SUMMARY REPORT:

CENTRE MOUNTED TANK SYSTEM FOR GM 1500 PICKUP TRUCKS

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PREFACE

This report summarizes the development and testing of a centre mounted tank system installed in GM 1500 series pickup trucks (model years 1973 to 1987). The work described herein was performed at the request of Dr. Ken Digges of the Automotive Safety Research Institute.

The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of Dr. Ken Digges.

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1. INTRODUCTION

A fuel system retrofit program is being considered for the 1973 to 1987 General Motors C/K pickup truck to improve system integrity. The truck model years in question have the fuel tank mounted between the vehicle frame rails and exterior body. It has been shown that when this vehicle is struck in the side by another vehicle, the fuel tank is susceptible to damage [Ref. 1]. The damage, in one form or another, may lead to fuel leakage and the increased potential for post-crash fires.

A retrofit program is under evaluation to determine if an alternative fuel tank and/or location could provide increased crashworthiness of the fuel tank system. Six alternative fuel tanks systems have been identified as potential solutions for alleviating the fuel tank integrity related to side impacts of GM C/K pickup trucks (model years 1973 to 1987). They are:

1. Standard side mounted tank with tank protection.
2. Custom fabricated centre tank.
3. Side mounted fuel cell.
4. A rear mounted tank in the spare tire wheel well.
5. Plastic side mounted tank with check valve.
6. A bed mounted tank.

The considerations behind the selection of the alternative systems are described in Biokinetics report R99-13 [Ref. 2].

This summary report deals solely with the development and testing of the second option in which the standard tank is replaced with a custom fabricated steel tank located between the frame rails.

The standard fuel tank, on the model years in question, is mounted on the outside of a vehicle frame rail. In the event of a side impact collision, the tank in this location is highly exposed to damage from an impinging vehicle. The intent of the centre mounted system was to relocate the fuel tank into a position that offers better protection during a side impact collision. When installed between the frame rails, the tank is better shielded by both the structure of the cab and the box and by the frame rail.

The performance of the tank protection system was evaluated under full-scale side impact loading conditions. Five trucks were impacted by a bullet vehicle travelling between 40 mph and 50 mph.

2. TEST PREPARATION

2.1 VEHICLE MODIFICATIONS

The standard fuel tank system on five pickup trucks was replaced with a custom fabricated steel tank that was installed in between the vehicle frame rails. Prior to the modifications each vehicle's condition and configuration was inspected and is summarized in Appendix A.

On two of the trucks a second tank system, in addition to the centre mounted tank, was installed in the bed of the truck. The presence of the bed mounted tanks is recorded here but their performance is discussed in a separate report [Ref. 3]. A summary of the fuel tanks installed in the trucks is presented in Table 1.

Table 1: Summary of installed fuel tanks.

Truck No.	Test No.	Model Year	Tank 1	Tank 2
2	RP 01-009	1987	Custom fabricated, steel, centre mounted.	None
6	RP 01-036	1987	Custom fabricated, steel, centre mounted with check valve and plastic shield.	Standard steel tank with check valve.
7	RP 01-037	1987	Custom fabricated, steel, centre mounted tank with check valve.	Standard steel tank with check valve.
8	RP 01-038	1986	Custom fabricated, steel, centre mounted tank with check valve.	None
9	RP 01-039	1986	Custom fabricated, steel, centre mounted tank with check valve.	None

The design of the centre tank and mounting brackets changed based on information gained during the testing. The evolution of the centre mounted tank system is described in the following sections.

2.1.1 CENTRE TANK DESCRIPTION , TRUCK 2 (TEST RP 01-009)

This was the first test with a centre mounted tank system. As discussed previously, the intention of this system is to move the fuel tank away from the area of impact. In this truck, the tank was installed between the driver's side frame rail and the drive shaft, thereby minimizing the length of the fuel filler tubes needed to connect to the filler neck on the driver's side of the truck. However, in this position the exhaust system, which normally occupied this space, needed to be re-routed to the right side of the vehicle, as shown in Figure 1.

Figure 1: Location of the centre tank and the re-routed exhaust system in truck 2 (test RP 01-009).

The tank was held in place in three locations (see Figure 1). The front of the tank was supported by a cantilever support arm that fastened to a frame rail cross member. The middle of the tank was strapped down to a substantial "L" shaped bracket that supported the tank from underneath. A strap that attached to the frame rail and a cross rail supported the rear of the tank. Close-up views of the three tank support brackets are shown in Figure 2 to Figure 4.

Figure 2: Front support bracket for the centre mounted tank.

Figure 3: Middle support bracket for the centre mounted tank.

Figure 4: Rear support bracket for the centre mounted tank system.

The filler tube ran from the top of the tank over the frame rail and then connected to the filler neck. The routing of the filler tube is shown in Figure 5.

Figure 5: Routing of the fuel filler hose.

The tank was custom fabricated at a welding shop specializing in fuel tanks. A typical tank is shown in Figure 6 and its specifications are summarized in Table 2. Drawings of the tank and mounting brackets are contained in Appendix B.

Figure 6: Typical centre mounted tank.

Table 2: Specifications of centre tank installed in truck 2 (test RP 01-009).

