VOLUME I

FAILURE MODES OF GENERAL MOTORS C/K LIGHT TRUCK OUTBOARD FRAME, SIDE-MOUNTED FUEL CONTAINMENT SYSTEM

and

APPENDIX A1 through A17

Prepared by

Mark W. Arndt
Arndt & Associates, Ltd.
Tempe, Arizona

March 24, 1994

Rev. 3/24/94

Table of Contents

Rev. 3/24/94

FAILURE MODES OF GENERAL MOTORS C/K LIGHT TRUCK, OUTBOARD FRAME, SIDE-MOUNTED FUEL CONTAINMENT SYSTEM

I. INTRODUCTION

This document will report the crash-induced failure modes and potential failure modes of the General Motors C/K truck fuel containment systems[1] which are predictable, and in most cases observable, in both experimental[2] and real-world crashes.[3] To identify the failure modes discussed in this report, the following principle of crashworthy fuel containment design is used: Design a fuel containment system which is incapable of developing deformations[4] producing strains which exceed or closely approach the system's fracture limit in survivable crashes.

II. FAILURE MODE 1: FAILURE BY VIRTUE OF FUEL TANK POSITION/MOUNTING

The tank position/mounting is intertwined with other fundamental failure modes of the fuel containment system such that it is difficult, if not impossible, to discuss the fuel tank

---

[1]It is worth noting that there are differences in fuel containment system designs used in General Motors C/K trucks between 1973 and 1987; however, all systems have similar locations and many similar failure modes.

[2]Many examples of failures observed as the result of crash tests conducted by General Motors are included in this report as illustrations of failures. Tests used as examples include development and certification tests of trucks with production and experimental fuel systems. While one in general should use engineering judgment in drawing parallels between fuel system performance in staged crash test and production fuel system performance in real-world crashes, the examples provided are useful and significant.

[3]The real-world crashes included in this report are drawn from the investigative files of Arndt & Associates, Ltd. In most cases, a personal inspection or investigation was requested by a plaintiff who was either contemplating or involved in litigation against General Motors.

[4]Deformation in the broadest sense may be acceptable, possibly desirable; deformation meaning changes in form, shape, or location, but never meaning deformations producing strains that approach or exceed a system's failure limit.

position/mounting without considering the array of other General Motors C/K truck fuel system failure modes. Rarely do General Motors C/K truck fuel containment systems leak by only one failure; rather, an array of failures results which has a fundamental link to the fuel tank position or system crash performance. There are numerous examples of failures occurring in General Motors C/K truck fuel containment systems, due to the effects of their position and mounting.

A. TANK LOCATION

The fuel tank is located in a zone of primary crush and intrusion. In Appendix A1, a page from both the 1973 and the 1985 General Motors Body Builders Guides illustrate one configuration of the fuel tank in its position outboard of the truck frame rail. A photograph of a 1978 4x2 truck and a photograph of a 1985 4x4 truck with post-1983 shields demonstrate photographically similar configurations. In many types of crashes producing side damage,[5] the fuel tank of the General Motors C/K truck is positioned such that forces generated by impacting structures are reacted through the fuel tank. In crashes producing side damage, the fuel tank and other vehicle structures absorb crash energy.[6] A fuel tank simply should not be an energy-absorbing structure in a vehicle crash.

Because the fuel tank of the General Motors C/K truck fuel containment system is an energy-absorbing structure in a zone of

[5]It is important to distinguish between side impact crashes and crashes producing side damage. Crashes which appropriately would be coded with a principal direction of force or damage of one o'clock or eleven o'clock cause side damage which produces General Motors C/K truck fuel system failures.

[6]An illustration of this point is shown in Appendix A2, containing page 12 of General Motors report, "Evaluation of Safety of General Motors 1973 - 1987 C/K Pickup Trucks, Part I: Initial Response of General Motors Corporation to NHTSA's letter of April 9, 1993." April 30, 1993.

primary crush and intrusion, unpredictable tank deformations occur which cause the following:

1. Upsets of the Fuel Tank Sender Unit

The sender unit is a device which is mounted on the top of the fuel tank and is held in place using a circular cam-locking device. Appendix A3 contains pages from the 1973 and 1983 General Motors Product Description Manuals. A photograph of a typical fuel tank sender unit is also contained in Appendix A3.

The sender unit, by virtue of its design, causes localized discontinuity in the fuel tank surface. This discontinuity manifests itself in two ways. First, the sender unit and its mounting system are stiff relative to a deforming fuel tank, and second, the sender unit protrudes above the surface of the fuel tank, making it vulnerable to impacts. Sender unit failures occur in crashes in which fuel tank deformation causes distortion or movement around the sender unit and in crashes in which crash-induced fuel tank or truck structural movement exposes the sender unit to contact.

