

Brake Effectiveness During Sudden Unintended Acceleration

By Dr. Ronald A. Belt
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It is often claimed by skeptics of sudden acceleration that manufacturers always design their cars so that “the brakes will always overcome the engine”. Automobile publications like Motor Trend magazine, Car and Driver magazine, Edmunds, blog writers, NHTSA and even some auto manufacturers all claim that this is true. But these same skeptics never state what brake pedal force is required to overcome the engine. It stands to reason that if there is no limit on how much force can be applied to the brake pedal, then surely enough brake force can be generated to overcome the engine. But most drivers are not built like Andre the Giant, or a 6’2” weight lifter who can do leg squats while pressing 400 lbs. Cars must be designed to be operated by smaller men and women, even petite women who are older and frail, as well as large strong men, or the number of cars sold will decrease and the price of cars will increase.

Back in 1970, the USA’s NHTSA sponsored a study¹ at the University of Michigan to determine the maximum brake pedal force that could be applied by an average man and woman. They needed to know this maximum force because NHTSA had to specify a realistic brake pedal force in their Federal Standards for testing the brakes on all passenger vehicles manufactured for the USA market. Their official results, which still stand today, are shown in Figures 1 and 2.

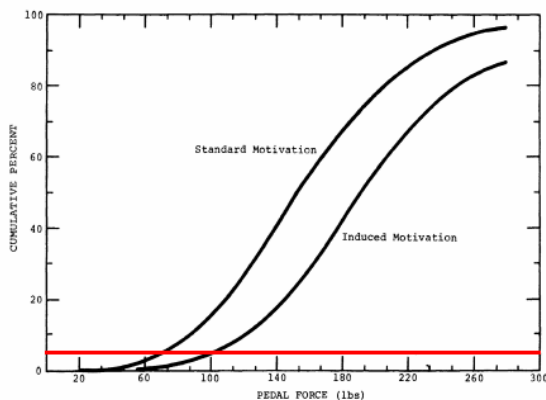


Fig 1. Cumulative percent pedal force for 276 females¹

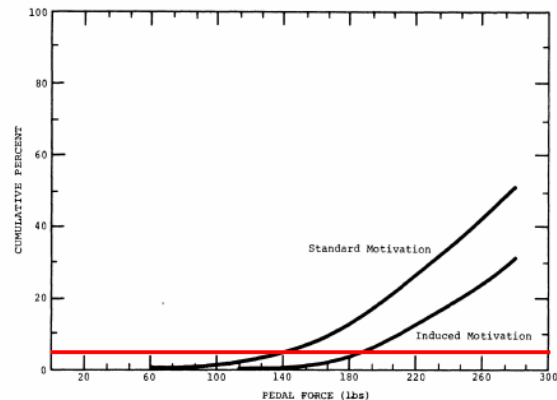


Fig 2. Cumulative percent pedal force for 323 males¹

These figures show the percent of subjects tested who could not apply the given pedal force. As the pedal force increases, more subjects could not apply the given pedal force.² Since manufacturers and NHTSA want most drivers to be able to apply the pedal force that they test the cars with, they agreed to select a pedal force that only 5% of the drivers could not achieve, or that 95% of drivers could achieve. The above figures show that in normal situations the maximum pedal force is only 70 lbs for female

¹ R.G. Mortimer et al, “Brake Force Requirement Study: Driver Vehicle Braking Performance as a Function of Brake System Design Variables”, Summary Final Report Contract FH-11-6952, National Highway Safety Bureau, U.S. Department of Transportation, April 10, 1970, p. 43 and 44.

² “Standard motivation” means stopping in a normal stopping situation with a normal deceleration of 0.75 g. “Induced motivation” means a panic stop situation with the maximum possible deceleration.

drivers and 140 lbs for male drivers. Therefore, the study recommended: “A force of 85 lbs is therefore suggested by these data as the maximum brake pedal effort for vehicle deceleration in the order of 0.75 g.”

