How Brakes Can Fail During a Sudden Acceleration Incident

by

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Abstract: NHTSA's 1989 report by Pollard and Sussman entitled "An Examination of Sudden Acceleration" (aka, the "Silver Book") defines sudden acceleration incidents (SAI) as "unintended, unexpected, high-power accelerations from a stationary position or a very low initial speed accompanied by an apparent loss of braking effectiveness". When Audi drivers in the 1980's reported that during their incidents the brakes lacked effectiveness, NHTSA tested the brakes under simulated conditions and found that they remained fully operable after the incidents. Therefore, NHTSA's report concluded that "no plausible mechanisms could be identified for temporary, self-correcting brake failure which are relevant to SAI". This led them to conclude that the cause of SAI in Audi 5000 vehicles was the driver confusing the accelerator pedal for the brake pedal when trying to stop the vehicle after the idle stabilizer initiated the SAI by suddenly opening to create an acceleration of less than 0.3 g for less than 2 seconds (excessive creep). In all subsequent cases of alleged sudden acceleration incidents, NHTSA has continued to deny petitions for an investigation of the vehicles involved by citing their 1989 conclusion that the driver confused the accelerator pedal for the brake pedal. This paper refutes NHTSA's 1989 conclusion by explaining how the brakes of the Audi 5000 appeared to lack effectiveness during the incidents while remaining fully operable after the incidents.

I. Introduction

Many drivers have reported that their brakes have failed during their sudden acceleration incident. Some have even reported that during their sudden acceleration incident the vehicle seemed to speed up when they pressed on the brake pedal. In nearly all of these incidents, examination of the brakes after the incident showed that the brakes remained fully functional after the incident. As a result, NHTSA concluded that the driver must have been pressing on the accelerator pedal instead of the brake pedal to cause the incident. Many drivers have disagreed with this conclusion because they are sure that they were pressing on the brake pedal during the incident and not on the accelerator pedal.[1] But NHTSA investigators countered that drivers must have been mistaken during the incident, and merely <u>believe</u> that they were pressing on the brake pedal while they were <u>really</u> pressing on the accelerator pedal. As a result of NHTSA's conclusion of pedal confusion -- starting with their 1989 report by Pollard and Sussman entitled "An Examination of Sudden Acceleration" (aka, the "Silver Book"), and repeated in all subsequent denials of driver petitions for vehicle investigations after sudden acceleration incidents -- all vehicle manufacturers and their lawyers, police investigators, media reporters, and nearly all commenters on internet discussion groups believe that sudden acceleration incidents are caused by pedal confusion, and not by a vehicle defect.

Attempts have been made to explain the drivers' perceptions of brake failure during a sudden acceleration incident by citing the temporary loss of the brake booster during the incident. This can occur when a vacuum-operated brake booster loses manifold vacuum because of repeated pumping of the brakes. This can cause a 4x to 5x increase in the required brake pedal force needed to stop the vehicle while leaving the mechanical brakes fully functional after the

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1. A few drivers have claimed to have evidence that their foot was on the brake pedal and not on the accelerator pedal because either they themselves observed their foot on the brake pedal during the incident or a passenger in the car observed that their foot was on the brake pedal during the incident.

incident. This might explain some incidents in which a weaker driver could not apply a sufficient braking force to stop a vehicle with a powerful engine that produces a lot of torque. However, this explanation does not apply to newer vehicles with electrically-powered brake boosters, such as electric vehicles, and to many new ICE vehicles. Although some sudden acceleration incidents may be explained by the time delay needed to apply the brakes after an increase in engine RPM occurs due to a defect, no one has been able to explain how the brakes can fail during a sudden acceleration incident and still remain operable after the incident.

II. Perceived Cause of Brake Failure

This author will now explain why some drivers perceive that the brakes have failed during a sudden acceleration incident and yet remain operable after the incident. The explanation is similar for both ICE vehicles and electric vehicles. But the explanation differs slightly in one detail for the two types of vehicles. We will start by explaining sudden acceleration in ICE vehicles.

