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Administration

# **Technical Assessment of Toyota Electronic Throttle Control (ETC) Systems**

**February 2011**

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## **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.

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## EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration (NHTSA) issues this report to present our studies and findings concerning unintended acceleration (UA)<sup>1</sup> in vehicles manufactured by Toyota. This report should be read in conjunction with the report issued by the National Aeronautics and Space Administration (NASA) concerning the electronic throttle control (ETC) system<sup>2</sup> in Toyota vehicles. In March 2010, NHTSA enlisted the support of NASA in analyzing the Toyota ETC system to determine whether it contained any vulnerabilities that might realistically be expected to produce UA in a consumer's use of those vehicles. NASA did not find an electronic cause of large throttle openings that can result in UA incidents. NHTSA did not find a vehicle-based cause of those incidents in addition to those causes already addressed by Toyota recalls.

In addition to enlisting NASA to identify any vulnerabilities in the Toyota ETC system, NHTSA has obtained the services of the prestigious National Academy of Sciences (NAS) to examine the broad subject of UA across the automotive industry, and the safety implications of electronic control systems that are increasingly common in motor vehicles. NHTSA expects to receive recommendations from NAS in the fall of 2011 on how NHTSA might use its research, rulemaking, and enforcement authority to address any such implications identified by the panel.

NHTSA has conducted several investigations into causes of the alleged UA in Toyota vehicles and, in 2010, conducted an additional in-depth study of that subject in connection with the NASA study. This report presents details regarding those investigations, as well as NHTSA's most recent study and results of those efforts. The report concludes by outlining the current and future work that the agency is conducting in an effort to develop countermeasures to ensure that the risk of future fatalities and injuries resulting from UA are minimized. Several potential

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<sup>1</sup> In this report, "unintended acceleration" refers to the occurrence of any degree of acceleration that the vehicle driver did not purposely cause to occur. Contrast this with the term "sudden acceleration incident," which refers to "unintended, unexpected, high-power accelerations from a stationary position or a very low initial speed accompanied by an apparent loss of braking effectiveness." *An Examination of Sudden Acceleration*, DOT-TSC-NHTSA-89-1 at v. As used here, unintended acceleration is a very broad term that encompasses sudden acceleration as well as incidents at higher speeds and incidents where brakes were partially or fully effective, including occurrences such as pedal entrapment by floor mats at full throttle and high speeds and incidents of lesser throttle openings at various speeds.

<sup>2</sup> In an ETC system, the vehicle's throttle is controlled electronically based on signals transmitted from the accelerator pedal. In a mechanical system, a physical linkage between the accelerator and throttle controls acceleration.

causes of UA were investigated, including vehicle-based defects, such as mechanical or electrical failures, and other causes, such as electromagnetic interference and pedal misapplication.

Through analysis and investigations, NHTSA identified two types of vehicle-based mechanical defects as causes of UA. Those were related to pedal entrapment and “sticky pedal.” At the urging of NHTSA, Toyota has already recalled more than seven million vehicles because those defects could result in UA. To determine whether the scope of the pedal entrapment and sticky pedal recalls was sufficiently broad to include all of the vehicles subject to these defects and to address all vehicle-based causes of UA known to Toyota, NHTSA initiated a recall query (RQ) in February 2010 and analyzed tens of thousands of Toyota documents. NHTSA’s examination of the voluminous data did not reveal any previously unknown potential causes of UA.

NHTSA’s vehicle characterization analysis and testing supported NASA’s review. NHTSA found no previously unknown defects in the test vehicles and determined that their braking systems were capable of overcoming all levels of acceleration, including wide open throttle. As explained in this report, under certain conditions the vacuum assist that helps drivers apply brake pedal force can be diminished; such as by prolonged and repeated rapid use of the brakes. Therefore, where the accelerator pedal is stuck in a high throttle position (as can occur in a pedal entrapment situation), it is possible that brakes can lose their ability to stop a vehicle.

After conducting the most exacting study of a motor vehicle electronic control system ever performed by a government agency, NASA did not find that the ETC electronics are a likely cause of large throttle openings in Toyota vehicles as described in consumers’ complaints to NHTSA. NASA found that many safety features are designed into the ETC system to prevent UA and, if faults are detected, to cause the initiation of safe modes of operation that limit acceleration (e.g., limp home, fuel cut strategies). NASA found no flaws in the software code controlling the Toyota ETC system that would cause UA. NASA also found that electromagnetic compatibility (EMC) testing at exposure levels well above current certification standards did not produce an open throttle. NASA found no evidence that any failures of the ETC system had an effect on the performance of the braking system.

NASA’s study confirmed that there is a theoretical possibility that two faults could combine under very specific conditions to affect the ETC systems so as to create an unintended UA, but

did not find any evidence that this had occurred in the real world or that there are failure mechanisms that would combine to make this occurrence likely. NASA identified certain aspects of the ETC system that could produce very small throttle openings (less than 5 degrees) that are readily controlled by minimal braking force and pose no appreciable safety risk. NASA also identified certain apparently rare conditions that could lead to a fail safe mode that may involve small, irregular throttle openings in vehicles equipped with potentiometer pedal sensors that experience a particular kind of resistive short circuit. However, in these very rare events, simply releasing the accelerator pedal closes the throttle and the brakes are fully operational. NHTSA does not find these minor, controllable conditions to constitute significant safety risks. Of course, NHTSA will continue to monitor all UA complaints and address any such risks that may emerge.

NHTSA and NASA both reviewed relevant consumer complaints and warranty data in great detail. Both agencies noted that publicity surrounding NHTSA's investigations, related recalls, and Congressional hearings was the major contributor to the timing and volume of complaints. Both also noted that the vast majority of complaints involved incidents that originated when the vehicle was stationary or at very low speeds and contained allegations of very wide throttle openings, often with allegations that brakes were not effective. NHTSA's analysis indicated that these types of complaints generally do not appear to involve vehicle-based causes and that, where the complaint included allegations that the brakes were ineffective or that the incident began with a brake application, the most likely cause of the acceleration was actually pedal misapplication (i.e., the driver's unintended application of the accelerator rather than, or in addition to, the brake).<sup>3</sup>

The results of NHTSA's field inspections of vehicles involved in alleged UA incidents during 2010 supported this analysis. Those vehicle inspections, which included objective evidence from event data recorders, indicated that drivers were applying the accelerator and not applying the brake (or not applying it until the last second or so), except for one instance involving pedal entrapment.

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<sup>3</sup> Pedal misapplication is a known cause of unintended acceleration. Perhaps the most tragic example was a July 16, 2003 incident in Santa Monica, California that resulted in 10 fatalities and 63 injuries (occurring over the course of 750 feet of vehicle movement). The National Transportation Safety Board's report on the incident is available at <http://www.nts.gov/publicIn/2004/har0404.pdf>. A more recent report from the board examines pedal misapplication in large vehicles. See <http://www.nts.gov/publicIn/2009/SIR0902.pdf>.

However, NHTSA does not have reason to believe that pedal misapplication is a cause of the relatively few, prolonged, high speed UA incidents that present the greatest safety risk. NHTSA believes that those incidents are most likely the result of pedal entrapment by a floor mat that holds the accelerator pedal in an open throttle position.

In summary, the combined work of NASA and NHTSA identified no electronic cause of UA incidents involving large throttle openings and no reason to believe that any failure of the ETC system would affect a vehicle's braking system. Based on NASA's findings, observations, and recommendation and its own work, NHTSA has decided to take several actions aimed at diminishing the risk of UA and strengthening the agency's ability to address current and future issues related to the safety of electronic control systems:

- NHTSA will consider initiating rulemakings on brake override systems, keyless ignition systems, and event data recorders. Brake override systems may prevent or mitigate some UA incidents by ensuring that, when the brake is applied, the braking system has priority over the throttle. NASA observes in its report (Observation O-2) that such a system “provides a broad overarching defense against unintended engine power” from a wide range of causes. Keyless ignition systems can exacerbate UA incidents (particularly prolonged incidents involving a stuck accelerator pedal) if the driver cannot determine how to shut off the engine quickly. Event data recorders can provide crash investigators objective information relevant to UA incidents that result in crashes sufficient to trigger the devices.
- NHTSA will begin preliminary research on the reliability and security of electronic control systems by examining existing industry and international standards for best practices and relevance to automotive applications. In this research, NHTSA will give full consideration to NASA's recommendation that NHTSA consider controls for managing safety critical functions as currently applied to the railroad, aerospace, military, and medical sectors. NHTSA will also give full consideration to NASA's findings and observations as they relate to the use of diagnostic trouble codes in conveying safety-critical information to drivers, safety-critical software design and validation methodologies, and robust fail-safe strategies that protect against two-fault scenarios (including those involving resistive short circuits and latent faults). The agency

anticipates that the NAS panel will offer recommendations on these subjects and wishes to enhance its own understanding of the subject area.

- NHTSA will begin research on the placement of accelerator and brake pedals and driver usage of pedals. NHTSA is interested in learning whether pedal misapplication can be significantly reduced through pedal placement specifications and operational characteristics.
- Along with NASA, NHTSA will brief the National Academy of Sciences panel that is conducting a broader study of UA and electronic control systems to ensure that the panel has the benefit of the work done by the two agencies.
- NHTSA will continue its plans to enhance its knowledge and capabilities in the area of safety-critical vehicle electronics, including electronic control systems, both by ensuring that current staff continues to be well informed on the developing technologies and potential safety issues and by hiring (as agency needs dictate and funding permits) more staff with the necessary expertise.

## **1.0 BACKGROUND**

Under the Motor Vehicle and Traffic Safety Act, vehicle and equipment manufacturers have a duty to conduct recall actions when they learn that their products either do not comply with a Federal Motor Vehicle Safety Standard (FMVSS) or contain a safety-related defect. NHTSA has the authority to conduct investigations to determine whether a noncompliance or safety defect exists. If NHTSA concludes that a recall is required but the manufacturer does not agree, NHTSA can order the manufacturer to conduct a recall. NHTSA can seek enforcement of such an order in Federal court, where it would have to prove the noncompliance or safety defect.

To demonstrate the existence of a safety defect, NHTSA needs to show both that a defect exists and that it is safety-related. To do so, NHTSA would need to prove that a substantial number of failures attributable to the defect have occurred or is likely to occur in consumers' use of the vehicle or equipment and that the failures pose an unreasonable risk to motor vehicle safety.

NHTSA's Office of Defects Investigation (ODI) receives tens of thousands of Vehicle Owner Questionnaires<sup>4</sup> (VOQs) and voluminous early warning information from manufacturers every year, both of which are sources of information on potential defects. ODI's screening divisions (the Early Warning Division and the Defects Assessment Division) constantly review these and other sources of information to identify possible safety defect trends. When they observe what may be a defect trend they recommend that one of the investigating divisions open an investigation. After thorough discussion involving ODI management and screening staff, ODI decides whether to open an investigation.

ODI investigations begin with a preliminary evaluation (PE), which is generally completed within 120 days. If ODI believes it has sufficient evidence to warrant further investigation and the manufacturer does not agree to do a recall, ODI opens a more in-depth Engineering Analysis (EA). During both stages of an investigation ODI seeks relevant information from the manufacturer and continues to review information from consumers, sometimes interviewing them and examining their vehicles or equipment for evidence of a defect. Manufacturers of vehicles and equipment conduct several hundred safety recalls each year in the United States.

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<sup>4</sup> VOQs are complaints received from consumers about possible safety problems they have experienced with their vehicles or motor vehicle equipment. NHTSA receives 30,000 to 40,000 VOQs in an average year, but received more than 50,000 in just the first nine months of 2010.

The majority of the recalls occur without NHTSA's having opened an investigation. Manufacturers have a duty to conduct the recalls when they learn of a safety defect or noncompliance. But many of the largest recalls result from NHTSA's investigations, particularly its defect investigations. For example, of the 16.4 million vehicles recalled in 2009, 49 percent of those vehicles were covered by recalls influenced by NHTSA's investigations, although only 30 percent of the recalls were influenced. Also included in the overall 2009 vehicle total are over four million Toyota vehicles that, although not counted among the influenced recalls, were recalled for UA issues based on NHTSA's strong urging as it prepared to open investigations on those matters.

### **1.1 UA-Related Defect Investigations Involving Toyota Products**

NHTSA has conducted eight separate investigative actions involving UA in Toyota products since calendar year 2000. Seven of the investigations involved vehicles equipped with Toyota's ETCS-i electronic throttle control (ETC) system. Of the eight, two actions were initiated as a result of internal NHTSA evaluations; both of these resulted in safety recalls. Five actions were conducted at the request of outside parties, via a defect petition<sup>5</sup> (DP), and one action was opened based on NHTSA's assessment and a DP. None of these last six investigations resulted in a safety recall. Table 1 summarizes the eight actions. In addition, NHTSA has conducted a review of recent Toyota recalls involving UA to determine whether the scope of those recalls was sufficient. This inquiry, known as a Recall Query, is described below.

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<sup>5</sup> The defect petition process is described at 49 USC 30162 and 49 CFR Part 552. The statute provides concerned citizens and other interested parties a means by which they can request that the agency conduct an analysis of a potential safety defect issue and make a determination as to whether a formal investigation is warranted. Generally speaking the analysis conducted during a petition is the same as that conducted in a preliminary evaluation initiated by ODI.

**Table 1: Summary Details of the Eight ODI UA Investigations Conducted Since CY 2000 Involving Toyota Products**

Act. #	Open Year	Init. By*	Invest. ID(s) <sup>6</sup>	Toyota/Lexus Products	ETC	Subject	Result
1	2003	DP	DP03-003	MY 1997-2000 Lexus GS and LS	Y	Unintended Engine Speed Increase/Sudden Acceleration	Denied <sup>7</sup>
2	2004	DP & ODI	DP04-003 PE04-021	MY 2002-2003 Toyota Camry and Lexus ES300	Y	Electronic Throttle Control System	Granted Closed
3	2005	DP	DP05-002	MY 2002-2005 Toyota Camry and Lexus ES300/330	Y	Uncontrollable Accelerations Due to ETC	Denied <sup>8</sup>
4	2006	DP	DP06-003	MY 2002-2006 Toyota Camry and Solara	Y	Engine Surging	Denied <sup>9</sup>
5	2007	ODI	PE07-016 <sup>10</sup> EA08-010	MY 2007-2008 Lexus ES350 and Toyota Camry	Y	Pedal Entrapment, Accessory All-Weather Floor Mat	Recall 07E-082 <sup>11</sup>
6	2008	ODI	PE08-025 EA08-014	MY 2004 Toyota Sienna	N	Pedal Entrapment, Interior Trim Panel	Recall 09V-023 <sup>12</sup>
7	2008	DP	DP08-001	MY 2006-2007 Toyota Tacoma	Y	Sudden/Uncontrolled Acceleration	Denied <sup>13</sup>
8	2009	DP	DP09-001	MY 2002-2003 Lexus ES300 and MY 2007 ES350	Y	Unwanted/Unintended Acceleration	Denied <sup>14</sup>

\*- ODI indicates action initiated by internal evaluation, DP indicates initiation at request of outside party.

<sup>6</sup> Additional details of each action can be found at <http://www-odi.nhtsa.dot.gov/defects/> by searching for the investigation ID.

<sup>7</sup> See 68 FR 55076

<sup>8</sup> See 71 FR 164

<sup>9</sup> See 72 FR 10815

<sup>10</sup> The PE, or preliminary evaluation, is the initial opening action which was subsequently upgraded to an EA, or an engineering analysis.

<sup>11</sup> See <http://www-odi.nhtsa.dot.gov/recalls/recallsearch.cfm>, search for 07E082

<sup>12</sup> See <http://www-odi.nhtsa.dot.gov/recalls/recallsearch.cfm>, search for 08V023

<sup>13</sup> See 73 FR 51551

<sup>14</sup> See 74 FR 56686

The first investigative action, opened in 2003, was initiated at the request of a petitioner who owned a 1999 Lexus LS400 who experienced three occurrences of UA allegedly occurring when the accelerator pedal was not applied, one of which resulted in a low-speed crash (for which the petitioner received a traffic citation). The petitioner cited other VOQ reports as evidence of a defect. ODI conducted a VOQ-based assessment of UA rates on the subject Lexus in comparison to two peer vehicles and concluded the Lexus LS400t vehicles were not over-represented in the VOQ database. Accordingly the petition was denied; a Federal Register notice detailing the agency's analysis was published.<sup>15</sup>

In late 2003, NHTSA conducted a pre-investigative assessment<sup>16</sup> on the MY 2002-2003 Toyota Camry based on its review of vehicle owner complaints alleging UA in these ETC-equipped vehicles. One of several changes incorporated in MY 2002 Camry revisions was the implementation of ETC, which was highlighted in the ODI analysis as a potential area of concern. The initial evaluation (conducted by an ODI engineer with a graduate degree in electrical engineering) cited 38 VOQs as potentially involving an ETC problem. Shortly thereafter, in early 2004, ODI also received and reviewed a DP involving UA concerns on MY 2002-2003 Lexus ES300, so-called sister vehicles to the Camry model that share the same ETC system. The petitioner alleged an ETC malfunction caused a low speed crash<sup>17</sup> while parking and cited 37 additional VOQs as evidence of a possible defect in the ETC system. During its review ODI eliminated from its further consideration 34 of the reports cited by the petitioner on the basis that they involved minor UA incidents more characteristic of a drivability<sup>18</sup> concern than a safety defect.

Given its concern for consumer safety and the relatively new but increasingly common use of ETC technology, the agency opened an investigation in March 2004, to assess whether the ETC system may have been the cause of the apparent increase in the number of UA reports. The launching of the investigation was widely publicized by media outlets resulting in a significant increase in consumer complaints alleging UA affecting not only the subject but other vehicle

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<sup>15</sup> See 68 FR 55076.

<sup>16</sup> ODI refers to these analyses as an Initial Evaluation, or a "package," in this case IE03-072.

<sup>17</sup> ODI staff met with the petitioner and visited the site of the crash, a parking lot located in Rockville, MD, test drove the Petitioner's vehicle, and reviewed its service history. No evidence as to causation was found.

<sup>18</sup> "Drivability" refers to vehicle characteristics that may cause some level of concern to the driver but generally do not involve a safety issue, such as very short duration hesitation while accelerating.

models as well, including some which did not contain an ETC system. During the investigation ODI determined from interviews that many of the VOQ reports could not be explained by a failure of the ETC system in that the circumstances drivers described (significant brake application with no braking effect) would have necessitated a failure of the braking system. In its post-incident vehicle inspections ODI did not find physical evidence, such as a failed component or the recording of a diagnostic failure code, which would support the existence of a vehicle-based cause of either an ETC or a brake system failure.

During the course of the investigation NHTSA gained detailed knowledge of the Toyota ETC system's functionality through technical meetings held with Toyota's system engineers and from additional information obtained from Toyota, much of which is proprietary or otherwise confidential in nature and, therefore, pursuant to Federal law and regulation, could not be publicly released by NHTSA. This knowledge, along with the absence of physical evidence of an ETC system failure and NHTSA's prior experience investigating UA, including application of the principles stated in the 1989 report "An Examination of Sudden Acceleration,"<sup>19</sup> led the agency to conclude that the incidents being described in the VOQ reports were not being caused by the ETC system. Accordingly, the investigation was closed in July 2004 without further action.