The only official brake tests that the US government requires all manufacturers to pass is specified by the following US government documents:

- 1) CFR-2011-title49-vol6-sec571-105, and
- 2) CFR-2011-title49-vol6-sec571-135.

These tests specify a maximum brake pedal force of ≤ 65 N (14.6 lbs) for a lightly loaded vehicle or ≤ 500 N (112.4 lbs) for a fully loaded vehicle.³ The testing is done while stopping the vehicle from a higher speed under normal stopping conditions⁴ while the transmission is either in NEUTRAL or in DRIVE with the accelerator pedal released. The stopping distance under these conditions must be less than some maximum distance (like 70 meters) or some distance S that is a function of the vehicle's velocity V at a reduced test speed (such as $S \leq 0.10V + 0.0060V^2$ or $S \leq 0.10V + 0.0067V^2$). These conditions reproduce the normal stopping conditions for two cases: a) when the engine is providing some of the braking force while the transmission is in DRIVE, and b) when the engine is providing no braking force while the transmission is in NEUTRAL. The condition of sudden acceleration, in which the engine is at high speed and opposing the braking force, is not addressed by these braking tests because this is not a normal vehicle condition.

So, what about the case where the vehicle's power brakes fail to operate? This may happen in a vehicle with a gasoline engine when the engine speed is so high that no manifold vacuum is produced to operate the power brakes.⁵ In this case, the brakes revert to the mechanical brakes only. The difference in brake pedal force between these two cases is about a factor of 2.6, as shown in Figure 3.⁶ This means that it takes 2.6 times the pedal force without power boost than it does with power boost. This can increase the maximum pedal force of 70 lbs for females and 100 lbs for males to 182 lbs for females and 260 lbs for males. According to Figs 2 and 3, this excludes about 70% of all females and 40% of all males. (This is confirmed by NHTSA's comment on the last page of this document).

Figure 4 shows how a total or partial boost failure can change the rate of deceleration of the vehicle. For example, if a vehicle can decelerate at 0.9 g when the boost is 80% of maximum, then the deceleration will decrease to 0.5 g when the boost decreases to 32%, or the deceleration will decrease to 0.3 g when the boost decreases to 0% (no boost). This change of deceleration rate with boost level does not include the effects of engine torque increase in the case where the engine speed has increased

³ The reader will note that a force of 112 lbs already excludes about 18% of the female population.

⁴ If the vehicle has power brakes, then normal stopping conditions includes the power brakes.

⁵ In vehicles with diesel engines, where manifold vacuum is practically absent because the engine is normally run with the throttle held wide open, the power brakes are operated by a vacuum produced by an air pump or a hydraulic pump that changes the pressure in an accumulator. Some vehicles with gasoline engines use this same boost technique.

⁶ This factor may vary with different braking system designs. But boost ratios are typically between 2 and 5.

to the maximum possible engine speed. In this case the engine torque opposes the brake torque, making the stopping distance even longer than when the boost is absent.

