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Objective of the Meeting:

Educate industry stakeholders such as EPA on SAE Truck and Bus Aerodynamic and Fuel Economy (AFE) Committee J1321 standard, its use, limitations, relationship with other SAE standard products and the approach used to guide the revision of current products and development of future products. The material presented will focus on clarifications of SAE J1321 and not interpretation of the document.
SAE TRUCK AND BUS STANDARDS

GLOBAL GROUND VEHICLE STANDARDS

- Motor Vehicle Council
- Truck and Bus Council
- Fuel and Lubricants Council
- Materials, Processes and Parts Council
- Construction, Agricultural and Off Road Machinery Council
- Specialized Vehicle and Equipment Council

TECHNICAL STANDARDS BOARD
- Aerospace Standards
- Ground Vehicle Standards
- Motor Vehicle Council
- Truck and Bus Council
- Fuel and Lubricants Council
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TRUCK AND BUS COUNCIL
- Truck and Bus Aerodynamics and Fuel Economy (AFE) Committee
- Truck and Bus Advanced and Hybrid Powertrain Steering Committee
- Truck and Bus Human Factors Committee
- Truck Crashworthiness Committee
- Truck and Bus Windshield Wipers and Climate Control Committee
- Truck and Bus Total Vehicle Steering Committee
- Truck and Bus Tire Pressure Management Systems Committee
- Truck and Bus Tire Committee
- Truck and Bus Aerodynamics and Fuel Economy (AFE) Committee
- Truck and Bus Electrical - Electronic Steering Committee
- Truck and Bus Event Data Recorder Committee
- Truck and Bus Electrical Systems Committee
- Truck and Bus Low Speed Communication Network Committee
- Truck Bus Control and Communications Network Committee
The Truck and Bus Aerodynamic and Fuel Economy Committee reports to the Total Vehicle Steering Committee of the Truck and Bus Council. The committee has the authority to establish and discharge task forces and subcommittees as necessary for initiating, developing, reviewing, and approving Recommended Practices, Standards, and Information Reports related to the aerodynamics and fuel economy of single unit trucks, tractor-trailer combination vehicles and buses of all weight categories intended for highway use.

All committee work products are based upon established engineering and scientific principals and supported by peer reviewed published technical reports. The aerodynamics of trucks and buses are extremely complex requiring unique testing and evaluation tools to represent critical flow features that allow an accurate determination of vehicle aerodynamics. The committee develops testing and analysis procedures for aerodynamic investigations of operational vehicles, concept vehicles, and a wide range of vehicle components including both passive and active technologies. Representative aerodynamic technologies include such items as fairings, flow control systems, boat tails, and skirts.
A second and equally important committee work area is the development of procedures to determine the fuel economy of a complete vehicle or the change in fuel economy of a vehicle resulting from a change in a vehicle system. Fuel economy testing and analysis procedures are developed for on-road and on-track testing of trucks and buses. These procedures are required to address the unique testing requirements associated with changes in all vehicle systems such as aerodynamics, fuel, lube, drive train, and tires.

A critical element of all committee work is to ensure the latest test equipment, facilities, and instrumentation technology as well as current and rigorous engineering procedures are included in all committee work products. The committee works with other SAE committees and councils, truck and bus organizations as well as academia and government agencies. Committee members include individuals from original equipment manufacturers, suppliers, consulting firms, government employees, academia and others involved in the truck and bus industries.
This document describes a rigorous-engineering fuel-consumption test procedure that utilizes industry accepted data collection and statistical analysis methods to determine the change in fuel consumption for trucks and buses with GVWR of more than 10,000 pounds. The test procedure may be conducted on a test track or on a public road under controlled conditions and supported by extensive data collection and data analysis constraints. The on-road test procedure is offered as a lower cost alternative to on-track testing but the user is cautioned that on-road test may result in lower resolution (or precision) data due to a lack of control over the test environment. Test results that do not rigorously follow the method described herein are not intended for public use and dissemination and shall not be represented as a J1321-Type II test result.

This document:

(1) Describes test procedures that determine and document the percent change in fuel use due to a change in vehicle/powertrain configuration, set-up, or operation for a measured set of environmental conditions present during the test.

(2) Identifies parameters that improve the precision of the measured fuel use data relative to environmental test conditions.