NHTSA's 2004 determination did not settle the matter, as evidenced by the defect petitions submitted in 2005, 2006, 2008, and 2009 requesting that the agency investigate the Toyota ETC system as the cause of UA incidents. Although each petition had variations on the products involved and alleged somewhat different forms of UA manifestations and concerns, all four cited the high number of UA-related VOQ reports as a basis for the request, suggesting that the number of VOQ reports in itself was evidence of an underlying ETC defect.<sup>20</sup> NHTSA reviewed each petition request thoroughly, including meeting with and inspecting each petitioner's vehicle, conducting hundreds of interviews of the drivers involved in the cited reports, sending information request letters to Toyota and thoroughly reviewing the responses provided, having a supplier conduct destructive testing of a suspect component removed from a petitioner's vehicle, and holding meetings with Toyota on the technical issues. At the conclusion of these actions,

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<sup>19</sup> Full report available at <http://www.volpe.dot.gov/hf/docs/sudaccel.pdf>.

<sup>20</sup> Additional media reports for each action led to additional VOQ reports being filed, although at a lower level than publicity effects seen in 2004, thus further adding to the volume of Toyota UA reports.

ODI denied three of the petitions on the basis that the evidence supporting an ETC-related defect was not present. ODI denied the 2009 petition on the basis of Toyota's announcement of Safety Recall 09V-388 to address pedal entrapment issues, which in ODI's assessment addressed the issue reported by the petitioner. Federal Register notices (cited in the footnotes accompanying Table 1, above) were published for each action.

During this period, ODI diligently reviewed and, as warranted, investigated UA reports involving Toyota products, as evidenced by the opening of the 2007 and 2008 investigations (described below), both of which were initiated as a result of ODI assessments, and both of which resulted in a safety recall. The 2007 action was opened in March 2007, only a few months after the subject vehicles were introduced into the U.S. market, and NHTSA opened the action based on only five VOQs alleging the UA concern.

Whereas the reports studied in the 2004 action (and the related petitions) commonly alleged vehicle self-acceleration during low speed driving (typically while parking) after which the vehicle returned to normal operation, the reports associated with the 2007 investigation concerning the 2007 Lexus differed significantly. In fact many of these reports differed from any other UA report ever received by NHTSA. In these VOQs the complainants reported they had intentionally applied the accelerator to increase vehicle speed after which the vehicle continued to produce maximum power even though they had removed their foot from the accelerator. In some cases the incidents continued at high speeds for several minutes and miles apparently because drivers unfamiliar with the operation of the keyless (push button) ignition system, or how to shift the vehicle to neutral, could not bring the vehicle under control. The common thread ODI discovered in these incidents was the apparent use of an unsecured all-weather floor mat supplied by Toyota at its dealerships that was so constructed that, when out of position, it could entrap a fully depressed accelerator pedal.<sup>21</sup>

Due to the level of severity of the incidents being experienced NHTSA requested that Toyota conduct a safety recall of those mats even though the cause of the incidents was determined to be

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<sup>21</sup> Entrapment was caused by a mechanical interference of the accelerator pedal with a groove of the rubber all-weather floor mat, as described in VRTC Memorandum Report EA07-010-VRTC-DCD7113, 2007 Lexus ES350 Unintended Acceleration; <http://www-odi.nhtsa.dot.gov/acms/docServlet/Artemis/Public/Pursuits/2007/EA/INFR-EA07010-28888.pdf>. In this case, entrapment involves the mat being in a position under the bottom of the accelerator, making the entrapment difficult for the driver to perceive quickly. In other scenarios, pedals can be entrapped by mats or other objects being on top of them.

mis-installed (double stacked and/or unsecured) all-weather floor mats trapping the accelerator pedal in the full-open position.<sup>22</sup> In the recall action (07E-082), which covered the all-weather floor mats sold for use in the MY 2007-2008 Camry and Lexus vehicles, Toyota provided a redesigned all-weather floor mat that substantially reduced the chance of an entrapment even when it was not properly installed. At the time of the recall announcement Toyota issued notices to dealers and vehicle owners regarding the dangers of the floor mats and the actions to take should an entrapment occur, and NHTSA issued a similar media release, noting that the dangers of pedal entrapment by unsecured floor mats exist in many vehicles.

The 2008 action (09V-023), which involved the Toyota Sienna minivan and was opened based on one VOQ report and one non-dealer (Toyota) field report, also involved an entrapment issue. In this case a trim panel on the center console could trap the accelerator in a partially open position if the retaining device (a plastic pin sometimes referred to as a Christmas tree), that was intended to secure the panel was missing. The pin was believed to have been present at the time of vehicle manufacture. However if the pin was not reinstalled during a subsequent service procedure a hazard could result. Toyota's recall replaced the trim panel with one that could not interfere with the accelerator even if the retaining clip was missing.<sup>23</sup>

## **1.2 Other UA Related Toyota Recalls**

Toyota has recently conducted two other recalls involving UA concerns, one for an additional pedal entrapment concern not addressed in the 2007 floor mat recall, and one for a "sticky pedal" condition. ODI was preparing to open investigations in both these situations and strongly urged Toyota to move quickly. Toyota announced the recalls before ODI had opened formal investigations in either case.

### **1.2.1 Pedal Entrapment Recall**

On August 28, 2009, a fatal crash occurred near San Diego, California. Shortly thereafter the incident was investigated by NHTSA and the San Diego County Sheriff's Department. Evidence at the crash site showed that an unsecured and incompatible all-weather floor mat was thermally fused to the bottom edge of the accelerator pedal in a position known to cause unwanted

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<sup>22</sup> When the floor mat is properly secured on the retaining hooks it cannot interfere with the accelerator pedal. The retention hooks are not tall enough to secure two or more stacked mats.

<sup>23</sup> Toyota conducted two other recalls for UA concerns since calendar year 2000. One recall was 06V-253, the other was 05V-565, and both involved accelerator pedal entrapment concerns from nearby components.

acceleration.<sup>24</sup> The vehicle was a Lexus ES350 that a dealer had provided to the consumer as a loaner vehicle. However, the suspect floor mat was designed for a Lexus RX SUV and was longer (longitudinally) than the mat that would have been proper for the Lexus ES350. At the time NHTSA investigators viewed the wreckage, the accelerator pedal was still fused to the floor mat, apparently melted in that position by the heat of the fire that followed the crash. Combining this observation with the circumstances known to have occurred immediately prior to the crash, including extremely high speeds and the driver's inability to control the speed,<sup>25</sup> NHTSA concluded that the excessive speed was caused by pedal entrapment. The San Diego County Sheriff's Department shared this view.<sup>26</sup> Supporting this conclusion was the fact that another customer of the dealership had used the same vehicle just three days earlier and complained of unintended, high-speed acceleration caused by the pedal having been trapped by the mat until he was able to stop the acceleration by freeing the pedal from the mat.

The San Diego tragedy made clear to NHTSA that the entrapment problem could occur in unexpected ways and that recalling the mats and educating drivers and dealers about not using unsecured, improper, or stacked mats was not going to adequately address the risk. As a consequence, NHTSA began to explore additional remedial options focusing primarily on the pedal design of a number of Toyota vehicles, not because of any known malfunction in their operation but because their shape, and the manner in which they interacted with the floor board, tended to make pedal entrapment more likely.

As NHTSA prepared to open an investigation on the pedal design it informed Toyota that the company needed to address this risk promptly as a vehicle defect issue, and requested that Toyota conduct a recall. Toyota responded to NHTSA by announcing a recall (09V-388) to replace or reshape the pedals in 3.8 million vehicles and sent its official notice of the recall to NHTSA on October 5, 2009. NHTSA also pressed the company to include a brake override

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<sup>24</sup> NHTSA vehicle inspection: <http://www-odi.nhtsa.dot.gov/acms/docServlet/Artemis/Public/Pursuits/2009/DP/INME-DP09001-37211P.pdf>

<sup>25</sup> NHTSA's inspection found that the brake pads, rotors, and calipers were extremely heat damaged from the driver's efforts to stop the vehicle during the incident.

<sup>26</sup> See San Diego County Sheriff's Department Incident Report concerning August 2009 crash in Santee, California (Case No. 09056454).

system (BOS) on models that have keyless ignition systems as part of its recall.<sup>27</sup> BOS is a safety feature that gives priority to the signal from the brake pedal and returns the engine to idle when it detects the brake and accelerator being simultaneously applied. After further discussion between NHTSA and Toyota concerning the scope of the recall, Toyota expanded the pedal entrapment recall to include an additional 1.1 million vehicles, submitting the notice to NHTSA on January 27, 2010 (10V-023).

### **1.2.2 CTS Pedals Sticking**

Unlike the pedal entrapment recall, this recall (10V-017) involves the internal working of the pedal assembly. (The affected pedals are manufactured by CTS Corporation, which is based in Elkhart, Indiana.) Another distinguishing factor is that the pedal entrapment situations involve instances of full acceleration that are initially intended by the driver, while this problem generally involves occurrences at lower power levels where the car continues to accelerate because the pedal does not return fully, or returns slowly, when the driver lessens pressure on the pedal. Some Toyota vehicle owners have complained of certain symptoms in vehicles equipped with those pedals. Those symptoms include a feeling that it is harder than normal to depress the pedal or that, when depressed, it is slower to return. In some circumstances, the situation can involve the pedal not returning at all from the position to which it was depressed. The problem is mechanical in nature and does not involve a flaw in the electronic signal being sent from the pedal sensor to the throttle.

In November 2009, NHTSA received several Toyota field reports concerning incidents in which pedals were slow to return or sticking in a number of different Toyota models from various model years. NHTSA reviewed those reports as part of its screening for possible defect trends. However, before NHTSA had decided whether or not to open an investigation, Toyota contacted the agency in January 2010 about the specific problem it had identified with the CTS pedal. At the agency's insistence, Toyota met with NHTSA technical staff and leadership to review and demonstrate the problem with the CTS pedals. Based on the information presented, NHTSA told the company it expected very prompt action. Two days later, on January 21, Toyota announced the recall, covering some 2.3 million vehicles (many of which are also covered by the pedal

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<sup>27</sup> Although NHTSA often provides suggestions, the recall remedy is ultimately determined by the company. In this case, the company did include BOS in the remedy for the vehicles equipped with keyless ignitions but not for those with traditional, keyed ignition systems.

entrapment recall and will receive both remedies). Toyota had the supplier produce a new pedal design that addressed the issue of excessive friction which caused the “sticky pedal” and also devised an interim remedy to eliminate the safety risk by altering the pedal while new ones are being manufactured. To date NHTSA has identified only one VOQ report it believes involves this condition, although other VOQ reports may involve the “sticky pedal” defect.

### **1.2.3 Recall Query**

On February 16, 2010, NHTSA opened a recall query (RQ 10-003) to determine whether the scope of the pedal entrapment and sticky pedal recalls was sufficiently broad to include all of the vehicles subject to these defects and to address all vehicle-based causes of UA known to Toyota. NHTSA obtained tens of thousands of documents from the company and has examined them carefully. Some of the information obtained in this inquiry has been useful in preparing this report, particularly information on warranty repairs. NHTSA’s examination of the voluminous data did not reveal any previously unknown potential causes of UA.

### **1.3 Congressional Hearings**

The January 2010 recalls brought the total number of Toyota vehicles recalled for UA-related issues in just four months above seven million and led to enormous media and Congressional interest. In the next four months, Congressional committees held seven hearings on the recalls, unintended acceleration, NHTSA’s defects investigation program, and related legislative proposals. Witnesses at some of the hearings indicated that they believed that some kind of electronic defect was responsible for UA in Toyota vehicles and that their ETC systems may be susceptible to electromagnetic interference (EMI). One witness<sup>28</sup> described experiments he had done in which the introduction of certain faults produced UA in some Toyota vehicles. Some witnesses questioned whether NHTSA had the expertise to find electronic defects or sufficient investigative resources to address possible defects in the nation’s large vehicle fleet.

As discussed above, NHTSA’s previous investigations had not revealed a defect in the Toyota ETC system but had revealed other problems related to UA that had led to recalls. When the Secretary of Transportation and NHTSA Administrator appeared at these hearings, they made clear that NHTSA would conduct further, in-depth studies to determine whether the Toyota ETC

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<sup>28</sup> Professor Gilbert of Southern Illinois University

system may have a defect and whether electronic control systems in other vehicles may be susceptible to safety-related defects.

#### **1.4 NHTSA Initiatives**

In March 2010, NHTSA launched two major studies designed to answer questions surrounding the issue of UA. The first was an in-depth examination of whether Toyota's ETC system contained possible defects that could be causing UA. For this study, NHTSA retained the National Aeronautics and Space Administration (NASA), an organization with established expertise in electronics, systems analysis, and software, to assist in and support its examination of the Toyota ETC system. For the longer term, the agency sought recommendations from the National Academy of Sciences (NAS) on the nature and extent of UA and safety issues related to electronic vehicle controls generally.

#### **1.5 Study of Toyota's ETC System and UA Potential**

NHTSA's study of Toyota's ETC system, which was supported in large part by NASA's work, was designed to obtain a more in-depth understanding of that system and possible safety vulnerabilities that could lead to UA. This critical information would provide the basis for an agency decision on whether to initiate a new defect investigation or other action concerning the ETC system. NASA's Engineering and Safety Center (NESC) has widely recognized expertise in the full range of engineering disciplines, problem solving experience, and a systems engineering focus. In addition to requesting a thorough examination of the ETC system and its possible vulnerabilities, the agency also asked NASA to determine whether any vulnerabilities identified through its work could realistically be expected to occur in a consumer's use of the vehicles (i.e., in the real world).

NASA's examination of the Toyota ETC system is detailed in NASA's companion report, issued simultaneously with this report. That report constitutes the most in-depth examination of a motor vehicle manufacturer's electronic control system ever conducted by a government agency. A summary of NASA's findings, observations, and recommendations appears below.

#### **1.6 NAS Study**

At the same time it was working with NASA to begin the study of Toyota's ETC system, NHTSA enlisted the National Academy of Sciences (NAS) to study broader questions. NHTSA

asked NAS to assemble an independent panel of experts to study the causes and solutions for UA generally. NHTSA also asked NAS to look carefully at the range of electronic control systems in today's vehicles and the strategies manufacturers are using to ensure their safety. NHTSA asked the panel for recommendations in these areas in terms of research, rulemaking, or enforcement activities and on the resources the agency needs to address any areas of concern. NHTSA expects to receive the NAS recommendations in the fall of 2011.

## **2.0 STUDY OF TOYOTA'S ETC SYSTEM AND UA POTENTIAL: NHTSA'S ACTIVITIES**

### **2.1 Purpose**

As explained above, NHTSA retained NASA to study the Toyota ETC system and has been working very closely with NASA on the project. At the same time, NHTSA embarked on additional activities to facilitate resolution of concerns about UA incidents in Toyota vehicles. NHTSA conducted a thorough examination of relevant complaint data to help determine the problem's scope. NHTSA also analyzed Toyota warranty data to determine whether there was evidence of any trends suggesting a problem related to the ETC system or components. The agency also examined data from Toyota field inspections related to possible UA incidents. NHTSA conducted a series of field inspections of Toyota vehicles alleged to be involved in recent UA incidents to determine whether they might reveal evidence of a vehicle-based defect. NHTSA also obtained a number of vehicles involved in alleged UA incidents and similar vehicles not engaged in such incidents to permit detailed examination of actual vehicles for any evidence of possible defects that might be causing UA, whether mechanical or electrical.

The combined NHTSA and NASA work was intended to provide NHTSA with the information it needed to determine what additional steps may be necessary to identify the causes of UA in Toyota vehicles and determine whether a previously unknown electronic defect may be present in those vehicles and warrant a defect investigation. We believe the combined work has accomplished those purposes.

## **2.2 Review of Consumer Complaint Data**

### **2.2.1 Consumer Complaints to NHTSA**

NHTSA received more than 38,000 owner complaints (also referred to as Vehicle Owner Questionnaires, or VOQs) during 2009 and over 65,000 in 2010, through the Auto Safety Hotline,<sup>29</sup> its web site,<sup>30</sup> and the US mail. As explained below, the huge increase in the complaint volume in 2010 was apparently related to the publicity concerning the UA issue, which affected the rate of complaints on UA and non-UA issues as well as complaints concerning non-Toyota products. The complaint information, which is voluntarily provided by consumers (who often lack expertise in automotive technology), is entered into the NHTSA consumer complaint database, and catalogued according to vehicle or equipment make, model, model year, and the affected part (component description), assembly, or system as identified by the consumer.<sup>31</sup> Complaint data are available as-received<sup>32</sup> on NHTSA's web site for all to review. NHTSA technical staff read each complaint as it is received as part of a continuous review to identify potential trends that may indicate the presence of an emerging safety defect. The same data are also used to support existing safety defect investigations. When appropriate, NHTSA technical staff will conduct follow-up interviews and sometimes field visits to verify complaints that point to possible safety defect concerns.

### **2.2.2 Identifying Complaints Related to UA**

Consumer complaints to NHTSA often allege certain conditions that may not be attributed to a specific vehicle component. "Unintended Acceleration" (UA) is one such condition. As alleged in consumer complaints to NHTSA, UA applies to a wide variety of conditions that include:

1. Engine idle fluctuations;
2. Unexpected but modest increases of engine power while driving;
3. Cruise control behavior;
4. Incidents in parking lots where vehicles unexpectedly accelerate; and
5. On-road prolonged high-speed incidents.

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<sup>29</sup> (888) 327-4236

<sup>30</sup> <http://www.safercar.gov/>.

<sup>31</sup> Over 80% of complaints received in the last year are filed directly by the consumer on NHTSA's web site.

<sup>32</sup> Personal identifiers protected by the Privacy Act and profanity are removed from the narratives.

Each of these incidents may be caused by design characteristics of the vehicle, driver behavior, vehicle mechanical conditions (such as floor mats, sticky pedals, or others), or potential malfunctions in the engine/transmission systems and their controlling electronics. Many UA complaints received by NHTSA (and in fact the majority of those that occur at low initiation speeds and involve high power) also mention that the brakes were ineffective in stopping or slowing down the vehicle.

Consumer complaints are not marked with any type of condition code to designate the ones that involve or allege UA. UA incidents cannot be reliably identified by a particular vehicle component code in the database because those codes are typically assigned by the complainant (who may or may not choose an appropriate code) and because they also correspond to non-UA conditions such as stalling and hesitation. Accordingly, NHTSA made use of a keyword search<sup>33</sup> of the VOQ complaint narrative field to identify a statistically relevant (and sufficiently large) sample of complaints alleging the broadest possible range of UA concerns, and that were received over the last decade. NHTSA's search criteria were intentionally very broad so as to identify as many relevant complaints as possible and, as a result, swept in complaints that did not involve UA.<sup>34</sup> Therefore, a careful reading of each complaint was required to clarify whether or not it actually involved a UA incident.