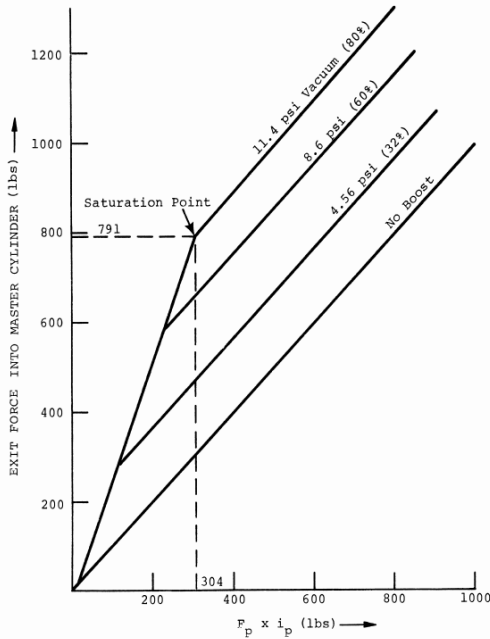


Fig 3. Power boost characteristics⁷

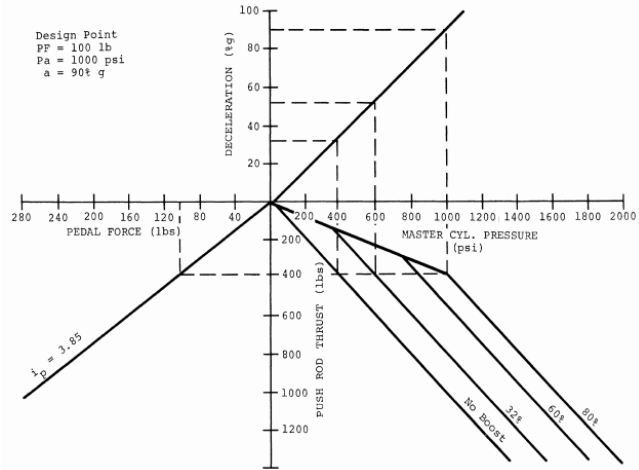


Fig 4. Braking performance diagram⁸

Some skeptics of sudden acceleration have performed their own tests to prove that the brakes will always overcome the engine. For example, Motor Trend magazine tested seven cars using a procedure in which they accelerated each of the cars to just under 60 mph, floored the gas, and then within two seconds nailed the brakes while keeping the gas pedal floored.⁹ They then measured the distance it took to bring each of the cars to a complete halt from 60 mph, and compared that to the tested 60-0 mph braking distances. Their results are shown in Table 1.

Table 1 shows that the stopping distances of the Chevy Malibu and the Ford Fusion were 28% and 23% longer, respectively, with the throttle wide open than with they were with the standard government test. The Toyota Camry, the Subaru Legacy, and the Nissan Altima were the same because they had brake override which automatically cut the engine power when the brake was applied. The Honda Accord and the Hyundai Sonata were about the same for no apparent reason. Motor Trend concluded from these results that “even if a vehicle’s electronic throttle system somehow triggered an

⁷ R.G. Mortimer et al, “Brake Force Requirement Study: Driver Vehicle Braking Performance as a Function of Brake System Design Variables”, Summary Final Report Contract FH-11-6952, National Highway Safety Bureau, U.S. Department of Transportation, April 10, 1970, p. 135.

⁸ Ibid, p. 137.

⁹ In vehicles lacking a brake override feature, this test adds torque to the wheels to oppose the braking torque instead of subtracting torque from the wheels to assist the braking torque. In vehicles with a brake override feature, this test reduces the engine speed to idle during braking if the brake pedal and the accelerator pedal are pressed at the same time, which subtracts torque from the wheels to assist the braking torque.

unintentional acceleration incident, modern braking systems are good enough to over-power the engine and bring the vehicle safely to a halt within a reasonable distance”. Even then, they state that “A key point to remember, however: you must brake HARD. Merely squeezing the brakes on a runaway vehicle will gradually overheat them to the point where they’ll fade to uselessness.”

The flaw in Motor Trend’s test procedure was that they did not measure the brake pedal force. If the test was performed by a strong male driver, then the brake pedal force could easily have exceeded the maximum force that some females, and even some males, could apply. Since this brake pedal force was not measured, one cannot say whether these same results can be achieved by the average driver.