In all ICE vehicles, both gasoline-powered and diesel-powered, engine torque varies with engine RPM as shown in Figure 1. Normal engine operation is shown in green. Normally, the driver starts from a stop by shifting the transmission into DRIVE and then pressing on the accelerator pedal to increase the throttle opening. This causes the engine RPM to increase and the engine torque to rise. The vehicle transmission starts out in the lowest forward gear, which produces the greatest torque to the drive wheels. The engine RPM's increase slowly because of the load placed on the engine by the drive train. As the engine RPM's slowly increase, the vehicle velocity increases, and the transmission shifts from the lowest gear into the next higher gear to keep the engine RPM's low while continuing to apply torque without going past the RPM at which the maximum torque occurs. This constrains operation along the green path shown in the figure, with the engine RPM's never exceeding the RPM at which the maximum torque occurs.

When the driver wants to slow down, he releases the accelerator pedal, which causes the throttle opening to decrease and the engine torque to decrease to its idle value. With the accelerator pedal released, the diver can then apply the brake pedal to slow the vehicle down even faster. When the brakes are applied, the brakes increase the load torque on the engine, which opposes the torque produced by the engine. This higher load torque causes the engine RPMs to decrease faster than if no brakes were applied, causing the torque produced by the engine to decrease faster. The driver perceives that applying the brakes causes the vehicle to slow down faster than with no brakes applied because the engine torque decreases in response to the brake torque being applied.

During sudden acceleration the engine RPM's increase suddenly without the driver stepping on the accelerator pedal. While the vehicle remains stationary, the engine RPM's increase rapidly from the idle value of 800 RPM along the red curve A to B to C as determined by the throttle opening.[2] The engine RPM's rise rapidly because there is no load on the engine due to delayed

2. The throttle opening during sudden acceleration is determined by the defect mechanism that causes the sudden acceleration. In most cases of sudden acceleration the throttle opening is 100%. But in the case of Audi 5000 vehicles between 1982 and 1987, the throttle appears to have remained closed during the sudden acceleration, with the idle air control valve suddenly opening to 100%. This would have corresponded to a throttle opening of about 20%.

engagement of the transmission gears, which leaves the gears temporarily in NEUTRAL.[3] About 1 to 3 seconds after the RPM's have started to rise, the engine operation reaches point C, at which the transmission gears finally engage into the lowest gear in DRIVE or REVERSE. The transmission drops into the lowest gear because the vehicle is usually not moving at the start of the sudden acceleration, or is moving only very slowly. This lowest gear puts a sudden load on the engine, causing the vehicle to lurch forward or backward. The vehicle continues to move forward or backward because the throttle remains open and not under the driver's control.

