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Standard Test Method for Evaluation of Load-Carrying Capacity of Lubricants Under Conditions of Low Speed and High Torque Used for Final Hypoid Drive Axles¹

This standard is issued under the fixed designation D6121; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method is written for use by laboratories that use the portions of the test method that refer to ASTM Test Monitoring Center (TMC) services (see [Annex A1 – Annex A4](#)). Laboratories that choose not to use the TMC services may simply disregard these portions.

The TMC provides reference oils, and engineering and statistical services to laboratories that desire to produce test results that are statistically similar to those produced by laboratories previously calibrated by the TMC.

In general, the Test Purchaser decides if a calibrated test stand is to be used. Organizations such as the American Chemistry Council require that a laboratory utilize the TMC services as part of their test registration process. In addition, the American Petroleum Institute and the Gear Lubricant Review Committee of the Lubricant Review Institute (SAE International) require that a laboratory use the TMC services in seeking qualification of oils against their specifications.

NOTE 1—The advantage of using the TMC services to calibrate test stands is that the test laboratory (and hence the Test Purchaser) has an assurance that the test stand was operating at the proper level of test severity. It should also be borne in mind that results obtained in a non calibrated test stand may not be the same as those obtained in a test stand participating in the ASTM TMC services process.

1. Scope*

1.1 This test method is commonly referred to as the L-37 test.² This test method covers a test procedure for evaluating the load-carrying, wear, and extreme pressure properties of a gear lubricant in a hypoid axle under conditions of low-speed, high-torque operation.

1.2 This test method also provides for the running of the low axle temperature (Canadian) L-37 test. The procedure for the

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.B0.03 on Automotive Gear Lubricants & Fluids.

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² Until the next revision of this test method, the ASTM Test Monitoring Center (TMC) will update changes in this test method by means of Information Letters. This edition includes all Information Letters through No. 16–1. Information Letters may be obtained from the ASTM Test Monitoring Center, 6555 Penn Ave, Pittsburgh, PA 15206, Attn: Administrator. The TMC is also the source of reference oils.

low axle temperature (Canadian) L-37 test is identical to the standard L-37 test with the exceptions of the items specifically listed in [Annex A9](#). The procedure modifications listed in [Annex A9](#) refer to the corresponding section of the standard L-37 test method.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3.1 *Exceptions*—In [Table A12.1](#), the values stated in SI units are to be regarded as standard. Also, no SI unit is provided where there is not a direct SI equivalent.

1.4 *This standard does not purport to address all of the safety concerns, if any, 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.* Specific warning information is given in Sections 4 and 7.

*A Summary of Changes section appears at the end of this standard

2. Referenced Documents

2.1 *ASTM Standards*:³

D235 Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2 *Military Specification*:⁴

MIL-PRF-2105E Lubricating Oil, Gear, Multipurpose

2.3 *AGMA National Standard*:⁵

Nomenclature of Gear Tooth Failure Modes

2.4 *SAE Standard*:⁶

SAE J308 Information Report on Axle and Manual Transmission Lubricants

SAE J2360 Lubricating Oil, Gear Multipurpose (Metric) Military Use

3. Terminology

3.1 *Definitions of Terms Specific to This Standard*:

3.1.1 *abrasive wear, n—on ring and pinion gears*, removal of material from the operating surface of the gear caused by lapping of mating surfaces by fine particles suspended in lubricant, fuel, or air or imbedded in a surface.

ASTM Distress Rating Manual No. 21⁷

3.1.2 *adhesive wear, n—on ring and pinion gears*, removal of material from the operating surface of the gear caused by shearing of junctions formed between operating surfaces in direct metal-to-metal contact; sheared-off particles either remain affixed to the harder of the mating surfaces or act as wear particles between the surfaces.

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3.1.3 *broken gear tooth, n—*a gear tooth where a portion of the tooth face is missing and the missing material includes some part of the top land, toe, heel, or coast side of the tooth.

3.1.3.1 *Discussion*—This condition is distinct from and more extensive than “chipping,” which is defined in 3.1.5.

3.1.4 *burnish, n—on ring and pinion gears*, an alteration of the original manufactured surface to a dull or brightly polished condition.

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3.1.5 *chipping, n—on ring and pinion gears*, a condition caused in the manufacturing process in which a small irregular cavity is present only at the face/crown edge interface. The edge-chipping phenomenon occurs when sufficient fatigue cycles accumulate after tooth surface wear relieves the compressive residual stress on the tooth profile side of the profile-to-topland interface. Chipping within 1 mm of the

face/crown edge interface is to be called chipping, not pitting/spalling. **ASTM Distress Rating Manual No. 21**

3.1.6 *corrosion, n—in final drive axles*, a general alteration of the finished surfaces of bearings or gears by discoloration, accompanied by roughening not attributable to mechanical action. **ASTM Distress Rating Manual No. 21**

3.1.7 *cracked gear tooth, n—*a gear tooth exhibiting a linear fracture of the tooth surface.

3.1.8 *deposits, n—in final drive axles*, material of pasty, gummy, or brittle nature adhering to or collecting around any of the working parts.

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3.1.9 *discoloration, n—on ring and pinion gears*, any alteration in the normal color of finished steel surfaces.

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3.1.10 *pitting, n—on ring and pinion gears*, small irregular cavities in the tooth surface, resulting from the breaking out of small areas of surface metal.

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3.1.11 *ridging, n—on ring and pinion gears*, an alteration of the tooth surface to give a series of parallel raised and polished ridges running diagonally in the direction of sliding motion, either partially or completely across the tooth surfaces of gears.

