0.03 m ³ /h) for 30 min
Purge air during test	Flow 3.8 L/min (0.23 m ³ /h) over fuel sample

- 3.8.1 After completion of the cleaning procedures, locate the test ball in the retainer ring, install them in the ball chuck, and lock in place. Position the balance arm so the test ball will be out of contact with the assembled test ring.
- 3.8.2 Assemble the mandrel with test ring on the shaft and, using the micrometer, position the mandrel and test ring 1.0 mm from the previous wear track, or if starting new, the edge of the test ring. Back the micrometer away from the mandrel. Check the balance arm level position and adjust it as required. (Make sure the four spring washers on the shaft are assembled in the () () position and the set screws are tightened on the flats of the shaft.)
- 3.8.3 Install the reservoir, fill it with test fuel obtained in accordance with ASTM D 4306, and start the purge air through the fuel. Start the motor and adjust the speed to 240 rpm. Continue this pretreatment for 30 min.
- 3.8.4 Switch the purge air so that it flows across the top of the fuel sample while leaving the motor running. Verify that the fuel temperature and humidity are correct.
- 3.8.5 Attach the 500 g weight to the balance arm (produces 1000 g loading at the ball contact point), carefully lower the arm so the ball contacts the test ring. Start the timer and fill out entries in the test log sheet.

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- 3.8.6 Continue the test for 30 min. Carefully lift the balance arm, and remove the weight. Shut off the motor, remove the reservoir cover, and the test ball.
- 3.8.7 Remove the reservoir and dispose of the used fuel into a waste container. Clean the equipment for the next run.
- 3.8.8 Remove the ball and retaining ring as a unit.

4. TEST RESULTS:

4.1 Calculation - Measurement of WSD:

- 4.1.1 With the test ball still in the retainer ring, position the ball under the microscope at 100X, turn on lighting, and focus on the ball surface at wear scar.
- 4.1.2 Adjust the long-wear axis parallel to one reticule cross line. Read reticule scale or using the mechanical controls measure the major and minor axes of the wear scar. If the wear scar has an irregular shape, estimate a superimposed ellipse, and record dimensions.
- 4.1.3 The reported WSD of each sample is the average in millimeters of the major and minor axes of the wear scar. $WSD = (\text{major axis} + \text{minor axis}) / 2$.

5. REPORT:

A report data sheet shall be used to record pertinent test data. Precise record keeping of test conditions is very important to accurately interpret test results. Recorded data as a minimum shall include: date, test ring number, wear track number, ball number, fuel type, source, test load, fuel temperature, % RH, dimensions of wear scar axes, and calculated WSD.

The change to a case hardened test ring has resulted in a significant increase in WSD for a given fuel. A fuel that produced a WSD of about 0.60 mm with the AIR1794 "cylinder" produces about 0.80 to 0.95 mm WSD with the AIR1794A Falex test ring. See the WSD comparison (Figure 3) included at the end of this document. Results obtained with the cylinder were subject to an undesirable lack of repeatability, therefore, Figure 3 should be regarded for historical reference only. Figure 3 represents data available (summer 88) and is subject to change. Revision "A" of ARP1797 will also contain a larger test ball WSD requirement.

PREPARED BY SUBCOMMITTEE AE-5B, AIRCRAFT ENGINE FUEL SYSTEMS
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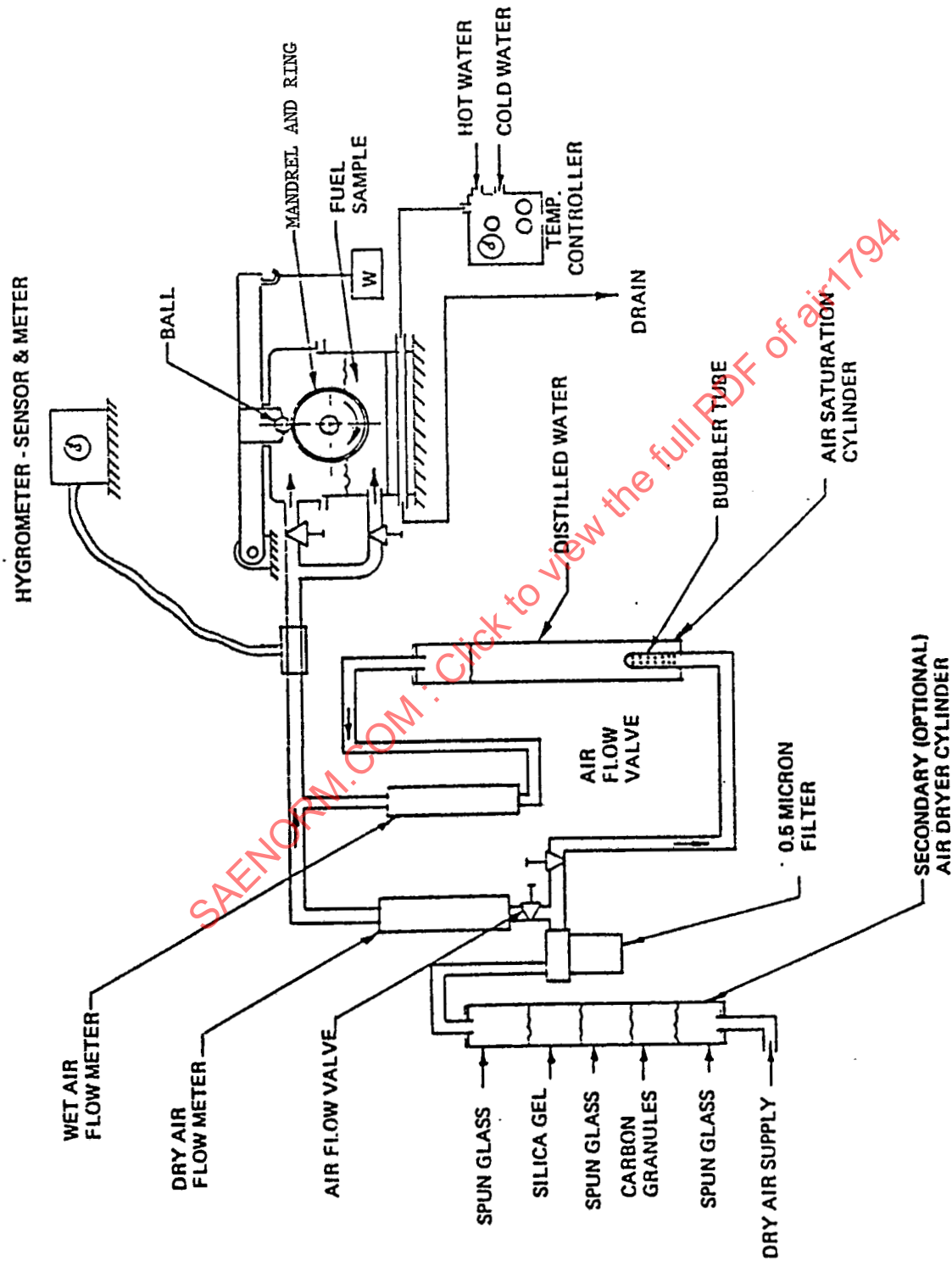


FIGURE 1 - Schematic - Ball-On-Cylinder Lubricity Tester