NHTSA embarked on this study early in 2010.<sup>35</sup> From January 1, 2000, to March 5, 2010,<sup>36</sup> NHTSA received over 400,000 complaints of all types (Table 2). Of this total, over 19,000 met the UA keyword search criteria. These complaints were manually reviewed to assess whether a UA incident was alleged. Further review of each report identified certain objective information from the narrative, such as initiation speed, or the location where the incident occurred. And when factual information was sparse, inferences about the conditions present at the time of the

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<sup>33</sup> Keyword search overview and terms available in Report No. NHTSA-NVS-2011-ETC-SR01.

<sup>34</sup> The keyword search also identified various unrelated conditions such as vehicle drivability/hesitation and ABS braking concerns that were not UA related.

<sup>35</sup> The output of NHTSA's work was required to commence the NASA assessment.

<sup>36</sup> NHTSA's detailed analysis of complaint data covers this decade-long time period, a cut-off chosen when the analysis began early in 2010. Of course, NHTSA has continued to review and analyze complaints received since the end of this period, and discusses some of those complaints in this report, but did not incorporate the newer complaints into this analysis except to show broad trends through the end of 2010.

incident were made based on the context described in the narrative.<sup>37</sup> This process revealed approximately 9,700 UA-Related Complaints for all model years (MY) 1998-2010 vehicles, of which approximately 3,000 were Toyota vehicles.<sup>38</sup>

**Table 2: Identification of Likely Toyota UA VOQs**

Category	No. of VOQs
Total VOQs received from 1/1/2000 to 3/5/2010	426,911
UA related VOQs ID'd by key-word search	19,269
VOQs remaining after manual review	11,454
MY1998-MY2010 - only	9,701
Toyota- only	3,054

This body of complaints underwent further review that will be discussed in later sections. The review included targeted follow-up interviews of the complainants, cross-checking against other data sets, and decisions as to the appropriate category for each complaint.

### **2.2.3 Timing of Toyota Complaints: The Effects of Publicity**

NHTSA assumes that not all incidents are reported and that, accordingly, each complaint represents a greater number of unreported real-world failures. All things being equal, the ratio of complaints to these failures is expected to remain constant. An emerging safety defect will increase the number of real-world failures, raising the number of complaints without altering the ratio. Other factors such as publicity, which can alert people to both a specific possible safety issue and to the option of filing a complaint with NHTSA, can produce significant complaint volumes without indicating a corresponding increase in the number of real-world failures.

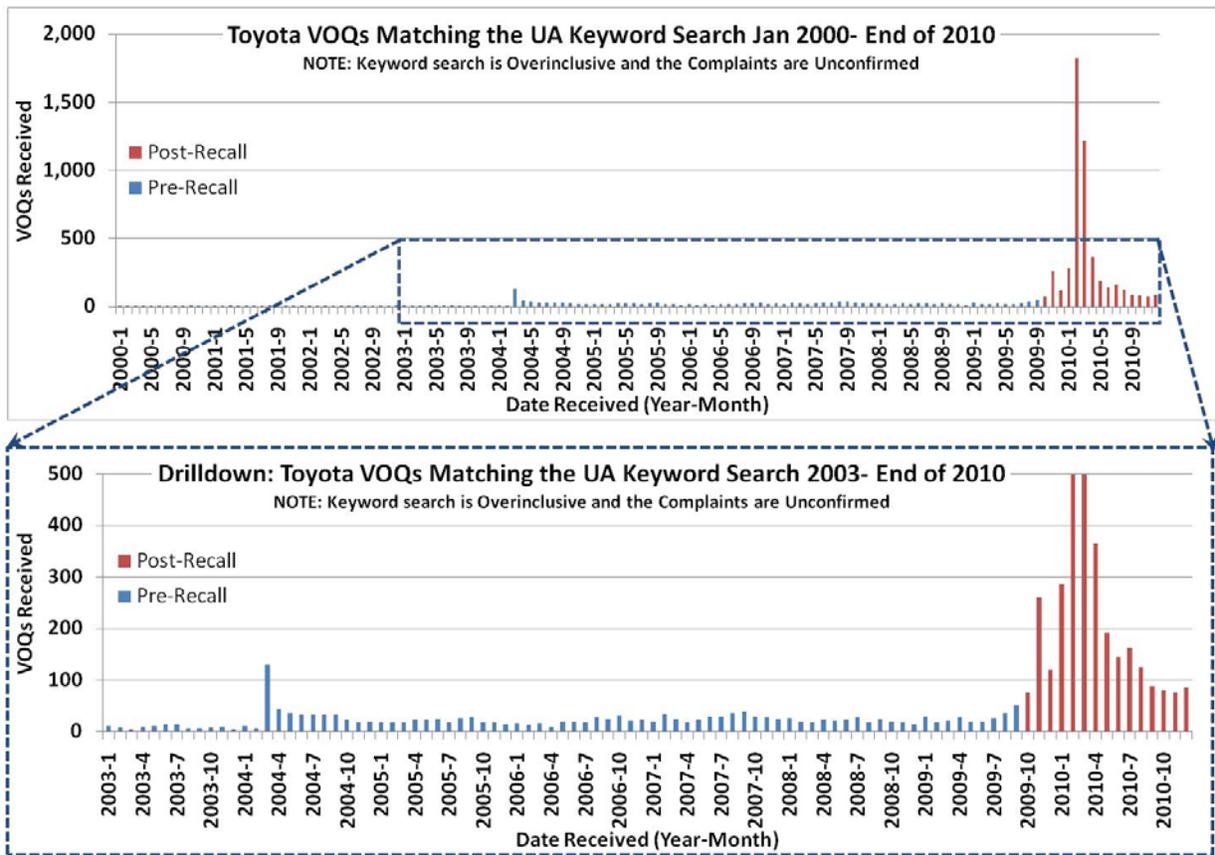
<sup>37</sup> For example, if the location was not explicitly identified but a narrative indicated that the vehicle was in Reverse at the time of the incident, the initiation speed was low, and the vehicle was not in traffic, the vehicle was likely conducting a parking maneuver.

<sup>38</sup> NHTSA's keyword search, although broad enough to identify VOQs that did not involve UA, also did not identify every UA VOQ present in the database. For the reasons discussed in the text above, in its primary search NHTSA did not use the component code as a search criterion due to its lack of precision in a context as broad as UA. However, to double check, NHTSA did a separate, even broader review of the VOQ database for reports alleging UA using the component code category as a search criterion. That assessment, which focused primarily on reports involving the Vehicle Speed Control component code and Camry vehicles, identified an additional 381 MY 1998 to 2010 Camry VOQs, of which 235 did not allege a UA incident. NHTSA's review of the remaining 146 Camry VOQs determined that the additional reports largely mirrored the same distribution among incident types as those identified from the keyword search and that their incorporation into the analysis would have a negligible impact on its outcome. Therefore, those 146 reports are not included in the analysis of Camry discussed in this section.

For example, NHTSA's complaint volume spiked in March 2004, (after four months of pre-investigative screening of the problem) when NHTSA opened an investigation (PE04-021) of electronic throttle control concerns in the 2002-2003 Camry, Solara, and ES300 (Figure 1). However, it is unlikely that this spike was caused by a sudden increase of the in-field failures at that time. Rather, the spike was likely related to publicity surrounding the opening of the investigation. Complaints also ramped up starting in September 2009, through the end of March 2010. Publicized events during this time period included the fatal ES350 crash near San Diego, California in late August of 2009, announcement of a safety recall involving the accelerator pedal being entrapped by out of position floor mats (Safety Recall 09V388) in early October, an expansion of the October recall and announcement of a new recall for a "sticky pedal" defect in January 2010, and the early 2010 Congressional hearings. A majority (71%) of the complaints presented in Figure 1 were reported after the announcement of the pedal entrapment recall in October 2009, with almost half (43%) received in the months of February and March 2010.<sup>39</sup>

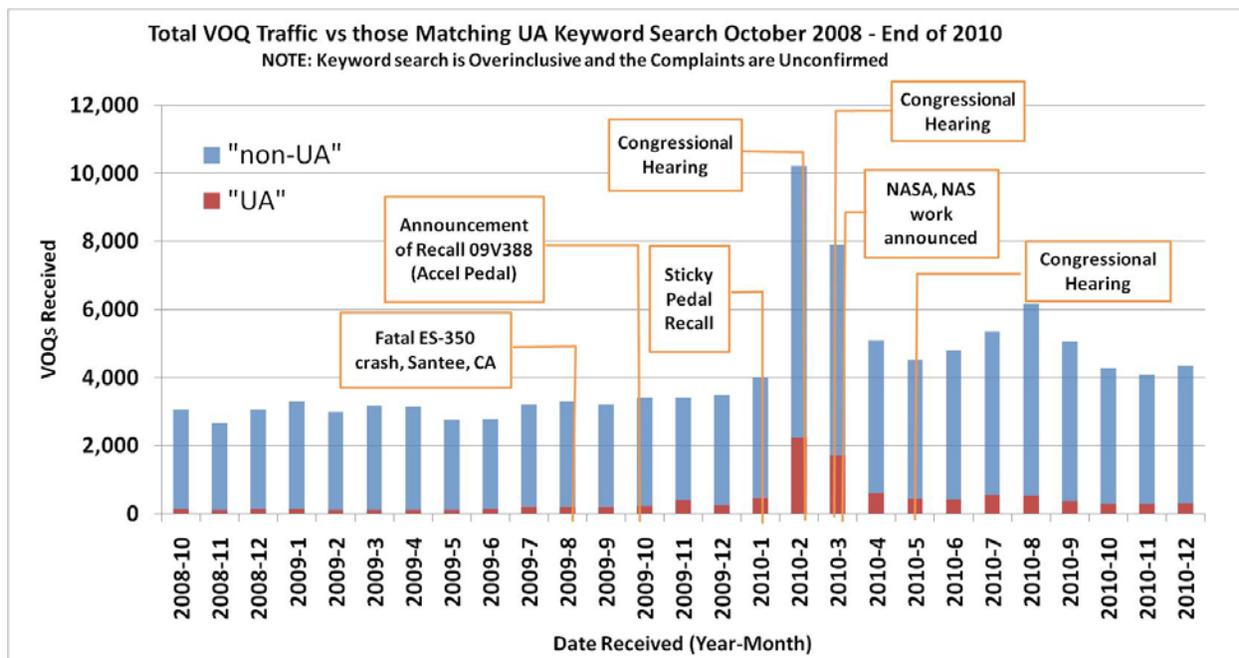
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<sup>39</sup> The trend is strikingly clear in the subset of these complaints involving fatalities allegedly related to UA in Toyota vehicles. (A complete discussion of this subject appears below in the section on complaints alleging fatalities.) In the ten years from 2000 until just prior to the October 2009 recall, NHTSA had received 11 such complaints involving 15 fatalities, including the four deaths in the August 2009, near San Diego, California. Of those, NHTSA has confirmed a vehicle-based cause only in the San Diego crash (pedal entrapment by an improper, unsecured floor mat). Note that this same condition was identified in an additional fatal crash examined by NHTSA that was not reported as a consumer complaint. By March 5, 2010, (i.e., in just five months) NHTSA had received an additional 39 complaints involving 45 fatalities possibly related to UA in Toyota vehicles. Half of these recently reported incidents dated back over two years, some as far back as 2001. Of the total number (75) of fatal incidents reported as of December 31, 2010, nearly a third (22) involved vehicles that were not equipped with ETC. NHTSA has obtained additional facts on many of these recently reported incidents but has not yet encountered evidence pointing to a vehicle-based cause in any of them.



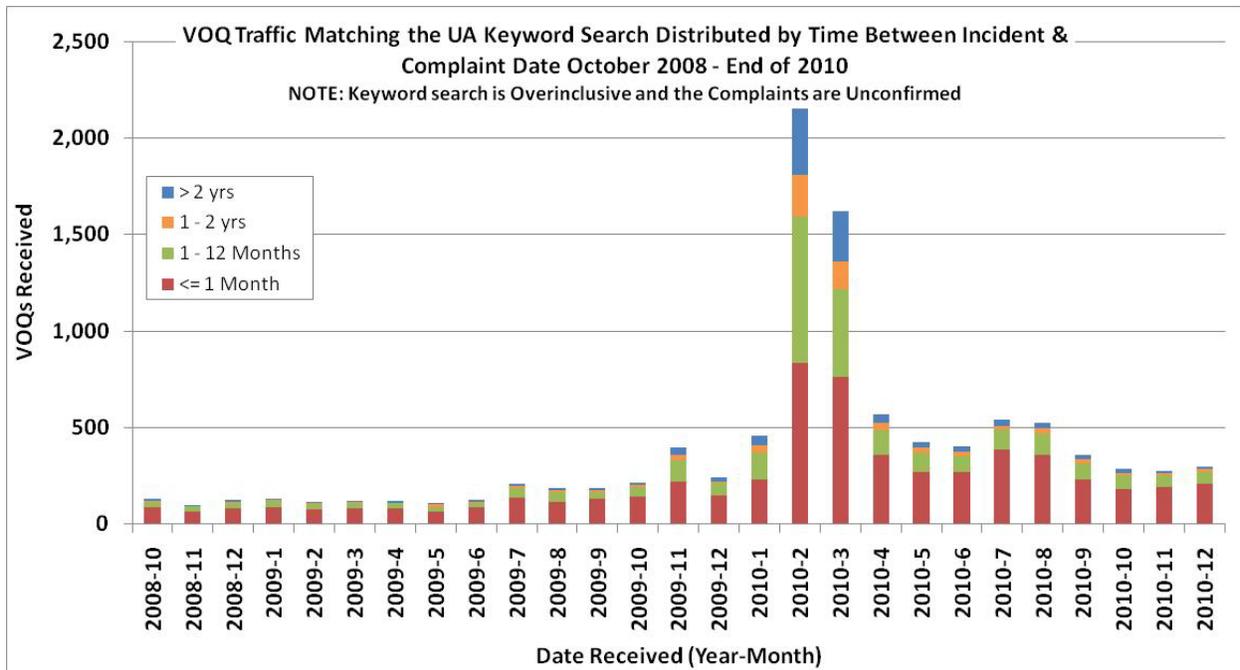
**Figure 1: Consumer Complaints to NHTSA Alleging Unintended Acceleration in MY 1998-2010 Toyota Vehicles**

Although the proportion of complaints concerning UA allegations rose considerably, the publicity surrounding certain events substantially increased the flow of complaints to NHTSA in all categories, not just UA, as Figure 2 illustrates. Although Toyota vehicles accounted for a disproportionate share of the influx of complaints, complaint volumes on vehicles of all major manufacturers were affected.



**Figure 2: Recent VOQ Traffic to NHTSA – UA vs. Non-UA**

The time lag between incidents and complaints about them is also affected by publicity. Throughout the past decade, a majority (64%) of complaints (UA and non-UA) were filed within a month of the incident’s occurrence. In contrast, during the heightened publicity in early 2010, complaints pertaining to recent UA incidents were less than half of the total (42%), and a quarter (26%) of UA complaints filed pertained to incidents over a year old. This time lag suggests that a major portion of the increased complaints was the reporting of older incidents rather than an uptick in new incidents (Figure 3).



**Figure 3: Recent UA VOQ Traffic to NHTSA – Older Incidents vs. New Incidents**

The important point is that, unlike the actual rate of occurrences in the field, the rate at which occurrences are reported to NHTSA may be greatly influenced by intense publicity surrounding investigations and recalls. This fact requires careful consideration when drawing conclusions based on the sheer volume of complaints received on any subject. Notwithstanding these limitations, the consumer complaints are a valuable defect screening tool and play a central role in NHTSA’s decisions on whether and when to open an in-depth investigation and, even after a publicity spike, specific complaints offer considerable insight into the circumstances surrounding the various safety defects investigated by NHTSA.

**2.2.4 Brake Effectiveness as an Element of Complaint Analysis**

NHTSA often conducts interviews with those who report UA incidents to gain understanding, from the driver’s perspective, of the level of engine power produced and, if brakes were used, the effectiveness of the brakes. Many of the complaints alleging incidents of UA, particularly those

involving crashes, report experiencing both high engine power<sup>40</sup> and ineffective brakes. This type of allegation has been common both before and since the introduction of ETC. Three general factors are identified that may affect brake effectiveness during a UA event: (1) brake malfunction; (2) brake fade; or (3) reduced vacuum assist not related to a malfunction.<sup>41</sup> Brake malfunction is the only one of these factors that could affect brake effectiveness on the initial brake application in a UA event. No evidence of such malfunctions has been found in post-incident inspections and service of vehicles involved in UA events. The latter two factors are believed to have contributed to vehicle control issues in a number of long duration incidents that initiated at highway speed, including the only two fatal crashes in which a vehicle-based cause of UA has been identified.<sup>42,43</sup> These mechanisms do not explain allegations of brake ineffectiveness in the events that initiate at low speeds, which available evidence indicates are most likely caused by the driver pressing the accelerator when intending to apply the brake.

#### *Brake system malfunctions*

Brake systems are designed to tolerate single faults and maintain braking capability. Single point faults that result in complete loss of braking are extremely rare. Component faults that could result in circuit failure (e.g., master cylinder seal or brake line) would result in soft brake pedal with extended pedal travel and increased stopping distance. Loss of brake vacuum assist (e.g., brake booster seal or check valve) would result in a hard brake pedal and require much greater brake pedal force from the operator to achieve a given deceleration. If these types of failures occurred suddenly, a crash may result. However, each of these conditions involves mechanical failures that should be evident on post-vehicle inspection. If such faults existed prior to the UA incident, they would have been evident to the driver. There is no known reason for

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<sup>40</sup> Some complaints allege that the unintended high engine power occurred after the accelerator pedal had been intentionally pressed to the floor (e.g., to pass a slower moving vehicle, merge into highway traffic or maintain speed up a grade). When the driver subsequently attempted to decrease throttle, the engine remained at high power – which is consistent with a stuck throttle condition. Other complaints allege that engine power increased spontaneously, often in response to brake pedal application.

<sup>41</sup> The engine intake manifold is the source of vacuum used by the brake booster to provide power assist. The engine manifold produces less vacuum as the throttle is opened from idle. Braking when the throttle is open will have full power assist for the first application only. If the brake pedal is “pumped” the booster reserve vacuum will be depleted after the first few applications.

<sup>42</sup> California Highway Patrol, Multidisciplinary Accident Investigation Team (MAIT) Report, Case Number BL-020-09, August 29, 2009. See also the San Diego County Sheriff’s Department Incident Report concerning August 2009 crash in Santee, California (Case No. 09056454). [

<sup>43</sup> ODI Unintended Acceleration Investigation - 2007 Toyota Camry - California, Case Number DS07035, Dynamic Science, July 2007, ([NHTSA SCI Electronic Case Viewer](#)).

such faults to coincide with a throttle system malfunction.<sup>44</sup> These types of failures would also be evident upon post-incident inspection and/or vehicle repair. Analysis of complaints, field investigations and warranty data has not identified any UA incidents in which a simultaneous brake system failure was a contributing factor.

### *Brake fade*

Brake fade is a reduction in braking effectiveness or stopping power that occurs due to friction-related thermal effects of repeated and/or sustained brake application, especially in high-speed conditions. Post-incident inspections of brake components removed from vehicles involved in high-speed, long-duration incidents have revealed evidence of this type of thermal degradation of friction materials indicative of prolonged braking at speed (Figures 4 and 5). This type of damage has only been observed in incidents that originated at highway speeds and involved prolonged open-throttle braking.<sup>45</sup> These types of events were first observed by NHTSA in 2006 in MY 2007 Lexus ES 350 vehicles<sup>46</sup> and, to date, such brake system overheating in UA incidents has only been observed in events involving throttles stuck wide-open due to pedal entrapment.