(3) Ensures uniformity and transparency of test results by defining the format and content required for reporting and the public use of all test results.
J1321 – 1986 VERSION
1981: Issued
Joint TMC/SAE Fuel Consumption Test Procedure – Type II

1986: Revised, minor updates
Joint TMC/SAE Fuel Consumption Test Procedure – Type II

2012: Revised, complete revision
Fuel Consumption Test Procedure – Type II
2011 status: 3 published test procedures

Areas of Concern: procedure claims

Areas of Concern: user assumptions
Repeat testing
Similar vehicles
Test result applicability

Concerns with test procedure (discussed in next section)
Single test validity
Precision claim
Run validity criteria
Weather constraints
Vehicle type & weight criteria
Time constraints
Wind and yaw effects
Test results reporting criteria
## 2011: SAE, TMC & EPA PROCEDURES

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>SAE J1321 (1986 version)</th>
<th>TMC RP 1102</th>
<th>EPA Smart/Way (pre 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Test Validity</td>
<td>Inconclusive</td>
<td>Inconclusive</td>
<td>Conclusive</td>
</tr>
<tr>
<td>Precision (assumed)</td>
<td>± 1%</td>
<td>± 1%</td>
<td>± 1%</td>
</tr>
<tr>
<td>Valid Run</td>
<td>Within 2% T/C ratio</td>
<td>Within 2% T/C ratio</td>
<td>Within 2% T/C ratio</td>
</tr>
<tr>
<td>Weather Recording</td>
<td>Once/run</td>
<td>Once/run</td>
<td>Once/run</td>
</tr>
<tr>
<td>Weather Criteria</td>
<td>None</td>
<td>None</td>
<td>Wind: &lt;12mph, gust &lt;15mph; Temp: 41° to 95°, range 30°; Rain: none</td>
</tr>
<tr>
<td>Vehicle Type</td>
<td>Not similar</td>
<td>Not similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Vehicle Weight</td>
<td>Not similar</td>
<td>Not similar</td>
<td>Similar</td>
</tr>
<tr>
<td>Test site</td>
<td>On-Track &amp; On-Road</td>
<td>On-Road &amp; On-Track</td>
<td>On-Track</td>
</tr>
<tr>
<td>Run Length</td>
<td>&gt;40 miles</td>
<td>&gt;28 miles</td>
<td>&gt;40 miles</td>
</tr>
<tr>
<td>Run Fuel Use</td>
<td>&gt;30% tank or 6 gal.</td>
<td>&gt;20% tank or 3 gal.</td>
<td>&gt;30% tank or 6 gal.</td>
</tr>
<tr>
<td>Run Time Repeat</td>
<td>± .5%</td>
<td>± .5%</td>
<td>± .5%</td>
</tr>
<tr>
<td>T to C Run Time</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Fuel Management</td>
<td>Gravimetric</td>
<td>Gravimetric</td>
<td>Gravimetric</td>
</tr>
<tr>
<td>Yaw Effects</td>
<td>Circular Route</td>
<td>Circular Route</td>
<td>Circular, Oval</td>
</tr>
</tbody>
</table>

**BOLD items vary between procedures**
1. Test accuracy (precision) is within ±1%.
   (Accuracy requires knowledge of a known reference value.
   Contradicts claims 2, 3 and 5. See following chart.)

2. A single test is inconclusive.
   (Contradicts claims 1 and 5.)

3. Test results must be repeatable to have validity.
   (Repeatability does not guarantee validity.)

4. Test on circular route to minimize effects of yaw angle.
   (Circular routes do not ensure lowest average yaw conditions)

5. The more variables controlled the more conclusive the results.
   (Contradicts claims 1, 2 and 3.)
**AREAS OF CONCERN - PROCEDURE CLAIMS**

Is the accuracy of a valid test ±1%?
No. Accuracy can not be determined.

Is the precision (confidence interval) of a valid test ±1%?
Not guaranteed. See statistical analysis results below.

<table>
<thead>
<tr>
<th><strong>DATA:</strong></th>
<th>24 valid tests (2% T/C criteria) from 4 test tracks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RESULT FORMAT:</strong></td>
<td>value % ± confidence interval (CI) %</td>
</tr>
<tr>
<td><strong>VALID TEST RESULT CRITERIA:</strong></td>
<td>value &gt; CI</td>
</tr>
<tr>
<td>• 42% of test results were not valid:</td>
<td>value &lt; CI</td>
</tr>
<tr>
<td>• 58% of test results were valid:</td>
<td>value &gt; CI</td>
</tr>
<tr>
<td>• 25% of test results satisfy CI claim:</td>
<td>CI ≤ ±1 %</td>
</tr>
<tr>
<td>• 75% of test results did not satisfy CI claim:</td>
<td>CI ≤ ±1 %</td>
</tr>
<tr>
<td>- Largest CI: ± 3%</td>
<td></td>
</tr>
<tr>
<td>- Average CI: ± 1.8%</td>
<td></td>
</tr>
</tbody>
</table>
Repeat Testing?
False Assumption: A repeat test is accomplished by using two test vehicles in the same test.
Fact: A repeat test requires a complete NEW test at original test site with original equipment under same conditions.