Appendix B1 contains the results of General Motors 30 mph car-to-truck crash test, C-5318,[7] in which leakage resulted due to direct contact between crash-deformed structures outboard of the fuel tank and the sender unit. Appendix B2 contains the results of General Motors 50 mph

[7]C-5318 is a 30 mph (49.8 km/h) 90 degree car-to-truck crash test of a 1980 K-truck with experimental plastic half shells enclosing the upper and lower halves of the fuel tank.

car-to-truck crash test, C-5831,[8] in which, among other failures, leakage resulted from fuel tank sender unit deformation at the tank mounting area. Examples of sender unit failures in real-world crashes are shown in Appendices B3 and B4.

2. Failure in or Adjacent to Seam Welds due to Deformations, Dynamic Internal Fuel Tank Pressure, and Localized Stress Risers

Because of the extreme deformation and collapse that can occur to a truck fuel tank by virtue of its energy absorbing function and location in a zone of primary crush and intrusion, strains adjacent to and in the seam welds of the fuel tank may result in large fuel leakage producing failures. Some of these seam weld-related failures are simply associated with crushing the tank too much. Other seam weld failures are associated with, in addition to tank collapse, deformation of the tank into structures around the fuel tank, for example, the front leaf spring mount of the rear suspension.

Appendix B5 contains results of a General Motors 50 mph car-to-truck crash test C-5601,[9] in which, among other failures a 300 mm (11.8 in) fracture of the forward, outboard tank seam weld occurred. The tank's contents,

---

[8]C-5831 is a 50 mph (79.1 km/h) 90 degree car-to-truck crash test of a 1984 K-truck with the "latest production 1984 plastic fuel tank shield, extension bracket, and sender unit design--propshaft support cross member to frame gusset (and) proposed 1985 transmission cross member." page 1, C-5831.

[9]C-5601 is a 50 mph car-to-truck test of a 1982 K-truck with modifications to the fuel containment system which included: "1) Plastic upper filler neck retainer, 2) Steel brackets added to existing gas tank support brackets at side impact area, 3) Plastic .150" thick shield added over new steel brackets. Shield covers full length of tank." page 1, C-5601.

approximately 17 gallons, were released in 10 seconds. An example of a real-world crash in which the forward seam weld has failed due to tank crush is shown in Appendix B6.

3. Puncture by Sharp, Impacting Structures

The surface of the fuel tank is subjected to direct contact with sharp, impacting structures. Direct contact by impacting structures produces punctures and tears of the fuel tank. These types of fuel tank punctures and tears are most notable but not limited to real-world crashes in which significant longitudinal movement of the impacting structure occurs relative to an unshielded truck fuel tank. Impacting structures, usually the damaged front end of a striking vehicle, produce an unpredictable array of sharp, penetrating/tearing objects which can directly impinge upon an unshielded fuel tank in a crash.

Minor crashes, as demonstrated in the real crash illustrated in Appendix B7, can produce fuel tank punctures by impacting structures when the fuel tank is located in a primary zone of crush and intrusion.

Appendices B8 and B9 illustrate real crashes in which significant tears of the fuel tank result, due to the tank's position and its vulnerability to impingement by sharp, impacting structures.

4. Impingement by Deforming Truck Structures

Because the fuel tank is located in the area where significant vehicle deformation is likely to occur, structures of the truck cab, frame, and bed can deform and present puncture-producing objects and shapes to the fuel tank. Many of the truck body sub-structures are relatively stiff and, if deformed appropriately in a crash, can cause significant tank strain, punctures, tears, or other failures. An example of such a body structure-induced tear of a fuel tank is illustrated in Appendix B10. The real crash in Appendix B10 demonstrates the movement of a truck cab sub-structure into a forward corner of the fuel tank. The truck cab sub-structure was originally located forward and above the fuel tank position.

5. Tank Shape

The fuel tank, by virtue of its square cross section, is incapable of efficiently rearranging its shape while being crushed and as a result cannot accommodate its liquid volume. The traditional shape of fuel tanks mounted in zones of anticipated crush is flat, with a high length to height ratio. (For example, General Motors rear-wheel drive A, B, and C-body cars with aft-of-axle fuel tanks are "flat" tanks.) These flat designs actually increase the volume of the fuel tank when crushed from behind. The effect of having a fuel tank with reduced capability of accommodating crush is dynamic internal pressure during crashes. This increase in internal pressure rarely, by itself, causes failure; rather, it contributes to failures due to other mechanisms.