**Figure 4: Left-front inboard brake pad; 2007 Lexus ES350 (ODI 10182245)**

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<sup>44</sup> Reduced vacuum assist caused by multiple brake applications with the engine operating at a significant throttle opening is considered separately.

<sup>45</sup> While the precise initiation point is not always known, these incidents have involved several miles of braking at WOT before the event ends by the driver regaining control (e.g., freeing the accelerator pedal, shifting to Neutral, turning off the engine) or crashing.

<sup>46</sup> Visit <http://www-odi.nhtsa.dot.gov/defects/> to review field investigation memoranda for investigation files PE07-016 and EA07-010, or <http://www-odi.nhtsa.dot.gov/complaints/> to review consumer complaint and field investigation memoranda for ODI complaint numbers 10174732/10176450, 10182245 and 10189655.



**Figure 5: Left-front inboard brake pad; 2009 Lexus ES350 (ODI 10284881)**

Incidents initiating from stopped or slowly moving vehicles comprise the majority of reported UA incidents and an even larger proportion of crashes, particularly for the MY 2002 through 2006 Camry vehicles that experienced the highest rates of UA complaints and crashes. Since these incidents occur at much lower speeds and are much shorter in duration than the high-speed incidents associated with pedal entrapment, brake fade is not a plausible explanation for the alleged brake ineffectiveness.<sup>47</sup>

#### *“Pumping” the brakes*

Pedal entrapment incidents begin when the driver attempts to release the accelerator pedal after a hard application. The vehicles are usually traveling at high speeds on highways with surrounding traffic. It may take the driver a few moments to recognize that the throttle is stuck. Drivers interviewed by NHTSA have reported using the brake to control vehicle speed in the initial moments. Some report pumping the brakes because the brakes appear to be ineffective at slowing or stopping the vehicle when initially applied. Braking effort quickly becomes more difficult as the reserve vacuum in the brake booster is depleted by the first few pedal applications with the throttle fully open. Once the driver subsequently makes the decision to stop the vehicle fully, it has been very difficult for drivers to overcome the power of the engine and the kinetic energy of the vehicle, which increases exponentially with vehicle speed, particularly for vehicles equipped with more powerful engines. The problem is compounded in vehicles with push-button ignitions and serpentine shift gates with sequential sport shifting, which have been noted to be

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<sup>47</sup> While NHTSA has not conducted testing to determine the conditions necessary to experience brake fade, extensive high- and low-speed open-throttle brake testing conducted by NHTSA did not result in any evidence of the brake component heat damage observed in the prolonged high-speed incidents.

difficult for drivers attempting to turn the engine off or shift to neutral in emergency/panic situations.

The low speed incidents are different in the drivers' use of controls (accelerator and brake pedals) before and after incident initiation. The incidents begin during maneuvers when the driver is attempting to slow the vehicle, with many explicitly stating that the UA began when the brake pedal was depressed.<sup>48</sup> Review of information contained in complaints, driver interviews and field investigations indicates that the driver is attempting to stop the vehicle (or hold it stationary in the case of UA involving from stopped vehicles) in the initial application of the brake. Only a few drivers have indicated they pumped the brake pedal during these types of UA incidents and those that did stated that they did so because the brakes were not effective when initially applied. Testing of the Camry vehicles has demonstrated that a normally functioning brake system is capable of overcoming full engine power with brake pedal efforts any typical driver should be capable of achieving on the initial application. No evidence of brake system faults has been noted in owner complaints of UA, warranty claim records or in field investigations of UA incidents conducted by NHTSA and Toyota that could explain a loss of vacuum assist or other brake system fault coincident with the UA event. There is no plausible explanation for brake ineffectiveness upon the initial application in these types of UA incidents. Analysis of Electronic Data Recorder (EDR) data collected during field investigations of UA incidents with driver claims of sudden full engine power with ineffective brakes have found that the brakes were not applied.

Accordingly, in analyzing UA complaints, NHTSA finds claims of brake ineffectiveness credible only in situations involving medium to high initiation speeds and repeated pumping of the brakes (which can deplete the vacuum assist) and high speed, long duration events with repeated attempts to use the brakes (where brake fade can occur, particularly in high powered vehicles with stuck throttles).

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<sup>48</sup> No mechanism has been identified that could cause the throttle to open because of brake application and any engine power increases that may occur during a brake application should be easily controllable by the driver.

### **2.2.5 Analysis of Alleged UA Complaints**

NHTSA conducted a detailed analysis of complaints that fit a very broad description of UA received from January 2000, through March 5, 2010. The analysis focused on distinguishing between the circumstances involved in the incidents according to the speed at which the incident reportedly began (initiation speed), the location (parking lot, driveway, highway, etc.), whether a crash occurred, and the reported or apparent action of the driver. The major insights derived from the analysis are that a substantial majority of the incidents begin at a very low speed or a stationary position and frequently involve parking maneuvers, and that in most of these types of incidents and in many highway incidents the driver claimed or apparently intended to use the brake, but any braking that did occur was not effective. These points hold true with great consistency when scrutinizing UA incidents across the entire auto industry, just Toyota vehicles, or just certain Toyota models.

Different incident types with very different circumstances, causes, and hazards are included within the UA complaints identified. To better differentiate UA incident types, efforts were made to classify each complaint by its circumstances according to a single speed range (stationary, low, medium, and high) at the time of incident initiation. Table 3 covers the reported UA incidents (5,512 out of a total of 9,701 for the whole period) concerning all manufacturers' vehicles in MY 1998-2010 in which detailed review of the VOQ could reliably indicate the initiation speed of the incident.<sup>49</sup> The table lists the distribution of complaints, crashes, and crash risk (percentage of VOQs involving a crash) by identified initiation speeds.

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<sup>49</sup> Some complaint narratives are too ambiguous to reliably support this type of binning. Others cite multiple events with dissimilar circumstances. While each complaint was reviewed and considered, the unknowns and multiples were not included in these types of tables.

**Table 3: UA Consumer Complaints by Initiation Speed (All Manufacturers)<sup>50</sup>**

<b>Initiation Speed</b>	<b>Total VOQs (5,512)</b>	<b>Subset: Crashes (2,039)</b>	<b>Crashes / VOQ</b>
Stationary	36%	33%	34%
Low Speed (< 15 mph)	33%	51%	57%
Medium Speed (15 - 45 mph)	12%	9%	28%
High Speed (> 45 mph)	19%	7%	13%
Grand Total	100%	100%	37%

A majority of complaints (69%) and crashes (84%) with known single initiation speeds occurred at stationary and low speeds. At the same time, high-speed incidents account for a small portion of the total and just 7% of the reported crashes. Further review of the stationary and low speed incidents (combined) found that parking space entry and exit accounted for the largest share of these incidents (40% of VOQs, 64% of crashes). Many of the parking maneuver narratives reported incidents characterized by high engine power either after the driver applied the brake or immediately after shifting the transmission. In most cases, the brakes were reported as ineffective. These circumstances tend to align with either a pure pedal misapplication (applying the accelerator instead of the brake) or dual pedal application (brake and accelerator pedals applied).

Complaints to NHTSA alleging UA and pertaining to Toyota vehicles (3,054 complaints) received additional review. Table 4 lists the distribution of complaints, crashes, and crash risk by identified initiation speeds for those complaints where that information could be discerned.

**Table 4: UA Consumer Complaints by Initiation Speed (Toyota – Only)<sup>51</sup>**

<b>Initiation Speed</b>	<b>Total VOQs (2,244)</b>	<b>Subset: Crashes (1,038)</b>	<b>Crashes / VOQ</b>
Stationary	21%	19%	40%
Low Speed (< 15 mph)	47%	65%	65%
Medium Speed (15 - 45 mph)	13%	10%	34%
High Speed (> 45 mph)	19%	6%	15%
Total / Overall	100%	100%	46%

In numbers almost identical to the industry-wide figures, a significant majority of Toyota UA complaints (68%) and reported crashes (85%) occurred at stationary or low initiation speeds.

<sup>50</sup> This table omits 4,189 complaints that involved either undetermined or multiple initiation speeds.

<sup>51</sup> This table omits 810 complaints that involved either undetermined or multiple initiation speeds.

High-speed incidents account for a small portion of the total complaints and very small portion of the crashes. Parking space entry and exit accounted for half (51%) of the stationary and low speed complaints and a majority (70%) of crashes. Within parking maneuvers, parking space entry accounted for approximately triple the number of complaints or crashes as parking space exits.

Because the focus of the study was Toyota’s ETC system, and because Camry models accounted for the greatest portion of complaints concerning UA models, NHTSA’s complaint analysis focused on ETC-equipped Camrys in great detail. MY 2002 was the first year that the Camry was equipped with ETC. The MY 2002-2006 Camry model line accounts for just over half (57%) of ETC-equipped Camry production and a significant majority of UA complaints and crashes (64% and 78%, respectively) concerning ETC-equipped Camry models reported to NHTSA. Another new generation of the Camry model was introduced in MY 2007, and the study has examined that generation as well, although not in quite the same depth as the first generation of ETC vehicles.<sup>52</sup>

Table 5 lists the distribution of complaints, crashes, and crash risk by identified initiation speeds for these ETC-equipped Camry vehicles.

**Table 5: UA Consumer Complaints by Initiation Speed (MY 2002-2010 Camry – Only)<sup>53</sup>**

<b>Initiation Speed</b>	<b>Total VOQs (664)</b>	<b>Subset: Crashes (383)</b>	<b>Crashes / VOQ</b>
Stationary	23%	25%	61%
Low Speed (< 15 mph)	51%	63%	72%
Medium Speed (15 - 45 mph)	13%	8%	37%
High Speed (> 45 mph)	12%	3%	16%
Total / Overall	100%	100%	58%

<sup>52</sup>Substantial changes in a vehicle’s design occur from time to time, and manufacturers frequently refer to these changes as new platforms, which can be thought of as new generations of the original vehicle. Relevant platform changes in the Camry vehicles were introduced for Model Year (MY) 1996, when the V20 platform (which did not include ETC) was fielded; MY 2002 (when the V30 platform, which did include ETC, began), and MY 2007 (when the V40 platform, also including ETC, began). Because the complaint data reviewed were limited to MY 1998 at the oldest, references to the V20 Camry will not cite the earlier model years. In this report then we will refer to these different platforms by groupings of the included model years. For example, the V20 platform will be referred to as “MY 1998-2001.”

<sup>53</sup> This table omits 184 complaints that involved either undetermined or multiple initiation speeds.

The patterns apparent in the data for all manufacturers' vehicles and Toyota vehicles generally hold true for ETC-equipped Camrys as well. A very large majority of complaints (74%) and crashes (88%) involve incidents that occurred at stationary or low initiation speeds, and high-speed incidents accounted for a small portion of the total complaints and just 3% of the reported crashes. Further review of the stationary and low speed incidents found that parking space entry and exit accounted for over half (58%) of these complaints and a majority (70%) of crashes. Within parking maneuvers, parking space entry occurred at over twice the rate of complaints or crashes as parking space exits.

NHTSA's analysis<sup>54</sup> of the ETC- equipped Camry complaints focused on certain details in addition to initiation speed. NHTSA assessed the driver's stated intent with regard to brake and accelerator use, circumstances that implied<sup>55</sup> such use, and reported use of cruise control or concerns expressed about the vehicle's drivability. NHTSA looked carefully at previous consumer interviews related to these complaints and conducted a large number of new interviews as well.<sup>56</sup> The additional information available and improved office learning throughout the UA study enabled additional judgment to be made concerning the scenarios covered by the Camry VOQs. VOQs for the three most recent Camry generations (including, for comparative purposes the MY 1998-2001 mechanical throttle Camrys) were characterized according to two broad initiation speed ranges and reported driver control operation or stated concern (e.g., cruise control or drivability) at incident initiation (Table 6).

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<sup>54</sup> NHTSA's complaint analysis focused heavily on incident initiation conditions. NASA conducted its own analysis of the same complaint data, more broadly on the Toyota complaints, and then focusing in on the MY 2002 – 2010 Camry. NASA's analysis differed in that it strove to assess the apparent power developed by the engine and effectiveness of the brakes to align the complaints with a particular degree of throttle opening and then a likely throttle control concern. This effort, conducted jointly with NHTSA, added an additional layer of review to the ETC- equipped Camry complaints and included conditions reported throughout the incident. Notwithstanding the differences in the approaches, the two analyses show similar results.

<sup>55</sup> For example, "Apply Brakes" scenarios were associated with over half (59%) of complaints and a strong majority (85%) of crashes involving ETC- equipped Camrys. In these complaints, most (66%) complaint narratives explicitly stated that the brakes were applied. Brake use was inferred for the balance by identifying maneuvers cited in the narrative that are associated with brake use. These most frequently (22%) involved parking space entry and exit maneuvers. Less frequently observed (7%) were driver statements citing maneuvers that would require a brake application such as shifting the transmission into Drive or Reverse, creeping the vehicle along in a parking lot, or approaches to traffic- controlled intersections.

<sup>56</sup> Over half (57% or 488 / 848) MY 2002 – 2010 Camry VOQs were subject to follow-up effort with 357 leading to dialogue with complainants. Half of the interviews pertained to complaints received in 2009 or 2010 (a third in 2010 only).

**Table 6: MY 1998-2010 Camry VOQs by Initiation Speed**

Initiation Speed	Scenario / Driver Intent	VOQs			Crashes		
		MY 1998 - 2001	MY 2002 - 2006	MY 2007 - 2010	MY 1998 - 2001	MY 2002 - 2006	MY 2007 - 2010
		non-ETC (110)	ETC (544)	ETC (304)	non-ETC (56)	ETC (341)	ETC (96)
Low Speeds (<15 mph)	Apply Brakes	48%	69%	25%	75%	85%	61%
	Apply Accelerator	12%	4%	4%	4%	3%	3%
	Release Accelerator	5%					
	Idle / Normal Operation	3%	1%	3%			
Roadway speeds (> 15 mph)	Apply Brakes	7%	6%	7%	9%	3%	9%
	Apply Accelerator			0.3%			
	Release Accelerator	12%	3%	23%	7%	1%	11%
	Cruise Control	0%	1%	5%			
	Drivability	1%	7%	23%			
Other / UNK	1%	0%	1%	2%	0%	1%	
Unknown	Unknown	12%	10%	10%	4%	8%	14%
Overall		100%	100%	100%	100%	100%	100%

Incidents initiating at low speeds (i.e., from a stationary position or at a speed less than 15 MPH) in scenarios where the driver was applying the brakes constitute by far the largest overall share of complaints and crashes. Complaints throughout this category imply or explicitly state that the vehicle accelerated immediately after the brake was applied and generally describe an incident that runs its course in seconds and spanned very short distances. Most complaints in this category cite only the one incident and state or imply there were no other ongoing drivability concerns with the subject vehicle. Only a tiny number (eight) of the complaints in this category aligned with ETC warranty claims of any type. The warranty claims and their related complaints were scattered over a seven year period and all but one were serviced for non-UA conditions. Similar to prior sections, parking maneuvers accounted for over half (61%) of these complaints. Pulling into a parking space / stall or garage were by far the most common parking maneuvers reported. This category also accounts for an overwhelming majority of crashes experienced regardless of whether the vehicle was equipped with ETC. When complaint volumes are adjusted for population and field exposure, the two generations of ETC- equipped Camrys show comparable complaint and crash rates.

Roadway speed incidents occurring after rapidly accelerating and then releasing the accelerator (e.g., passing a vehicle or merging into traffic) in the MY 2007–2010 Camry constituted the second largest share of complaints and crashes for that generation and generally coincided with entrapment of the accelerator pedal by the floor or mat, a condition addressed by a safety recall.

These complaints generally described longer duration incidents (closer to a minute, in some cases longer), multiple attempts to stop the vehicle<sup>57</sup> and, in a few cases, overheated brakes. Several complaints specifically stated that the floor mats had interfered with the accelerator pedal.

Incidents beginning at roadway speeds with brake use cited constituted the third largest share of complaints with known circumstances and crashes. With the exception of initiation speed, crash circumstances were similar to those discussed in the previous section -- the incident occurred in a situation where the driver intended to apply the brakes (e.g., deceleration with slowing traffic or when approaching an intersection). Complaints frequently stated that the vehicle accelerated in response to the brake application. Only four of the complaints in this section align with ETC warranty claims. In all cases, the warranty claims occurred years prior to or after the incident date.

Vehicle drivability concerns at roadway speeds constituted a major share (23%) of UA complaints involving the MY 2007–2010 Camry but caused no crashes, indicating that they posed minimal safety consequences. In contrast to many of the other ETC Camry UA complaint types, conditions were reported as ongoing, e.g., that the vehicle would frequently hesitate and then lurch in response to an accelerator application. These complaints aligned with a number of technical service bulletins meant to address phenomena such the tendency of the vehicle to “shudder” at a certain speed range due to an intentional transmission design element and engine hesitation.

NHTSA identified four complaints from this period (2000 through March 5, 2010) that appear to involve impaired vehicle operation that may be related to the occurrence of a resistive short in the pedal position sensor. In one case, NHTSA obtained the pedal and tested it, finding a resistive short in the pedal position sensor. NASA subsequently examined the pedal, confirmed the existence of the short, and found a “tin whisker” to be the cause of the resistive short. In one other case, NHTSA has obtained the pedal and determined the presence of a resistive short but had not determined the mechanism of the short at the time of this report. NHTSA does not have access to the removed pedals in any of the other two cases. (Each of the four complaints

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<sup>57</sup> Examples of these attempts are: prolonged brake applications, shifting the transmission into Park, turning the engine off, removing floor mats from the footwell, and attempting to raise pedals with hands and toes.

involved a MY 2002-2006 Camry with potentiometer type pedal sensor) in which the driver reported an impaired ability to accelerate (a lack of response to pedal application) combined with “jerky” acceleration that made driving difficult, with the engine always returning to idle when the pedal was released. Additionally, the vehicles were put into limp-home mode due to the occurrence of the short. In these cases, the brakes fully controlled the acceleration and the owner brought the car in for servicing, resulting in pedal replacement. These situations are unlike the most common allegations of UA in which acceleration allegedly continues even when the accelerator is released and, very often, the brakes allegedly have little or no effect. In these cases, releasing the accelerator stops the acceleration and the brakes function normally. NHTSA and NASA conducted vehicle testing using the same resistive short as found in the failed pedal (see NASA’s report for full details). The tests indicated that the fail-safe mode in these vehicles does not operate in the same way at all times when this specific condition occurs, and varies depending upon how quickly the accelerator pedal is pressed. However, the single short did not itself produce a UA condition (which would require the occurrence of a second fault) and, in the reported cases, the occurrence of the short resulted in a form of impaired operation that caused the driver to seek attention from a dealer, illuminated the malfunction indicator light (“MIL”), and stored a DTC in the ECM. These complaints are discussed more fully in the warranty section, below.