Material	Sheet steel
Thickness	0.060”
Weight of Tank (lbs)	37.5
Weight of Brackets (lbs)	14.25
Capacity (US gal)	17
Cost of Tank	$375.00 US
Cost of Brackets	$50.00 US

2.1.2 CENTRE TANK DESCRIPTION , TRUCK 6 (TEST RP 01-036)

To avoid the additional effort and cost associated with installing the centre mounted tank on the driver’s side of the vehicle, the centre tank was relocated between the passenger’s side frame rail and the drive shaft. The design of the tank was essentially a mirror image of the tank presented in Figure 6. However the tank’s volume was increased from the previous 17 gallons capacity to 19 gallons. Additionally, a plastic shield was placed over the two sides and the bottom of the tank, as seen in Figure 7.

Figure 7: Rear view of centre mounted tank with the plastic shield covering bottom and both sides of the tank.

The installation of the tank on the passenger side of the truck necessitated a longer filler tube to connect the tank to the filler neck on the driver’s side of the truck box. The filler tube runs from the top of the tank over the drive shaft, the exhaust system and the left frame rail to the filler neck. The routing of the filler tube is shown in Figure 8.

Figure 8: Routing of the tube (test RP 01-036).

Similarly to the first test (RP 01-009) the tank was held in place with three mounting brackets identical to those previously used.

A check valve was installed to prevent fuel spillage in the event that the filler line was torn from the tank. The check valve was bolted to the top of the tank (see Figure 9).

Figure 9: Check valve bolted to the tank.

The check valve was purchased from:

G.T. Products Inc.
315 S. First Street
P.O. Box 1404, Ann Arbor
MI 48106 Tel: (734) 761-7666

The specifications for the tank system are summarized in Table 3. Drawings of the tank and mounting brackets are contained in Appendix B.

Table 3: Specifications of centre tank installed in truck 6 (test RP 01-036).

Material	Sheet steel
Thickness	0.060”
Plastic Shield	1/8” impact ABS plastic
Weight of Tank (lbs)	45.0
Weight of Brackets (lbs)	14.3
Capacity (US gal)	19
Cost of Tank	$375.00 US
Cost of Brackets	$50.00 US

2.1.3 Centre Tank Description, Truck 7 (test RP 01-037)

The centre tank and the mounting brackets in this test were identical to the tank installed in truck 6 (RP 01-036). However, the plastic shield was not used.

2.1.4 Centre Tank Description, Truck 8 (test RP 01-038)

The centre tank and mounting brackets installed in truck 8 was identical to the tank in truck 6 and 7. A plastic shield was not used.

2.1.5 Centre Tank Description, Truck 9 (test RP 01-039)

The centre tank and mounting brackets installed in truck 9 were modified slightly from those installed in trucks 6, 7 and 8. The modification to the tank consisted of adding a 1 inch radius to the lower edges of the tank. The purpose of the radius is to reduce localized stress resulting from folding a right angle edge, such as those on previous tanks, in on itself. The material for the middle bracket was changed from steel channel with right angle edges to steel tubing that has rounded and thus less aggressive edges. A drawing for the new bracket is contained in Appendix B. The new modified tank and bracket is compared to the old components in Figure 10.

Figure 10: Rounded lower edge and tubular centre bracket on new centre tank used in test RP 01-039. Right photo is tank used in previous tests.

A shield was placed over the fuel lines that run along the inside of the frame rail to protect them from the transmission housing that comes into close proximity with the rail as a result of the vehicle deformations that occur during the impact. The shield was fabricated from 1/8” mild steel with a high-density crushable polypropylene insert. The fuel line shield is shown in Figure 11.

Figure 11: Shield placed over the fuel lines (test RP 01-039).

2.2 TEST SET-UP

The full-scale side-impact testing of the pickup trucks were conducted at PMG's facility in Blainville, Quebec. The test set-up and preparation matched, wherever possible, a test conducted at TRC and documented in TRC's Test Report 930324 [Ref. 4].

2.2.1 TRUCK PREPARATIONS

GM 1500 series pickup trucks, model years 1986 or 1987, were used for testing. The truck ride height and weight were adjusted to correspond with that reported in TRC's Test Report 930324 [Ref. 4]. Some of the pickup trucks were painted light blue to improve contrast for the high-speed cinematography. Additionally, photographic targets were placed along the sides and centreline, including the top view of the pickup bed (see Figure 12).

Figure 12: Typical labelling of pickup trucks.

The fuel tanks and mounting brackets were painted contrasting colours of red and yellow respectively.

2.2.2 Bullet Vehicle Preparation

The bullet vehicles consisted of Chevrolet Caprice automobiles (model years 1990 to 1994). Similarly to the trucks, photographic targets were placed along the sides and centreline of the bullet vehicles.

The ride height of the bullet vehicles was adjusted to compensate for braking. VRTC had determined that under heavy braking the front of the vehicle lowered by 2.9 inches as measured from the front bumper centreline and the rear of the vehicle raised up by 2.5 inches at as measured from the centreline of the rear bumper. To achieve the braking attitude, the vehicle's ride height was first adjusted to correspond to the pre-test attitude reported in TRC's Report 930324 and then the front and rear axle were loaded and unloaded respectively, until the desired front and rear bumper heights were achieved.

