SAE International™ SURFACE VEHICLE STANDARD

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Adaptive Cruise Control (ACC) Operating Characteristics and User Interface

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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 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 commercial vehicles. Furthermore, this document does not address future 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 Collision Warning (FCW).

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 ISO Publications—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 15622—Transport information and control systems—Adaptive cruise control systems—Performance requirements and test procedures.
ISO 2575:000/Amd1—Road vehicles—Symbols for controls, indicators and telltales.

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this specification.

2.2.1 UMTRI PUBLICATION—Available from UMTRI, RIPC, 2901 Baxter Road, Ann Arbor, MI 48109-2150. Email: umtridocs@umich.edu, 734-764-2171.

ACC Field Operational Test Fancher, P. S., Ervin, R. D., Sayer, J. R., Hagan, M., Bogard, S., Bareket, Z., Mefford, M. L., Haugen, J. (1998). Intelligent Cruise Control Field Operational Test (Final Report). (Report No. DOT HS 808 849). The University of Michigan Transportation Research Institute, Ann Arbor, MI.

***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 engine, powertrain, and/or the service brake.

3.2 Brake—Vehicle component that develops forces intended to slow the vehicle motion.

NOTE— For purposes of this document, transmission downshifting and retarders are treated as brakes.

3.3 Clearance (c)—Distance from the forward vehicle's trailing surface to the subject vehicle's leading surface. See Figure 1.

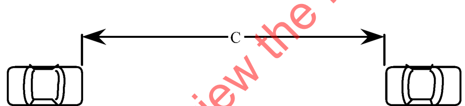

FIGURE 1—CLEARANCE

3.4 Conventional Cruise Control—System capable of controlling the speed of a vehicle, as selected by the driver.

3.5 Forward Vehicle—Vehicle immediately in front of, moving in the same direction, and traveling on the same roadway path as the subject vehicle.

3.6 Free-Fowing Traffic—Smooth flowing, light-to-heavy traffic, excluding stop and go and emergency braking situations.

3.7 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.

3.8 Maximum Set and Operating Speed (v_{max})—Maximum speed at which a driver can set (engage) and operate a cruise control system (ACC or conventional).

3.9 Minimum Operating Speed for Automatic Positive Acceleration (v_{low})—Minimum speed below which ACC will not engage, resume, or positively accelerate.

3.10 Minimum Set Speed (v_{set_min})—Lowest speed at which a cruise control system (ACC or conventional) can be engaged by the driver.

3.11 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.

3.12 Maximum Sensor Range (d_{max})—Maximum distance which the ACC system sensor can reliably measure to a forward 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 immediately forward vehicle, given the current vehicle speed. See Figure 2.

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

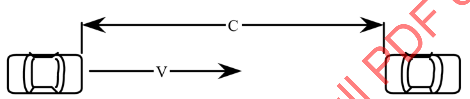

FIGURE 2—TIME GAP

4. Requirements

4.1 Sensor Capability

4.1.1 RESPONSE TO MOTORIZED VEHICLES—ACC systems shall 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 owner's manual, if the ACC system does not respond to stationary vehicles.

4.2 Operational Characteristics

4.2.1 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 be 11.2 m/s (25 mph), ±10%.

4.2.2 MINIMUM OPERATING SPEED FOR AUTOMATIC POSITIVE ACCELERATION—The minimum operating speed (v_{low}), from which automatic positive acceleration can be achieved, shall be 8.9 m/s (20 mph), ±10%.

4.2.3 ACC OPERATION BELOW MINIMUM OPERATING SPEED—The ACC system may continue to brake below the minimum operating speed. If an ACC system disengages to stand-by after the minimum operating speed is reached, the driver shall be informed (see 4.3.3). There shall not be an instantaneous release of the braking force.

4.2.4 MAXIMUM SET AND OPERATING SPEED—The maximum ACC operating speed (v_{max}) should be determined by the maximum sensor range (d_{max}) divided by the current selected time gap (τ), where:

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

See ISO 15622 for compliance test procedure.

4.2.5 MINIMUM STEADY-STATE FOLLOWING TIME GAP—The minimum steady-state following time gap (tmin) shall be no 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.

4.2.6 TIME GAP SETTINGS—At least one value of time gap (τ) that is 1.5 s, or greater, shall be provided.

4.2.7 LONGITUDINAL DECELERATION CAPABILITY NOTIFICATION—The driver shall be informed, at a minimum in the owner's manual, of the deceleration capability of the ACC system.

4.2.8 ILLUMINATION OF STOP LAMPS

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

4.2.8.2 Stop lamps should be illuminated whenever the ACC vehicle speed is decreasing at a rate of 2.4 km/h/s (1.5 mph/s) or greater as a result of decelerations produced by means other than application of the service brake. The stop lamps should remain illuminated at least until vehicle speed is decreasing by less than 1.6 km/h/s (1 mph/s).