Similar Vehicles?
False Assumption: Vehicles are similar if they are of the same general type.
Fact: Similar vehicles must have similar external shape, powertrain, tires, weight, etc…

Applicability of test results?
False Assumption: Results are applicable to all vehicles of same general type and for all weather, routes, and loads.
Fact: Result are only applicable to test vehicles at test conditions.
### CONCERNS ADDRESSED: J1321 REVISION

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Test Validity</td>
<td>Inconclusive</td>
<td>Inconclusive</td>
<td>Conclusive for test conditions</td>
</tr>
<tr>
<td>Precision (assumed)</td>
<td>± 1%</td>
<td>± 1%</td>
<td>Calculated</td>
</tr>
<tr>
<td>Valid Run</td>
<td>Within 2% T/C ratio</td>
<td>Within 2% T/C ratio</td>
<td>Value &gt; Error</td>
</tr>
<tr>
<td>Weather Recording</td>
<td>Once/run</td>
<td>Once/run</td>
<td>Continuous</td>
</tr>
<tr>
<td>Weather Criteria</td>
<td>None</td>
<td>Wind: 25mph, gust 30mph; Temp: 36° -105°; Rain: yes</td>
<td>Wind: ≤12mph; Wind: Between runs ≤5mph; Temp: 40° -100°, range 30°; Rain: No</td>
</tr>
<tr>
<td>Vehicle Type</td>
<td>Not similar</td>
<td>Not similar</td>
<td>Identical</td>
</tr>
<tr>
<td>Vehicle Weight</td>
<td>Not similar</td>
<td>Not similar</td>
<td>Identical</td>
</tr>
<tr>
<td>Test site</td>
<td>On-Track &amp; On-Road</td>
<td>On-Road &amp; On-Track</td>
<td>On-Track (On-Road option)</td>
</tr>
<tr>
<td>Run Length</td>
<td>&gt;40 miles</td>
<td>&gt;28 mi, Tcorr: &gt;140 mi</td>
<td>Track: &gt;50 mi, Road: &gt;100 mi</td>
</tr>
<tr>
<td>Run Fuel Use</td>
<td>&gt;30% tank or 6 gal.</td>
<td>&gt;20% tank</td>
<td>&lt;50% tank</td>
</tr>
<tr>
<td>Run Time Repeat</td>
<td>± .5%</td>
<td>± .5%</td>
<td>± .25%</td>
</tr>
<tr>
<td>T to C Run Time</td>
<td>None</td>
<td>None</td>
<td>± .50%</td>
</tr>
<tr>
<td>Yaw Effects</td>
<td>Circular or L Route</td>
<td>Circular or L Route</td>
<td>Wind Criteria, Vehicle Specs</td>
</tr>
</tbody>
</table>

**BOLD items vary between procedures**
CONCERN: The original document claims that if a test satisfies all test criteria it is invalid unless the test is repeated and produces repeatable results. However, repeatability does not guarantee validity. Validity is the degree to which an observed result, such as a difference between two measurements, can be relied upon and not attributed to random error in sampling or in measurement.

REVISION: A test is valid if it satisfies all test criteria. Implemented critical test constraints to minimize random errors and employ statistical analysis of test data to assess random errors. Statistical analysis of test data is not used to validate a test. Test results are valid only for the vehicle configuration, test conditions and test cycle under which the test was conducted. The general applicability of a valid test result to different environmental factors may be determined when a subsequent valid test result produces a statistically similar value to the initial valid test result.

BENEFIT: Implementing test process and data analysis controls improves data quality and reduces data uncertainty. Eliminating the requirement to repeat a test reduces cost without impacting test result confidence.
CONCERN: Use of a 2% T/C window to define outliers and to determine run (data) validity arbitrarily biases the assessment of test-process variability and technology-performance variability resulting in test results that increase risk to the end user of the technology.

REVISION: All runs are valid and all test data collected from each run are valid if they do not violate a test process constraint. All valid test data must be included in the statistical analysis process. Test data may be excluded from the statistical analysis if a documented equipment failure/malfunction, driver error or a violation of a test constraint has occurred. The source of the failure must be recorded and documented in the test report.