2.2.3 Cinematography

A total of 7 high-speed film cameras were set up to record the impact. This included two overhead shots (one wide, one tight), two underside shots from a pit (one wide, one tight), one left shot, one right shot and one onboard shot to record occupant movement. For some tests a second onboard high-speed camera was used. Furthermore an additional panning, real-time video camera was used to follow the bullet vehicle to the impact. The positioning of the cameras are depicted in Figure 13.

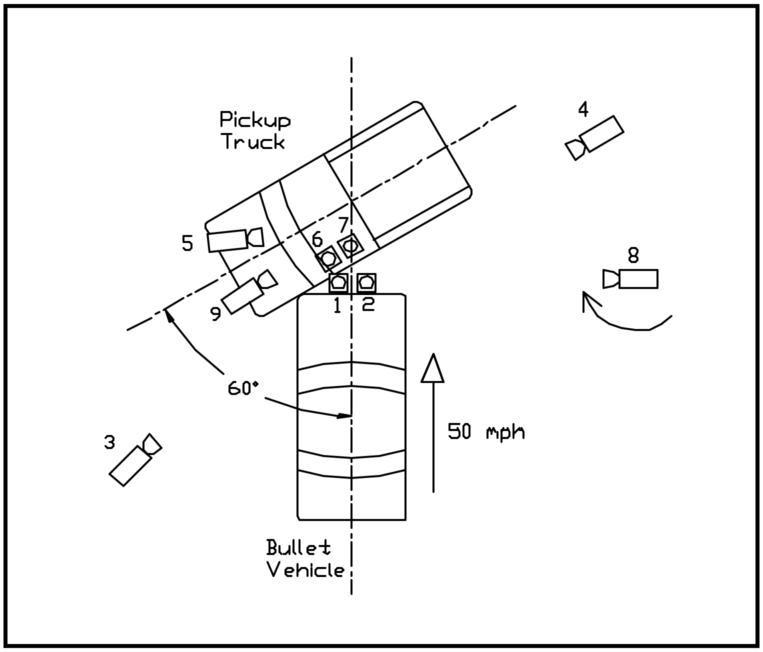


Figure 13: Test vehicle orientation and camera positions for RP 01-009 (other tests are the mirror of that shown).

2.2.4 Crash Test Dummies

A driver and/or a passenger side dummy were placed seated in the pickup trucks. The trucks' occupants were a DOT SID and/or a 50^{th} percentile Hybrid III crash test dummy. The type and position of the dummies varied from test to test and are reported in the individual section describing the tests. An additional 50^{th} percentile Hybrid III dummy was positioned in the driver's seat of the bullet vehicle. The placement of the dummies was accomplished as per the dummy positioning procedure of FMVSS 214 "Positioning Procedure for Side Impact Dummy". Instrumentation was installed in the dummies for some of tests. Typical placement of the truck's occupants is shown in Figure 14.

Figure 14: Occupant placement in the pickup truck.

2.2.5 Vehicle Measurements

Pre-crash measurements and photographs were taken of both the bullet and struck vehicles. Similarly, the deformation of the both vehicles was measured following the crash. Additional post-crash photographs were taken to document the resting position of the vehicles and test dummies and the condition of the fuel tanks.

2.2.6 Fuel

FMVSS 301 requires that the fuel tanks be filled to within 90% to 95% of capacity with Stoddard solvent. In order to test to the worst case of potential build-up of hydrodynamic pressure the fuel tanks in the trucks were filled to 95% of their capacity.

The fuel tank of each truck was inspected following the crash to determine whether leaking had occurred. If the amount of leakage was within the limits specified by FMVSS 301, a rollover test was performed to further evaluate leakage.

2.2.7 Test Configuration

The test configuration consisted of a side-impact to the driver's side of the pickup truck. The bullet vehicle travelled at 50 mph, +/- 2 mph while the truck was stationary prior to impact. The truck was impacted at 60° from the front of the truck and inline with centreline point between the cab and the truck box as depicted in Figure 13. The intended accuracy of the impact point was +/- 2.0 inches.

The test configuration was altered for one of the tests. The bullet vehicle was replaced with a FMVSS 301 rigid moving barrier travelling at 40 mph with a trajectory that was perpendicular to the longitudinal axis of the truck and centred on the space between the truck box and the cab.

3. TESTING AND RESULTS

The following sections include a description and summary of testing of the centre mounted tank systems. The initial configuration of the pickup trucks prior to the test is described and observations taken following the collision are presented.

Each test includes a brief summary of the test parameters but more details can be found in PMG Technologies test reports (Ref. 5 to Ref. 9).

3.1 TEST RP 01-009

3.1.1 VEHICLE CONFIGURATION

Vehicle	1987 Chevrolet Custom Deluxe 1500
Fuel Tank System #1	Custom fabricated, steel tank (16 gauge), centre-mounted, between frame rail and drive shaft on the driver's side of the vehicle.
	Check valve: None
	Capacity: 17 gallons
Fuel Tank System #2	None
Driver Dummy	DOT SID with no instrumentation.
Passenger Dummy	50th percentile Hybrid III with no instrumentation.