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3.1.12 *rippling, n—on ring and pinion gears*, an alteration of the tooth surface to give an appearance of a more or less regular pattern resembling ripples on water or fish scales.

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3.1.13 *scoring, n—on ring and pinion gears*, the rapid removal of metal from the tooth surfaces caused by the tearing out of small contacting particles that have welded together as a result of metal-to-metal contact. The scored surface is characterized by a matte or dull finish.

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3.1.14 *scratching, n—on ring and pinion gears*, an alteration of the tooth surface in the form of irregular scratches, of random length, across the tooth surface in the direction of sliding of the surfaces.

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3.1.15 *spalling, n—on ring and pinion gears*, the breaking out of flakes of irregular area of the tooth surface, a condition more extensive than pitting.

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3.1.16 *surface fatigue, n—on ring and pinion gears*, the failure of the ring gear and pinion material as a result of repeated surface or subsurface stresses that are beyond the endurance limit of the material. It is characterized by the removal of metal and the formation of cavities.

AGMA National Standard

3.1.17 *wear, n—on ring and pinion gears*, the removal of metal, without evidence of surface fatigue or adhesive wear, resulting in partial or complete elimination of tool or grinding marks or development of a discernible shoulder ridge at the bottom of the contact area near the root or at the toe or heel end

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁴ Available from Standardization Documents Order Desk, Bldg 4, Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5098.

⁵ American Gear Manufacturers Assn. (AGMA), 1500 King St., Suite 201, Alexandria, VA 22314.

⁶ Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, <http://www.sae.org>.

⁷ Formerly known as CRC Manual 21. Available from the ASTM website, www.astm.org, (TMCML21).

of pinion tooth contact area (abrasive wear).

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4. Summary of Test Method

4.1 Prior to each test run, inspect the test unit (final axle assembly) and measure and record confirming manufacturing specifications.

4.2 Begin the test when the axle assembly is installed on the test stand and charged with test lubricant.

4.3 *Gear Conditioning Phase*—Run the charged test unit for 100 min at 440 wheel r/min and 395 lbf-ft (535 N·m) torque per wheel, maintaining an axle sump temperature of 297°F (147 °C). (**Warning**—High-speed rotating equipment, electrical shock, high-temperature surfaces.)

4.4 *Gear Test Phase*—Next, run the test unit for 24 h at the operating conditions dictated by the hardware batch and type combination (see 10.2.3.1).

4.5 The test is completed at the end of the gear test phase. Visually inspect the test parts.

4.5.1 Remove the ring gear, pinion, and pinion bearing, and rate for various forms of distress. Use the condition of the ring gear and pinion to evaluate the performance of the test oil.

5. Significance and Use

5.1 This test method measures a lubricant’s ability to protect final drive axles from abrasive wear, adhesive wear, plastic deformation, and surface fatigue when subjected to low-speed, high-torque conditions. Lack of protection can lead to premature gear or bearing failure, or both.

5.2 This test method is used, or referred to, in the following documents:

5.2.1 American Petroleum Institute (API) Publication 1560.⁸

5.2.2 STP-512A.⁹

5.2.3 SAE J308.

5.2.4 Military Specification MIL-PRF-2105E.

5.2.5 SAE J2360.

6. Apparatus

6.1 *Test Unit*—The test unit is a new complete hypoid truck axle assembly less axle shafts, Dana Model 60, 5.86 to 1 ratio.¹⁰ See **Annex A9** for part numbers.

6.2 *Test Stand and Laboratory Equipment:*

6.2.1 *Axle Vent*—Vent the axle to the atmosphere throughout the entire test and arrange the vent so that no water enters the housing.

⁸ “Lubricant Service Designations for Automotive Manual Transmissions, Manual Transaxles, and Axles,” available from American Petroleum Institute, 1220 L St. NW, Washington, DC 20005.

⁹ “Laboratory Performance Tests for Automotive Gear Lubricants Intended for API GL-5 Service.”

¹⁰ The sole source of supply of the apparatus known to the committee at this time is Dana Corp., P.O. Box 2424, Fort Wayne, IN 46801. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

6.2.2 *Axle Cover*—The axle cover may have a port installed to allow for ring gear inspection after the gear condition phase (see 10.1). See **Fig. A5.1** for an example.

6.2.3 *Test Stand Configuration*—Mount the complete assembly in a rigid fixture as shown in **Fig. A6.1**. Mount the test unit in the test stand with pinion and axle shaft centerlines horizontal.

6.2.4 *Temperature Control*—The test axle housing shall include a means of maintaining the lubricant at a specified temperature. This shall include a thermocouple, a temperature recording system, and a cooling method.

6.2.4.1 *Thermocouple*—Determine the thermocouple location on the rear cover using the cover plate temperature sensor locating device as shown in **Fig. A7.1**.

(1) Install the thermocouple such that the thermocouple tip is flush with the cover plate lip by placing the cover plate face on a flat surface and inserting the thermocouple into the cover plate until the thermocouple tip is flush with the flat surface.

(2) Lock the thermocouple into place.

6.2.4.2 *Temperature Recording System*—The temperature recording system shall record the temperature of the test oil throughout the test.

6.2.4.3 *Axle Cooling*—Use three spray nozzles to distribute water over the cover plate and axle housing as shown in **Fig. A8.1**. Actuate the water control valve by the temperature PID control system. See **A9.3.2.1** for L-37 Canadian Version test.