In summary, a significant majority of the UA complaint and crash volume (both in Toyota and non-Toyota vehicles) is concentrated in high throttle, low initiation speed incidents often called “sudden acceleration,” i.e., high power accelerations from a stationary position or very low initial speed where the driver claims use of the brake with a loss of braking effectiveness.<sup>58</sup>

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<sup>58</sup> The complaint analysis (as well as the analysis of UA complaints alleging fatalities and NHTSA’s field inspections conducted in 2010) revealed that older drivers were disproportionately involved in alleged UA incidents. NHTSA is concerned about that relationship and is conducting human factor research aimed at identifying causes and possible remedial measures. A current study, *Pedal Application Errors*, reviewed media reports in the United States between 2000 and 2010 to identify crashes attributed to unintended acceleration in which the driver apparently mistook the accelerator for the brake or that were attributed to unspecified vehicle causes. In addition, a panel of Certified Driver Rehabilitation Specialists provided information about medical conditions and other driver characteristics that could increase the likelihood of either making a pedal error, or failing to recognize and correct such an error. Upcoming project activities will examine older drivers’ pedal behaviors during on-road driving. Participants will drive an instrumented vehicle in which posture, leg and foot movements will be recorded. The study is designed to provide insight into driver foot movements associated with pedal applications that might contribute to pedal errors. Participants will include groups with selected medical conditions, as well as a group of normally-aging controls. The study seeks to identify the degree of functional loss associated with each medical condition that may increase risk of unintended accelerations.

NHTSA believes that these incidents are very likely the result of pedal misapplication. This conclusion is based on the fact that application of the brake alone cannot cause acceleration and that there is generally no evidence of a vehicle-based cause of the acceleration or of brake failure in these incidents. Properly functioning brakes will provide enough force to overcome engine torque, even at full throttle, and the conditions that can lead to loss of brake effectiveness (brake fade and loss of vacuum) are not relevant to these types of incidents. Moreover, NASA indicates in its report that it did not identify any failures in the Toyota ETC system that impacted the braking system. Therefore, even if (as appears extremely unlikely), some type of flaw in that system caused a UA incident, such a flaw would not be induced by applying the brake or inhibit braking. The complainant's apparently good faith assertion about having applied the brake is contradicted by the absence of braking effectiveness, but strongly suggests that the driver was in fact applying force to a pedal. NHTSA's field inspections in 2010, which included examination of all aspects of 58 alleged UA crashes, including available Event Data Recorder (EDR) data, demonstrated that in nearly every incident of this type where evidence was obtained there was no evidence of a vehicle defect, evidence was present of the accelerator being applied, and evidence was present of either no braking in the final seconds or braking only in the last second or so. (The one exception involved pedal entrapment by a floor mat.)

Analysis of the medium and high speed incidents involving Camrys revealed that some of those complaints concerned claimed brake applications leading to acceleration. Due to the absence of any evidence of a vehicle-based defect in these situations and the fact that brake application alone cannot cause acceleration, these types of complaints also most likely involve pedal misapplication. Here again, NHTSA's field examination of vehicles in 2010, some of which involved incidents at these speeds, supports this analysis of the complaints. Another subset of the medium and high speed incidents appeared to involve a stuck accelerator pedal, an issue addressed by two major Toyota recalls involving pedal entrapment and sticky pedals. Drivability complaints such as idle fluctuation, transmission shift quality, and cruise control behavior constitute another significant portion of the complaints but rarely pose discernable safety risks. Efforts to link the complaints reviewed here to specific vehicle-based causes through repair record review and comparison to large warranty data sets (see below) have not identified vehicle-based causes other than those already subject to Toyota's safety recalls.

### 2.3 Summary of Warranty Data Analysis and NHTSA Technical Assessment of Toyota ETCS-i<sup>59</sup>

Toyota’s ETCS-i electronic throttle control (ETC) consists of a simplistic electro-mechanical hardware system controlled by an electronic control module (ECM) with sophisticated control and diagnostic software. In May 2010, NHTSA made a request for warranty data on all ETCS-i equipped vehicles sold in the U.S., asking Toyota to provide details for any claim involving, a) one of the primary ETC hardware components, the ECM, the throttle actuator, the accelerator pedal, and any related wiring or harness connectors, or b) any of the diagnostic trouble codes (DTCs) that relate to a potential failure of the hardware or ETC system. Toyota provided its response in June 2010, which consisted of nearly 430,000 repair claims on a population of nearly 16 million vehicles. At the highest level a warranty claim rate of just under 3% was noted. However, on further review, over half of the claims were determined to be related to a recognized quality issue involving the Corolla ECM that ultimately resulted in a safety recall (10V-384). The hazard involved in that recall was stalling, not UA. The claim details by part group for all ETC models are shown in Table 7 below.

**Table 7: Count of Claims by Part Group, All ETC Vehicles**

<sup>1</sup> – Production counts are based Toyota’s EWR submission to NHTSA

<b>Warranty Claims Counts and Rates</b>			
<b>Part Group</b>	<b>Claims</b>	<b>Percent</b>	<b>Rate</b>
Engine Control Module	360,545	84.1%	2.29%
Throttle Actuator	40,608	9.5%	0.26%
Others	14,734	3.4%	0.09%
Accelerator Pedal	7,062	1.6%	0.05%
Connectors	3,338	0.8%	0.02%
Wiring Harnesses	2,613	0.6%	0.02%
<b>Total:</b>	<b><u>428,900</u></b>	<b><u>100.0%</u></b>	<b><u>2.72%</u></b>
<b>Production:</b>	<b><u>15,743,863<sup>1</sup></u></b>		

As discussed in the NASA report, the primary focus of the NASA–NHTSA study was the MY 2002-2006 Camrys which, compared to other Toyota models, were the subject of a greater volume of complaints. The MY 2007–2010 Camry was used as a comparator vehicle.

<sup>59</sup> This is a summary of a more detailed analysis NHTSA conducted. The warranty data is withheld subject to a pending request for confidential treatment.

Combined, these two generations of ETC-equipped Camrys comprise 3.4 million vehicles (22% of the population of vehicles in the warranty data) but yielded about 23,000 claims, a little over 5% of the total claims. The overall Camry claim rate was 0.7%, a low claim level uncharacteristic of that observed in defect investigations involving similar systems or components. The Camry claims are summarized by model year in Table 8.

**Table 8: ETC Related Warranty Claims for the Camry Model**

		Camry ETC Claim Counts and Rates by Part Group and MY									
		Model Year	Vehicle Product'n <sup>2</sup>	ECM	Throttle Actuator	Accel. Pedal	Wire Conect.	Wiring Harness	Others <sup>4</sup>	Totals	Rate
Vehicle Platform/Generation	V30/31 Camry	2002	433,112	2,727	1,121	183	63	0	827	4,921	1.14%
		2003	390,691	4,607	699	68	44	0	321	5,739	1.47%
		2004	321,673	1,369	1,306	149	50	2	1,264	4,140	1.29%
		2005	406,091	804	1,251	97	47	8	809	3,016	0.74%
		2006	197,656	270	165	25	27	8	164	659	0.33%
	V40 Camry	2007	649,461	1,352	470	244	55	67	648	2,836	0.44%
		2008 <sup>1</sup>	227,177	188	99	90	20	19	166	582	0.26%
		2009 <sup>1</sup>	447,884	243	182	271	10	14	167	887	0.20%
		2010 <sup>1</sup>	317,765	71	13	161	5	10	38	298	0.09%
		<b>Totals</b>	<b>3,391,510</b>	<b>11,631</b>	<b>5,306</b>	<b>1,288<sup>3</sup></b>	<b>321</b>	<b>128</b>	<b>4,404</b>	<b>23,078</b>	<b>0.68%</b>
		<b>Rate</b>	<b>0.343%</b>	<b>0.156%</b>	<b>0.038%</b>	<b>0.009%</b>	<b>0.004%</b>	<b>0.130%</b>	<b>0.68%</b>		

**Key:**  contacting type resistive potentiometer position sensors  
 non-contacting type Hall Effect based position sensors

**Notes:** 1 - MY range may still be within the new-vehicle warranty period  
 2 - production counts are based on Toyota's EWR submissions to NHTSA  
 3 - ~ 700 claims occurred after January 1, 2010, see detailed report  
 4 - some claims coded 'Others' are unrelated to the study, see detailed report

The ECM experienced the highest level of Camry claim rate by component at 0.3%. However NHTSA's sampled review of the qualitative content of the claim data, the consumer complaint description and technician comments, found that only 2% of the ECM warranty claims appeared to relate to ETC system concern. For comparison purposes, a 2009 investigation (EA09-006) which involved an ECM for a stability control system experienced warranty rates approaching 25% (and resulted in a safety recall). For the throttle actuator, which NASA's assessment indicated is unlikely to be a source of UA, the claim rate is lower at 0.2%, while a comparison 2005 investigation (EA05-021) involving an ETC throttle actuator on Volvo vehicles experienced a 25% warranty rate (and resulted in a safety recall). The accelerator pedal claims are even lower at 0.04%. A review of the qualitative content for the throttle actuator and pedals

primarily showed indications of failsafe operation (discussed below) with little if any evidence suggesting the occurrence of UA. The claim trend by model year is declining. NHTSA concluded that the warranty data, at rates several orders of magnitude lower than comparable investigations, did not indicate the presence of a wide-spread component-based defect trend in the Camry products.

NASA's analysis of the ETCS-i system identified a potential vulnerability for the accelerator pedal signals to be corrupted by outside influences. The pedal signals are analog electrical voltages produced by two sensors in the accelerator pedal. The two voltages, known as VPA signals (VPA1 and VPA2) vary proportional to pedal position and act as inputs that the ECM interprets as the driver's request for engine power. The ECM monitors the VPA signals to determine the proper position for the throttle valve, the device which regulates engine power, while also running diagnostic routines intended to identify potential faults. A significant level of effort was expended by the NASA-NHTSA team to fully identify and understand the vulnerabilities and diagnostic weaknesses surrounding the VPA signals.

While the hardware configuration is relatively simple the software system is much more complex. To perform the normal ETC function of controlling power as well as conducting diagnostics the ECM uses complex and sophisticated software algorithms. Learning algorithms allow the system to know when the pedal is released or pressed. Threshold tests (high or low voltages, signal frequencies, etc.) are used to evaluate signals for validity. Failsafe strategies are implemented in response to a detected fault(s). Among other DTCs, the Camry ETC system uses eight (8) diagnostic monitors that evaluate the VPA signals and produce a trouble code when a fault is determined, one for each monitor. At detection, the ECM stores the DTC in memory, illuminates a malfunction indication lamp (MIL) on the instrument panel, and implements a failsafe mode. Toyota uses two failsafe strategies for the VPA signals. One failsafe that occurs when a single VPA signal fails (the other signal is used redundantly), which is referred to as the "limp home" mode, results in a limited throttle opening (15 degrees above idle) and a brake override strategy that returns the engine to idle whenever the brake is applied; the vehicle remains drivable, although at diminished power. The second failsafe, the "at idle" mode, occurs when both VPA signals are lost. In this mode the engine remains at idle always, effectively disabling the vehicle.

NHTSA reviewed the warranty data to evaluate the claims indicating the presence of ETC-related diagnostic codes, paying particular attention to those that involved the VPA signals. In total 404 claims involving 465 DTCs related to the pedal signals were found, as shown in Table 9. Although occurring at a very low rate (14 DTCs/100,000 vehicles), lower than the component replacement rates above, NHTSA noted that 332 of the claims involved one particular diagnostic code (P2121<sup>60</sup>), one of the more complex diagnostic routines that monitors correlation of the two VPA signals. For Camry, the MY 2002–2006 vehicles use a potentiometer type pedal sensor, while the MY 2007-2010 Camry models use a Hall Effect type sensor. Three hundred and ten (310) of the P2121 DTCs involved the potentiometer type sensor, 22 for the Hall Effect sensors. The two sensor types have different electrical characteristics that cause them to behave differently in the presence of certain faults, and accordingly NASA and NHTSA evaluated each in significant detail.

**Table 9: Accelerator Pedal Related DTC Counts and Rates Code and MY**

Camry Accelerator Pedal Related DTC Claim Counts by DTC Codes and MY													
MY	Prodct'n	P1120	P1121	P2120	P2121	P2122	P2123	P2125	P2127	P2128	P2138	Totals	Rate/100k
2002	433,112	17	136	1	0	0	0	0	0	0	0	154	35.56
2003	390,691	0	4	1	12	2	0	0	4	4	1	28	7.17
2004	321,673	0	3	3	92	25	0	0	3	20	5	151	46.94
2005	406,091	0	3	3	52	8	0	1	5	5	2	79	19.45
2006	197,656	0	0	0	8	4	0	1	3	0	0	16	8.09
2007	649,461	0	0	0	10	0	0	1	0	1	1	13	2.00
2008	227,177	0	0	1	4	2	0	1	0	0	0	8	3.52
2009	447,884	0	0	0	6	1	0	2	2	1	0	12	2.68
2010	317,765	0	0	0	2	2	0	0	0	0	0	4	1.26
<b>Totals</b>	<b>3,391,510</b>	<b>17</b>	<b>146</b>	<b>9</b>	<b>186</b>	<b>44</b>	<b>0</b>	<b>6</b>	<b>17</b>	<b>31</b>	<b>9</b>	<b>465</b>	<b>13.71</b>
	<b>Rate/100k</b>	<b>0.50</b>	<b>4.30</b>	<b>0.27</b>	<b>5.48</b>	<b>1.30</b>	<b>0.00</b>	<b>0.18</b>	<b>0.50</b>	<b>0.91</b>	<b>0.27</b>	<b>13.71</b>	

Key:   
 Contacting resistive pot sensors and Phase I software (only two P codes used)   
 Codes not available in Phase I software (Phase II software only)   
 Contacting resistive pot sensors and Phase II software   
 Non-contacting Hall Effect sensors and Phase II software

For the potentiometer equipped vehicles a review of Toyota data (warranty return analysis) and a failed pedal assembly obtained from a VOQ complainant (ODI 10304268) identified a failure mechanism affecting the VPA signals. To date, four such failures have been identified, two by Toyota, and two by the NASA-NHTSA team. The failures were produced by the formation of a tin whisker between tin plated electrical conductors within the sensor housing. Tin whiskers are one example of a group of resistive fault failure mechanisms that can introduce partial resistances and/or partial shorts into electrical circuits. For the potentiometer sensor harmful resistive faults are detected by the diagnostic monitor, resulting in a DTC and limp-home mode

<sup>60</sup> The P1121 DTC use in MY 2002 is an earlier form of the P2121 DTC, and thus is included in this analysis.

failsafe; however, certain resistive shorts can cause a vehicle drivability issue that presents an unusual mode of operation that, in the broadest sense of the term, could be considered a type of small throttle opening UA.

Of the 831 Camry UA VOQs reviewed in the study NHTSA has identified two that have and two that may have experienced resistive VPA shorting resulting in the drivability issue mentioned above. When specific resistive shorts between VPA1 and VPA2 occur, the system generally produces a DTC and MIL and, in the initial drive cycle, the vehicle is limited to limp-home mode. However, after the initial drive cycle, depressing the accelerator pedal, unless done quickly, initially has no effect on engine output (a dead spot) until it is depressed slightly further, at which point the throttle may open more than expected and cause the vehicle to jerk forward, which could be described as a limited form of UA. However, the UA only occurs in response to accelerator pedal application and when the pedal is released the throttle closes and the UA ends,<sup>61</sup> the brakes are not affected by this condition and therefore work normally. The amount of throttle opening that occurs at the bottom of the dead spot is dependent on a number of factors (see the detailed report for a further explanation) but 10 to 15 degree openings have been observed by NHTSA. For the four VOQ reports possibly involving this condition, none resulted in a crash or injury, all resulted in a DTC and a pedal replacement, and all drivers reported the dead spot and jerking condition that occurred when the accelerator was depressed. NHTSA's current assessment is that the frequency of this condition is very low. However NHTSA will monitor for additional field failures. The likelihood of a more severe UA incident arising from tin whisker shorting is very low.

The situation for the Hall Effect pedal sensors is different. Unlike the potentiometer sensors, these devices use an electronic device (an integrated circuit, or IC) to stabilize the outputs. As a result, resistive shorting has less of an effect on the VPA signals. In fact, as has been demonstrated by researchers and other members of the public, under very specific conditions harmful VPA resistive shorts could exist in the Hall Effect-equipped Camry and go undetected by the ECM. Should a second specific fault then subsequently combine with the existing fault

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<sup>61</sup> Many VOQ reports involving the potentiometer equipped Camry vehicles state that a UA incident involving high power and apparent loss of braking occurred when the accelerator was not being depressed, or initiated when the brake pedal was depressed, and accordingly NHTSA does not believe this condition would be a plausible explanation for these type incidents.

the throttle can open without driver intent.<sup>62</sup> The NASA-NHTSA team has confirmed that, as a theoretical matter, dual fault scenarios are a potential risk on the Hall Effect sensors, but neither agency has reason to believe that this theoretical risk explains the wide throttle openings mentioned in owners' complaints to NHTSA. It is important to understand that in these scenarios the faults must occur within precise resistance ranges and in the proper time sequence; otherwise they are detected (or are not a hazard) and result in a failsafe condition. NASA has studied the complete family of dual fault scenarios, for both Hall Effect and potentiometer sensors types, and discusses them at length in its report. However, because the circumstances that produce detected faults are much more likely than those that produce undetected faults, both NASA and NHTSA expect that if such faults were occurring in consumers' use of the vehicle that evidence of detected faults, where the range of resistance or the sequence of the faults do not meet the narrow criteria to escape detection, would be present in field data such as warranty and other complaint data. There is no evidence of such dual faults in the data.

While the theoretical risk exists for the Hall Effect type sensors in the two-fault scenario, it is also important to note that a failure mechanism that can produce either of the required faults has not been identified. As explained in NASA's report, the Hall Effect sensor design has been modified to address the failure mechanism (tin whiskers) found in the potentiometer pedal sensor. Warranty component replacement and DTC rates, an order of magnitude lower than the potentiometer sensors, do not support the presence of a defect trend, and do not provide evidence of near misses that are expected if actual in-service failures are occurring. NHTSA's review of 188 UA incidents involving Hall Effect equipped Camrys taken from Toyota's SMART database did not show evidence of an ETC-related DTC, nor the presence of either the first or second fault required for a dual fault scenario, in any of the 188 cases. Review of 284 ECM warranty return analyses did not identify a mechanism for resistive shorting of the APM signals for either the Hall Effect or potentiometer sensor. The Hall Effect Camrys are equipped with Event Data Recorders (EDR) which capture pre-crash data in certain UA incidents. NHTSA's analysis of EDR data, which is discussed elsewhere in this report, also does not support the presence of a vehicle-based causation for the UA incidents studied. Safety Recall 09V-388 retrofitted a brake override strategy onto the Hall Effect equipped Camry which adds additional protection against

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<sup>62</sup> One such scenario has been demonstrated in laboratory testing by Dr. David Gilbert of Southern Illinois University Carbondale.

the theoretical dual fault scenarios. Therefore, although theoretically possible, NHTSA believes the likelihood of a dual fault failure scenario occurring in consumers' use of the Hall Effect equipped Camry is very low. Moreover, should it ever actually occur, this potential ETC system problem would not affect the vehicle's braking system.