3.1.2 TEST PARAMETERS

Impact Velocity (actual)	x-Impact Point Obtained	z-Impact Point Obtained
51.0 mph	0.5" towards the front	0.5" towards the top

3.1.3 TEST DESCRIPTION

Pre and post test photographs of the truck and the Caprice bullet vehicle are shown in Figure 15 to Figure 17.

Figure 15: The final resting position of the truck and bullet vehicle in test RP 01-009.

Figure 16: Pre and post test views of the GM pickup truck (test RP 01-009).

Figure 17: Pre and post test views of the Caprice bullet vehicle (test RP 01-009).

Overall, the tank system was well protected by the structure of the truck cab and by the frame rail. However, the empty space created by removing the tank allowed the bullet vehicle to penetrate deep into the side of the truck, resulting in significant damage to the body of the truck, as shown in Figure 18.

Figure 18: Damage to the truck (test RP 01-009).

The truck was lifted of the ground during the impact and was flipped onto its side, damaging the anti-rollover bar that was affixed to the passenger side of the vehicle. The final resting position of the truck is shown in Figure 19. If the anti-rollover bar, which resists the moment created by the bullet vehicle travelling under the truck, did not fail then the loading on the tank may have been higher possibly resulting in more damage to the tank.

Figure 19: Final resting position of the truck (test RP 01-009).

Following the impact there was a minimal amount of fluid spillage, which was well within the requirements of FMVSS 301. However, to further confirm the integrity of the tank, the truck was inverted as per FMVSS 301 (see Figure 20).

Figure 20: Inversion of the truck following the impact (test RP 01-009).

The inversion test confirmed that fuel tank system installed in this truck met all of the fuel leakage requirements specified in FMVSS 301.

3.1.4 Post Crash Observations

The filler cap, the filler hose and vent line survived the impact without sustaining any noticeable damage.

The tank support brackets had minor bending but were still securely fastened to the truck (see Figure 21 and Figure 22).

Figure 21: Tank mounting brackets following the test (test RP 01-009).

Despite some large denting on the exposed face the fuel tank, as shown in Figure 22, only minor damage to the tank was observed.

Figure 22: Denting to the fuel tank and damage to the tank mounting brackets (test RP 01-009).

Fuel leakage stemmed from a poor seal between the sending unit and the sending unit receptacle that was welded to the tank (see Figure 23). The sending unit and its receptacle are standard GM parts that were fitted to the centre tank. As already mentioned the leak was not enough to result in failure of the system.

Figure 23: Sending unit seal where leakage occurred (test RP 01-009).

3.2 TEST RP 01-036

3.2.1 VEHICLE CONFIGURATION

Vehicle	1987 Chevrolet Custom Deluxe 1500
Fuel Tank System #1	Custom fabricated, steel tank (16 gauge), centre-mounted, between frame rail and drive shaft on the passenger's side of the vehicle. A plastic shield was placed over the sides and bottom of the tank.
	Check valve from G.T. Products Inc.
	Capacity: 19.0 gallons
Fuel Tank System #2	Bed mounted steel tank.
Driver Dummy	50th percentile Hybrid III with instrumentation
Passenger Dummy	None

3.2.2 TEST PARAMETERS

Impact Velocity (actual)	x-Impact Point Obtained	z-Impact Point Obtained
50.9 mph	1.8" towards the front	1.4" towards the top

3.2.3 TEST DESCRIPTION

Pre and post test photographs of the truck and the Caprice bullet vehicle are shown in Figure 24 to Figure 26.

Figure 24: Final resting position of the truck and bullet vehicle in test RP 01-036.

Figure 25: Pre and post test views of the GM pickup truck (test RP 01-036).

Figure 26: Pre and post test views of the Caprice bullet vehicle (test RP 01-036).

The centre tank in this truck was installed between the passenger side frame rail and the drive shaft. Additional protection to the tank was provided by means of a plastic shield covering the sides and bottom of the tank. Since the tank was installed on the passenger side of the vehicle the impact was to the same side as the tank.

3.2.4 POST CRASH OBSERVATIONS

The tank with the plastic shield and the mounting brackets survived the collision with very little damage as can be seen in Figure 27 and Figure 28.

Figure 27: Centre tank and plastic shield following after the collision (test RP 01-036).

Figure 28: Plastic shield and centre mounting bracket. (Note: the rear bracket is concealed under the plastic shield.)

Although the tank survived the collision all of the contents of the tank were completely expelled. As indicated in the vehicle configuration details (Section 3.2.1), a second tank was installed in the bed of the truck requiring a fuel line switching valve so that the motor could function with either of the two tank systems. This valve was crushed between the frame rail and the transmission housing during the test, effectively severing the fuel lines from both tanks leading to the engine. All of the fluids from both tanks were siphoned under the influence of gravity. The location of the switching valve is shown in Figure 29 and the severed fuel lines are shown in Figure 30.

If a truck is to be fitted with two tanks, thereby necessitating a switching valve, the valve must be better located or additional protection must be incorporated into the fuel system design to prevent similar damage to switching valve from occurring.

