INTERNATIONAL

SURFACE VEHICLE RECOMMENDED PRACTICE

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Adaptive Cruise Control (ACC) Operating Characteristics and User Interface

RATIONALE

This Surface Vehicle Recommended Practice contains the basic minimum recommended practices for the control strategy, functionality, driver interface elements, system diagnostics, and vehicle response to recognized failure for Adaptive Cruise Control (ACC) systems, with a focus on the ACC system operating characteristics and elements of the user interface. ACC is intended to provide longitudinal control of equipped vehicles under free-flowing traffic conditions. Both (i) ISO 15622 – *Transport information and control systems – Adaptive Cruise Control systems – Performance requirements and test procedures* [2009-08-28] and (ii) ISO 22179 – *Intelligent Transport Systems – Full Speed Range Adaptive Cruise Control Systems – Performance requirements and test procedures* [2007-06-14] documents were reviewed. Updates in this version of J2399 represent a consensus, based on (i) the latest publications and references pertaining to ACC, (ii) a service brake definition, (iii) clearer explanations and/or definitions of ACC operational characteristics, and (iv) possible ACC test procedures.

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1. SCOPE

Adaptive cruise control (ACC) is an enhancement of conventional cruise control systems that allows the ACC-equipped vehicle to follow a forward vehicle at a pre-selected time gap, up to a driver selected speed, by controlling the engine, power train, and/or service brakes. This SAE Standard focuses on specifying the minimum requirements for ACC system operating characteristics and elements of the user interface. This document applies to original equipment and aftermarket ACC systems for passenger vehicles (including motorcycles). This document does not apply to heavy vehicles (GVWR > 10,000 lbs. or 4,536 kg). Furthermore, this document does not address other variations on ACC, such as "stop & go" ACC, that can bring the equipped vehicle to a stop and reaccelerate. Future revisions of this document should consider enhanced versions of ACC, as well as the integration of ACC with Forward Vehicle Collision Warning Systems (FVCWS).

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 15622:2010 Intelligent transport systems - Adaptive Cruise Control Systems - Performance Requirements and Test Procedures

ISO 22179:2009 Intelligent Transport Systems - Full Speed Range Adaptive Cruise Control Systems - Performance Requirements and Test Procedures

ISO 2575:2010/Amd 1 Road vehicles - Symbols for controls, indicators and tell-tales

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

Bareket, Z., Fancher, P., Peng, H., Lee, K., and Assaf, C. (2003). Methodology for Assessing Adaptive Cruise Control Behavior. *IEEE Transactions on Intelligent Transportation Systems*, *4*(3). pp. 123-131.

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Koziol, J., Inman, V., Carter, M., Hitz, J., Najm, W., Chen, S., Lam, A., Penic, M., Jensen, M., Baker, M., Robinson, M., Goodspeed, C. (1999). *Evaluation of the Intelligent Cruise Control System Volume 1 – Study Results* (DOT-VNTSC-NHTSA-98-3 & DOT HS 808 969). Cambridge, MA: John A. Volpe National Transportation Systems Center, U.S. Department of Transportation.

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Lee, K. and Peng, H. (2004). Identification and Verification of a Longitudinal Human Driving Model for Collision Warning and Avoidance Systems. *International Journal of Vehicle Autonomous Systems, 2*(1-2). pp. 3-17.

Lin, T.W., Hwang, S.L., and Green, P. (2009). Effects of Time-Gap Settings of Adaptive Cruise Control (ACC) on Driving Performance and Subjective Acceptance in a Bus Driving Simulator. *Safety Science*, *47*(5). pp. 620-625.

Moon, S., and Yi, K. (2008). Human Driving Data-Based Design of a Vehicle Adaptive Cruise Control Algorithm. *Vehicle System Dynamics*, *46*(8). pp. 661-690.