Table 1. Motor Trend magazine’s brake testing results¹⁰

Braking distances from 60 mph							
	CHEVY MALIBU	FORD FUSION	HONDA ACCORD	HYUNDAI SONATA	NISSAN ALTIMA	SUBARU LEGACY	TOYOTA CAMRY
Brake pedal only	130 ft	124 ft	125 ft	123 ft	124 ft	121 ft	128 ft
At wide-open throttle	167 ft	152 ft	129 ft	124 ft	124 ft	124 ft	128 ft

Car and Driver magazine did a similar test. They chose a V-6 [Camry](#), an [Infiniti G37 convertible](#), and a hugely powerful 540-hp Roush Stage 3 [Mustang](#). First, they drove the cars at 70 mph and 100 mph in the lowest possible gear to simulate a sudden acceleration.¹¹ They then measured the distance it took to bring each of the cars to a complete halt from 60 mph, and compared that to the tested 60-0 mph braking distances. Their results are shown in Table 2. The Infinity G37 behaved the same in both tests because its brake override system automatically cut the engine power when the brake was applied. The Toyota Camry did not have brake override at the time of the test, so its stopping distance was about 9% greater when stopping from 70 mph. The stopping distance from 100 mph was about 20% greater. The stopping distance of the Roush Mustang from 70 mph was about 40% greater with the throttle applied. But the stopping distance of the Roush Mustang from 100 mph was a whopping 300% greater with the throttle applied than with the throttle released. In fact, Car and Driver stated that “it wasn’t clear from behind the wheel that the Mustang was going to stop”. But it “finally did stop in a puff of brake smoke.” They finally concluded that “even in the most extreme case, it should be possible to get a car’s speed down to a point where a resulting accident should be a low-speed and relatively minor event”. They also concluded that brake override was important, and that “Toyota should add this feature post-haste”.

¹⁰ <http://www.motortrend.com/news/unintended-acceleration-test/>

¹¹ In vehicles lacking a brake override feature, this test adds torque to the wheels to oppose the braking torque instead of subtracting torque from the wheels to assist the braking torque. In vehicles with a brake override feature, this test reduces the engine speed to idle during braking if the brake pedal and the accelerator pedal are pressed at the same time, which subtracts torque from the wheels to assist the braking torque.

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Table 2. Car and Driver’s brake testing results¹²

Braking distances	From 70 mph			From 100 mph		
	INFINITY G37	TOYOTA CAMRY (268 HP)	ROUSH MUSTANG (540 HP)	INFINITY G37	TOYOTA CAMRY (268 HP)	ROUSH MUSTANG (540 HP)
Brake pedal only	X ft	174 ft	X ft	X ft	X ft	X ft
At wide-open throttle	X ft	190 ft	X + 80 ft	X ft	X + 88 ft	X + 903 ft

These two tests sound convincing to some readers because the cars eventually stopped. But the flaw in both tests was that they did not measure the brake pedal force. The drivers in both cases could apply whatever brake pedal force was needed to get the results they were seeking. It stands to reason that the stopping distances will be less if the brake pedal force is allowed to be as large as possible. This is why the government specifies a maximum brake pedal force in their tests with the throttle closed. Not all drivers can apply the same brake pedal force as an athletic 6’2” male driver who can use the seat back for additional leverage. In particular, older drivers, smaller drivers, and female drivers may find it difficult to get these same results because they can’t press the brake pedal as hard as one of these test drivers. These are precisely the type of drivers that are found most often in sudden acceleration incidents.

This absence of pedal force data was not present in another test performed by the Ford Motor Company back in the mid 90’s. They accelerated a Ford Crown Victoria from a stop at full throttle with the brakes applied.¹³ They then measured the brake pedal force that was required to stop the vehicle. They wanted to be able to state that the brakes would prevent the car from moving with a wide open throttle. But in this case their own video shows that vehicle moved and the brake pedal force required to stop the vehicle was 175 lbs. This force was so high that it exceeded the pedal force that over 50% of all females and 10% of all males could apply. When NBC’s Pierce Brosnan confronted former NHTSA director Michael Brownlee with this result, Mr. Brownlee stated that 175 lbs was a significant change from the understanding his investigators had ten years earlier when NHTSA performed its examination

¹² <http://www.caranddriver.com/features/how-to-deal-with-unintended-acceleration>

¹³ See the video "Runaway Cars" Segment 4 - Sudden Acceleration" at <https://www.youtube.com/watch?v=95Q9g6dJZUo>, and "Runaway Cars" Segment 5 - Sudden Acceleration" at <https://www.youtube.com/watch?v=QtGa3syllns>.

of sudden acceleration¹⁴ by Pollard and Sussman (aka, NHTSA's "Silver Book"). Because of this fact, he believed that sudden acceleration needs to be re-examined.