Figure 29: The location of the switching valve identified by the arrow. (test RP 01-0036)

Figure 30: Fuel lines that were torn from the tank switching valve (test RP 01-036).

Although technically this test would have failed the requirements of FMVSS 301 it is worthy to note that had only the centre tank been installed and thus a switching would not have been required, the tank would have passed the test. With this in mind the fuel lines were plugged and the tank was refilled with fluid such that a rollover test could be performed to confirm the integrity of the tank itself (see Figure 31).

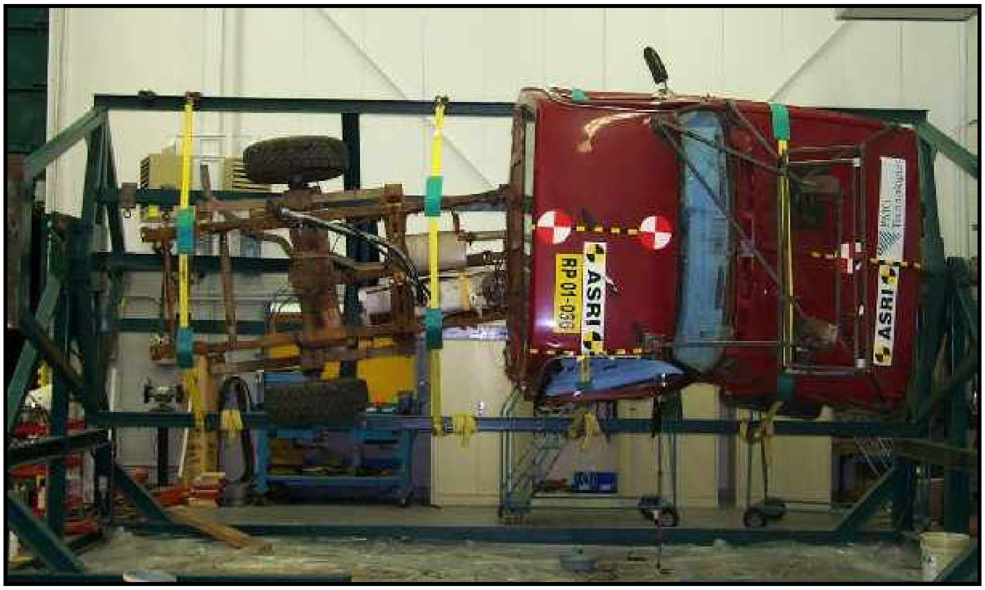


Figure 31: Rollover test to confirm centre tank integrity (test RP 01-036).

There was no leaking observed during the rollover test confirming that the integrity of the centre mounted tank remained intact.

3.2.5 Dummy Response Data

The response data of the 50th percentile Hybrid III dummy seated in the driver's seat of the pickup truck is summarized in Table 4. The graphical data is contained in PMG's Test Report RP 01-036 (Ref. 6).

Table 4: Response data for the 50th percentile Hybrid III truck driver and truck accelerations (test RP 01-036).

	Direction	**Min**	**Max**
Linear head accelerations (g)	X	-8.5	1.9
	Y	-19.3	5.7
	Z	-1.8	32.7
	Rslt	0.1	33.3
Upper neck loads (N)	X	-308.7	82.6
	Y	-625.4	234.5
	Z	-117.3	1544.3
	Rslt	0	1600.9
Upper neck moments (N-m)	X	-37.4	24.4
	Y	-19.7	11.4
	Z	-13.2	6.2
	Rslt	0	39.7
Linear chest accelerations (g)	X	-6.8	4
	Y	-12.7	0.4
	Z	-3.0	10.4
	Rslt	0	13.4
Linear pelvis accelerations (g)	X	-7.1	1.7
	Y	-21.4	2.9
	Z	-7.9	8.6
	Rslt	0	23.2

Based on the response data, injury parameters were calculated and compared to allowable limits. The various injury criteria are summarized in Table 5. More details with regards to the calculations can also be found in PMG's Report RP 01-036 (Ref. 6).

Table 5: Calculated injury criteria for the 50th percentile Hybrid III truck driver (test RP 01-036).

Injury Criteria	Requirement	Results
HIC unlimited	< 1000	243
HIC 15	< 1000	90
HIC 36	< 1000	186
Peak resultant head acceleration	< 80 g	33.3 g
Peak resultant chest acceleration	< 60 g	13.4 g
3 ms clip head acceleration	< 80 g	32.86 g
3 ms clip chest acceleration	< 60 g	13.3 g
Neck injury criteria Nij	< 1	0.5

As seen in Table 5 the injury criteria values calculated are all well below the allowable threshold limits, thereby suggesting that, from the perspective of the driver, this particular crash is not life threatening despite the apparent severity of the crash.

3.3 Test RP 01-037

3.3.1 Vehicle Configuration

Vehicle	1987 GMC Sierra 1500
Fuel Tank System #1	Custom fabricated, steel tank (16 gauge), centre-mounted, between frame rail and drive shaft on the passenger's side of the vehicle.
	Check valve from G.T. Products Inc.
	Capacity: 19.0 gallons
Fuel Tank System #2	Bed mounted steel tank.
Driver Dummy	50th percentile Hybrid III with instrumentation
Passenger Dummy	DoT SID with instrumentation.