Najm, W., Stearns, M., Howarth, H., Koopmann, J., and Hitz, J. (2006). *Evaluation of an Automotive Rear-End Collision Avoidance System* (DOT-VNTSC-NHTSA-06-01 & DOT HS 810 569). Cambridge, MA: John A. Volpe National Transportation Systems Center, U.S. Department of Transportation.

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3. DEFINITIONS

For the purpose of this document, the following definitions apply.

3.1 ADAPTIVE CRUISE CONTROL (ACC)

Enhancement to conventional cruise control systems (see conventional cruise control) that allows the subject vehicle to follow a forward vehicle at a pre-selected time gap by controlling the propulsion system and/or the service brake, up to a maximum speed set by the driver.

3.2 CLEARANCE (c)

Distance from the forward vehicle's trailing surface to the subject vehicle's leading surface. See Figure 1.

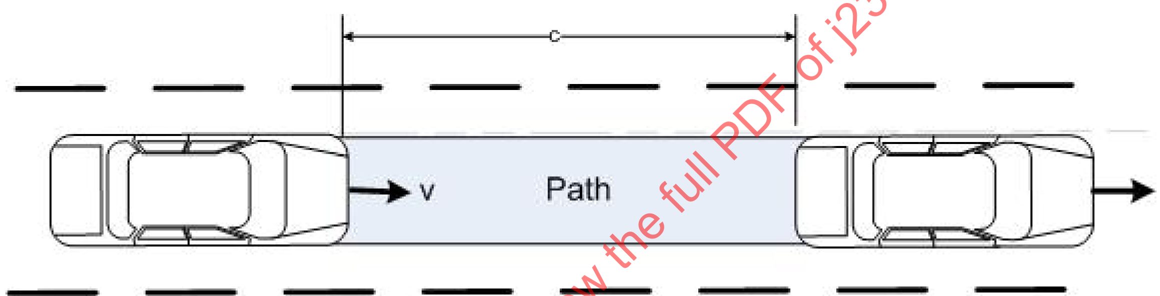

FIGURE 1 - CLEARANCE

NOTE: Clearance is also sometimes referred to as following distance or following gap or distance gap.

3.3 CONVENTIONAL CRUISE CONTROL (CCC)

System capable of controlling the speed of a vehicle, as selected by the driver without consideration of in-path (see Figure 1) forward vehicles.

3.4 FORWARD VEHICLE

Vehicle immediately in front of, moving in the same direction, and traveling on the same roadway path (see Figure 1) as the subject vehicle.

3.5 FREE-FLOWING TRAFFIC

Smooth flowing, light-to-heavy traffic, excluding stop and go and emergency braking situations.

3.6 MAXIMUM SELECTABLE TIME GAP (τ_{max})

Largest available value of time gap, τ, that can be selected by the driver, in systems that permit driver selection of time gap.

3.7 MAXIMUM SET AND OPERATING SPEED (v_{max})

Maximum speed at which a driver can set (engage) and operate a cruise control system (adaptive or conventional).

3.8 MINIMUM OPERATING SPEED FOR AUTOMATIC POSITIVE ACCELERATION (v_{low})

Minimum speed below which ACC will not engage, resume, or positively accelerate.

3.9 MINIMUM SET SPEED (v_{set_min})

Lowest speed at which a cruise control system (adaptive or conventional) can be engaged by the driver.

3.10 MINIMUM STEADY-STATE FOLLOWING TIME GAP (τ_{min})

Minimum value of time gap, τ, that can be set either by the driver or the ACC system.

3.11 MAXIMUM SENSOR RANGE (d_{max})

Maximum distance the ACC system sensor can reliably measure to a forward vehicle.

3.12 SERVICE BRAKE

The primary vehicle component that develops forces intended to slow the vehicle motion.

NOTE 1: From Federal Motor Vehicle Safety Standards 49 CFR Part 571.3 Definitions: Service brake means the primary mechanism designed to stop a motor vehicle.

NOTE 2: From SAE J1100 (6) Revised 2009-11: The term brake or brake pedal refers to the service brake in all instances.