B. FUEL TANK AND TRUCK STRUCTURE MOVEMENT DURING CRASHES

The fuel tank is located in a primary zone of crush and intrusion. In this zone, the General Motors truck fuel tank is susceptible to failure by virtue of crash-induced movements of the fuel tank and the truck structures.

Located outboard of the fuel tank are portions of the truck cab and truck bed structures. When viewed from the side, these structures cover most of a General Motors fuel tank. In side crashes which produce underride damage or damage on the lower truck structures, the fuel tank and outboard truck structures move such to cause failures. This crash-induced movement is characterized by a deforming (folding) inward and upward movement of the truck structures outboard of the fuel tank and by a downward and inward deformation (rotation) of the fuel tank. These crash-induced movements expose and subject the fuel containment system to several potential failures.

An illustration of crash-induced movement of the fuel containment system is shown in three General Motors crash tests, C-5308,[10] C-5318,[11] and C-5601.[12] Partial results of these tests are contained in Appendices B11, B12, and B13 respectively. Photographs from C-5308 demonstrate the exposure of the fuel tank outboard side by virtue of the upward folding of the truck structures in a 30 mph car-to-truck test of a 1981 C-truck. Photographs from C-5318 demonstrate outboard truck structure upward folding and tank downward rotation in a 30 mph car-to-truck test of a K-truck. Finally, test C-5601, a car-to-truck test at 50 mph of a K-truck, shows the near 90 degree post-impact rotation of the fuel tank.

Fuel tank rotation causes the filler neck to pull apart, particularly in pre-1984 filler necks in which no break-away feature is provided. Overall, crash-induced fuel tank and truck structural movements tend to expose more surface of the fuel tank to the intruding and puncture-producing structures and cause the fuel tank to absorb more of the collision force.

---

[10] C-5308 is a 30 mph, 90 degree car-to-truck crash test of a 1981 C-truck with two experimental plastic half-shells installed around the fuel tank upper and lower halves.

[11] Ibid.

[12] Ibid.

Crash-induced movement of fuel containment systems produced after 1983 with shields covering the bottom half of the fuel tank may proceed to such an extent that the upper, unshielded surface of the fuel tank is exposed to direct contact from impacting structures. A real-world illustration of collision-induced fuel tank and truck structure movements is shown in Appendix B14. In this crash, the rotation of the fuel tank, coupled with its exposure due to the truck structural movement, produced failure in the filler neck and contributed to the sender unit failure.

The propensity for fuel tank rotation is greatest in the K-truck, due to its relatively higher ride height. This propensity was partially addressed in K-trucks by General Motors' post-1984 fuel containment system improvement.

III. <u>FAILURE MODE 2</u>: <u>PUNCTURE BY SHARP OBJECTS SURROUNDING FUEL TANK</u>

There are numerous puncture-producing objects which are located by virtue of their design around the fuel tank of the General Motors C/K truck. One's reasonable expectations of fuel containment system design are violated by these puncture-producing objects. These components include the following:

A. FUEL TANK MOUNTING BOLT

These eight bolts mount the fuel tank bracket to the frame and provide sharp bolts pointing straight at the inboard side of the fuel tank. The bolt positions are identified by Item "2" on the attached page from the 1984 C/K truck Product Description Manual, Appendix A4, Figure A4.1. Some of the sharp points of bolts are located approximately one-half inch from the fuel tank inboard side. Photographs on Figure A4.2 and A4.3 of Appendix

A4 show the relative position of these mounting bolts at the forward tank mounting support.

Failures associated with these tank support mounting bolts are punctures and puncture-related tears of the tank's inboard wall. These failures occur when the fuel tank is deformed around its inboard support by virtue of crash-induced forces on the front, rear, and outboard side of the fuel tank. Examples of this failure mode in real crashes are illustrated in Appendices C1, C2,[13] and C3.

Appendix C1 shows a possible puncture of the fuel tank by this mechanism and is noteworthy in that this type of failure can be obscured by vehicle and fuel tank deformation. Often these failures are overlooked or must be implied by damage. A complete examination for this type of failure may require removing the fuel tanks.