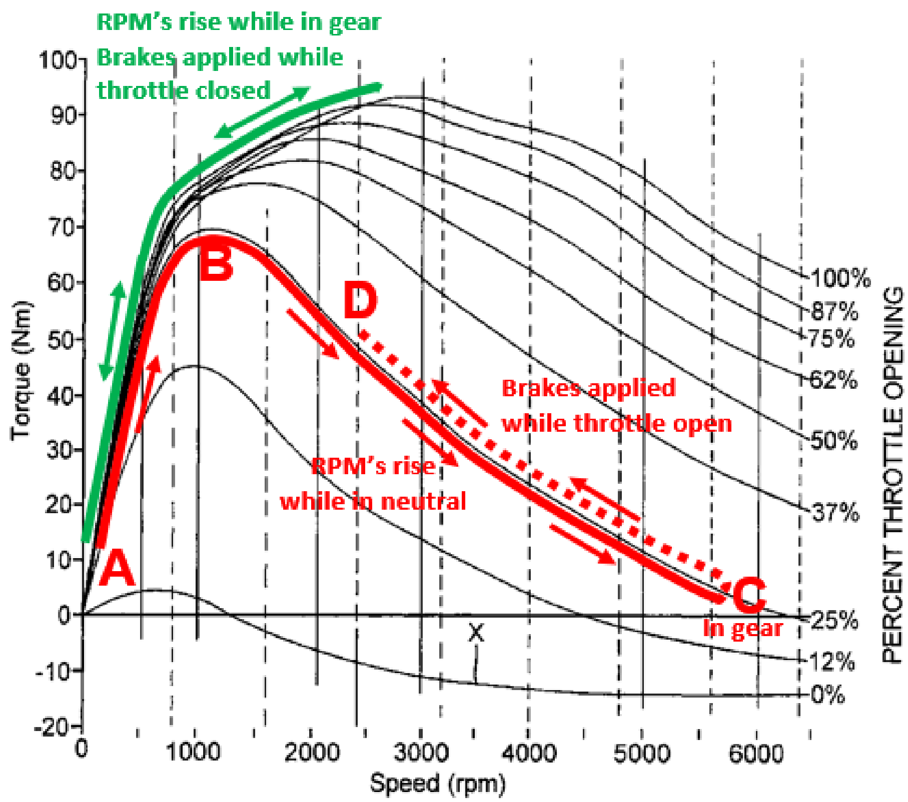

Figure 1. Engine torque versus engine speed for an ICE vehicle. During normal operation the engine follows the green curve to the left of the maximum points in the throttle opening curves. The engine torque increases as the engine RPM's increase and decreases as the engine RPM's decrease while braking with the accelerator pedal released and the throttle closed. During sudden acceleration, the engine RPM's increase rapidly following the red curve while the transmission remains in neutral due to delayed engagement. At point C the transmission drops into the lowest gear to begin vehicle motion. When the brakes are applied during sudden acceleration, the engine torque increases as the engine RPM's decrease because of the increased load on the engine produced by the brakes as a result of the engine operating to the right of the maximum torque position while the throttle remains open. The resulting increase in engine torque counters the braking torque, giving the driver the impression that the brakes are failing. In vehicles with engines that produce a lot of torque the driver may even perceive that the vehicle speeds up as the driver presses on the brake pedal during sudden acceleration.

3. For a discussion of delayed engagement and how it operates in various transmissions, see the author's paper entitled "Delayed Engagement as a Contributor to SUA" found at https://www.autosafety.org/dr-ronald-a-belts-sudden-acceleration-papers/. The frequency of sudden acceleration incidents seems to be higher in vehicles that have delayed engagement problems.

When the driver applies the brakes to try to stop the sudden acceleration, the load on the engine increases further, causing the engine RPM's to decrease. But as the engine RPM's decrease, the engine torque <u>increases</u> as a result of operating between points C and D to the right of the curve maximum where the curve slopes upward with decreasing engine RPM's. If the increase in the engine torque is low, then the increase in engine torque opposes or neutralizes the applied braking torque, causing the driver to perceive that the brakes are less effective or have failed completely. If the increase in the engine torque is higher than the applied braking torque because of a powerful engine, then the increase in engine torque causes the vehicle to accelerate as the driver applies the brakes. This is the reason many drivers involved in sudden acceleration incidents say that the brakes have failed or that pressing on the brake pedal caused the vehicle to accelerate. It is the perception of the driver-- resulting from the vehicle acceleration-- that the brakes are failing, and not the actual failing of the brakes. This perception of brake failure is correct because while the engine is operating to the right of the maximum RPM value, the engine torque <u>increases</u> as the engine RPM's decrease when the brakes are applied. This increase in engine torque counters the applied braking torque, making the driver perceive that the brakes are ineffective. The harder one presses on the brake pedal, the faster the engine RPM's decrease and the faster the engine torque increases to oppose the brake torque or to cause the vehicle to accelerate.

In vehicles powered by electric drive motors, the motor torque varies with motor RPM as shown in Figure 2. The torque in the base region varies with the battery current as controlled by the driver pressing on the accelerator pedal, and remains constant as the motor RPM's increase up to the base speed of around 2000 RPM. At motor RPM's higher than the base speed the drive motor torque decreases with increasing motor RPM's.