NOTE 3: From SAE J656 (3.92) Issued 1988-04: Service Brake System – The brake system generally used for retarding or stopping a vehicle.

3.13 SET SPEED

Desired travel speed, determined by the driver, for an ACC or conventional cruise control system.

3.14 STEADY STATE

Condition whereby the value of the described parameter does not change with respect to time, distance, etc.

NOTE: A vehicle traveling at constant speed can be described as traveling at steady-state speed.

3.15 SUBJECT VEHICLE

Vehicle equipped with the ACC system in question.

3.16 SYSTEM STATE

Particular operating mode of an ACC system.

3.17 TIME GAP (τ)

Time interval for traveling a distance equal to the clearance ‘c’ to the forward vehicle, given the current vehicle speed. See Figure 2.

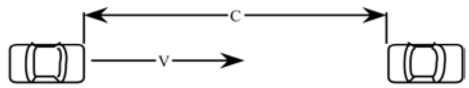

FIGURE 2 - TIME GAP

NOTE 1: Time gap is related to vehicle speed 'v' and clearance by: $\tau = c/v$.

NOTE 2: Time gap is also sometimes referred to as following time gap.

4. REQUIREMENTS

4.1 Sensor Capability

4.1.1 Response to Motorized Vehicles

ACC systems should be capable of responding to all licensable motorized road vehicles, including motorcycles, intended for use on public roads.

4.1.2 Response to Stationary Vehicles

Drivers shall be informed, at a minimum in the vehicle operator's instructions, if the ACC system does not respond to stationary vehicles.

4.2 Operational Characteristics

4.2.1 Selection of Set and Operating Speed

4.2.1.1 Driver Selection of Set Speed

ACC systems shall provide a means for the driver to select a desired set speed.

4.2.1.2 Minimum Set Speed

If vehicles are equipped with both conventional cruise control and ACC, the two systems should have the same minimum set speed (v_{set_min}). The minimum set speed (v_{set_min}) should not be less than 7.0 m/s (15 mph), ±10%.

4.2.1.3 Minimum Operating Speed for Automatic Positive Acceleration

The minimum operating speed (v_{low}), from which automatic positive acceleration can be achieved, shall not be less than 5.0 m/s (11 mph), ±10%.

4.2.1.4 ACC Operation Below Minimum Operating Speed

The ACC system may continue to decelerate below the minimum operating speed for automatic positive acceleration. If an ACC system disengages to stand-by (see Section 4.3.3) after the minimum operating speed is reached, the driver shall be informed. There shall not be an instantaneous release of the deceleration force when standby mode is initiated.

4.2.1.5 Maximum Set and Operating Speed

The maximum ACC operating speed (v_{max}) should be no greater than the limit determined by the maximum sensor range (d_{max}) divided by the current selected time gap (τ), where:

$$v_{max} = d_{max}/\tau \qquad \text{(Eq. 1)}$$

See ISO 15622 for compliance test procedure.

4.2.2 Selection of Set and Operating Time Gap

4.2.2.1 Minimum Steady-State Following Time Gap

The minimum steady-state following time gap (τ_{min}) shall not be less than 1.0 s. The actual time gap value may temporarily fall below τ_{min} as the subject vehicle responds to a forward vehicle.

NOTE: A steady-state following time gap of less than 1.0 s may be used if the manufacturer includes additional active safety features (such as forward collision mitigation braking, advanced braking, etc.) or more advanced tracking or communication capabilities to support braking, and the overall system performance can accommodate the shorter following time gaps.

4.2.2.2 Time Gap Settings

If the time-gap setting is adjustable by the driver, at least one value of time gap (τ) that is 1.5 s, or greater, shall be provided.

NOTE: If the system is not adjustable by the driver, then the time gap setting shall be greater than or equal to the minimum steady-state following time gap.

4.2.2.3 Default Time Gap

If the ACC system does not retain the last selected time gap after it is switched to ACC OFF, the system shall default to a time gap setting of 1.5 s or greater.