(1) Spray nozzles¹¹ shall be any combination of the following part numbers depending on how the system is plumbed: Straight Male NPT (Part No. 3/8GG-SS22), 90° Male NPT (Part No. 3/8GGA-SS22), Straight Female NPT (Part No. 3/8G-SS22), and 90° Female NPT (Part No. 3/8GA-SS22).

(2) Use a single control valve to control the cooling water supply. The control shall be a ½ in. (12.7 mm) two-way, C linear trim, air to close, Research Control valve. Use a single PID loop to maintain the axle lubricant temperature control for both the Standard and Canadian version test. A separate PID loop control for each version is not permitted. See **A9.3.2.2** for L-37 Canadian Version test.

(3) Use only ⅜ or ½ in. (9.5 mm or 12.7 mm) line material to the spray nozzles.

(4) Use a minimum supply water pressure of 25 psi (172 kPa) to the control valve.

(5) Use an axle box cover as shown in **Fig. A8.2**. The purpose is to contain water and eliminate drafts.

(6) Use a locating pin or stop block as an indexing device to ensure that all subsequent axle installations are consistently installed perpendicular with the axle housing cover to engine and transmission driveshaft centerline.

6.2.5 *Power Source*—The power source consists of a gasoline-powered V-8 engine capable of maintaining test conditions.

¹¹ The sole source of supply of the apparatus known to the committee at this time is Spray Systems Company, and the spray nozzles can be purchased through E.I. Pfaff Company, 3443 Edwards Road, Suite D, Cincinnati, OH 45208. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

6.2.6 *Dynamometers and Torque Control System*—Use two axle dynamometers with sufficient torque absorbing capacity to maintain axle torque and speed conditions. Suitable control equipment with sensitivity of adjustment to permit maintenance of test conditions is required.

6.2.7 *Dynamometer Connecting Shafts*—Fabricate shafts connecting the dynamometer to the axle shafts. Shafts shall be strong enough to handle the torques encountered and shall be dynamically (spin) balanced.

6.2.8 *Drive Shaft and Universal Joints*—Fabricate a shaft with universal joints connecting the manual transmission and test axle. The shaft shall have a 4 in. \pm 0.2 in. (10.1 cm \pm 0.51 cm) outside diameter with a 0.095 in. \pm 0.005 in. (0.24 cm \pm 0.013 cm) wall thickness. Shaft and universal joints should be strong enough to handle the torques encountered and shall be dynamically (spin) balanced.

6.2.9 *Transmission and Coupling*—Couple the engine to the test unit through a clutch and manual transmission of sufficient torque carrying capacity to operate normally under test conditions.

6.3 *Speed Measuring and Control System*, capable of measuring speed of both axles and also of maintaining test conditions.

7. Reagents and Materials

7.1 *Sealing Compound*, where necessary, Permatex No. 2, or equivalent.

7.2 *Solvent*—Use only mineral spirits meeting the requirements of Specification **D235**, Type II, Class C for Aromatic Content (0 % to 2 % vol), Flash Point (142 °F/61 °C, min) and Color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). (**Warning**—Combustible. Health hazard.) Obtain a Certificate of Analysis for each batch of solvent from the supplier.

8. Preparation of Apparatus

8.1 *Cleaning of Reusable Hardware*—Clean as necessary all reusable parts including axle shafts, thermocouples, axle housing cover, and all associated drain pans and funnels used for the addition of and collection of test oil.

8.2 Lab-built Axles:

8.2.1 To be approved to build axles acceptable for testing,

(1) obtain a separate approval for each of the two hardware types (lubrited and non-lubrited). Approval may be obtained for both hardware types or either hardware type independently;

(2) assemble three axles in accordance with subsection 8.4 using a new V1L528/P4T883A pinion and ring set. Run these axles in tests using a blind mix of the following TMC-assigned oils: one TMC 152-2 and two TMC 134's.

8.2.1.1 If all three of these tests are operationally valid and the 152-2 run meets the LTMS acceptance criteria for V1L528 hardware and both 134 run pinion results fail SAE J2360 acceptance criteria, the builder is approved to build axles for testing and the test stand is calibrated for the period described in 9.1.

8.2.1.2 If only the TMC 152-2 does not meet the LTMS acceptance criteria, rerun one TMC 152-2 fluid. If the repeat run meets LTMS acceptance criteria, the builder is approved to

build axles for testing and the test stand is calibrated for the period described in 9.1.

8.2.1.3 If only one of the two TMC 134 pinion results does not fail SAE J2360 acceptance criteria, rerun two consecutive TMC 134's. If the pinion results for both repeats fail SAE J2360 acceptance criteria, the builder is approved to build axles for testing and the test stand is calibrated for the period described in 9.1.

8.2.1.4 If two of the three tests do not meet their designated acceptance criteria, or the required repeats described in 8.2.1.2 or 8.2.1.3 do not meet the designated acceptance criteria, repeat 8.2.1.

8.3 *Serial Number Reporting*—When rebuilding an axle assembly, follow this template for creating a serial number: LAB-CXXXX-NN

where:

- LAB designates the assembly as being lab-built
- C is the one-character TMC coded lab designation
- XXXX is a unique 4-digit identifier for the housing
- NN is a 2-digit count of the number of rebuilds on the housing

8.3.1 Permanently mark the serial number into the axle tube at a location near the housing vent. Revise the 2-digit rebuild count number each time the assembly is rebuilt.

8.4 Preparation of Axle:

8.4.1 Use either a newly manufactured axle assembly or, if the lab-built provisions of 8.2 have been met, a new V1L528/P4T883A gear set assembled into a reused axle housing according to the Dana Model 60 Maintenance Manual and using components from the Dana rebuild parts list given in **Annex A9, Table A9.2**.