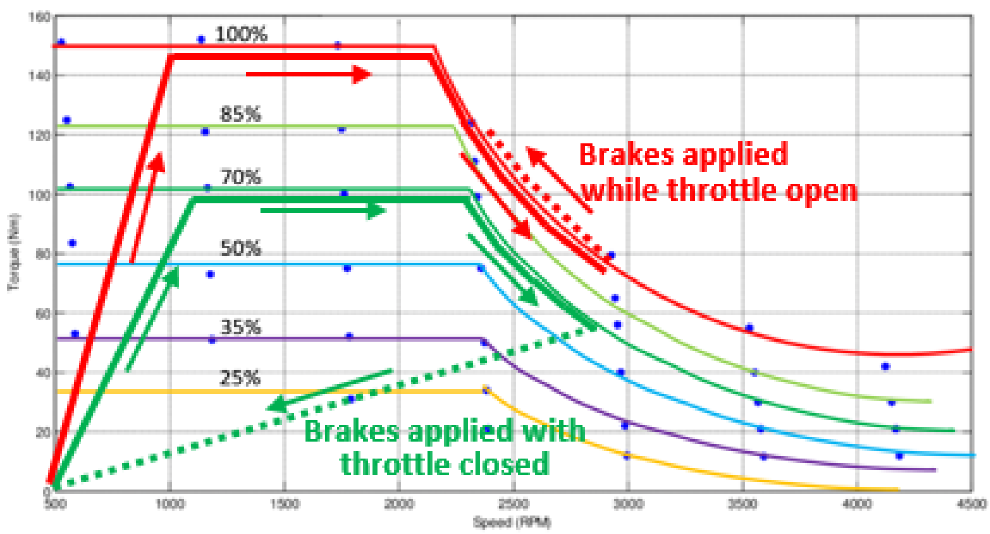

Figure 2. Motor torque versus motor speed for the drive motor of an electric vehicle. During normal operation the drive motor follows the green curve, causing the motor torque to decrease as the motor RPM's decrease while braking with the accelerator pedal released and no current applied to the motor. During sudden acceleration the motor follows the red curve, causing the motor torque to increase as the motor RPM's decrease while braking as current continues to be applied to the motor.[Endnote 1] The increased motor torque counters the braking torque, giving the driver the impression that the brakes are failing.

In some electric vehicles the drive wheels are directly connected to the drive motor without a geared transmission. In these vehicles, the vehicle speed is directly proportional the motor RPM as shown in Figure 3. This difference in drive train design causes the following differences between ICE vehicles and electric vehicles during sudden acceleration:

1) Increase in engine RPM's during sudden acceleration. In ICE vehicles, during sudden acceleration the engine RPM's increase while the transmission remains in neutral as a result of delayed engagement. This causes the engine RPM's to increase suddenly within less than 1-3 seconds because there is no load torque on the engine as the RPM's increase. In electric vehicles with direct drive there is no delayed engagement of the transmission gears. Instead, during sudden acceleration the motor RPM's increase while the drive train remains connected to the drive motor. This causes the motor RPM's to increase more slowly because the load torque from the drive train is applied to the drive motor as the RPM's increase. The vehicle speed in some electric vehicles can still increase quite rapidly as a result of the high battery currents produced.
2) Braking during sudden acceleration. In ICE vehicles, during sudden acceleration when the brakes are applied, the engine RPM's decrease because of the increased brake load on the engine being applied. But the effect on the vehicle speed depends on the total torque being applied to the drive wheels, which depends on the engine torque minus the braking torque. If the engine torque increases faster than the braking torque while the engine RPM's decrease during braking, then the vehicle speed may increase during braking instead of decreasing. In electric vehicles that have a direct connection of the drive motor to the drive wheels, the vehicle speed is always directly proportional to the drive motor speed. During sudden acceleration, when the brakes are applied to this type of vehicle, the motor torque will increase when the vehicle speed exceeds the base speed of approximately 70 to 90 km/hr (45 to 55 mi/hr). This increase in motor torque will cause the vehicle speed to decrease more slowly while braking during sudden acceleration, but will never result in the vehicle speed increasing while braking during sudden acceleration.