3.3.2 Test Parameters

Impact Velocity (actual)	x-Impact Point Obtained	z-Impact Point Obtained
40.1 mph	0.8" towards the front	0.1" towards the top

3.3.3 Test Description

Unlike the previous two tests the bullet vehicle in this test was a FMVSS 301 rigid moving barrier travelling at 40 mph. The truck was oriented such that the longitudinal axis of the barrier was 90^{O} to the longitudinal axis of the truck and centred on the space between the cab and the box as shown in Figure 32. FMVSS 301 requires that the rigid barrier impact the target vehicle at 30 mph, however, 40 mph was chosen as the impact speed to ensure compliance of the tank system. It was felt that if the tank system passed the test at elevated impact speeds then the system or slight variations of it would pass the standard 30 mph test without incident.

Figure 32: Over head view showing alignment of the barrier with the truck (test RP 01-037).

Pre and post test photographs of the tested vehicles are shown in Figure 33 to Figure 34.

Figure 33: The final resting position of the truck and rigid barrier in test RP 01-037.

Figure 34: Pre and post test views of the pickup truck (test RP 01-037).

The alignment of the barrier was such that the crush zone on the truck was aft of the A-pillar and forward of the rear axle (referring back to Figure 33). By avoiding these two rigid elements of the truck, maximum loading of the tank systems was achieved.

Following the test no fluid leakage from the centre tank was observed with the exception of a small leak in the box tank that was within acceptable limits.. Further confirmation of the centre tank system's integrity was obtained by subjecting the truck to a rollover test, as shown in Figure 35.

Figure 35: Inversion of the truck following the impact (test RP 01-037).

The rollover test confirmed that there were no leaks in the centre mounted tank.

3.3.4 POST CRASH OBSERVATIONS

In addition to the centre mounted fuel tank, a fuel tank was also installed in the bed of the truck. As in the previous test a switching valve was required for both tank systems to be functional. This valve was installed in the same location as in the previous test however it survived the test undamaged because of the different crushing pattern created by the barrier compared to the Caprice. The barrier loading was more distributed than that of the Caprice and resulted in less penetration into the vehicle. The location of the switching valve with respect to other truck components such as the frame rail and the transfer case is shown in Figure 36 for both before and after the test.

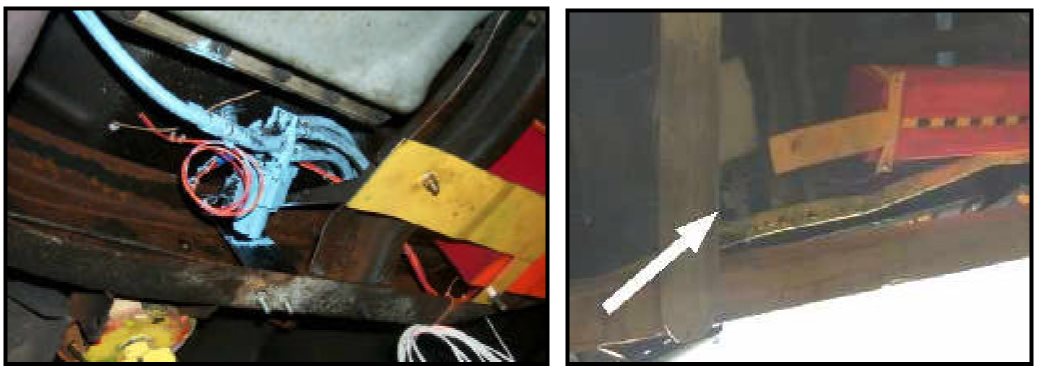


Figure 36: View of the switching valve before and after the test.

As seen in Figure 36 the spacing between the frame rail and the transfer case is relatively intact compare to the that observed in test RP 01-036 where the frame rail was almost in contact with the transfer case (refer back to Figure 29).

The centre tank and the bracket sustained minor damage. However, because of bending of the vehicle frame rail the tank was hanging down lower to the ground, as shown in Figure 37.

Figure 37: That hanging down low to the ground (test RP 01-037).

3.3.5 DUMMY RESPONSE DATA

The response data of the 50th percentile Hybrid III dummy seated in the driver's seat of the pickup truck is summarized in Table 6. Similarly the response data for the DoT SID passenger dummy is contained in Table 7. The graphical data is contained in PMG's test report RP 01-037 (Ref. 7).

Table 6: Response data for the 50th percentile Hybrid III truck driver and truck accelerations (test RP 01-037).

	Direction	Min	Max
Linear head accelerations (g)	X (see 1)	-46.2	42.6
	Y (see 1)	-470.8	84.4
	Z (see 1)	-32.8	66.1
	Rslt (see 1)	0.0	474.6
Upper neck loads (N)	X	-473.9	165.2
	Y	-132.0	3207.6
	Z	-586.4	1681.1
	Rslt	1.7	3383.2
Upper neck moments (N-m)	X	-117.8	44.2
	Y	-20.9	16.8
	Z	-3.5	32.5
	Rslt	0.0	119.2
Linear chest accelerations (g)	X	-3.7	17.2
	Y	-33.6	7.8
	Z	-3.2	17.5
	Rslt	0.0	34.4
Linear pelvis accelerations (g)	X	-4.9	11.0
	Y	-34.2	7.8
	Z	-3.6	12.8
	Rslt	0.0	35.3
Belt Loads (N)	Lap	-103.3	6407.0
	Shoulder	-94.9	2599.4

1- PMG reported that a component inside the head detached thus invalidating the head acceleration data.