8.4.2 When using an axle assembly rebuilt per 8.4.1 or an assembly from an older approved hardware batch that was not marked with contact pattern information by the manufacturer, apply gear contact pattern grease on the drive and coast side of the ring gear. Turn the input of the axle assembly while applying a resisting force to the ring sufficient to require an axle input torque of approximately 30 lbf-ft (40.7 N-m). Rotate ring and pinion through the gear contact pattern grease on the drive and coast side and verify that the patterns for both sides are acceptable. Record the drive side contact pattern length and flank values in the test report. Include drive side pattern photos of the ring gear in the test report.

8.4.3 If the axle assembly is a newly manufactured assembly received from Dana Corporation,¹⁰ the drive side contact pattern length and flank values will be marked on the axle housing. Record these drive side contact pattern values in the test report.

8.4.4 Use only axle assemblies having a length value of L^2 or L^3 and a flank value of F^{-1} , F^0 , or F^{+1} .

8.4.5 *Breakaway and Turning Torque Measurements*—Measure and record the breakaway and turning torques of the completely assembled test unit. Do not use any axle assembly where the breakaway or turning torque exceeds 55 lbf-in. (6.2 N-m).

8.4.6 *Backlash Measurements*—Record the backlash marked on the axle by the manufacturer. Use only axle assemblies having a manufacturer-reported backlash measurement from 0.004 in. to 0.012 in. (0.102 mm to 0.305 mm).

8.4.6.1 If the test axle is lab-built or is not marked with a manufacturer-reported backlash measurement, remove the cover plate and measure the backlash at four equally spaced locations. Record these four measurements and their average in the test report. Use only axle assemblies with an average backlash from 0.004 in. and 0.009 in. (0.102 mm to 0.229 mm).

8.4.7 *Cleaning*—Wash the test unit using a cleaning solvent (see 7.2). Pay particular attention to remove all preservative oil from the pinion bearings and any contact pattern grease that may be present. Dry by blowing with clean, dry compressed air.

8.4.8 Install axle shafts in test unit.

8.4.9 Lubricate the carrier bearings, pinion bearings, differential gears, and the ring gear and pinion, using 6.0 pt \pm 0.1 pt (2.8 L \pm 0.05 L) of test lubricant.

8.4.10 Install the axle cover plate with gasket (apply sealant, if needed). Do not drain the oil and recharge the test axle once the test oil has been charged to the axle.

8.5 Install the test unit on the stand with pinion and axle shaft centerlines horizontal. Connect dynamometers and drive shaft to the test unit.

9. L-37-specific Calibration and Standardization Items (See Annex A2 for General Calibration and Standardization Information)

9.1 *Reference Test Frequency*—The test stand calibration period is defined as four months or 650 test hours, whichever occurs first. It begins on the completion date of an operationally and statistically acceptable reference oil test as determined by the TMC. Any test started on or before the stand calibration expiration date is defined to have been run on a calibrated stand.

9.1.1 When a test stand is out of calibration for a period of six months or longer, renumber the stand, and follow LTMS guidelines for new stand introduction.

9.1.2 Report modification of test stand apparatus or completion of any nonstandard test on a calibrated test stand to the TMC immediately.

9.1.3 Alternate testing of L-37 and L-42¹² tests does not necessitate recalibration as long as the above requirements are met.

9.1.4 Within a calibration period, alternate testing using different gear batches and dynamometer torque conditions does not necessitate recalibration.

9.2 Every test start on any test stand shall receive a sequential test run number designated before testing begins. All tests, including aborted starts and operationally invalid tests, must retain their test number.

9.3 *Instrumentation Calibration*—Using known standards traceable to the National Institute of Standards and Technology (NIST)¹³ (or using physical constants), calibrate the axle speed measuring system, temperature control system, and torque measuring system immediately prior to every other calibration

¹² The L-42 procedure is currently being developed into a standard test method by Subcommittee D02.B0.

¹³ National Institute of Standards and Technology (formerly National Bureau of Standards), Gaithersburg, MD 20899.

test or every nine months, whichever occurs first. Recalibration of instrumentation in the event of failed or invalid first attempts at stand calibration are at the discretion of the test engineer.

10. Test Procedure

10.1 Gear Conditioning Phase:

10.1.1 Set the temperature control to maintain a lubricant temperature of 297 °F \pm 3 °F (147.2 °C \pm 1.7 °C). See A9.3.3.2 for L-37 Canadian Version test.

10.1.2 With the engine warmed up and with no load on the dynamometers, shift smoothly to a gear appropriate for the test conditions.

10.1.3 After reaching the appropriate gear, accelerate smoothly to 440 \pm 5 wheel r/min and apply dynamometer load to achieve a torque of 395 lbf-ft \pm 15 lbf-ft (535 N·m \pm 20 N·m) on each wheel (see Note 2).

NOTE 2—The time required to accelerate to the test conditions of 440 wheel r/min and 395 lbf-ft (535 N·m) is about 5 min.

10.1.4 The test starts when required speed and torque conditions are reached. Record the time as start of the test.

10.1.5 After reaching speed and torque conditions, run the test for 100 min \pm 1 min.

10.1.6 To ensure accuracy of the test, record speed, torque, and temperature at a minimum of once every minute.

10.1.7 At the end of the 100 min, and as the torque and linear speed ramp-down is started, set the axle lubricant temperature controller to a set point of 275 °F \pm 3 °F (135.0 °C \pm 1.7 °C). Shift transmission to neutral and ensure that the axles stop turning. Record ending time and temperature of the lubricant. See A9.3.3.3 for L-37 Canadian Version test.