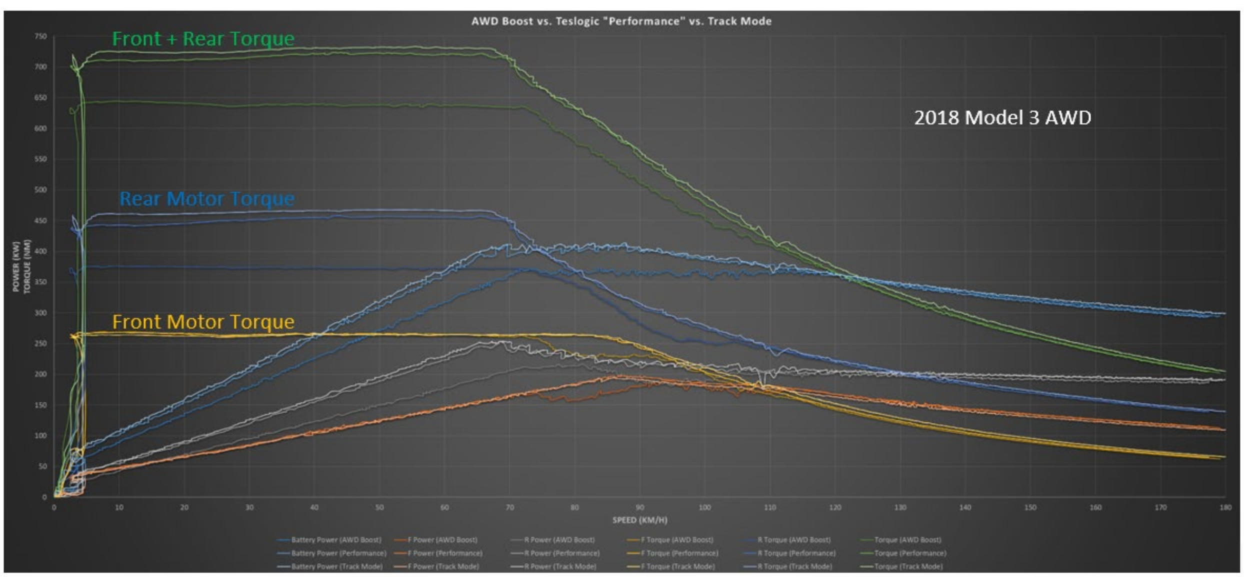

Figure 3. Motor torque versus vehicle speed for the two drive motors of a 2018 Model 3 Tesla with AWD. Only the maximum torques (100% throttle) are shown. Lower torques are obtained by using lower accelerator pedal settings that apply proportionally lower currents to the motors.

III. Testing the Brakes During a Simulated Sudden Acceleration.

NHTSA's 1989 report by Pollard and Sussman entitled "An Examination of Sudden Acceleration" (aka, the "Silver Book") contains a section E on testing the brakes of two Audi 5000 vehicles and several other vehicles during a simulated sudden acceleration. Brakes were tested under the following conditions:

1) Test Series 4 (With the vehicle stopped, shift to DRIVE then open throttle wide open. Apply brakes as soon as one can with throttle <u>remaining wide open until stopped</u> at 60, 100, and 150 lbs force and measure the time to stop and the total distance travelled with each force).
2) Test Series 5 (Same as Series 4 but throttle closed during the stop),.
3) Test Series 6 (With the vehicle stopped, shift to DRIVE then simulate a vacuum pump/dump valve C/C failure. <u>After the simulated C/C failure is applied</u>, apply the brakes as soon as one can <u>until stopped</u> at 60, 100, and 150 lbs force and measure the time to stop and the total distance travelled with each force).
4) Test Series 7 (With the vehicle stopped, actuate RESUME set at 65 mph in DRIVE to simulate a minimum speed circuit fault. Approximately 1 and 2 seconds after the RESUME has been applied, apply the brakes with pedal forces of approximately 60, 100, and 150 lb for each series and measure the time to stop and the total distance travelled with each force).
5) Test Series 8 (With the vehicle stopped, start the cruise control pump by shorting it to ground with the dump valve plugged. Then measure the minimum the brake pedal force (needed to shift out of Park and then maintained after shifting to Drive) to prevent the cruise control from causing the vehicle to move).
6) Test Series 9 (Measure the stopping distance and the pedal force needed to stop from 30 mph with the throttle closed during the stop). Test in both Drive and Reverse.
7) Test Series 10 (Measure the stopping distance and the pedal force needed to stop from 30 mph with the throttle wide open during the stop). Test in both Drive and Reverse.
8) Test Series 11A (Measure the stopping distance and the pedal force needed to stop from 30 mph with a with the throttle closed (normal) and with a 0.33 g (10.7 ft/sec/sec) deceleration). Test in both Drive and Reverse.
9) Test Series 11B (Measure the stopping distance and the pedal force needed to stop from 30 mph with a with the throttle held wide open and with a 0.33 g (10.7 ft/sec/sec) deceleration). Test in both Drive and Reverse.
10) Test Series 11C. (Measure the stopping distance and the pedal force needed to stop from 30 mph with the throttle wide open and the same braking force as applied in the original normal stop). Test in both Drive and Reverse.