Fig 5. Ford test demonstrating the ability to stop a vehicle with the accelerator pedal held down. Passenger states 175 lbs of pedal force was required.



Fig 6. Michael Brownlee, former Director of NHTSA responsible for 1989 Pollard Examination of Sudden Acceleration, stating that he believes sudden acceleration needs to be re-examined.

So, based on these tests, will the brakes always overcome the engine? The answer is an emphatic no, because it depends upon the brake pedal force that can be applied. And there will always be some portion of the driver population that is unable to apply the required brake pedal force.

The above tests all apply to the case where the vehicle is moving at a high speed when sudden acceleration occurs and the driver must bring the vehicle to a stop. This case applies to less than ten percent of all sudden acceleration cases. What about the remaining 90% of sudden acceleration cases in which the car's engine revs up suddenly while the vehicle is stopped at a traffic light or while moving slowly into or out of a parking space? Does the claim that "the brakes will always overcome the engine" apply to these cases?

If it is assumed that the driver causes the sudden acceleration by pressing on the accelerator pedal at the same time as the brake pedal, then one would think that the brake pedal should always overcome the engine and the vehicle should remain at rest. To assure that this will happen, NHTSA has proposed that all U.S. automobiles manufactured after 2012 should have a Brake Override System (BOS) which will turn off the fuel injectors whenever the brake and accelerator pedals are pressed simultaneously. This would cause the engine to remain at idle and prevent the vehicle from moving. But this proposal was never enacted into law. Therefore, brake override has remained a manufacturer option that may or may not be present. This may explain why, even with a Brake Override System widely advertised, some new vehicles have continued to experience sudden acceleration from a stop. The possibility of having a Brake Override System has forced skeptics to make a new assumption that the driver, instead of pressing both the brake and accelerator pedals at the same time, is actually pressing only the

¹⁴ J. Pollard and E. Sussman, "An Examination of Sudden Acceleration", report No. DOT-HS-807-367, performed by the U.S. Department of Transportation's Transportation Systems Center for NHTSA, January 1989. This report is referred to by the NHTSA as the "Silver Book" because it is frequently cited as evidence that sudden acceleration is not a vehicle problem.

accelerator pedal by mistake. This assumption is difficult to understand because the vehicle forces the driver to press on the brake pedal to shift the transmission out of PARK and into to DRIVE or REVERSE. Yet, sudden acceleration often happens simultaneously with this shifting. So how can the driver suddenly shift his foot from the brake pedal to the accelerator pedal to cause this sudden acceleration? And how can he do this without knowing that he had done it? The answer is that many drivers steadfastly maintain that their foot never left the brake pedal while the engine revved up “on its own”. Yet, we often hear from accident investigators and the press that “the driver pressed the accelerator pedal instead of the brake pedal”, or that “his foot slipped off the brake pedal and onto the accelerator pedal”. How do they know this when they have no evidence that this occurred other than the fact that the car’s engine suddenly revved up? The answer is that they don’t know this for sure. They merely assume that it is true because they can’t think of any way to cause an engine to speed up other than to step on the gas pedal. But this is a bad assumption because the engine’s management system has several ways of causing the engine to speed up without the driver pressing on the accelerator pedal. One of these ways is called an engine “idle-up” due to a sudden increase in the demand for supply current when an accessory such as an air conditioner turns on. Another way is explained by a theory of sudden acceleration proposed by Dr. Ronald Belt.¹⁵