B. FUEL TANK SUPPORT STRAP

Both front and rear fuel tank straps have sharp corners which rest in a depression near the upper, inboard corner of the fuel tank. The fuel tank straps clamp the tank tightly to the fuel tank support assembly. These straps rest on the fuel tank and can puncture the tank when relative movement occurs between the tank and its mounting components. The fuel tank straps are identified with arrows on the attached page from the 1984 C/K truck Product Description Manual, see Appendix A5, Figure A5.1. In Appendix A5, Figures A5.2 and A5.3, the configuration and shape of the fuel tank strap at the upper, inboard corner of the fuel tank is shown.

[13]The example in Appendix C2 involves a 1984 K-truck which had been "lifted" such that the truck frame was above its normal position relative to the axle and the truck body was above its normal position relative to the frame. The truck had larger than normal tires.

Failures associated with the tank strap at the upper, inboard corner of the fuel tank are usually cuts or tears. These failures occur when the fuel tank is forced forward or rearward relative to its proper position on the tank support assembly. Crashes which cause this type of fuel tank movement include front offset crashes, side-swipe crashes, and side impact crashes in which both vehicles are moving.

Except for a staged crash conducted by Failure Analysis Associates for General Motors in conjunction with its defense in Moseley versus General Motors, shown as an example in Appendix C4, this type of failure-causing leakage is not observed in any results of experimental crashes conducted by General Motors on C/K trucks.[14]

Further, examples of this failure mode are illustrated in Appendices C5, a failure in a side crash;[15] C6, a failure in an offset, side-swiping crash; and C7, a failure in an angle, offset frontal crash.

C. BOLTS/SCREWS PROTRUDING THROUGH CAB FLOOR

Components for the interior of the truck cab are mounted by several bolts and screws which protrude through the floor of the cab and present sharp, puncture-producing objects next to the upper, forward surface of the fuel tank. Photographs in Appendix A6 document the position of the bolts and screws. Figure A6.1 of Appendix A6 shows the position, as viewed from

[14] In the Failure Analysis Associates test, both vehicles were moving perpendicular to each other at impact, and the fuel tank was inspected after its removal from the truck. In this test, the side-impacted 1984 C-truck vehicle moving at 15 mph was struck at 90 degrees on its left side by a post-1988 General Motors C-truck moving at 48 mph.

[15] This example is the crash from which the litigation, Moseley versus General Motors, arose, resulting in an Atlanta jury finding the 1984 C-truck defective and awarding $105 million in compensatory and punitive damages.

inside the cab, of bolts at the forward and rear seat mounts and seat belt retractor mount. Figure A6.2 of Appendix A6 shows the position--as viewed from under the cab with the fuel tank removed--of the same bolts. Figure A6.3 of Appendix A6 shows the position of an interior trim mounting screw relative to the seat belt retractor mounting bolt--again, the fuel tank is removed.

The following specific failure modes exist for the screws described above:

1. **Seat Track Mounting Bolt**

The position of the seat track mounting bolt relative to the fuel tank is shown in Appendix A7, Figure A7.1. The photograph of Figure A7.1 was taken through a hole cut in the truck floor. Failures associated with the seat track mounting bolt are largely punctures and punctures with associated tearing. These punctures occur in the upper, forward surface of the fuel tank adjacent to the seat mounting bolt point protrusion.

Crashes which cause relative movement of the truck cab floor toward the fuel tank can produce tank punctures by the seat track mounting bolts. Examples of this failure mode can be seen in the crash shown in Appendix C8.

2. **Seat Belt Retractor Mount Bolt**

The position of the seat belt retractor mount bolt relative to the fuel tank is shown in Appendix A8. This bolt is located outboard of the aft seat track mounting bolt and relative to the fuel tank above the upper, inboard corner, forward of the fuel tank centerline. This bolt protrusion, like the seat mounting bolt, is likely to produce tank punctures and puncture-associated tears of the fuel tank in crashes which cause relative movement of the truck cab floor or rocker panel towards the fuel tank.

3. Truck Interior Trim Mounting Screws

Trim mounting screws which protrude through the cab floor provide puncture-producing mechanisms near the fuel tank. When present, they provide potential failure of the fuel tank. Appendix A9 shows trim mounting screws protruding through the truck cab floor relative to the fuel tank. Similar to the other bolts and screws which protrude through the truck cab floor, these screws can produce small punctures of the fuel tank in crashes which cause relative movement of the truck cab floor and fuel tank.

An example of cab trim screws puncturing fuel tanks is demonstrated in General Motors crash test C-3939.[16] In this crash test, which was a 20 mph right-side moving barrier test, a trim mount screw was observed to puncture a hole in the fuel tank which resulted in fuel leakage in excess of one ounce per minute. Appendix C9 contains the results of this test and photographs showing the bolt which caused the fuel tank puncture.