4.2.3 Longitudinal Deceleration Capability Notification

The driver shall be informed, at a minimum in the operator's manual, of the system performance limitations, such as a general description of the deceleration capability of the ACC system.

4.2.4 Illumination of Stop Lamps

4.2.4.1 Stop lamps shall be illuminated whenever the service brake is automatically applied by the ACC system.

NOTE: From Federal Motor Vehicle Safety Standards 49 CFR Part 571.108 Lamps, Reflective Devices, and Associated Equipment, TABLE I–a—REQUIRED LAMPS AND REFLECTIVE DEVICES: "Stop Lamps…Must be activated upon application of the service brakes."

4.2.4.2 Stop lamps should be illuminated whenever the ACC vehicle speed is decreasing at a rate that generally exceeds the rate of deceleration that can be achieved by simply releasing the accelerator pedal.

NOTE: This SAE recommendation is allowed by the Federal Motor Vehicle Safety Standards 49 CFR Part 571.108 Lamps, Reflective Devices, and Associated Equipment, TABLE I–a—REQUIRED LAMPS AND REFLECTIVE DEVICES: "Stop Lamps…May also be activated by a device designed to retard the motion of the vehicle."

4.2.4.3 Stop lamps should remain illuminated for a reasonable period of time to prevent flicker during short duration ACC brake commands.

4.2.5 Curve Capability Notification

The driver shall be informed, at a minimum in the operator's manual, that the ACC system's ability to follow preceding vehicles may be limited in a curve. Additionally, the vehicle detected signal, as described in Section 4.4.2 of this document, shall provide the driver with feedback when the forward vehicle can no longer be tracked through a curve.

4.2.6 ACC Operation with ABS and Traction Control

Automatic brake activation shall not lead to locked wheels for periods longer than anti lock devices (ABS) would allow. Automatic power control by ACC shall not lead to excessive positive wheel slip for periods longer than traction control would allow.

4.3 Operating State Transitions

4.3.1 ACC System States

At a minimum, ACC standby and ACC engaged system states shall be provided.

4.3.1.1 ACC Off

In this state direct access for activation of 'ACC engaged state' shall be disabled. To activate the ACC engaged state, the ACC system must be in the stand-by state.

4.3.1.2 ACC Stand-By

In this state the ACC system is ready for manual engagement by the driver or automatic re-engagement by the ACC controller (such as in the case of a temporary accelerator pedal override). No active control of speed and/or time gap shall be provided by the ACC system in this state.

4.3.1.3 ACC Engaged

In this state the ACC system shall actively control speed and/or time gap. The transition between speed control and time gap control shall be automatic.

4.3.2 ACC Disengagement via Service Brake

Any manually-initiated service-brake application by the driver while the ACC system is active, including brake "taps," shall lead to ACC system disengagement (stand-by). Automatic re-engagement by the ACC system shall not occur following driver-initiated disengagement via the service brake. With any simultaneous service brake and accelerator pedal applications, the service brake application shall take precedence.

4.3.3 ACC Disengagement via Accelerator

The driver shall always be permitted to override the engine power control and automatic braking via the accelerator pedal. Application of the accelerator pedal shall temporarily place an engaged ACC system in stand-by state, and under most conditions the ACC system should automatically transition back to the ACC engaged state when the accelerator pedal is released.

If the ACC system remains in a stand-by state upon release of the accelerator pedal, an alert (auditory, visual and/or haptic) shall inform the driver to take manual control. This alert may be provided before accelerator pedal release if the ACC system has determined it will remain in stand-by state.

4.3.4 ACC Disengagement via Clutch

For vehicles equipped with manual transmissions, ACC systems shall either temporarily suspend operation but remain in the ACC active state or transition to ACC stand-by if the driver depresses the clutch pedal. The ACC system may automatically transition back to the ACC engaged state when the clutch pedal is released by the driver. For systems incorporating the service brakes, automatic braking may be continued during use of the clutch pedal. After the ACC system releases the brakes, the system may either resume ACC control or transition to ACC stand-by in response to the driver depressing the clutch pedal.