Note that all of these tests on ICE vehicles were done while the engine was operating in the green region of Figure 1. Therefore, they did not simulate the case when the vehicle is operating in the red region of Figure 1, which is the case when the engine torque increases as the brakes are being applied while stopping during sudden acceleration with the transmission in the lowest gear. This is the case that causes the drivers to perceive that the brakes are failing because the engine torque increases in response to the brake torque being applied, which does not happen in the green region. Therefore, these tests failed to reproduce how the Audi 5000 vehicles really behaved during the original sudden acceleration incidents and what the drivers of these vehicles perceived as a result.

As a result of these incorrect tests, NHTSA concluded that when Audi drivers stated that the brakes seemed to fail during their sudden acceleration incidents, or even that the vehicle seemed to speed up in response to stepping on the accelerator pedal, that the drivers were mistaken about the position of their foot during the incidents. Therefore, based on test results showing that the brakes remained operable after the incidents, NHTSA concluded that the drivers had unknowingly stepped on the accelerator pedal instead of the brake pedal to cause the sudden acceleration incidents. And in all subsequent petitions for investigations of vehicles in sudden acceleration incidents over the past thirty years, NHTSA has continued to deny the petitions based on these same incorrect test results.

The brake test that should have been done is to first operate the engine in the red region by raising the engine speed above the RPM at which the maximum torque is produced while the transmission remains in the lowest gear in DRIVE.[4] This can be done by raising the engine RPM's while in NEUTRAL to some RPM above the RPM at which the maximum torque occurs, after which the transmission is shifted into LOW gear. Then, while the throttle continues to be applied, the brakes should be applied and the brake pedal force measured. In this case, one will find that the engine torque increases as the brake pedal force is applied to stop the vehicle, requiring a higher brake pedal force to stop the vehicle while operating in the red region. This is the cause of the perceived brake failure reported by many drivers during sudden acceleration incidents.

This increase in brake pedal force needed to stop the vehicle as the engine RPM decreases constitutes direct evidence that that the throttle remained open while the driver was applying force to the brake pedal during the Audi 5000 sudden acceleration incidents. Therefore, this provides direct evidence that the Audi drivers had their foot on the brake pedal during their sudden acceleration incidents (as they steadfastly maintained), and refutes NHTSA's conclusion that the drivers unknowingly stepped on the accelerator pedal instead of the brake pedal to cause the Audi sudden acceleration incidents. This same explanation applies to nearly all subsequent petitions to NHTSA for investigations of vehicles in sudden acceleration incidents over the past thirty years, which NHTSA has continued to deny based on their conclusion in the Audi investigation that the drivers stepped on the accelerator pedal instead of the brake pedal to cause the sudden acceleration incidents.