D. FORWARD LEAF SPRING MOUNT

The sharp corners of the bracket of the forward mount for the rear leaf spring, coupled with this proximity to many of General Motors C/K truck fuel tanks, can significantly puncture a truck fuel tank at its back, inboard corner. The attached excerpts from the 1985 GMC truck Body Builders Drawing and Supporting Data, Appendix A10, Figure A10.1 illustrate the relative

[16] C-3939 is a 20 mph rigid right side moving barrier impact of a 1975 C-truck, experimental body.

position of the fuel tank and the forward leaf spring mount. Photographs in Appendix A10, Figure A10.2 and A10.3 provide additional clarification of the relative position of these components. The photographs shown in Figure A10.2 and A10.3 are of a 1985 GMC-K truck. This post-1983 truck contained a partial shield which covered the bottom of the fuel tank.

Typically, failures from the forward leaf spring mount occur when the fuel tank is moved or deformed inboard and rearward into the mount. The forward leaf spring mount may cause a puncture by itself, or the localized deformation which occurs in the fuel tank causes a tearing compromise of the tank or the tank seam weld. The bracket causes local impingement in the fuel tank in conjunction with collision-induced deformation and/or tank internal pressure, the rise in which causes failures. This type of tank compromise usually occurs in side damage collisions.

Examples of this failure mode are illustrated in part by crash tests conducted by General Motors. A 20 mph rigid side moving barrier test of 1984 cab/chassis, General Motors crash test C-5686,[17] in Appendix C10 shows the damage and documents minor leakage at the rear, inboard corner of the truck fuel tank. General Motors crash test C-5686 demonstrates that, even in minor crashes, this failure mode is incipient. Appendix C11 gives a real-world example of a failure due to this mechanism. Finally, in the 50 mph car-to-truck test program which was initiated by General Motors in 1982, there are numerous examples of failure at the rear, inboard corner of the fuel tank due to an interaction of the forward leaf spring mount. Appendix

[17] C-5686 is a 20 mph rigid right side moving barrier impact of a 1984 C-truck cab chassis. A cab chassis has no bed installed and therefore is expected to sustain direct contact from impacting structures to the fuel tank.

C12[18] and C13[19] shows two General Motors tests which demonstrate this failure mechanism. The test in C12 is a test of a 1981 General Motors K-pickup truck (General Motors crash test C-5367) with plastic shields enclosing the upper and lower halves of the fuel tank. Leakage due to the failure occurred at the rate of two gallons per minute. In Appendix C13, General Motors crash test C-5618, a car-to-truck test of a 1982 C-truck with some of the fuel system improvements which were ultimately incorporated in 1984 trucks, resulted in a failure along the rear of the fuel tank due to contact with the forward leaf spring mount, emptying the entire contents of the fuel tank in five minutes.

E. FUEL LINE MOUNTING BRACKET BOLTS - RIGHT FRAME RAIL

There is an array of bolts associated with brackets which mount fuel lines and brake lines to the inboard side of the right frame. The threaded ends of the bolts extend through the frame rail and protrude, pointing toward the fuel tank. These protruding bolt points provide numerous puncture-producing objects pointing at the inboard edge of the fuel tank on the outboard surface of the frame.

Figure A11.1 in Appendix A11 shows the position of protruding brake and fuel line bracket mounting bolts on the outboard side of the right frame rail of a 1985 General Motors K-truck. (In this photograph, the fuel tank is removed.) Also shown in Figure A11.1 of Appendix 11 are protruding brake and fuel line bracket mounting bolts on the bottom flange of the right frame

---

[18]C-5367 is a 50 mph (79.2 km/h) car-to-truck test of a 1981 K-truck with two experimental plastic half-shells enclosing upper and lower halves of fuel tank.

[19]C-5618 is a 50 mph (81.6 km/h) car-to-truck test of a 1982 C-truck, prototype, with "Special features: 1.) Plastic upper filler neck retainer. 2.) Steel brackets added to existing gas tank support brackets at side impact area. 3.) Plastic .150 inch thick shield added over new steel brackets. Shield covers entire length of tank."

rail. Figure A11.2 of Appendix A11 shows a side view of the protruding bolts. In post-1983 fuel system containment designs, only those bolts protruding through the bottom flange of the frame are shielded from the fuel tank (assuming the shield stays in place, see Failure Mode 4).