4.3.5 Automatic Transition between ACC and Conventional Cruise Control

There shall be no automatic switching between ACC and conventional cruise control systems.

4.4 Displays

4.4.1 Time Gap Selection Indicator

For ACC systems that permit the driver to set a variable time gap, the selected time gap setting should be available to be displayed to the driver while the ACC is engaged. At a minimum, this information shall be displayed when the ACC system is first activated and when a different time gap is selected by the driver. The time gap display may be temporarily overridden while the driver is adjusting the set speed, adjusting the settings on other systems, or when higher priority messages take precedent.

4.4.1.1 Set Speed Indicator

At a minimum, the set speed shall be displayed when the driver engages the ACC system and when the driver selects a new set speed. The ACC set speed should generally be displayed when the ACC is not in standby mode and is actively controlling the speed and/or time gap of the vehicle.

4.4.2 Vehicle Detected Signal

A "vehicle-detected" indicator, indicating that the ACC system has detected a forward vehicle, shall be provided when the ACC system is in the engaged state.

4.4.3 System Malfunction Signal/Warning

Indication of ACC system malfunction shall be provided to the driver if the ACC system shuts down (relinquishes control) from a stand-by or engaged state or if the driver manually tries to engage a malfunctioning ACC system from the OFF state. The malfunction indication should remain active until the ACC system is switched OFF. If a symbol is used, this symbol should be a standardized symbol in accordance with ISO 2575 (see Appendix B).

4.4.4 Conventional Cruise Control and ACC Indicators

If both conventional cruise control (CCC) and ACC systems are offered on the same vehicle, there shall be separate and clear indications to the driver which, if either, system is engaged. If symbols are used, they should be standardized in accordance with ISO 2575 (see Appendix B).

4.4.5 Manual Control Alert

Either an auditory or haptic alert shall inform the driver to take control, and a visual alert shall supplement the auditory or haptic alert to provide context and explain the meaning of the alert to the driver:

a. Whenever there is an automatic, system-initiated transition (i.e., not triggered by the driver) from ACC engaged to manual control.

b. To indicate when the driver may need to intervene on automatic control and take manual control of the vehicle.

NOTE:Alternatively part b of this requirement may be replaced by a Forward Collision Warning alert. (See SAE J2400.)

4.5 Performance Evaluation Test Methods

The test procedure described in Appendix A should be used to verify the control functionality of the ACC system. The purpose of the procedure is to characterize performance of the entire ACC system including the sensor, control algorithm, and vehicle platform. Graphs and tables showing clearance, velocity, and time gap as functions of time should be recorded and saved for use in verifying test performance.

NOTE: The reader is also referred to ISO 15622 Sections 7.3 and 7.4 for additional test methods including a maximum detection range test and a target discrimination test.

4.5.1 Minimum Available (or Fixed) Time Gap Test

Perform the test procedure described in Appendix A using the smallest available time gap setting to ensure that the minimum steady-state time gap is greater than or equal to 1.0 s. Although the test is nominally performed with a forward vehicle traveling at approximately 97 km/h (60 mph), the test should also be performed at the minimum and maximum ACC operating speeds to ensure that the minimum 1.0 s time gap value is met throughout the operating speed range of the ACC system.

4.5.2 Maximum Available Time Gap Test

If the system allows multiple driver-selectable time gap settings, perform the test procedure described in Appendix A using the largest available time gap setting to ensure that there is a functional time gap setting that is greater than or equal to 1.5 s. Although the test is nominally performed with a forward vehicle traveling at approximately 97 km/h (60 mph), this test should also be performed at the minimum and maximum ACC operating speeds to ensure that the maximum available steady-state time gap meets or exceeds 1.5 s throughout the operating speed range of the ACC system.

5. NOTES

5.1 Marginal Indicia

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

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