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4. Some readers may argue that the RPM's created by the idle stabilizer in an Audi 5000 vehicle are not high enough to achieve operation in the red region of Figure 1. However, these readers should consult Figure B-4 on page B-5 in Appendix H of the Pollard and Sussman report, which shows the following figure:

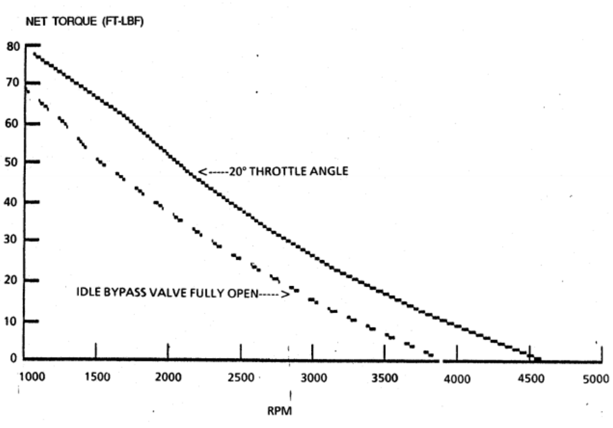

FIGURE B-4. NET ENGINE TORQUE (WARM)

Note that the engine torque in this figure decreases with increasing RPM's, implying that the engine is operating in the red region of Figure 1 when the idle stabilizer valve is fully open. This figure would be more recognizable if it did not omit the 0 to 1000 RPM region in which the engine torque increases with increasing RPM's, which includes the green region of Figure 1. It should also be noted that a turbocharger causes the peak RPM value to decrease compared to the peak RPM value of a non-turbocharged Audi 5000 engine.

IV. Conclusion

NHTSA's 1989 report by Pollard and Sussman entitled "An Examination of Sudden Acceleration" (aka, the "Silver Book") concluded that "no plausible mechanisms could be identified for temporary, self-correcting brake failure which are relevant to SAI". This paper, on the other hand, explains how drivers can perceive that the brakes have failed during a sudden acceleration incident and yet remain operable after the incident. Therefore, this paper explains how NHTSA's conclusion regarding brake failure in their 1989 report is incorrect. It further explains how the brake tests described in NHTSA's 1989 report failed to simulate properly the engine torque produced during a sudden acceleration incident in an Audi 5000 vehicle, and describes a brake test that should have been done that would have found a mechanism for a "temporary, self-correcting brake failure which is relevant to SAI".

NHTSA's failure to find this brake failure mechanism played a critical role in forming their conclusion that the only alternative for explaining Audi 5000 sudden acceleration incidents in which drivers claimed that the brakes appeared to fail was that the drivers unknowingly stepped on the accelerator pedal instead of the brake pedal to cause the sudden acceleration. And since NHTSA has continued to deny nearly all subsequent petitions for investigations of vehicles in sudden acceleration incidents over the past thirty years based on this conclusion in the Audi investigation, it implies that their denial of all these petitions is in error. Therefore, NHTSA is urged to accept the petitions that are currently pending for investigation of sudden acceleration in many vehicles, considering that "unknowingly stepping on the accelerator pedal instead of the brake pedal" may be a valid explanation for the cause of sudden acceleration in some sudden acceleration incidents, but not in all sudden acceleration incidents. NHTSA's denials of petitions for investigation of sudden acceleration in many vehicles over the past thirty years should also be reviewed.

Endnote 1. This is the case when sudden acceleration is caused by a temporary voltage dip in the 5V supply to the accelerator pedal sensor, which causes the digitized accelerator pedal sensor reading to increase while the analog accelerator pedal sensor output remains at 0% because the accelerator pedal is released. This is explained further in the paper entitled "*A Cause of SUA Common to All Vehicles with Electronic Throttles – 7/20/24*" by this author, available at https://www.autosafety.org/dr-ronald-a-belts-sudden-acceleration-papers/. Sudden acceleration can also be caused by a temporary voltage dip in the 12V supply to the high voltage sensor, which changes the operating point of the control system for the drive motor, causing the control system to operate in the field weakening region instead of the base region. In this case, the voltage dip causes motor operation in Figure 2 to jump suddenly from a point on the red curve in the base region near zero torque to a point on the red curve in the field weakening region at the same torque without increasing the torque to 100%. This is explained further in the paper entitled "*A Cause of Sudden Acceleration in Battery Powered Electric Vehicles*" by this author, available at https://www.autosafety.org/dr-ronald-a-belts-sudden-acceleration-papers/.