Failures associated with the protruding brake and fuel line bracket mounting bolts are punctures and puncture-related tears of the fuel tank inboard wall. These failures occur when the fuel tank is forcibly deformed toward the frame rail, as occurs in virtually all crashes producing side damage. As fuel tanks rotate downward and inward in underriding crashes, the protruding mounting bolts in the frame rail lower flange may puncture the fuel tank. An example of this failure mode in a real crash is shown in Appendix C14. In the real crash illustrated in Appendix C14, the brake and fuel line mounting bolt which protrudes on the outboard side of the right frame rail near the back of the fuel tank has punctured a hole in the fuel tank.

F. POST-1983 OUTBOARD FUEL TANK SUPPORT

For all post-1983 C/K truck tanks located outboard of the side frame rails, a change in the tank support assembly resulted in an extension of the tank support around the lower, outboard portion of the fuel tank. The support is mounted inboard of the plastic shield. Contrasting Figures A12.1 and A12.2, which are pages from the post-1983 and pre-1983 General Motors Product Description Manual, show the different designs of the fuel tank support.

The new outboard portion of the support with or without the shield in place can be forced forward or rearward relative to the fuel tank and tear large holes in the fuel tank. The photographs in Appendix A12, Figure A12.3 show the shape of the outboard end of the fuel tank support on a post-1983 fuel tank with the shield removed. Figure A12.4 shows the relative position of the fuel tank support to the fuel tank in a view from the front of the fuel tank and support. The fuel tank supports, by virtue of their spacing away from the fuel tank, can become caught or entrapped on intruding structures which move the brackets forward and rearward.

Failures caused by these supports to the fuel tank are likely to occur in side-swipe type crashes and side crashes with shallow engagement angles. The outboard end of the supports have sharp corners and edges which may puncture the fuel tank. Punctures from the outboard edge of the fuel tank support often produce larger tears of the outboard, lower fuel tank sides. Examples of failures from the outboard portion of the post-1983 fuel tank support are shown in real crashes illustrated in Appendices C15 and C16[20].

G. POST-1983 SHIELD MOUNTING BRACKETS

In 1984, several steel brackets were installed inboard of the fuel tank on the bottom flange of the frame rail to mount the plastic shield. The exact method of mounting the shield to the bottom of the frame rail was dependent upon whether or not a 20- or 16-gallon fuel tank was used. Figure A13.1 and A13.2 of Appendix A13 contains a copy from the General Motors Product Description Manual for the 1985 C/K truck for a 20-gallon and 16-gallon fuel tank respectively. The copied pages show the mounting of the shield to the tank supports and brackets on the bottom of the frame rail. The photograph of Figure A13.3 in Appendix A13 shows the right frame rail of a General Motors K-truck configured for mounting the shield for a 20-gallon fuel

[20] In this example, a 1985 K-truck sustained a side impact to its right side. The puncture from the outboard fuel tank support occurred to the left side tank and is possibly attributed to post-crash handling of the vehicle.

tank. There are three black-colored brackets that are mounted to or near the bottom flange of the frame rail. (The fuel tank in this photograph is removed.) Trucks with 16-gallon fuel tanks have only the forward bracket installed with the shield design so that it mounts directly to the bottom frame rail flange at its rearward end. Figures A13.4 and A13.5 of Appendix A13 show the rearward and forward shield mount brackets for a 20-gallon fuel tank. The photograph of Figure A13.6 of Appendix A13 shows the protruding bolt associated with the forward bracket of the shield mount. This bolt protrudes through the shield and points toward the fuel tank. Figure A13.7 shows the same bolt with the fuel tank absent.

Given that in crashes the fuel tank rotates downward and is deformed significantly by intruding structures, these shield mounting brackets present opportunities for tearing the fuel tanks on their sharp corners, edges, and bolt protrusions. One would expect these failures to occur in crashes where there is relative movement of the fuel tank into the brackets and into the brackets' sharp corners, edges, and protruding bolts.

H. INNER EDGE OF AFT TRUCK CAB/FORWARD EDGE TRUCK BED

The fuel tank is mounted between the outboard structures of the truck body bed and frame rail. At the back edge of the truck cab and at the forward edge of the truck body outboard of the fuel tank, there are sharp sheet metal edges which were the source of fuel tank failures in early trucks. The photograph in Appendix A14, Figure A14.1 shows the structures at the back of the cab and the front of the truck bed outboard of a fuel tank on a 1973 3/4 ton pickup truck. This photograph is taken from General Motors crash test C-2806.[21] Test C-2806 was a 30 mph

[21] C-2806 is a 30.7 mph rigid right side moving barrier test of a 1973 truck. The documentation of General Motors crash test C-2806 indicates that the truck bed was partially separated from the frame due to a previous test.

rigid side moving barrier test. The results of this test, contained in Appendix C17, show leakage due to contact by the truck bed at a rate of approximately 43 ounces per minute.