NOTE 3—The intent is to allow water to be added to the axle unit while it is still turning to cool the axle lubricant temperature and ensure that the water is shut off when the axle lubricant temperature drops below the set point.

10.1.8 Restart the test, as detailed in 10.3.1, if the test is stopped for any reason (power outage, maintenance, and so forth). This stoppage shall count as one of the allowed shutdowns during the test. Do not calculate deviation percent values or report out of limit operational values until test conditions are again achieved. If the test is stopped at the start of the conditioning phase, before speed and torque conditions are reached, the stoppage will not count as one of the allowed shutdowns.

10.2 Gear Test Phase:

10.2.1 Ensure that the temperature control is still set to maintain a lubricant temperature of 275 °F \pm 3 °F (135.0 °C \pm 1.7 °C). See A9.3.3.4 for L-37 Canadian Version test.

10.2.2 With the engine warmed up and with no load on the dynamometers, shift smoothly to a gear appropriate for the test conditions.

NOTE 4—The transition from the end of the conditioning phase (see 10.1.7) to the appropriate test gear of the gear test phase is approximately 5 min.

10.2.3 After reaching the appropriate gear, accelerate smoothly to 80 \pm 1 wheel r/min and apply dynamometer torque to achieve a torque of 1044 lbf-ft \pm 35 lbf-ft (1415 N·m

$\pm 47 \text{ N}\cdot\text{m}$) on each wheel. Hold at this condition until the axle lubricant temperature reaches $175 \text{ }^\circ\text{F} \pm 3 \text{ }^\circ\text{F}$ ($79.4 \text{ }^\circ\text{C} \pm 1.7 \text{ }^\circ\text{C}$).

NOTE 5—The time required to accelerate to the test conditions of 80 wheel r/min and 1044 lbf-ft (1415 N·m) is about 10 min.

10.2.3.1 Once the axle lubricant temperature reaches $175 \text{ }^\circ\text{F} \pm 3 \text{ }^\circ\text{F}$ ($79.4 \text{ }^\circ\text{C} \pm 1.7 \text{ }^\circ\text{C}$), immediately apply dynamometer load to achieve a torque of $1740 \text{ lbf}\cdot\text{ft} \pm 35 \text{ lbf}\cdot\text{ft}$ ($2359 \text{ N}\cdot\text{m} \pm 47 \text{ N}\cdot\text{m}$) on each wheel. When conducting tests with non-lubricated gear batch VIL500/P4T813 or lubricated gear batch VIL528/P4T883A, use the 13 % reduced contact stress requirements (see A9.4.1).

10.2.4 The test phase starts when required speed, torque, and temperature conditions are reached. Record the time as start of the test phase.

10.2.5 After reaching speed, torque, and temperature conditions, run the test for $24 \text{ h} \pm 0.2 \text{ h}$.

10.2.6 To ensure test accuracy, record speed, torque, and temperature at a minimum of once every minute.

10.2.7 At the end of 24 h, close the throttle smoothly, shift the transmission to neutral, and record time and temperature of the lubricant.

10.2.8 Disconnect the drive shaft and axle shafts from the dynamometers, and remove the test unit from the test stand while the test unit is hot.

10.2.9 Restart the test, as detailed in 10.3.1, if the test is stopped for any reason (power outage, maintenance, and so forth). This stoppage shall count as one of the allowed shutdowns during the test. Do not calculate deviation percent values or report out of limit operational values until test conditions are again achieved. If the test is stopped at the start of the test phase, before test conditions are reached (speed, load, and axle temperature), the stoppage will not count as one of the allowed shutdowns.

10.3 *Unscheduled Downtime*—An unscheduled downtime event is defined as any time the engine, or gears, or both, stop turning during the steady state gear conditioning or steady state gear test phases after test conditions are achieved.

10.3.1 *Restart After Unscheduled Downtime*—Restart the test as outlined in 10.3.1.1 through 10.3.1.5 any time there is an unscheduled downtime event.

10.3.1.1 Set the temperature control to maintain the lubricant temperature at the set point condition when the shutdown occurred.

10.3.1.2 With the engine warmed up and with no load on the dynamometers, shift smoothly to a gear appropriate for the test condition.

10.3.1.3 After reaching the appropriate gear, accelerate smoothly to the wheel r/min set point condition at the time of the shutdown.

10.3.1.4 If the restart occurs following a shutdown during the test phase, apply a dynamometer load on each wheel to achieve a torque value of $1044 \text{ lbf}\cdot\text{ft} \pm 35 \text{ lbf}\cdot\text{ft}$ ($1415 \text{ N}\cdot\text{m} \pm 47 \text{ N}\cdot\text{m}$) until the lubricant temperature reaches $175 \text{ }^\circ\text{F} \pm 3 \text{ }^\circ\text{F}$ ($79.4 \text{ }^\circ\text{C} \pm 1.7 \text{ }^\circ\text{C}$).

NOTE 6—If the restart occurs following a shutdown during the conditioning phase, follow 10.1.1 through 10.1.4 to restart the test.

10.3.1.5 Once lubricant temperature reaches $175 \text{ }^\circ\text{F} \pm 3 \text{ }^\circ\text{F}$ ($79.4 \text{ }^\circ\text{C} \pm 1.7 \text{ }^\circ\text{C}$), immediately apply dynamometer torque on each wheel to achieve the torque set point condition at the time of the shutdown.