BENEFIT: Including all valid data in the analysis process ensures that the natural variability (randomness) of the test process and/or the technology performance are evaluated without bias. This approach provides the customer with a true assessment of test quality and technology performance.
CONCERN: The assumption that the test has an accuracy of ±1% is misleading and incorrect. Accuracy of this test can not be determined. The above statement is discussing precision (confidence interval) of the test result and not accuracy of the test. There is no basis to claim a test result confidence interval based on an assumption derived from an undocumented data acceptance criteria (see Run Validity discussion).

REVISION: The confidence interval of a test result can only be determined from the statistical analysis of all test data. The test procedure was updated with a statistical analysis tool that allows for real-time and post-test data analysis and calculation of the confidence interval. All valid test data must be included in the J1321 statistical analysis process (see Run Validity discussion), which is unique to this procedure.

BENEFIT: Calculation of the test result confidence interval provides the customer with a true assessment of data quality and technology performance. Providing a real-time analysis tool allows for adjustments to the test program to obtain desired level of data quality.
PRECISION (CONFIDENCE INTERVAL)

Hypothetical Fuel Use Test Results

Example 1
Low Precision = Large Confidence Interval

Example 2
High Precision = Small Confidence Interval
In the example above, 2 runs that failed the 2% criteria were invalidated per the former process. The pre-2012 result shows 1.48% improvement with assumed +/- 1% accuracy.

Using the J1321 (2012) calculations spreadsheet, the Confidence Interval of that hypothetical 6 run test is actually +/- 2.36%.
If the 2 culled runs were the result of measurement variability and not the result of error in the test process (vehicle or driver malfunction, etc.), then J1321 (2012) considers these valid data points.

The inclusion of the 2 runs changes the nominal result slightly but improves the Confidence Interval.
The example above is representative of a highly controlled fuel use test. Small run variability (T/C range within 0.5%) produces a Confidence Interval less than +/- 1%.

In this case the high precision dataset allows the user to conclude a fuel economy improvement for a nominal change less than the traditional 1% limit.
CONCERN: The impact of changes in weather on aerodynamic resistance of each vehicle design is unique. Wind speed and direction can have the largest impact on test data quality. Additionally, wind speed and direction is highly heterogeneous in location and time resulting in significant variation in wind characteristics at a test site and over a test time period. As a result fuel consumption test procedures do not provide wind average effects but are best suited to provide a fuel consumption value over a limited range of wind conditions.

WEATHER REVISION: Wind speed, temperature, precipitation and data collection criteria were added to minimize test/data variability. Maximum test wind speed was set at 12mph and maximum allowable change in average wind speed between runs/segments is 5mph. Allowable temperature range is 40° to 100°F with a maximum change in temperature during a specific test set at 30°F.

VEHICLE REVISION: To minimize variability the procedure requires identical test and control vehicles. Constraints are imposed on vehicle mileage and tire mileage. Tires shall have at least 500 miles of wear. OEM test vehicles shall have at least 500 miles and all other test vehicles shall have at least 10,000 miles.

BENEFIT: Addition of weather constraints combined with the requirement to use identical test and control vehicles minimizes the impact of weather on the test data resulting in higher quality of data.
WEATHER AND VEHICLE CRITERIA

“Each Truck will trend differently with yaw.”

“Each DEVICE will trend differently with yaw.”

Graph showing the effect of yaw on CD (drag coefficient) for different vehicles and devices.

Sources:
- NASA
- NRC
- UMD
- UT
- SAE
- AIAA
Identical Control and Test Vehicles

Type II aerodynamic assessment may produce different results in different conditions.
CONCERN: Test route type, run distance and maximum fuel use criteria should be adjusted to minimize possible sources of random errors. Assumption that on-road testing produces results equivalent to on-track testing was not valid. Identical run length for on-road and on-track test would not produce equivalent results. Allowing 70% fuel tank volume to be consumed for each run could introduce air or contaminates into the engine.

REVISION: On-track testing is preferred with a minimum run length of 50 miles. On-road testing is allowed with a minimum run length of 100 miles. Maximum fuel use from the test tank shall not exceed 50% of the tank volume.

BENEFIT: Addition of on-track as the preferred test site combined with increase in run length and constraint of fuel use as percent of volume minimizes error sources resulting in higher quality of data.
CONCERN: Inconsistencies in drive cycle between Control and Test vehicles and for each vehicle can be a source of error. Failure to match the test run time of the Control and Test vehicles within a segment is a significant source of error. Allowing a 1% variation in time between runs for a vehicle within a segment is equivalent to a change in vehicle speed of .5mph.

REVISION: The difference in time for the Control and Test vehicles to complete the first Run in each Segment shall be less than 0.5% of the longest Run time for the vehicles. Time for each vehicle to complete all subsequent Runs in each Segment must be within \( \pm 0.25\% \) of the time for that specific vehicle to complete its first Run in the Segment.