#### **2.4 Complaints Concerning Fatal Incidents Allegedly Involving Unintended Acceleration in Toyota Vehicles Since 2000**

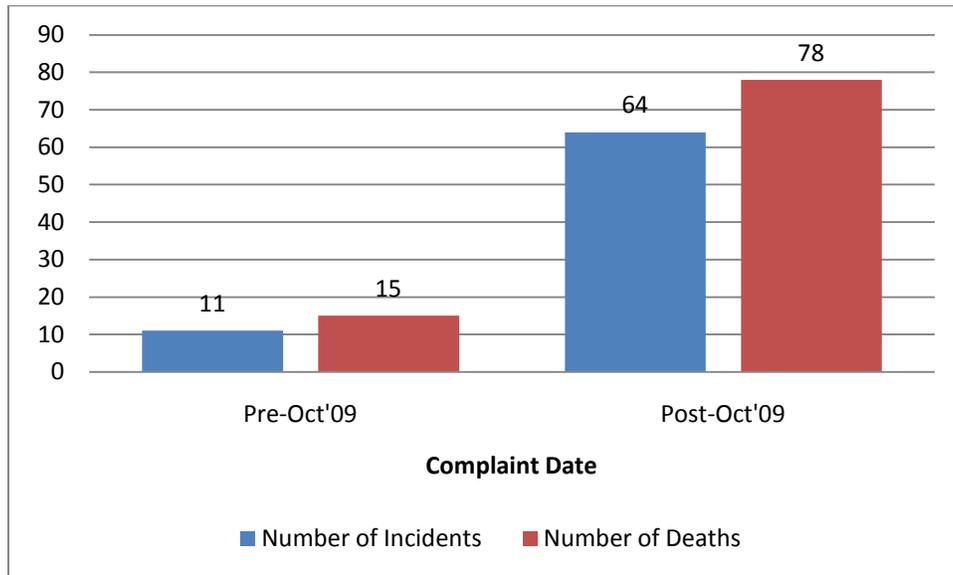
The fact that a consumer complaint alleging a fatal incident exists in NHTSA's database does not mean that NHTSA has determined that the incident arose from a vehicle-based cause. In fact, while NHTSA does not have complete information on all of these incidents, NHTSA believes that only one of the reported instances (and one unreported fatal incident) is traceable to a vehicle-based cause. An understanding of this point is necessary to gain an accurate picture of the scope and nature of the UA problem.

The criteria we used to search the agency's complaint database to identify fatal incidents that allegedly involved unintended acceleration in Toyota vehicles was overly broad so as to capture every possible incident. Our analysis included fatalities in Toyota vehicles, pedestrian fatalities and fatalities occurring in non-Toyota vehicles. Although we were particularly interested in vehicles with ETC, we included all incidents involving a Toyota vehicle, even vehicles with mechanical throttles. We included incidents reported to NHTSA from January 1, 2000, through December 31, 2010, giving us more than 10 years of complaints. The incidents also had to allege unintended acceleration. Incidents where "vehicle speed control" was identified as the component or the narrative contained text describing unintended acceleration such as "vehicle abnormally accelerated" or "the accelerator stuck" were included.

As of December 31, 2010, NHTSA received a total of seventy-five (75) complaints concerning fatal incidents that allegedly involve unintended acceleration in Toyota vehicles since 2000. The reports cover ninety-three (93) fatalities.

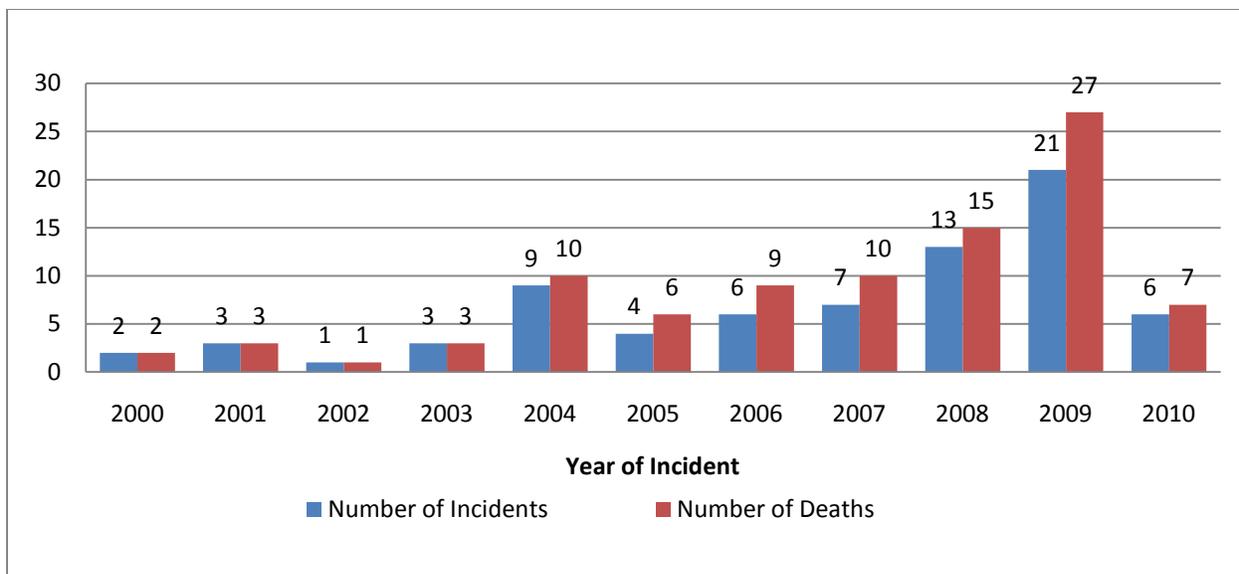
Publicity has affected the reporting of these incidents to NHTSA. The Toyota pedal entrapment recall was announced in October 2009, which provides a useful point of reference. Figure 6 shows fatal incidents by complaint date. Eighty-five percent of the incidents (64 out of 75) have been reported to NHTSA since October 2009. In fact, 58 of the incidents (77%) have been

reported just since the “sticky pedal” recall in late January 2010, which intensified public interest. The most incidents were reported in February and March of 2010, with 22 and 24 respectively. The latest incident was reported in June 2010. Although a significant time lag between an incident and the submission of a complaint does not diminish the complaint’s credibility, these numbers strongly suggest that publicity played a major role in the reporting of these incidents. Of the 11 incidents that were reported before October 2009, 10 involved vehicles with ETC. Of those 10, half (5) were reported during the 3-month publicity spike after the original investigation of ETC was opened early in 2004.



**Figure 6: Fatal Incidents by Complaint Date**

Even though most of these incidents were reported to NHTSA in 2010, very few of them actually occurred in 2010. Only six of the reported incidents (involving seven deaths) have occurred in 2010. Many of the occurrences were in 2009, but some of the recently received reports involve incidents dating back several years. Figure 7 shows fatal incidents by year of incident.



**Figure 7: Fatal Incidents by Incident Date**

In the context of this report, which is focused on the possibility of a safety-related defect in Toyota’s ETC system, the incidents of greatest relevance are those involving vehicles equipped with ETC. However, 29 percent of these incidents (22 of the 75) and almost one-third of the fatalities (29 of 93), including several reported recently, involve vehicles not equipped with ETC.

The incidents involve a variety of possible unintended acceleration conditions, ranging from events that occurred in parking lots with very low initial speeds to events that occurred on highways at higher speeds. Only nine of the fatal incidents occurred in parking lots, parking garages or private driveways, locations where the large majority of non-fatal UA incidents and crashes occurred. These incidents involved 10 fatalities. Thirty-two of the fatal incidents (45 fatalities) occurred on roadways with a speed limit of 45 mph or higher. In about two-thirds of the incidents, the driver did not survive the crash and, as a result, someone else was the source of the complaint to NHTSA.

Of the incidents reported to NHTSA in its complaint database, NHTSA has confirmed one fatal incident (the August 2009 crash near San Diego) as having a vehicle-based cause of unintended acceleration (pedal entrapment). This incident involved four deaths. (NHTSA has confirmed another incident involving one fatality that is not in its complaint database but was believed to be

caused by pedal entrapment.)<sup>63</sup> Following Toyota's pedal entrapment recall, NHTSA received two additional allegations of pedal entrapment in fatal crashes involving vehicles within the scope of the recall. However, NHTSA's analysis of those claims determined that neither included evidence of pedal entrapment in the police reports or other contemporaneous documents and both involved driver citations for impaired driving.<sup>64</sup>

The remaining incidents are unconfirmed allegations of unintended acceleration or, more typically, questions about whether fatal crashes may be related to UA. Some of these incidents were reported years after the incidents occurred by representatives or family members of the deceased, in some cases stating that they were looking for reasons to explain why the incidents occurred. In most of these cases, we did not find any substantial evidence to support or deny the claims or questions regarding unintended acceleration. Most of the incidents occurred in 2009 or earlier and for various reasons we were unable to obtain EDR information on those incidents. We did obtain EDR information for five of the cases. Although we were able to obtain most of the Police Accident Reports (PARs) for the cases (66 cases), most of the reports do not specifically state a possible cause for the accident. The following is the information we obtained from the EDR outputs and PARs indicating that, at least in those incidents vehicle-based unintended acceleration may not have been the cause:

- In 12 incidents the police believe alcohol and/or drugs was the major contributing factor in the crash, including seven incidents in which the drivers had BAC of 0.08 or greater and five incidents where BAC results were not available;
- EDR data for two of the incidents in which the drivers had BAC of 0.08 or greater showed no pre-impact braking;
- In 11 incidents the information in the PAR suggested that a medical condition may have caused the crash, including one in which the EDR showed no pre-impact braking and no acceleration;
- In four incidents information indicated pedal misapplication as the cause of the UA, including one in which the EDR showed no pre-impact braking and full acceleration; and

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<sup>63</sup> ODI Unintended Acceleration Investigation - 2007 Toyota Camry - California, Case Number DS07035, Dynamic Science, July 2007, ([NHTSA SCI Electronic Case Viewer](#)).

<sup>64</sup>NHTSA is investigating an additional case that occurred in Utah in November 2010. The case is still active and not complete. When the case is completed, it will be available on our website at: <http://www-nass.nhtsa.dot.gov/BIN/logon.exe/airmislogon>

- Less than one third (21) of the incidents actually appear to contain a specific allegation of UA. In the other incidents there is simply no evidence or even a specific claim that the acceleration that occurred was not intended (e.g., crashes where a vehicle runs off the road at a steady speed).

NHTSA is continuing to gather facts on some of these incidents.<sup>65</sup> The important point, however, is that any sound analysis of the subject must carefully distinguish the number of deaths that have occurred in alleged UA incidents from the much smaller number actually established to have been the result of a vehicle-based cause.

## **2.5 NHTSA Field Inspections in 2010**

### **2.5.1 Purpose**

In 2010, NHTSA conducted a series of field inspections of recent crashes involving Toyota vehicles involving allegations of UA.<sup>66</sup> Historically, NHTSA's UA field inspections relied solely on the documentation of the vehicle and scene physical conditions, as well as the vehicle service/warranty history and testimony from involved parties. As various manufacturers have installed event data recorders (EDRs)<sup>67</sup> in their vehicles and made available devices to read those recorders, NHTSA has incorporated them into its field inspections and crash investigations. EDRs enable NHTSA to collect objective evidence of driver actions immediately prior to the crash, which is especially important in UA incidents. NHTSA received its first Toyota EDR reader in early March 2010, and immediately began conducting field inspections of alleged UA incidents. Throughout March and early April, NHTSA obtained an additional nine EDR readers and trained<sup>68</sup> staff from its Office of Defects Investigation (ODI), Special Crash Investigation (SCI) office, and the Vehicle Research and Test Center (VRTC) in their use.

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<sup>65</sup> A disproportionate number of these incidents involve drivers over age 60, including some in their seventies and even eighties. NHTSA is interested in the role played by human factors in UA incidents and is conducting research on the greater likelihood of this type of incident among older drivers and possible solutions.

<sup>66</sup> This section summarizes NHTSA's field inspection activity. Greater detail can be found in the supplemental reports cited here.

<sup>67</sup> Event Data Recorders (EDRs) are devices that historically have been used to record information related to a vehicle crash. More specifics can be found in Report No. NHTSA-NVS-2011-ETC-SR04.

<sup>68</sup> A synopsis of EDR default data values and basic information on reading the outputs is enclosed in Report No. NHTSA-NVS-2011-ETC-SR05.

### **2.5.2 EDR Validation**

A commercially available EDR reader kit<sup>69</sup> manufactured by Bosch exists that covers many Chrysler, Ford, and General Motors vehicles. The Bosch EDR outputs are generally accepted when accompanied by consistent crash reconstruction work. No such acceptance exists for the prototype Toyota readers and, in fact, some parties have pointedly disputed the validity of their output.

NHTSA validated Toyota EDR pre-crash outputs in five major areas:

1. EDR data outputs were compared to the physical facts of each field inspection that was conducted;
2. Track testing<sup>70</sup> with independent instrumentation validated the pre-crash data elements for: brake light switch status, accelerator pedal position, and vehicle speed;
3. EDR reader veracity and consistency were verified by reading one of the track test EDRs with each of the kits in NHTSA's possession;
4. Comparison of data retrieved and reviewed with different EDR reader software versions showed consistent results,<sup>71</sup> and
5. An extensive study<sup>72</sup> of a fatal crash in which the EDR readings were publicly called into question yielded an explanation of anomalous post-crash data and verified that the pre-crash data were consistent with incident circumstances.

The validation work was extensive and is addressed in further detail in the appendices.

Notwithstanding the "prototype" labeling or characterization, NHTSA has high confidence in the veracity of pre-crash data recovered from Toyota's EDRs and this information is very valuable when considered in concert with the physical facts of a given incident.

### **2.5.3 Logistics**

Candidate incidents were selected from a variety of sources with the objective of identifying vehicles containing pre-crash-capable EDRs involved in alleged UA incidents with accessible

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<sup>69</sup> Crash Data Retrieval (CDR) kit sold by Bosch.

<sup>70</sup> Report No. NHTSA-NVS-2011-ETC-SR07.

<sup>71</sup> Report No. NHTSA-NVS-1022-ETC-SR08.

<sup>72</sup> Report No. NHTSA-NVS-2011-ETC-SR09.

pre-crash data. Accessibility covered several dimensions that included geography, incident timing, vehicle condition, and owner consent. The field inspections originated from a number of different sources with consumer complaints to NHTSA accounting for about half of the total. Additional sources included police agencies, Toyota data, media outlets, and insurance companies. In general, the inspections included a scene assessment, physical inspection of the vehicle, interrogation of the vehicle control systems with a Techstream diagnostic tool, recovery of the EDR data, and interview of any involved persons. Field inspections were conducted from the beginning of March through early August 2010, and are described in greater detail in Report No. NHTSA-NVS-2011-ETC-SR10.

#### **2.5.4 Results**

The 58 field inspections were categorized by finding and incident type. Further explanations of each are listed below. Tables listing all the cases by case number and outcome are enclosed in NHTSA-NVS-2011-ETC-SR11, and EDR data from the cases are contained in NHTSA-NVS-2011-ETC-SR12.

EDR data were unavailable in six incidents either because no data were found<sup>73</sup> (five cases), or because the subject vehicle contained an EDR whose data did not align with the crash reported by the driver.<sup>74</sup>

Not every incident reported as UA-related turns out to fit even the broad category. Further examination of 12 such incidents revealed a number of different conditions. Only one of these incidents involved significant vehicle acceleration<sup>75</sup> and none was found to have any braking of significance.

Five incidents were unexplained roadway/lane departures at speed. None of the information collected shows indications of attempts to manage a runaway vehicle (e.g., heated brakes or evasive maneuver markings on roadways or terrain). Scene evidence and data collected from the

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<sup>73</sup> Physical evidence from those incidents suggests that the vehicles did not experience a severe enough impact to enable the EDR.

<sup>74</sup> It did however contain data that were consistent with a less severe (non-UA) impact subsequent to repairs to the vehicle. It is believed that the EDR involved with the UA incident was removed and replaced when \$9,000 worth of repairs were conducted.

<sup>75</sup> This incident, involved a parallel parking maneuver on a city street in which the vehicle wheel was lodged against the curb while the driver applied progressively more accelerator input. The driver in this case alleged excessive engine power in response to an accelerator input and never alleged a brake application.

EDR show little or no acceleration and no brake use of significance. The remaining cases include subject vehicles striking other vehicles stopped in the roadway with no acceleration or brake use indicated, collisions at intersections, and one parallel parking attempt.

After subtracting the six incidents in which EDR data were not available and the 12 incidents that were not actually UA occurrences, 40 incidents of UA remained. One of those UA incidents turned out to be entrapment of an accelerator pedal by an all-weather floor mat. It initiated with an on-highway passing maneuver and ended with the vehicle traversing a T-intersection at the end of an exit ramp where the vehicle left the roadway. Pre-crash data retrieved from the subject vehicle EDR shows the vehicle traveling at high speeds with a relatively high unchanging accelerator pedal voltage and consistent brake light switch status of “ON” for the duration of the incident. Field inspection of the incident vehicle uncovered evidence that an OE Lexus all-weather floor mat had constrained the accelerator pedal after the driver released it at the onset of the incident.

NHTSA believes that the most likely cause of the remaining 39 UA incidents was pedal misapplication. Pedal misapplication refers to a situation in which a driver intends to apply the brake and inadvertently applies the accelerator instead or, in some cases, applies both the accelerator and the brake at the same time (dual application). Pre-crash EDR data provide direct and objective evidence of this condition.

EDR data for 29 (74%) pedal misapplication incidents showed no brake application whatsoever. An additional six (15%) showed a “late” brake application.<sup>76</sup> One case apparently involved dual pedal application.

Accelerator pedal position information was also reviewed to better account for the location of the driver’s feet. Thirty-five (90%) of the pedal misapplication incidents included either a sustained or increasing accelerator pedal application.

Twenty-eight (72%) of the pedal misapplication incidents examined initiated at speeds of 15 mph or less. All but one of these took place in a confined space such as a residential driveway or commercial parking lot. Those that initiated at higher speeds in traffic include circumstances

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<sup>76</sup> Here, a “late” brake application describes the brake light switch status transitioning to “ON” at either 1 sec prior to or at the event trigger. This timing/duration is insufficient to meaningfully slow the vehicle in a crash situation.

where the driver appeared to intend to use the brakes to decelerate, usually on approach to an intersection.

Parking maneuvers account for over half (24) of the pedal misapplication incidents with parking space entry outnumbering parking space exit by a ratio of 2:1. In-traffic deceleration accounted for the next largest share (7).

Driver ages were collected during the inspection activity. Thirty-one (79%) of the pedal misapplication incidents involved drivers 55 years or older at the time of incident. Twenty-four (62%) of the pedal misapplication incidents involved drivers 65 years or older at the time of incident.