11. Axle Post Test Measurements

11.1 Break and Turn Torques:

11.1.1 While the unit is hot, determine and record the torque required to break and to turn the pinion shaft of the completely assembled test unit.

11.1.2 Allow the unit to cool, and record the torques required to break and to turn the pinion shaft of the completely assembled test unit.

11.2 Drain the axle of test lubricant. This may occur anytime after 10.2.7 has been completed.

11.3 *Backlash Measurements*—Remove the cover plate. Record backlash at four equally spaced locations on the ring gear and calculate the average of the four readings.

11.4 Completely disassemble the differential and the pinion shaft assemblies for inspection.

12. Determination of Test Results¹⁴

12.1 *Pinion Bearing Rating*—Examine the bearings for wear, surface fatigue corrosion, and deposits in accordance with ASTM Distress Rating Manual 21.

12.2 Gear Rating:

12.2.1 Examine the tooth surfaces on the drive side of the pinion and ring gear for the following distresses in accordance with ASTM Distress Rating Manual 21 and Annex A12: burnishing, wear, pitting/spalling, ridging, rippling, scoring, discoloration, corrosion, and deposits. Rate the distress types of wear, rippling, and ridging using the ASTM Photographs for Gear Distress. The photographs shall be an ASTM item TMCGEARDISTRESS2010PR and shall have been issued on or after November 9, 2010.^{15,16}

12.2.2 Rate each distress by identifying its level of distress in accordance with Table A12.1. Four distress types (ridging, rippling, scoring, and wear) are assigned a numerical value between 0 and 10 corresponding to the rated level of distress, as shown in Table A12.1.

12.2.2.1 The pitting/spalling distress type is assigned a numerical value shown separately in Table A12.1.

TABLE 1 Transformations

Parameter	Transformation
Ridging	$-\ln(10.5 - \text{merit})$
Rippling	$-\ln(10.5 - \text{merit})$
Pitting/Spalling	$-\ln(10.5 - \text{merit})$
Wear	none

¹⁴ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1415.

¹⁵ Available from the ASTM website, www.astm.org.

¹⁶ Training for individuals rating gear sets for gear distress level may be coordinated through the ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA, 15206.

12.2.3 Transform the rated test results according to **Table 1**. Add any applicable corrections outlined in **12.3** and then un-transform the value for final result reporting.

12.3 *Correction Factors and Exclusions:*

12.3.1 *C1L426/P4L415A Nonlubricated Gear Set*—When using the nonlubricated hardware, gear set C1L426/P4L415A, determine a numerical pitting/spalling value, excluding any pitting/spalling value between 9.3 and 9.9, inclusively, in the wear step area of the drive side pinion tooth, as per **Annex A13**.

12.3.2 *V1L303/P4L514A Nonlubricated Gear Set*—When using the nonlubricated hardware, gear set V1L303/P4L514A, determine a numerical pitting/spalling value, excluding any pitting/spalling value between 3.0 and 9.9, inclusive, in the wear step area of the drive side pinion tooth, as per **Annex A13**.

12.3.3 *V1L686/P4L626A Lubricated Gear Set*—When using the lubricated hardware, gear set V1L686/P4L626A, for non-reference oil tests, add a correction factor of 0.5186 to the pinion transformed ridging test result, and add 0.9922 to the ring transformed ridging test result.

12.3.3.1 On the V1L686/P4L626A gear set, a thin polished line visible in the root heel of the pinion and on the crown of the ring gear might be evident. The polish line might vary in length and prominence due to the build position of the ring and pinion gears and manufacturing accuracy of the carrier. This condition is normal and not oil-related. Note this condition in the final test report comment section as *Root and Tip line polishing and a function of the gear set manufacturing process — V1L686/P4L626A*.

12.3.4 *V1L528/P4T883A Nonlubricated Gear Set*—When using the nonlubricated hardware gear set V1L528/P4T883A for non-reference oil tests, add 0.3365 to the transformed test result of both pinion ridging and pinion rippling. Rate each pinion tooth for pitting/spalling and report the fourth lowest tooth rating for the final pinion pitting/spalling test result.

12.3.4.1 See **A9.3.4** for L-37 Canadian Version test.

12.3.5 *V1L528/P4T883A Lubricated Gear Set*—When using the lubricated hardware gear set V1L528/P4T883A for non-reference oil tests, add 0.3365 to the transformed pinion ridging test result. Rate each pinion tooth for pitting/spalling and report the second lowest tooth rating for the final pinion pitting/spalling test result.

12.3.5.1 See **A9.3.4** for L-37 Canadian Version test.

12.4 For a test rating to be valid, the gears shall be rated by an individual who has participated in an ASTM gear-rater calibration workshop within the previous twelve months¹⁶ and has been calibrated as outlined in the L-37 Rater Calibration Monitoring System (RCMS). The RCMS calibration period is every six months or as otherwise required by the RCMS. A copy of the RCMS document is available on the ASTM Test Monitoring Center web page at <http://www.astmtmc.cmu.edu/>, or it can be obtained in hardcopy format from the TMC.

12.5 *Test Validity*—The test is determined to be operationally valid if the percent deviation of the critical operating parameters and number of shutdowns are within the limits specified and defined in **Annex A11**.

12.6 Consider as non-interpretable any non-reference oil test that has not been run in a calibrated test stand or not

conducted on approved hardware, or both. Indicate on the cover page of the test report that the test is non-interpretable and that it has not been conducted in a valid manner in accordance with the test method.