BENEFIT: The run time criteria ensures that drive cycles of Test and Control vehicles are matched and the drive cycles for each vehicle are being repeated. Providing matched and repeatable drive cycles minimizes error sources resulting in higher quality of data.
CONCERN: The gravimetric fuel use measurement approach is preferred. Limited experience with alternate methods prohibited their use. The failure to explicitly state which fuel consumption measurement/assessment methods are not allowed could result in the use of unacceptable methods.

REVISION: The use of the gravimetric measurement approach remains the preferred approach. Flow meters are allowed if they satisfy the calibration requirements outlined. The following fuel use measurement methods are not approved and shall not be used.

a) Data obtained from the electronic control module (ECM).
b) Volumetric measurements obtained by measuring fuel volume in the fuel tank.
c) Volumetric measurements obtained from a fuel dispensing system.

BENEFIT: Providing an alternate measurement approach with calibrated accuracy equivalent to the gravimetric method can reduce test cost. Explicitly restricting the use of specific methods reduces the possibility of sources of error.
CONCERN: The claim that the effect of “high or low yaw angle wind” on fuel consumption can be minimized with a “circular or closed loop of highways” is incorrect and misleading. Wind will impact the effective speed and yaw angle of the vehicles and alter the measured fuel consumption values. This error may be greater if the test vehicles are not identical. Testing in conditions with variations in wind speed will impact data quality and the ability to assess the vehicle modifications.

REVISION: Discussion of the limitations of the test procedure to assess the impact of wind on fuel consumption is provided. The user of the procedure is cautioned that it is not possible to obtain wind averaged fuel consumption value with this procedure or any other current fuel consumption test procedure due to the limited test mileage and the lack of control over environmental factors.

BENEFIT: Explicitly stating the inability of this method to resolve or account for wind or yaw effects reduces the misuse of the procedure and eliminates sources of error.
CONCERN: The procedure did not specify minimum reporting or documentation requirements. Typical reporting of results lack sufficient detail to allow the end user (customer) of the data to assess the quality of the test process and risk level associated with the technology.

REVISION: Only test results calculated values from the supplied software shall be reported. Reporting of test results shall be in accordance with the following format and shall contain all information noted below.

Test Result: (Percent Change in Fuel Consumed) ± (Percent Confidence Interval)
   @ Mean Vehicle Speed, Vehicle Weight, Gap, Aerodynamic Gap
   @ Mean Air Temperature ± change to min and max values
   @ Mean Wind Speed ± change to min and max values

BENEFIT: Requiring the reporting of test results in a specific format and with specific content will minimize the misrepresentation of test results and reduce risk to the testing organization and technology customer resulting in reduced cost to the industry.
RELATED AFE J DOCS
<table>
<thead>
<tr>
<th>Topic</th>
<th>AFE J Docs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J1321</td>
</tr>
<tr>
<td>Aerodynamic data</td>
<td>no</td>
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<tr>
<td>Rolling resistance data</td>
<td>no</td>
</tr>
<tr>
<td>Fuel use data</td>
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<td>Total accuracy determination</td>
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<td>Differential accuracy determination</td>
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<tr>
<td>Measure yaw effects</td>
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<td>Correct for yaw effects</td>
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<td>Vehicle component data</td>
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<td>Full vehicle data, 2</td>
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<tr>
<td>J3015 impact</td>
<td>yes</td>
</tr>
<tr>
<td>J2971 impact</td>
<td>yes</td>
</tr>
</tbody>
</table>

NOTE:
1. Possible with a control vehicle
2. Trailer is defined as a vehicle

* Document under revision
** Document under development
CONCERNS: The previous document lacked statistical analysis of test data and constraints on test criteria required to resolve small fuel consumption differences. Results from previous versions of this procedure have been reported without precision tolerances. Did not address modern after treatment system operation.

SCOPE: This test procedure utilizes industry accepted data collection and statistical analysis methods to determine the difference in fuel consumption between vehicles with a gross vehicle weight of more than 10,000 pounds. This test procedure can be used for an evaluation of two or more different vehicles but is not to be used to evaluate a component change.

BENEFIT: Provides criteria and controls to the test process and data analysis to improve data quality and reduce data uncertainty.

CONTENT: Limited application of procedure to complete vehicles, detailed test constraints, multiple test processes w/wo control vehicle, data quality control and reporting, includes after treatment fuel consumption.

J1321 LINK: Provides guidelines and criteria for the application of J1321 and J1526.
WRAP UP
Questions?
Submit follow-up questions to:

Jana Wright, SAE Standards Specialist at jwright@sae.org or 248-273-2456