So, let’s assume that the engine revs up on its own while the driver’s foot remains on the brake pedal. Will the brakes overcome the revving engine and cause the vehicle to remain at rest? In this case a new human factor comes into play besides the brake pedal force. It is known as the perception response time, or brake response time, or driver reaction time. This is the time it takes from an initiating event until the brake pedal is moved a specified amount in response to that event.¹⁶ This time is on the order of 1.5 seconds. This time is well known in traffic accident investigation circles, where an event occurs while the vehicle is traveling at a high speed and the driver must react to the event before he can apply the brakes to cause the vehicle to stop. During this time the vehicle can travel an appreciable distance before the brake is fully applied, after which the stopping distance of the brakes comes into play.

Applying this driver reaction time of 1.5 seconds to the case of sudden acceleration from a stop, let’s assume that the vehicle’s engine speed suddenly jumps to the maximum engine speed possible within the short time of one second. If it takes 1.5 seconds from the time that the driver hears the engine speed increase to the time that the driver begins to press on the brake, then the vehicle will move some distance during this time because the engine is going at full speed and this higher speed causes a significant torque on the wheels. Remember, the brakes are not yet applied, so the vehicle will certainly move. How far and how fast? Well, if manufacturers boast that their vehicles can accelerate from 0 to 60 in several seconds, then in 1.5 seconds the vehicle speed must increase to some number before braking begins to occur. If we can estimate this speed, then we can determine how far the vehicle can travel from a stop before braking begins to occur.

¹⁵ See Dr. Belt’s papers at <http://www.autosafety.org/dr-ronald-belt%E2%80%99s-sudden-acceleration-papers>.

¹⁶ See https://en.wikipedia.org/wiki/Braking_distance.

Figure 7 shows a plot of vehicle speed versus time for a car in a drag race starting from a stopped position.¹⁶ Since it is a drag race, we can assume that the driver is flooring the accelerator pedal to get the maximum possible vehicle speed. The plot shows that the speed of the race car increases with time, with several flat spots at different times that correlate with a change of gears. This drag race data approximates the case of sudden acceleration, but it is not identical to it because the engine speed in a drag race increases more slowly than in a sudden acceleration incident as a result of the torque on the engine from the powertrain slowing the engine down. If we read the value of the vehicle speed at the elapsed time of 1.5 seconds, we can use this as an estimate of the vehicle speed at the time the brakes are applied after a sudden acceleration from a stop.

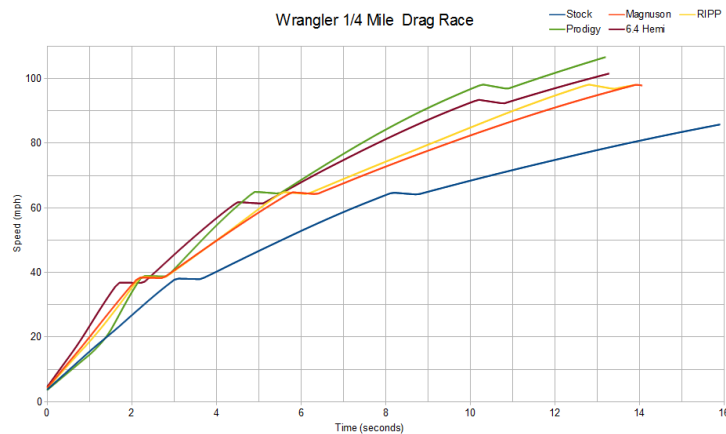


Figure 7. Vehicle speed versus elapsed time for five drag race cars¹⁷

Now the data in Figure 7 applies only to the vehicles shown in the figure. Similar data for other vehicles are shown in Appendix A. If we look at all these plots, we can see that after 1.5 seconds an arbitrary vehicle may be traveling at a speed of anywhere between 10 and 40 MPH. At this time the brakes are applied, and the vehicle's stopping distance can be calculated from the braking data for the initial vehicle speed of 10 to 40 MPH. If we add up the distances travelled during the reaction time and the braking time, we can estimate the total distance traveled.