4.2.8.3 Stop lamps should illuminate for a minimum of 0.5 s to prevent lamp flickering caused by short duration ACC brake commands.

4.2.9 CURVE CAPABILITY NOTIFICATION—The driver shall be informed, at a minimum in the owner's manual, of the ACC system's ability to follow preceding vehicles in a curve.

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. No longitudinal control 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.

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 should not occur following driver-initiated disengagement via the service brake. With any simultaneous 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 shall 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 can 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—In ACC systems that permit the selection of time gap, the selected time gap setting shall be displayed to the driver. At a minimum, this information shall be displayed when the ACC system is first activated and when a different time gap is implemented. The time gap display may be temporarily overridden while the driver is adjusting the set speed.

4.4.2 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 also be displayed when the ACC vehicle is accelerating to attain a set speed that is 8 km/h (5 mph) or greater than its current speed.

4.4.3 VEHICLE DETECTED SIGNAL—A “vehicle-detected” indicator, indicating that the ACC system has detected a forward vehicle, should be provided when the ACC system is in the engaged state.

4.4.4 SYSTEM MALFUNCTION SIGNAL/WARNING—The driver shall be informed immediately if, because of an ACC system malfunction, 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).

4.4.5 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).

4.4.6 MANUAL CONTROL ALERT—At a minimum, an alert (auditory, visual, and/or haptic) shall inform the driver to take control:

a. Whenever there is an automatic or system initiated transition 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. Alternatively 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 provide a checkout of the control functionality of the ACC system. The purpose of the procedure is to characterize performance of the entire ACC system that includes 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.

4.5.1 MINIMUM AVAILABLE 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—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.

PREPARED BY THE SAE SAFETY AND HUMAN FACTORS COMMITTEE

APPENDIX A

ACC SYSTEM CHARACTERIZATION PROCEDURE

A.1 Time Gap Test Description—This test procedure is a generic, fundamental task that an ACC system should perform associated with closing-in on a forward vehicle starting from a long range. The test procedure does not cover all aspects of ACC driving. However, it covers important situations and it provides a good basis for checking the performance of an existing ACC system with regard to its time gap settings.

The input to these tests is the speed of the forward vehicle. The results of the tests are based upon measurements of clearance (c) and velocity (v), where c = the range to the forward vehicle and v = the velocity of the ACC equipped vehicle. The computed quantity "Time Gap", symbolized as τ, is useful for interpreting results. The equation for τ is:

$$\tau = c/v \qquad \text{(Eq. A1)}$$

In steady following with $v \sim v_f$, τ should be approximately equal to the driver selected time gap (τ_{set}) used in the time gap controller. In the context of this test, the goal of the time gap control system is viewed as trying to cause τ to approach τ_{set}.

Each test examines the transition from (a) operating in a manner similar to that of a conventional cruise control, to (b) operating in a time gap control mode. When the forward vehicle is first detected, the ACC vehicle is using v_{set} and not τ_{set} to determine its speed. However, as the ACC vehicle closes in, the time gap controller is automatically activated. The ACC system slows the ACC equipped vehicle to match the speed of the forward vehicle and maintains a clearance determined by the pre-selected time gap (τ_{set}).

A.1.1 Initial Conditions

A.1.1.1 INITIAL CONDITION FOR THE SPEED OF THE FORWARD VEHICLE

v_f = 97 km/h (26.8 m/s) ± 3 km/h, or 60 mph (88 ft/s) ± 2 mph

A.1.1.2 INITIAL CONDITIONS FOR THE ACC VEHICLE

v_{set} =113 km/h or 70 mph
v = 113 km/h (31.4 ms) ± 5 km/h, or 70 mph (103 ft/s) ± 3 mph)
c > 107 m (350 ft)
τ set = τ min , or τ max

A.1.1.3 RUN CONDITIONS—Starting from the specified initial conditions, operate the ACC system until the following condition ($v \sim v_f$ and $c \sim \tau * v_f$) is established.

A.1.2 Example—τ_{set} = 1.4 s (implies c = 37.5 m at 96.6 km/h, or 123 ft at 60 mph)

A.1.2.1 EXAMPLE RESULTS—Typical results for this test are shown in Figure A1. The process of slowing from the ACC vehicle's initial velocity to v_f is relatively long (30 to 60 s). At the beginning of the sequence, before the system starts to respond to the forward vehicle, the vehicles are separated by more than 3.5 s, and τ decreases linearly. At about τ = 2.3 s, the time gap starts changing more slowly as it approaches the selected time gap τ_{set} = 1.4 s. Typical variations in speed and grade will cause time gap margin τ to be within 10% of τ_{set} when nominally steady following conditions are reached. Furthermore, this system tends to operate at 1.5 s rather than 1.4 s. In practice, the actual steady-state time gap is best described as 1.5 s in this case.