Table 7: Response data for the DoT SID passenger dummy (test RP 01-037).

	Direction	**Min**	**Max**
Linear head accelerations (g)	X	-16.0	19.2
	Y	-495.5	44.8
	Z	-24.0	100.5
	Rslt	-24.0	504.0
Upper Thorax Accelerations (g)	Y	-268.5	221.2
	Opposite Y	-142.6	132.4
Lower Thorax Accelerations (g)	Y	-195.5	173.2
	Opposite Y	Na	Na
Lower Spine Acceleration (g)	Y	124.2	78.5
Pelvis Acceleration (g)	Y	-139.2	62.7
Belt Loads (N)	Lab	-9.5	1384.4
	Shoulder	-12.9	607.7

Based on the response data, injury parameters were calculated and compared to allowable limits. The various injury criteria are summarized in Table 8. More details with regards to the calculations can be found in PMG's Report RP 01-037 (Ref. 7).

Table 8: Calculated injury criteria for the driver and passenger dummies (test RP 01-037).

Injury Criteria	**Requirement**	**Results**	
		Hybrid III Driver	**DoT Passenger**
HIC unlimited	< 1000	7109 (see 1)	6509
HIC 15	< 1000	7109 (see 1)	6509
HIC 36	< 1000	7109 (see 1)	6509
Peak resultant head acceleration	< 80 g	474.6 (see 1)	504.0
Peak resultant chest acceleration	< 60 g	34.4	_
3 ms clip head acceleration	< 80 g	149.15 (see 1)	_
3 ms clip chest acceleration	< 60 g	30.45	_
Neck injury criteria Nij	< 1	0.4	_
TTI	< 85	_	129
Pelvis acceleration (lateral)	< 130 g	_	139.2

(1) PMG reported that a component inside the head detached thus invalidating the head acceleration data.

The passenger dummy, seated on the struck side of the vehicle, sustained substantial loading to the head chest and pelvis. A review of the video footage of the collision suggests that the passengers head likely contacted the solid steel face of the rigid barrier, thus explaining the high head acceleration and HIC values that were observed. Additionally, high chest and pelvis accelerations were also the result of the close proximity of the passenger to the struck side of the vehicle and the vertical extent of loading presented by the moving barrier.

It was clear from video footage of the dummies that the driver's head hits the passenger dummy's shoulder at approximately the time corresponding to the large peak measured in the driver head's lateral direction. It is this peak which is primarily responsible for the large injury values reported in Table 8. Unfortunately, PMG reported that a component inside the head detached and they suggest that the head data may be invalid.

Putting the driver's head results aside, the chest and pelvis acceleration data and the neck loads presented in Table 8 suggest that the loading severity to the driver dummy was much lower than that of the passenger dummy and below suggested tolerance levels.

3.4 TEST RP 01-038

3.4.1 VEHICLE CONFIGURATION

Vehicle	1986 Chevrolet Wrangler 1500
Fuel Tank System #1	Custom fabricated, steel tank (16 gauge), centre-mounted, between frame rail and drive shaft on the passenger's side of the vehicle.
	Check valve from G.T. Products Inc.
	Capacity: 19.0 gallons
Fuel Tank System #2	None
Driver Dummy	50^{th} percentile Hybrid III with instrumentation
Passenger Dummy	None

3.4.2 TEST PARAMETERS

Impact Velocity (actual)	x-Impact Point Obtained	z-Impact Point Obtained
50.9 mph	1.0" towards the front	0.9" towards the top

3.4.3 TEST DESCRIPTION

The bullet vehicle for this test was again a Chevrolet Caprice. Photographs of the truck and bullet vehicle are shown in Figure 38 to Figure 40.

Figure 38: The final resting position of the truck and the bullet vehicle in test RP 01-038.

Figure 39: Pre and post test views of the GM pickup truck (test RP 01-038)

Figure 40: Pre and post test views of the Caprice bullet vehicle (test RP 01-038).

The truck was carried laterally with all four of its tires lifted completely off the ground during the initial phase of the impact. When the tires came back into contact with the ground both the far side tires were torn from their rims causing the driver's side to sit lower than the struck side of the vehicle, see Figure 41. This may have resulted in a slight in increased static loading on the tank when the vehicles came to rest.

Figure 41: Far side tires were torne from their rims during the collision (test RP 01-038)

The fuel line leading to the engine was severed during the test (see Figure 42), resulting in a substantial gravity fed fluid leak. All leaking stopped when the fuel lines were cut near the sending unit with a pair of shears.

Figure 42: Severed fuel line (test RP 01-038).