If we do a few calculations, we find:

- a) Assuming a constant acceleration, for a speed of 40 MPH after 1.5 seconds we find:

Average acceleration:

$$\begin{aligned}
 &= (v_f - v_i)/t \\
 &= (40 - 0) \text{ MPH} / 1.5 \text{ sec} \\
 &= 40 (5280 \text{ feet/hour}) \times (\text{hour}/3600 \text{ sec}) / 1.5 \text{ sec} \\
 &= 40 (5280) / (3600) (1.5) \text{ feet/sec}^2 = 39.1 \text{ feet/sec}^2
 \end{aligned}$$

Distance travelled during driver's reaction time:

$$\begin{aligned}
 &= \frac{1}{2} at^2 \\
 &= \frac{1}{2} (39.1 \text{ feet/sec}^2) (1.5 \text{ sec})^2
 \end{aligned}$$

¹⁷ <http://jeeplab.com/showthread.php?251-SC-vs-HEMI-Let-the-TRASH-talk-begin!>

= 44 feet

b) For a speed of 10 MPH after 1.5 seconds instead of 40 MPH this will change to 11 feet.

Therefore, we see that a typical car will travel somewhere between 11 and 44 feet during the driver's reaction time before he can begin to apply the brakes. This is a significant distance which does not correspond to most people's idea of the brakes overcoming the engine. The reason is that it takes time to begin to apply the brakes. We won't compute the distance travelled during the braking time because this distance depends upon the brake pedal force that can be applied. But the point is made that the vehicle can travel a significant distance before the brakes can bring the vehicle to a stop.

So can the brakes overcome the engine in this case? Certainly, because the vehicle eventually comes to a stop. But before it can come to a stop, it will have travelled a significant distance during which it can produce a lot of damage. And in the process, the vehicle can attain a speed of 10 to 40 MPH, which can create a lot of momentum to allow it to jump over curbs and knock down store fronts or even brick walls.

Note added 29 April 2016:

Technical Report Documentation Page		
1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Technical Assessment of Toyota Electronic Throttle Control (ETC) Systems		5. Report Date January 2011
		6. Performing Organization Code NVS
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration 1200 New Jersey Ave., S.E. Washington, DC 20590		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Ave., S.E. Washington, DC 20590		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes The National Aeronautics and Space Administration's (NASA) Engineering and Safety Center (NESC) has provided substantive technical support to assist in the National Highway Traffic Safety Administration's (NHTSA) assessment of Toyota electronic throttle control (ETC) systems. NASA's report of their study is released as a separate publication.		

REDACTION NOTE

Since public release of this report on February 8, 2011, the Agency has revised its redactions to the document to release certain material previously deemed confidential under U.S.C. § 30167. This document, which was posted April 15, 2011 to NHTSA's web site, replaces the one posted previously and contains the Agency's revised redactions.

The above report states on p55:

The amount of brake pedal force required to hold the test vehicles stationary with a wide open throttle ranged from 15.0 lbs. to 43.6 lbs. with vacuum assist, which is well within the braking capabilities generated by the vast majority, if not all, drivers. Without vacuum assist, force required to remain stationary ranged from 86.7 lbs. to 268.2 lbs.(which is beyond the reasonable amount of force a driver could apply). NHTSA's complaint database does not contain any instances of stationary Camrys lacking vacuum assist, so these latter measurements are based on a purely hypothetical situation.

This is just weasel-wording. It does not mean that vacuum assist was present in all instances. It just says that the database does not have this information.

⁸¹ 112.4 lbs. (500N) is used as a standard maximum braking force used in brake testing under CFR49 571.135. This value was adopted in part, for international harmonization of standards as noted in FR Volume 60/No. 22.