NHTSA's field inspections of Toyota vehicles in 2010 did not provide evidence of any vehicle-based cause of UA of which NHTSA was previously unaware. (One incident appeared to involve pedal entrapment by a floor mat.) The inspections indicated that many UA incidents continue to occur as the result of the driver's inadvertent application of the accelerator pedal rather than the brake or due to simultaneous application of the accelerator and brake. Vehicle characteristics such as pedal placement may have the effect of increasing the likelihood of pedal misapplication.

## **2.6 NHTSA Acquisition, Characterization, and Testing of Vehicles**

NHTSA obtained 20 Toyota vehicles to permit extensive testing and examination based on any electronic vulnerabilities that NASA's study might reveal and NHTSA's need to understand the basic characteristics of the vehicles that might have an effect on UA.<sup>77</sup> We chose two types of vehicles: (1) eleven "design" vehicles that had not been involved in UA incidents but were examples of models of interest, and (2) nine "complaint" vehicles that had allegedly been involved in UA incidents. Table 10 shows the make, model, and model year of each of the vehicles studied:

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<sup>77</sup> NHTSA-NVS-2011-ETC-SR13.

**Table 10: Make, Model, Year of Design vs. Complaint**

Vehicle Identifier C = Complaint D = Design	Vehicle Location	Vehicle Model Year	Vehicle Model	Trim Level	Vehicle Color	Engine	VIN	UA VOQ	Mileage
1D	VRTC	2002	Camry	SE	Silver	V6	4T1BF30K02UXXXXXX	No	125331
2D	VRTC	2002	Camry	XLE	Dark Gray	L4	4T1BE32K82UXXXXXX	No	69721
3D	VRTC	2001	Camry	LE	White	L4	JT2BG22KX10XXXXXX	No	94006
4D	VRTC	2007	Camry	SE	Red	L4	4T1BE46K574XXXXXX	No	89964
5D	VRTC	2006	Camry	LE	Silver	L4	4T1BE32K96UXXXXXX	No	55319
6D	VRTC	2007	Camry	LE	Green	L4	4T1BE46K57UXXXXXX	No	161690
7D	Goddard	2005	Camry	XLE	Gray	L4	4T1BE32K65UXXXXXX	No	69634
8D	VRTC	2001	Camry	XLE	Champagne	V6	4T1BF28K31UXXXXXX	No	88651
9D	VRTC	2005	Camry	LE	Charcoal	V6	4T1BF32K55UXXXXXX	No	69649
10D	VRTC	2007	Camry	LE	Green	V6	4T1BK46K97UXXXXXX	No	53322
11D	Goddard	2005	Camry	XLE	Silver	V6	4T1BF30K55UXXXXXX	No	65199
12C	EMI Facility	2007	Camry	XLE	Burgundy	V6	JTNBK46K073XXXXXX	10319201	44673
13C	EMI Facility	2002	Camry	XLE	Champagne	V6	4T1BF30K92UXXXXXX	10319308	195266
14C	EMI Facility	2004	Camry	XLE	Champagne	V6	4T1BF30K34UXXXXXX	10321093	77739
15C	EMI Facility	2003	Camry	XLE	Deep Purple	L4	4T1BE32K33UXXXXXX	10283433	52773
16C	VRTC	2009	Camry	NA	Blue	L4	4T1BE46K39UXXXXXX	10326631	23763
17C	VRTC	2004	Camry	LE	Champagne	L4	4T1BE32K64UXXXXXX	10316061	47776
18C	EMI Facility	2004	Camry	LE	Blue	L4	4T1BE32K04UXXXXXX	10327490	61039
19C	EMI Facility	2007	Camry	LE	Gray	L4	4T1BE46K27UXXXXXX	10326416	37385
20C	VRTC	2004	Camry	LE	Tan	L4	4T1BE32K64UXXXXXX	10290867	54822

The Camry models account for about a third of all the complaints and more than half the crashes reported to NHTSA as UA events over the last decade. Accordingly, the Camry seemed like the most promising model in searching for a vehicle-based defect. Complaint rates for the first model years of the MY 2002-2006 Camry, and the MY 2007-2010 Camry are somewhat higher than for other model years of those generations, suggesting that the model changes may relate to any potential causes of unintended acceleration. Accordingly, in seeking design vehicles we obtained examples of the MY 2002 and 2007 Camry.

We also acquired the last build years for model generations adjacent to models that demonstrated high rates of unintended acceleration to encompass all mid-model upgrades and changes associated with a specific generation. This included the last year of the MY1996-2001 Toyota Camry (2001) and the last year for the MY2002-2006 Toyota Camry (combined 2005 and short build year 2006). We included both four-cylinder (L-4) and six-cylinder (V-6) engines from each model to encompass differences in wiring, grounding, components, and powertrain performance. We also included vehicles that have been reprogrammed with brake override software to compare them to the same models that do not have the software revision. The MY2007-2009 Toyota Camry (2007) was included in this group.

In order to select vehicles that had allegedly been involved in UA incidents (complaint vehicles) we analyzed vehicle complaint data from vehicle owner questionnaires (VOQs) and other sources to identify possible candidate vehicles. We contacted owners of selected vehicles to further explore the details of the alleged incidents. This included some site visits and in-person interviews. We then selected vehicles to obtain for testing and evaluation. Selection criteria included vehicles for which floor mat entrapments and “sticky pedals” were not claimed as causes by the complainant. The vehicles had to be drivable. If essential electronic components had been replaced, those vehicles would have been disqualified from testing. When we acquired vehicles we also received their repair history documentation.

In addition to the Camry design and complaint vehicles selected for characterization and testing due to their prominence in the complaint data, NHTSA acquired three other Toyota vehicles that had been involved in noteworthy UA incidents including a 2008 Toyota RAV4, a 2007 Lexus ES350, and a 2010 Toyota Corolla.<sup>78</sup> While they were not specifically the subject of the NASA ETC review or of this report, VRTC subjected these vehicles to examination and testing similar to what was done with the 20 Camrys.<sup>79</sup> To date, no testing in any of these three vehicles has produced incidents of UA caused by factors other than floor mat entrapment or “sticky pedals.”

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<sup>78</sup>Complainant test vehicles other than Camrys include: 1) 2008 Toyota RAV4, ODI Complaint No. 10328464, 2) 2007 Lexus ES350, ODI Complaint No. 10182245, and 3) 2010 Toyota Corolla, ODI Complaint No. 10327521.

<sup>79</sup> The 2007 Lexus ES 350 has undergone the most extensive testing of these three vehicles, including all of the characterization testing discussed in this section, additional testing of the accelerator control circuits to detect anomalies, a broad range of EMC testing using the same parameters applied to the complaint vehicles, and specific testing of aspects of the vehicle’s operation mentioned in the complaint, NHTSA has not found any problems with the vehicle other than its susceptibility to pedal entrapment by the type of all-weather floor mat that was in the vehicle at the time of the incident.

NHTSA will continue to examine these vehicles with whatever additional testing might be appropriate (e.g., continued mileage accumulation to see if the complained-of behavior might re-appear).

## **2.7 Vehicle Characterization Test Methodology**

Test vehicles had various features and capabilities measured to discover whether factors other than electronics may contribute to instances of unintended acceleration.

All acquired vehicles were subjected to all characterization tests. Vehicle characterization efforts were divided into eight modules. Some modules documented vehicle history and confirmed fitness for test use. Other modules tested braking and acceleration performance under changing conditions.

### **2.7.1 Module 1 – Preliminary Inspections and Visual Verification**

This module began the processing of each vehicle and verified the basic information and condition of the vehicle. Vehicle features and options were documented along with a multitude of other visually verifiable items. Examples include but are not limited to: make, model, year, color, trim level, engine, vehicle identification, mileage, tire type/tread depth, etc.

Documentation from this module also identified whether the vehicle was acquired because it was a complaint vehicle (denoted with a “C”) or a vehicle acquired for a design change comparison (denoted with a “D”). If it was identified as a complaint vehicle, this triggered the collection of other documents associated with the incident. Malfunctioning or abnormal conditions were then recorded for corrective action in Module 2, 3, or 4.

### **2.7.2 Module 2 – Comprehensive Inspections and Electronic Interrogation**

In this module, significant interrogation of vehicle systems took place and results were recorded. Event data recorders were imaged, electronic control unit diagnostic trouble codes (DTCs) were downloaded, and technical service bulletins and recall fulfillment were verified. Accelerator pedal position sensor voltages and rates were measured. Transmission specifications were documented. Repair history was researched. Functionality of vehicle systems was confirmed by

a certified mechanic. Any deferred maintenance was either corrected during this module or the vehicles were scheduled for repair in Module 4 – Repairs and Restoration.

### **2.7.3 Module 3 – Drivability Fitness**

Each vehicle was subjected to a test drive by a certified mechanic to determine if the vehicle was performing appropriately. This included all relevant systems on the vehicle, with special emphasis on systems that were given authority over the accelerator control system, such as cruise control. If the vehicle was in the population receiving brake override reprogramming, then the presence of brake override was confirmed. Any deficiencies found would cause the vehicle to be scheduled for repair in Module 4 – Repairs and Restoration, with the exception of complaint vehicles, where deficiencies would have been studied further to determine if they were related to the alleged defect. Deficiencies would have been items such as worn wheel bearings, poor alignment, braking problems, electrical charging problems, etc. though no test vehicles exhibited these conditions.

### **2.7.4 Module 4 – Repairs and Restoration**

This module addressed all known deficiencies in a given vehicle that would otherwise have invalidated or compromised the performance of the vehicle during testing, with the exception of complaint vehicles. Successful completion of the module confirmed that the vehicle was safe for testing.

### **2.7.5 Module 5 – Acceleration and Braking Assessment**

This module contained the dynamic portion of the testing that measured the effect of full throttle acceleration on the performance of brake systems that a driver could expect during unwanted acceleration events. Here each vehicle underwent acceleration and braking performance tests to quantify the effectiveness of brake systems with and without the assistance of vacuum. Tests included baseline acceleration, followed by a series of acceleration tests while braking using standard FMVSS 135 brake pedal forces of the following values: 0 lbs., 15 lbs. (67N), 50 lbs. (222N), 112 lbs. (500N), and 225 lbs. (1,000N). Subsequent braking tests were conducted using similar forces to measure stopping distances of each vehicle traveling at 65 mph. These tests were conducted with 1) no acceleration, 2) full acceleration with vacuum assisted braking, and 3)

full acceleration without vacuum assisted braking. Brake pedal pressures were controlled with a pressure regulated pneumatic cylinder actuated at the appropriate time. At the beginning of each vehicle's brake test module and again at the end of the module, a 100-0 mile per hour panic stop was conducted to measure the permanent effect of the repeated brake tests on stopping capability. Brake temperatures were monitored to ensure that brakes were not above 300 degrees Fahrenheit prior to any brake test. The braking tests were conducted with new friction materials and rotors, and had been processed through appropriate burnishing procedures in order to appropriately wear the brakes to a slightly worn condition similar to what would be expected from several miles of normal stop and go driving. Five of the vehicles submitted for testing, all 2007-2009 Camrys, were reprogrammed by Toyota with brake override to measure the software effectiveness in slowing the vehicle while applying engine throttle. These brake tests demonstrated a quantifiable benefit of the brake override system in terms of reduced stopping distance. In some tests brake override was intentionally disabled in order to measure and compare braking performance.

#### **2.7.6 Module 6 – Gearshift Lever**

During an unwanted acceleration event, the ability to quickly and simply disengage the engine from the transmission and drive wheels becomes an effective means of averting what can otherwise quickly become an emergency situation. The gearshift pattern and required movements to achieve drive, neutral, reverse, and park were measured, photographed, and documented. Extra efforts, such as squeezing a button on the shifter to place the vehicle into any gear were recorded. Transmission features such as the number, type, and condition of mounts were noted. The number of forward gears was identified.

#### **2.7.7 Module 7 – Ignition Switch Control Functionality**

When a driver encounters an unwanted acceleration situation, the ability to turn power off to the engine becomes a valuable countermeasure. The functions of the keyed ignition have remained relatively unchanged over the years, but a pushbutton ignition requires a driver to learn new procedures, not all of which may be intuitive. With regard to an unwanted acceleration event, the most relevant of these new procedures is the emergency shutdown operation. The presence of a key or pushbutton ignition switch control system was documented to help understand

difficulties motorists may encounter when attempting to turn off the engine in an emergency condition.

### **2.7.8 Module 8 – Pedal Position**

Module 8 measured the orientation, location, and operation of the accelerator and brake pedals in relation to the driver. Pedal interaction with the floor pan was also characterized.

Brake and accelerator pedal position, static step-over distance between the brake and accelerator pedal, dynamic step-over (i.e., critical vertical offset,<sup>80</sup>) and horizontal relative location was measured. Documentation included pedal construction and material.

Contours and dimensional measurements of the floor pan and associated protective materials and pedal interaction with the floor pan was described and documented. The propensity for the interaction between the floor pan and accelerator pedal to lead to pedal entrapment was evaluated using a series of attributes that are believed to mitigate or aggravate instances of pedal entrapment including:

1. Spring return force;
2. Pedal hinging methods;
3. Geometric interaction with the floor pan; and
4. Positive backstop location.

Original carpeted floor mats and all-weather floor mats were placed in various orientations in the driver's foot well area to determine whether an interference condition with the accelerator pedal actuation could occur.

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<sup>80</sup> Dynamic step-over, also referred to as critical vertical offset is the perpendicular distance between the surface of the brake pedal and the surface of the accelerator pedal, required to cause a stationary vehicle to begin to move while depressing both the brake pedal and accelerator pedal simultaneously with a specified brake pedal force. Static step-over measures the perpendicular distance between the surface of the pedals when the pedals are at rest and not being applied.

## **2.8 Vehicle Characterization Test Results**

### **2.8.1 Foot Pedals Interface and Electronic Accelerator Pedals**

The electronic accelerator pedal and electronic throttle control were introduced in Toyota Camrys in MY 2002. This changed the way the driver interfaced with the accelerator control system. While depressing the electronic accelerator pedal still caused the engine to produce power, it did so at a different rate and with a different level of effort from the operator.

Electronic accelerator pedals found in 2002 and newer Camrys provided faster throttle response with less pedal displacement than cable driven throttles. Increased responsiveness is a typical characteristic of ETC as compared to mechanical linkage accelerator control systems. With the introduction of ETC, the mechanical accelerator system of a cable and remotely located spring at the far end of the cable was replaced with electronic sensors with springs located next to the driver's foot. The cable mechanism had compliance (slack) that was not emulated by the electronic pedal, which caused the ETC pedal to be more responsive. The electronic accelerator pedal-force-versus-displacement effort in the 2002 Camry was measured and found to be somewhat similar to the brake pedal-force-versus-displacement effort, which could make it more difficult for an operator to discern the difference between the two pedals merely by the feel of the pedal. This similarity in feel between the two pedals could theoretically increase the likelihood of pedal misapplication, although NHTSA has no evidence that the change produced that result.

In models tested, which provided a very limited sample for making this type of comparative measurement, the lateral separation distance (open space) between the brake and accelerator pedals decreased beginning in 2002, mostly due to the accelerator pedal having been moved closer to the steering wheel centerline (to the left), which could make it more feasible, as a matter of geometry, for a driver to apply both pedals with one foot than had been the case in previous Camry models. More important, however, is the actual lateral separation between the accelerator and brake pedals. In the specific vehicles tested, some variation in lateral separation distance was found, but none measured less than 63.5 mm. Therefore, regardless of the fact that the accelerator pedal was moved closer to the steering wheel center line, these vehicles are well within the range of peer vehicles with regard to lateral separation, which is an important

consideration in assessing whether the pedal placement can contribute to the occurrence of pedal misapplication.

Static step-over height (the vertical difference between accelerator and brake pedals when neither is applied) is another factor to consider with regard to pedal misapplication. The vehicles tested were within Toyota's earlier specifications for step-over, except for one that measured just 22 mm, although this pedal was slightly twisted during brake testing.

In general, the changes made to the pedal operation at the time that ETC was introduced in the MY 2002 Camry were typical of the changes inherent in the shift from mechanical pedals to electronic pedals; the electronic pedals exhibit somewhat quicker response with less displacement. The changes made to pedal placement in this new model, which included moving the accelerator pedal a bit closer to the steering wheel center line, did not result in abnormal lateral spacing between the accelerator and brake. NHTSA does not have a basis for concluding that any of these pedal characteristics made pedal misapplication more likely than in other vehicles. However, the work done on these issues combined with the fact that pedal misapplication continues to be a leading cause of UA gives NHTSA reason to learn more about the auto industry's pedal placement and operation criteria as they may relate to pedal misapplication. NHTSA plans to explore these issues through future research.

### **2.8.2 Acceleration and Braking**

How vehicles perform when their brakes are applied is relevant to whether they could overcome or prevent a UA incident. NHTSA wanted to determine how the test vehicle performed in certain situations where brakes were in normal operating condition and also when braking vacuum was depleted (which could occur in prolonged UA incidents where drivers pump the brakes).

Vacuum assisted brakes, standard on most autos manufactured today, rely on engine vacuum to provide braking assistance. Braking vacuum in the tested Camrys multiplied the brake gain by five to six times the force applied to the pedal. If the brakes were pumped more than once while the accelerator was depressed, vacuum was partially, if not fully depleted and would not regenerate until the throttle plate moved to a more closed position. Without vacuum, a significant increase in operator effort was required to stop the vehicle.

When braking was applied in one continuous motion where vacuum assist was operating normally and the engine was at full throttle, all tested Camrys either came to a stop from 65 MPH or almost to a stop with 112 lbs. or less of brake pedal force.<sup>81</sup>

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.

In short, the braking systems on these vehicle were found more than adequate to be effective in nearly every type of potential UA incident, even those involving a wide open throttle, unless the vacuum has been depleted by pumping the brake. Even in that case, the brake can overcome engine torque, although the brake pedal force necessary to do so increases substantially with the speed at which the incident occurs. These conclusions are important for two reasons: (1) they do not support assertions made in many UA complaints that a vehicle's brakes were not effective in overcoming a UA event, particularly at lower speeds; and (2) they help explain some of the much more infrequent higher speed incidents involving the more powerful vehicles where, perhaps due to a loss of vacuum assist, braking was reported to be difficult.

### **2.8.3 Gearshift and Transmission Shifting**

Shifting the transmission was more complicated with the newer models. In 2002 and model years prior, moving the shifter from park to drive required only one longitudinal movement. By 2007, shifting to drive also required at least one lateral movement for four cylinder vehicles and two lateral movements for V-6 Camrys. In all test vehicles, the transmission shifter was mechanically linked to the transmission. Placing the vehicle into park or reverse at highway speeds and under acceleration caused the vehicles to go to neutral and did not cause any of the vehicles to engage those shift positions; though this action caused both 2001 Camrys to stall.

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<sup>81</sup> 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.

#### **2.8.4 Floor Pan Geometry**

Foam padding was placed under the carpet toward the front of the floor pan in the driver's foot well area beginning in MY 2007. This foam was not present behind the accelerator pedal, creating a cavity where the accelerator pedal could pass the plane of the floor pan foam. Objects such as floor mats that could be pulled into this cavity would have a higher likelihood of creating pedal entrapment than those without the contoured padding. This condition was alleviated in the 2009 pedal entrapment recall because the shortened pedals are less capable of passing the plane of the floor pan foam.