Subsequent to the earliest truck models, General Motors changed the design of the cab and body structures outside of the fuel tank to make them more friendly. These design changes, as well as a protective body flange, intended to decrease punctures due to penetration of body components outboard of the fuel tank, were incorporated into a 1978 Chevrolet pickup truck tested by General Motors. This 20 mph rigid side moving barrier test, C-4421,[22] resulted in a hole in the tank caused by the rear edge of the truck cab. This test and the deformation and failure are documented in Appendix C18.

Ultimately, General Motors conducted successful 20 mph rigid side moving barrier tests with an improved lower, rear cab structure outboard of the fuel tank, General Motors crash test C-4475.[23] It is clear that impingement of the fuel tank due to the structures at the back of the cab and outboard of the fuel tank continues, as shown in General Motors crash test C-4475 contained in Appendix C19 in which no fuel leakage occurred, but impingement from the structures outboard of the tank continues to occur.

It is interesting to note the effects of different structures outboard of the fuel tank. Appendix C20 shows the results of

---

[22]C-4421 is a 20 mph rigid right side moving barrier test of a 1978 C-truck "with a proposed 1979 filler pipe mounting, fuel cap design, and protective body flange with rounded lower edge."

[23]C-4475 is a 20 mph rigid right side moving barrier test of a 1978 C-truck, "Prototype fuel filler pipe mounting and cap design with dual side fuel tanks. Vehicle incorporates protective body flange with rounded lower edge plus radiused lower inboard back corner."

General Motors crash test C-4246[24] in which a "typical" service cab was installed on the back of a 1977 K-20 pickup. In test C-4246, a 20 mph rigid side moving barrier impact caused a failure, due to impingement of the lower weld flange of the service body into the fuel tank. In a subsequent test, a change in the service body weld resulted in no fuel leakage. Appendix C21 shows the results of General Motors crash test C-5988[25] in which a 20 mph rigid side moving barrier struck a 1983 C-truck with a proposed 1985 running board. While no fuel leakage resulted, significant deformation of the fuel tank due to the effect of the running board is observed.

One would expect puncture and cutting-type failures of the fuel tank inboard of the aft edge of the truck cab or the front edge of the truck bed from this failure mechanism. Earlier model General Motors trucks would be more susceptible to this failure mechanism than later models; however, given the relative stiffness of the body structures relative to the fuel tank, a general susceptibility of puncture from these structures exists. Figures A14.2 and A14.3 in Appendix A14 show the configuration of the structures on a 1985 General Motors K-truck with a fuel tank removed. The shield which was incorporated in 1984 and later General Motors C/K trucks largely addressed the lower speed puncture failures which occur from these body structures.[26]

---

[24] C-4246 is a 20 mph rigid right side moving barrier test of a 1977 K-truck. "Vehicle equipped with a typical service body supplied by Truck Body and Equipment Associates."

[25] C-5988 is a 20 mph (33.7 km/h) rigid side moving barrier crash test of a 1983 C-truck. Production "vehicle equipped with proposed 1985 running boards supplied by parts division."

[26] In cases of crash-induced truck structure movement and fuel tank downward rotation (see Failure Mode 2), the shield does not cover the exposed, outboard and upper fuel tank surface.

IV. FAILURE MODE 3: FILLER NECK/CAP FAILURES

A. FILLER NECK

There are numerous differences in filler neck design from truck to truck and from model year to model year; however, the fundamental filler neck design is made up of rubber-like hoses clamped to steel tubes. The fundamental filler neck design has a short steel pipe soldered to the fuel tank. This short steel pipe is connected with hose clamps to an intermediate hose. The intermediate hose is then connected by hose clamps to an upper steel filler pipe. In some cases, a second intermediate hose is employed in the filler neck to the upper steel pipe. Examples of various filler neck designs are shown in Appendix A15 which includes all pages of the 1984 General Motors Product Description Manual describing C/K truck filler neck configuration.

Prior to 1984, the upper steel portion of the filler neck was rigidly attached to the side panel of the truck bed; there was no break-away feature for this filler pipe. The fuel cap and upper filler neck were recessed behind a small access door in 1980. After 1983, a break-away housing was employed for attaching the upper steel pipe to the truck side panel. The photographs in Appendix A16 show the configuration of a filler neck on a 1985 K-truck fuel tank removed from the truck.