12.7 Any reference or non-reference oil test exhibiting a broken or cracked pinion or ring gear tooth is non-interpretable. Note any broken teeth in the comment section of the test report.

12.8 Rate only the corrosion on the contact surface of the drive side of any pinion or ring gear tooth. Enter the corrosion rating in the rating section of the rating form. Note any corrosion on the pinion and ring in a non-contact surface area in the comment section of the rating form.

13. Report

13.1 For reference oil tests, use the standardized report form set available from the TMC.

NOTE 7—Report the non-reference oil test results on these same forms if the results are intended to be submitted as candidate oil results against a specification.

13.1.1 Fill out the report forms according to the formats shown in the data dictionary.

13.1.2 Transmit results to the TMC within 5 working days of test completion.

13.1.3 Transmit the results electronically as described in the ASTM Data Communications Committee Test Report Transmission Model (Section 2 — Flat File Transmission Format) available from the ASTM TMC. Upload files via the TMC's website

13.2 Report all reference oil test results, whether aborted, invalidated, or successfully completed, to the TMC.

13.3 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits.

13.4 *Precision of Reported Units*—Use the Practice **E29** rounding off method for critical pass/fail test result data. Report the data to the same precision as indicated in data dictionary.

13.5 In the space provided, note the time, date, test hour, and duration of any shutdown or offtest condition. Document the outcome of all prior reference oil tests from the current calibration sequence that were operationally or statistically invalid.

13.6 If a calibration period is extended beyond the normal calibration period length, make a note in the comment section and attach a written confirmation of the granted extension from the TMC to the test report. List the outcomes of previous runs that may need to be considered as part of the extension in the comment section.

13.7 Attach to the test report a plot of the temperature data recorded.

14. Precision and Bias

14.1 *Precision*—Test precision is established on the basis of reference oil test results (for operationally valid tests) monitored by the ASTM TMC. The data are reviewed semiannually

by the L-37 Surveillance Panel. Contact the ASTM TMC for current industry data. **Table 2** summarizes reference oil precision of the test as of March 29, 2005.

14.1.1 Intermediate Precision Conditions—Conditions where test results are obtained with the same test method by the same laboratory, with the same gear batch using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

NOTE 8—“Intermediate precision” is the appropriate term for this test method, instead of “repeatability,” which defines more rigorous within-laboratory conditions.

14.1.1.1 Intermediate Precision Limit (i.p.)—The difference between two results obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in **Table 2** in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result \pm Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

14.1.2 Reproducibility Conditions—Conditions where test results are obtained with the same test method using the same gear batch on the same test oil in different laboratories with different operators using different equipment.

14.1.2.1 Reproducibility Limit (R)—The difference between two results obtained under reproducibility conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in **Table 2** in only one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result \pm Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

14.2 Bias—No estimate of bias for this test method is possible because the performance results for an oil are determined only under specific conditions of the test and no absolute standards exist.

15. Keywords

15.1 abrasive wear; adhesive wear; bearing failure; final drive axle; gear; gear failure; hypoid axle; L-37; lubricants; surface fatigue

ANNEXES

(Mandatory Information)

A1. ASTM TEST MONITORING CENTER ORGANIZATION

A1.1 Nature and Functions of the ASTM Test Monitoring Center (TMC)—The TMC is a non profit organization located in Pittsburgh, Pennsylvania and is staffed to: administer engineering studies; conduct laboratory inspections; perform statistical analyses of reference oil test data; blend, store, and ship reference oils; and provide the associated administrative functions to maintain the referencing calibration program for various lubricant tests as directed by ASTM Subcommittee

D02.B0 and the ASTM Executive Committee. The TMC coordinates its activities with the test sponsors, the test developers, the surveillance panels, and the testing laboratories. Contact TMC through the TMC Director at:

ASTM Test Monitoring Center
6555 Penn Avenue
Pittsburgh, PA 15206-4489
www.astmtmc.cmu.edu

TABLE 2 Reference Oil Test Precision Data

NOTE 1—These statistics are based on the L-37 Standard version test results obtained on Test Monitoring Center Reference Oils 151-2, 151-3, 152, 152-1, 153, 153-1, 155, and 155-1 as of June 2015. There are no statistics for the Canadian version test at this time.

Legend:

$S_{i.p.}$ = intermediate precision standard deviation,

$i.p.$ = intermediate precision,

S_R = reproducibility standard deviation, and

R = reproducibility.

Hardware Type	Variable	$S_{i.p.}$	$i.p.^A$	S_R	R^A
Lubrited	Pinion ridging, merit	1.482	4.150	1.482	4.150
	Pinion rippling, merit	0.580	1.624	0.594	1.663
	Pinion pitting/spalling, merit	0.728	2.038	0.753	2.108
	Pinion wear, merit	0.571	1.599	0.589	1.649
Non-lubrited	Pinion ridging, merit	0.649	1.817	0.676	1.893
	Pinion rippling, merit	0.551	1.543	0.577	1.616
	Pinion pitting/spalling, merit	0.818	2.290	0.818	2.290
	Pinion wear, merit	0.683	1.912	0.683	1.912

^A This value is obtained by multiplying the standard deviation by 2.8.

A1.2 Rules of Operation of the ASTM TMC—The TMC operates in accordance with the ASTM Charter, the ASTM Bylaws, the Regulations Governing ASTM Technical Committees, the Bylaws Governing ASTM Committee D02, and the Rules and Regulations Governing the ASTM Test Monitoring System.