### **3.0 STUDY OF TOYOTA'S ETC SYSTEM AND UA POTENTIAL: NASA'S ACTIVITIES**

#### **3.1 Scope of NASA Study**

The scope of the NASA Toyota unintended acceleration study was to determine if there are design and implementation vulnerabilities in the Toyota ETC system that could possibly cause UA that can realistically be expected to occur in consumers' use of these vehicles, and, if so, whether these failure modes can be specifically identified and demonstrated through testing of vehicles or vehicle components.

When completed, the analysis and testing were intended to identify potential vulnerabilities (whether electronic, mechanical, or human), if any, and answer the following questions:

1. What specific conditions, both internal and external, are necessary for these failure conditions to occur?
2. Are those conditions evident in the reported cases found in consumer complaints, warranty data, field investigations, and physical/forensic examination of parts collected from the field? If not, is there other evidence that the conditions can realistically be expected to occur in the vehicle's operating environment?
3. What physical or electronic evidence does the failure produce? If none, why?
4. What are the expected ranges in severity (throttle opening) and duration that could be caused by the failure?
5. Could the failure have any effect on other interfaces, such as braking system?

### **3.2 Methodology**

The methodology used by NASA in its study is described in the NASA report. In summary, NASA employed a functional safety approach to explore the potential for UA based on an understanding of the ETC design and its implementation and how the integrated system and its component elements may be vulnerable. Where potential vulnerabilities were identified, laboratory and vehicle tests were designed to determine whether the vulnerabilities were actually present. Then, NASA examined complaint and warranty data to determine whether any of the potential vulnerabilities had exhibited themselves in the real world.

### **3.3 Peer Review**

To provide an additional level of independent examination, NHTSA tasked the Volpe Center to conduct a peer review of the test plans developed by NASA and VRTC to study the problem of Toyota UA. The Volpe Center put together a panel of experts to help conduct this review. A summary of the peer review process is contained in Report No. NHTSA-NVS-2011-ETC-SR14.

## **4.0 NASA FINDINGS, OBSERVATIONS, AND RECOMMENDATIONS**

NASA undertook its study of Toyota's ETC system to support NHTSA's efforts to understand and analyze the safety of that system. Below we set forth the findings, observations, and recommendations as taken directly from the NASA report. The NASA organization that conducted the study is the NASA Engineering and Safety Center (NESC).

### **4.1 Findings**

The majority of the engineering analysis associated with the study of UA was limited to MY 2005 Camry, L4 ETCS-i. Some analysis and testing was completed on MY 2005 L4 and V6, and a MY 2007 ETCS-i simulator. EMC testing was only performed on VOQ vehicles from MY 2002, 2003, 2004, and MY 2007. The following findings are based on this engineering analysis and testing.

F-1. No TMC vehicle was identified that could naturally and repeatedly reproduce large throttle opening UA effects for evaluation by the NESC team.

- F-2. Safety features are designed into the TMC ETCS-i to guard against large throttle opening UA from single and some double ETCS-i failures. Multiple independent safety features include detecting failures and initiating safe modes, such as limp home modes and fuel cut strategies.
- F-3. The NESC study and testing did not identify any electrical failures in the ETCS-i that impacted the braking system as designed.
- a. At large throttle openings (35 degrees (absolute) or greater), if the driver pumps the brake, then the power brake assist is either partially or fully reduced due to loss of vacuum in the reservoir.
  - b. NHTSA demonstrated that a MY 2005 Camry with a 6 cylinder engine travelling at speeds up to 30 mph can decelerate at better than 0.25g with 112 lb<sub>f</sub> on the brake while the throttle is open up to 35 degrees (absolute), with a depleted vacuum assisted power brake system.
- F-4. For pedal assembly failures to create large unintended throttle openings, failures need to mimic valid accelerator pedal signals.
- a. Two failures in the precise resistance range, to create the exact circuit configuration in the correct time phase are necessary for this functional failure to occur. Failure to meet these restrictive conditions will generate a DTC.
  - b. Some first failures in dual failure scenarios of Hall Effect accelerator pedal systems might not be detectable by the ECM or via diagnostic data to the OBD interface.
  - c. A review of the warranty data does not indicate an elevated occurrence of pedal or ECM related DTCs relative to UA VOQs.
- F-5. Destructive physical analysis of a failed pedal assembly from a VOQ vehicle with a DTC found a tin whisker<sup>82</sup> had formed a 248 ohm resistive short between VPA1 and VPA2. A second tin whisker of similar length was growing from a 5 volt source terminal adjacent to a pedal signal output terminal, but had not made contact with any other terminals. Inspection of “non-failed” potentiometer pedals revealed tin whiskers present in similar locations as the failed pedal.

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<sup>82</sup> Tin whiskers are electrically conductive, crystalline structures of tin that sometimes grow from surfaces where tin (especially electroplated tin) is used as a final finish. <http://nepp.nasa.gov/whisker/>

- a. Destructive physical analysis shows the Denso Hall Effect accelerator pedal sensor is protected against the tin whisker resistive shorts. The CTS pedal provides physical separation between the VPA1 and VPA2 thereby removing one component of the dual fault scenarios.
- F-6. Vehicle testing of a MY 2005 Toyota Camry demonstrated that a 248 ohm short between VPA1 and VPA2 results in different vehicle responses depending on the sequence of operations following the fault. In all cases, releasing the accelerator pedal closes the throttle, and brakes are fully operational.
- a. If the resistive short occurs while the vehicle is off, starting the vehicle with the accelerator pedal partially depressed will not trigger a diagnostic trouble code. When the accelerator is pushed slowly, the vehicle has a jumpy response, and is capable of full throttle without throttle brake override. When the accelerator pedal is pushed quickly, the fail-safe limp home mode is active including brake override.
  - b. If the resistive short occurs while driving, a DTC is declared along with a MIL, and fail-safe limp home mode is active including throttle brake override capability.
  - c. If the key is cycled after the resistive short, the DTC and MIL remain. When the accelerator is pushed slowly, the vehicle has a jumpy response, and is capable of full throttle without throttle brake override. When the accelerator pedal is pushed quickly, the fail-safe limp home mode is active including brake override.
  - d. If the battery is disconnected with the resistive short, or the DTCs are otherwise cleared, DTCs will not return. When the accelerator is pushed slowly, the vehicle has a jumpy response and is capable of full throttle without throttle brake override. When the accelerator pedal is pushed quickly, the fail-safe limp home mode is active including throttle brake override.
- F-7. Functional failures of the cruise control can result in 0.06 g's, or 2.12 kph/s, acceleration and may not generate a DTC; however, there are multiple methods for cancelling or turning off cruise control.

- F-8. Functional failures of idle speed control, transmission control, VSC, and throttle control may result in throttle openings of less than 5 degrees above idle and may not generate a DTC. Per a NESC team request:
- a. NHTSA demonstrated that a MY 2005 Camry with a 6 cylinder engine can be held in a stopped condition with a brake pedal force of approximately 8.5 lb<sub>f</sub> with throttle openings up to 5 degrees above idle.
- F-9. Comprehensive electromagnetic compatibility testing well beyond recommended certification levels was performed on six different TMC VOQ vehicles to determine EMC levels that could have an effect. No throttle control vulnerabilities from EMC radiated testing were identified that would result in throttle increase.
- F-10. Extensive software testing and analysis was performed on TMC 2005 Camry L4 source code using static analysis, logic model testing, recursion testing, and worse case execution timing. With the tools utilized during the course of this study, software defects that unilaterally cause a UA were not found.

## 4.2 **Observations**

- O-1. Resolution of a UA depends on driver awareness of mitigations, driver response, UA situations (e.g., open highway, crowded parking lot), and other factors (e.g., environmental). Some VOQs indicate that some drivers may not know or understand the vehicle response for the hazard controls at their disposal and how to use them. For example:
- a. Shifting to neutral with the resulting high engine speed will not harm the vehicle.
  - b. Pumping the vacuum assist brakes can decrease their effectiveness.
  - c. Turning the vehicle off while driving may require a different sequence than when the vehicle is stopped and will not lock the steering wheel.
  - d. Shifting patterns vary between vehicles and within a vehicle may require different motions to get to neutral when in modes other than drive and reverse.
- O-2. During testing, the limp home mode safety feature closed the throttle when the brake was pressed. When the brake can override the throttle command it provides a broad defense

- against unintended engine power whether caused by electronic, software, or mechanical failures.
- O-3. Failures of safety critical systems in the ETC do not provide the same driver information as failures that occur in the safety critical brake systems. A unique red ‘warning light’ is illuminated for the brake system, while only a generic, multi-purpose check engine light occurs for off-nominal ETC conditions.
  - O-4. The Government-mandated (Environmental Protection Agency) DTCs are for emission control and are not mandated to cover safety critical failures.
  - O-5. Vehicles that are operated with an active accelerator pedal sensor fault, either with the MIL on or off, may be susceptible to the effects of second faults, leading to possible unintended accelerations.
    - a. NHTSA evaluated 188 Swift Market Analysis Response Team (SMART) data sets from TMC complaint vehicles and found no proof that the second fault is occurring and resulting in UA in those vehicles.
  - O-6. While not resulting in a design vulnerability, the MY 2005 Camry source code required unique code inspection tools, and manual inspections due to:
    - a. The TMC software development process uses a proprietary developed coding standard.
    - b. Industry standard static analysis tools provide automated code inspections based upon industry standard code implementations.
  - O-7. There are no methods for capturing pre-event software state and performance following a UA event either on the vehicle or as a diagnostic tool.
  - O-8. The available incident reporting databases are valuable for identifying potential vehicle symptoms related to UA events. However, voluntary reporting systems may not allow for accurate quantitative estimates of incident rates or statistical trends.
  - O-9. A review of HF literature related to UAs indicates that pedal misapplication remains an identified cause of some UAs. However, it is not possible to accurately estimate from available survey and laboratory data how frequently this error is an underlying cause.
  - O-10. Given that driver errors such as pedal misapplications are best characterized as low-probability random process events, it is difficult to study them in a controlled laboratory environment (e.g., human-in-the-loop driving simulation studies). Manipulations that

might be performed to increase the observed frequency might also compromise the ability to generalize the findings under consumers' use of the vehicle.

- O-11. Design features, such as sport shifter and push button stop, might compromise the driver's ability to recover from a UA event. Such features may be indicative of broader driver-vehicle integration issues and therefore may merit further consideration.

#### **4.3 NESC Recommendation**

- R-1. It is recommended that NHTSA consider whether additional study, government regulation, or policy is warranted based on the findings and observations within this report.
- a. Controls for managing safety critical functions, as currently applied to the railroad, aerospace, military and medical sectors, warrant consideration.

### **5.0 NHTSA'S PLANNED ACTIONS BASED ON THE STUDY OF TOYOTA'S ETC SYSTEM AND UA POTENTIAL**

#### **5.1 NASA's Findings**

Based on NASA's evaluation of Toyota's ETC system and NHTSA's own review of data and examination of vehicles as explained in this report, NHTSA concludes that the Toyota ETC system does not have design or implementation flaws that could reasonably be expected to cause UA events involving large throttle openings as described in consumer complaints to NHTSA. Failures that mimic valid accelerator pedal signals can be induced to produce large throttle openings. However, no single failure can produce such a condition. Two failures in the precise resistance range necessary to create the exact circuit configuration in the correct time phase are necessary for this functional failure to occur. As NHTSA understands the situation, the likelihood of two such specific failures occurring in a consumer's use of a vehicle in the precise resistance range and in the required sequence necessary to produce the UA condition is remote. Moreover, the occurrence of such failures outside of these very narrow conditions will always set a diagnostic trouble code (DTC). Thus, if these failures have occurred, they would be much more likely to occur in the far larger zone that would produce a DTC than in the exceedingly narrow set of conditions that would not produce a DTC. The absence of any trend of such DTCs

being set and recorded in warranty data strongly suggests that the much more unlikely events that do not leave a DTC are not occurring in the real world.

NASA did determine through microscopic analysis of a failed pedal obtained from a field incident that certain resistive faults can result from the presence of tin whiskers within the accelerator pedal position sensor. In vehicles with potentiometer sensors (MY 2002-2006), NASA found that this kind of resistive short generally produces a DTC, warning light, and fail-safe operation, but results in different vehicle responses depending on the subsequent operation of the vehicle following the occurrence of the fault. In the field incident in which the pedal examined by NASA was involved and in the only other three incidents that appear to be of that nature found in the VOQs, the resistive short triggered a DTC and fail-safe operation. In each case, the owner brought the vehicle for servicing because of the lack of acceleration and somewhat jumpy throttle response and the vehicle was repaired without damage or injury. Also, the unwanted acceleration in this situation is relatively small (up to 15 degrees of throttle opening), ceases immediately when the accelerator pedal is released, and is readily controlled by braking, which is unaffected. Moreover, NHTSA's analysis of its own complaint data and Toyota's warranty data indicates that conditions that produce a DTC related to pedal failure are very rare in these vehicles, indicating an extremely small likelihood of such conditions, and an even more remote chance of conditions producing such a short without producing a DTC. Accordingly, there is currently no evidence of a real-world safety risk produced by this phenomenon. However, the nature of the fail-safe operation after the first drive cycle suggests Toyota has adopted an imperfect fail-safe strategy for that particular kind of fault.

In the case of vehicles with Hall Effect sensors (MY 2007 and later), NASA indicated that the presence and growth of tin whiskers within the sensor circuitry is significantly less likely than in earlier models due to the Hall Effect sensors' circuit board terminal architecture and construction. NHTSA's own analysis of complaint and warranty data supports that view. Moreover, NHTSA's examination of data obtained from the engine control modules of nearly 200 vehicles of this type that were involved in alleged UA incidents found no evidence that a latent resistive short producing abnormal pedal sensor voltages was present in those vehicles.

NHTSA is aware that, as NASA has found, certain “functional failures”<sup>83</sup> of idle speed control, transmission control, vehicle stability control, or the throttle assembly can result in a throttle opening of less than five degrees and may not leave a DTC. NHTSA has conducted the testing referred to in NASA’s finding on this point indicating that vehicles experiencing these phenomena in the worst case (i.e., an occurrence from a standing start, where the additional acceleration would be most perceptible) can be held in a stopped condition with a brake pedal force of about 10 lbs. This is a very small amount of pedal force. NHTSA testing indicates that drivers generally apply an average of 8.0 lbs. of force to hold a vehicle in a stopped position on level ground. Accordingly, although these phenomena could explain some complaints involving very small amounts of acceleration from a stopped position, NHTSA does not believe that these conditions present safety risks to the vehicle occupants. NHTSA understands that the cruise control system has two possible vulnerabilities that could result in a throttle increase but concludes, based on NASA’s findings on this subject, that these vulnerabilities produce negligible acceleration and no safety hazard.

NHTSA notes that NASA specifically states that it did not identify any ETC failures that impact the braking system. NHTSA concludes that any claimed lack of braking effectiveness in a UA incident could not be attributable to a failure in the ETC system. In other words, if the braking system of a Toyota vehicle fails, an electronic fault in the ETC system is not the cause.

NHTSA also notes that NASA’s extensive electromagnetic compatibility testing of the Toyota vehicles indicated no throttle control vulnerabilities despite the fact that the testing went well beyond recommended certification levels.<sup>84</sup> NHTSA understands that NASA’s unprecedented software testing and analysis of the ETC source code demonstrated no evidence of software coding flaws in the ETC system that could produce UA. Moreover, NHTSA is well aware, as NASA has found, that the safety features designed into the Toyota ETC system serve to prevent large throttle opening UA caused by ETC failures.

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<sup>83</sup> NHTSA does not consider these phenomena failures in the way it uses that term because they are in many cases design features that produce very limited uncommanded acceleration.

<sup>84</sup> EMI testing produced one failure in a Denso accelerator pedal that was not related to UA. This is described in NHTSA-NVS-2011-ETC-SR15.

## **5.2 NASA Observations**

NHTSA appreciates NASA's observations. Those concerning software issues will inform NHTSA's planned actions with regard to safety-critical control systems. Those concerning the nature of warnings given to the driver in the event of failures of safety-critical systems will be considered in determining any necessary changes to the agency's standard concerning safety-related visual displays in the vehicle. The observation on DTCs not clearly distinguishing safety-critical failures will be considered as part of NHTSA's continued review of electronic control systems. NHTSA will consider NASA's observations on brake override, push-button stop and the possible driver confusion caused by some sport shift modes as it decides on potential rulemaking options related to UA events. NHTSA will consider NASA's observations on pedal misapplication as it continues its research efforts in that area.

## **5.3 NASA's Recommendation**

NASA made a very broad recommendation that NHTSA review the findings and observations in its report and consider whether additional study, regulation or policy is warranted. NHTSA has carefully reviewed NASA's findings and observations and explains below how its planned actions will address them. NASA's recommendation included one more specific suggestion: controls for managing safety-critical functions – as currently applied to the railroad, aerospace, military and medical sectors – warrant consideration. NHTSA fully agrees with that suggestion and will consider such controls in its further work on vehicle electronics.

## **5.4 NHTSA's Planned Actions**

Having fully considered NASA's complete report and based on NHTSA's own activities and observations on these subjects, NHTSA plans to take the following actions:

- NHTSA will consider initiating rulemakings on brake override systems, keyless ignition systems, and event data recorders. Brake override systems may prevent or mitigate some UA incidents by ensuring that, when the brake is applied, the braking system has priority over the throttle. NASA observes in its report (Observation O-2) that such a system “provides a broad overarching defense against unintended engine power” from a wide range of causes. Keyless ignition systems can exacerbate UA incidents (particularly

prolonged incidents involving a stuck accelerator pedal) if the driver cannot determine how to shut off the engine quickly. Event data recorders can provide crash investigators objective information relevant to UA incidents that result in crashes sufficient to trigger the devices. These devices are currently voluntarily installed on 85% (est.) new vehicles in the U.S.

- NHTSA will begin preliminary research on the reliability and security of electronic control systems by examining existing industry and international standards for best practices and relevance to automotive applications. In this research, NHTSA will give full consideration to NASA's recommendation that NHTSA consider controls for managing safety critical functions as currently applied to the railroad, aerospace, military, and medical sectors. NHTSA will also give full consideration to NASA's findings and observations as they relate to the use of diagnostic trouble codes in conveying safety-critical information to drivers, safety-critical software design and validation methodologies, and robust fail-safe strategies that protect against two-fault scenarios (including those involving resistive short circuits and latent faults). The agency anticipates that the NAS panel will offer recommendations on these subjects and wishes to enhance its own understanding of the subject area.
- NHTSA will begin research on the placement of accelerator and brake pedals and driver usage of pedals. NHTSA is interested in learning whether the frequency of pedal misapplication can be significantly reduced through pedal placement specifications and operational characteristics.
- Along with NASA, NHTSA will brief the National Academy of Sciences panel that is conducting a broader study of UA and electronic control systems to ensure that the panel has the benefit of the work done by the two agencies.
- NHTSA will continue its plans to enhance its knowledge and capabilities in the area of safety-critical vehicle electronics, including electronic control systems, both by ensuring that current staff continues to be well informed on the developing technologies and potential safety issues and by hiring (as agency needs dictate and funding permits) more staff with the necessary expertise.