The hose in the filler neck design can accommodate large displacements; however, the strain limit of the hose to steel pipe joint occurs at relatively low forces. Tank rotation (Failure Mode 1) is a particularly lethal cause of filler neck compromise in crashes. The filler neck is also susceptible to direct intrusion or impact damage and excessive crash-induced movement of the fuel tank relative to the filler neck. These failures are associated with the relatively low toughness of the fuel filler neck design. Examples of filler neck failure in real-world crashes are shown in Appendices C22 and C23.

B. FUEL CAP

As with the filler neck, the C/K truck fuel cap, both its design and crash protection system, has undergone changes over the production life of the truck. The performance of a fuel cap is largely dependent upon its position/mounting in a vehicle and the fuel cap's ability to sustain impact. Initially, the C/K truck fuel cap was mounted such that it protruded from the truck bed; the fuel cap design itself did not reflect consideration for crash performance.

Improvement in the fuel cap crash performance design largely occurs in small, incremental steps, including at least the following: universal use of a recessed fuel cap;[27] improvements to the fuel cap crashworthiness;[28] further recess of the fuel cap behind an access door; use of a crashworthy, screw-on fuel cap; and finally, the utilization of a break-away mount of the upper fill pipe in conjunction with the crashworthy, screw-on fuel cap. The post-1983 fuel cap crash performance was adequate.

There are numerous examples of fuel cap leakage in General Motors crash tests performed on the C/K trucks. Experimental crash test fuel cap failures result in relatively small leakage; this may be attributed to the test method. In the real-world crash environment, impacting structures provide a wide variety of potential fuel cap failures.

---

[27] Initially, some truck bed configurations mounted the fuel cap flush. Subsequently, a recessed fuel cap, in which a circular recess of approximately 1/2 inch inboard of the bed sheet metal, was used.

[28] Initial attempts at fuel cap impact resistance provided a frangible fuel cap handle.

Fuel cap failures usually occur in crashes in which direct contact from an impacting object occurs, or crashes in which deformation of the truck structures around the fuel cap deform to such an extent that the fuel cap is upset.

An example of crash-induced fuel cap failure is contained in Appendix C24. This example illustrates a fuel cap which was stripped off the truck due to direct contact with the striking vehicle. In this example, even if the fuel cap had somehow managed to stay attached, significant fuel leakage would result, due to the inability of the fuel cap to accommodate the deformations of the cap/filler pipe sealing surface.

V. FAILURE MODE 4: POST-1983 FUEL TANK SHIELD DEFICIENCIES

A. SHIELD FAILS TO PROTECT FUEL TANK

The plastic shield which covers most of the bottom half of the fuel tank in post-1983 Chevrolet trucks fails to provide protection from puncture-producing mechanisms which are located on the truck and identified under the section Failure Mode 2. This shield probably has some effectiveness in protecting the tank from puncture-producing objects on impacting structures; however, because crash-induced fuel tank and truck movements occur, the shield will predictably provide inadequate coverage of the fuel tank upper surfaces. Even the structures outboard of the fuel tank at the back edge of the truck cab and front edge of the truck bed can be folded up as the tank rotates down, such that it comes in direct contact with the fuel tank outboard side and fuel tank sender unit. Previous examples of failures due to punctures in post-1983 fuel containment systems are shown in Appendices C3, C5, C7, C15, and C16.

B. SHIELD MOUNTING DEFICIENCIES

The shield is mounted at locations around the fuel tank by seven bolts and nuts at holes in the plastic shield (refer to Appendix A13). The shield mounting is insufficient to maintain the shield in its proper position, both during normal use and during crashes. The shield of the post-1983 General Motors C/K truck can break loose and fall completely or partially off because of its inadequate mounting. A shield which is partially disrupted from its mounting may be pulled all of the way off by an owner of a truck who does not like the way the shield looks when it hangs down in its partially mounted position. The photograph in Appendix A17 shows a shield on a 1984 truck which has begun to fall down from the front mounting. During crashes, the shield can be disrupted from its proper mounting location because of its relatively weak attachment to the truck. There is no assurance that the shield will maintain its proper position and provide the protection for which it was intended.

C. THE SHIELD ENTRAPS MOISTURE AND DEBRIS AND PROMOTES CORROSION

The shield will allow mud, dirt, debris, and moisture to be entrapped between the shield and fuel tank. Moisture at the fuel tank has promoted an accelerated rate of corrosion on General Motors truck fuel tanks which reduces fuel tank strength and increases the likelihood of fuel tank failure in crashes. This phenomenon is well documented by General Motors and others and will not be discussed here in detail.