A1.3 Management of the ASTM TMC—The management of the Test Monitoring System is vested in the Executive Committee elected by Subcommittee D02.B0. The Executive Committee selects the TMC Director who is responsible for directing the activities of the TMC.

A1.4 Operating Income of the ASTM TMC—The TMC operating income is obtained from fees levied on the reference oils supplied and on the calibration tests conducted. Fee schedules are established by the Executive Committee and reviewed by Subcommittee D02.B0.

A2. ASTM TEST MONITORING CENTER: CALIBRATION PROCEDURES

A2.1 Reference Oils—These oils are formulated or selected to represent specific chemical, or performance levels, or both. They are usually supplied directly to a testing laboratory under code numbers to ensure that the laboratory is not influenced by prior knowledge of acceptable results in assessing test results. The TMC determines the specific reference oil the laboratory shall test.

A2.1.1 Reference Oil Data Reporting—Test laboratories that receive reference oils for stand calibration shall submit data to the TMC on every sample of reference oil they receive. If a shipment contains any missing or damaged samples, the laboratory shall notify the TMC immediately.

A2.2 Calibration Testing:

A2.2.1 Full scale calibration testing shall be conducted at regular intervals. These full scale tests are conducted using coded reference oils supplied by the TMC. It is a laboratory's responsibility to keep the onsite reference oil inventory at or above the minimum level specified by the TMC test engineers.

A2.2.2 Test Stands Used for Non Standard Tests—If a non standard test is conducted on a previously calibrated test stand, the laboratory shall conduct a reference oil test on that stand to demonstrate that it continues to be calibrated, prior to running standard tests.

A2.3 Reference Oil Storage—Store reference oils under cover in locations where the ambient temperature is between $-10\text{ }^{\circ}\text{C}$ and $+50\text{ }^{\circ}\text{C}$.

A2.4 Analysis of Reference Oil—Unless specifically authorized by the TMC, do not analyze TMC reference oils, either physically or chemically. Do not resell ASTM reference oils or supply them to other laboratories without the approval of the TMC. The reference oils are supplied only for the intended purpose of obtaining calibration under the ASTM Test Monitoring System. Any unauthorized use is strictly forbidden. The testing laboratory tacitly agrees to use the TMC reference oils exclusively in accordance with the TMC's published Policies for Use and Analysis of ASTM Reference Oils, and to run and report the reference oil test results according to TMC guidelines. Additional policies for the use and analysis of ASTM Reference Oils are available from the TMC.

A2.5 Conducting a Reference Oil Test—When laboratory personnel are ready to run a reference calibration test, they shall request an oil code via the TMC website. 1-16a

A2.6 Reporting Reference Oil Test Results—Upon completion of the reference oil test, the test laboratory transmits the data electronically to the TMC, as described in Section 13. The TMC reviews the data and contacts the laboratory engineer to report the laboratory's calibration status. All reference oil test results, whether aborted, invalidated, or successfully completed, shall be reported to the TMC.

A2.6.1 All deviations from the specified test method shall be reported.

A3. ASTM TEST MONITORING CENTER: MAINTENANCE ACTIVITIES

A3.1 *Special Reference Oil Tests*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. Occasionally, the majority or even all of the industry’s test stands will conduct calibration tests at roughly the same time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss or gain in calibration status.

A3.2 *Special Use of the Reference Oil Calibration System*—The surveillance panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The surveillance panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration status is left pending for an excessive length of time. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the surveillance panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss or gain in calibration status. To ensure accurate stand, or laboratory, or both severity assessments, conduct non reference oil tests the same as reference oil tests.

A3.3 *Donated Reference Oil Test Programs*—The surveillance panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The surveillance panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the surveillance panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The surveillance panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

A3.4 *Intervals Between Reference Oil Tests*—Under special circumstances, such as extended downtime caused by industry wide parts or fuel shortages, the TMC may extend the intervals between reference oil tests. Such extensions shall not exceed one regular calibration period.

A3.5 *Introducing New Reference Oils*—Reference oils produce various results. When new reference oils are selected, participating laboratories will be requested to conduct their share of tests to enable the TMC to recommend industry test targets. ASTM surveillance panels require a minimum number of tests to establish the industry test targets for new reference oils.

A3.6 *TMC Information Letters*—Occasionally it is necessary to revise the test method, and notify the test laboratories of the change, prior to consideration of the revision by Subcommittee D02.B0. In such a case, the TMC issues an Information Letter. Information Letters are balloted semi annually by Subcommittee D02.B0, and subsequently by D02. By this means, the Society due process procedures are applied to these Information Letters.

A3.6.1 *Issuing Authority*—The authority to issue an Information Letter differs according to its nature. In the case of an Information Letter concerning a part number change which does not affect test results, the TMC is authorized to issue such a letter. Long term studies by the surveillance panel to improve the test procedure through improved operation and hardware control may result in the issuance of an Information Letter. If obvious procedural items affecting test results need immediate attention, the test sponsor and the TMC issue an Information Letter and present the background and data supporting that action to the surveillance panel for approval prior to the semiannual Subcommittee D02.B0 meeting.

A3.7 *TMC Memoranda*—In addition to the Information Letters, supplementary memoranda are issued. These are developed by the TMC and distributed to the appropriate surveillance panel and participating laboratories. They convey such information as batch approvals for test parts or materials, clarification of the test procedure, notes and suggestions of the collection and analysis of special data that the TMC may request, or for any other pertinent matters having no direct effect on the test performance, results, or precision and bias.