3.4.4 Post Test Observations

During the collision the right side frame rail was pushed into contact with the transmission housing, severing the fuel line which ran along the inside of the frame rail. The spacing between the frame rail and the transmission housing before and after the test is shown in Figure 43.

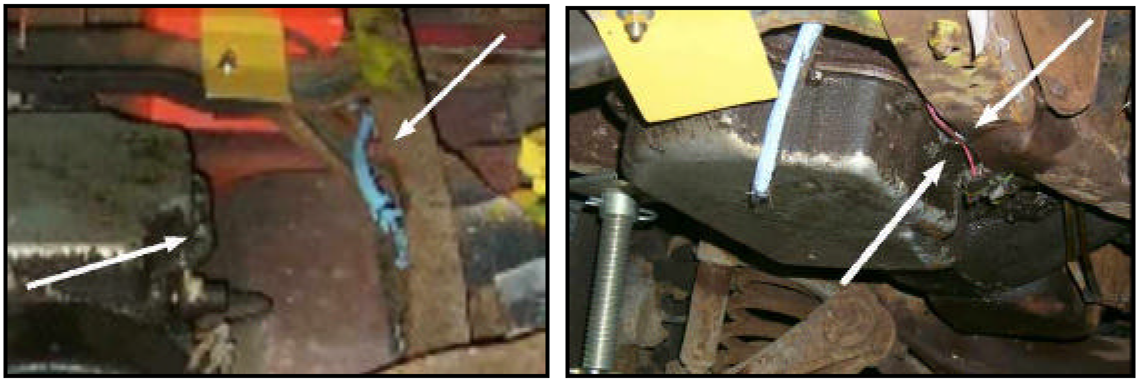


Figure 43: Spacing between the frame rail and the transmission housing that severed the fuel line (test RP 01-038).

The complete exhaust system, including the manifold, was removed from the truck to achieve a target truck weight of 4400 lb. One of the tubes from the manifold normally runs down between the frame rail and the transmission and its presence may have prevented the damage to the fuel line by acting as a somewhat rigid spacer between the rail and transmission providing clearance for the fuel line. A typical manifold on the GM truck is shown in Figure 44.

Figure 44: Typical exhaust manifold on the GM pickup trucks. (Although shown in the photo there is no switching valve in the current test).

The centre tank sustained substantial denting from various sources. The side of the tank near the front was damaged by the drive shaft. On the opposite side at the front, the threaded end of the bracket strap created a small dent. The middle of the tank was pushed in and upward by the bullet vehicle and the middle mounting bracket, and was dented on the inside by the drive shaft. An additional small dent was created on lower rear edge of the tank by the rear bracket strap. The damage to the tank is shown in Figure 45 to Figure 48.

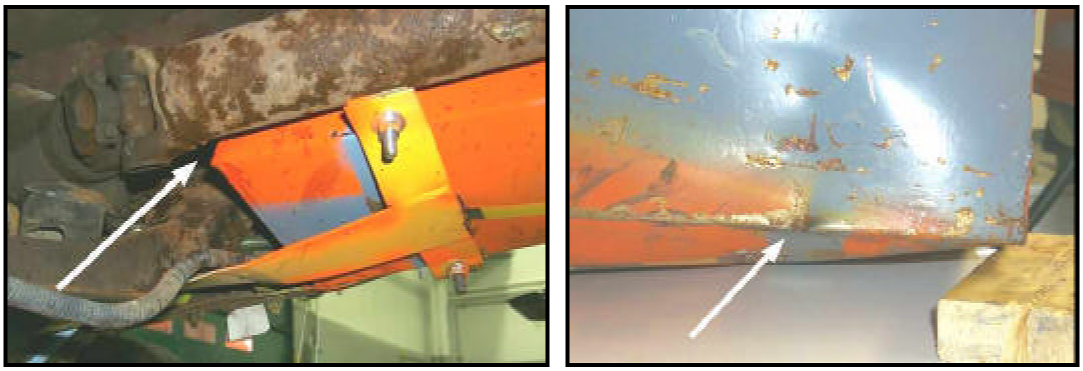


Figure 45: Damage to the front end of the tank front the drive shaft (left photo) and from the front mounting strap (right photo) (test RP 01-038).

Figure 46: Damage caused by the bullet vehicle loading the centre bracket (test RP 01-038).

Figure 47: Denting caused by the drive shaft (test RP 01-038).

Figure 48: Minor denting caused by the rear mounting strap (test RP 01-038).

Irrespective of the leakage from the fuel line, the tank itself initially appeared to be intact despite the substantial amount of deformation. To verify the tank's integrity, the tank was refilled with fluids and a rollover test was to be performed. However, during the refilling a hole was discovered in the side of the tank and the fluid flow rate from the hole exceeded the allowable limits of the of the FMVSS 301 requirement (the actual rate was not reported in the PMG report). The hole in the tank was created by the creasing of the lower edge of the tank at the centre bracket (see Figure 49).

Figure 49: Hole in the tank behind the centre bracket (test RP 01-038).

The inversion of the right angle edge of the tank resulted in high tearing stress and consequently the hole. Had the lower edge of the tank been fabricated with a radius instead of a right angle bend it is likely that the hole would not have occurred. Additionally, the edges of the steel channel used to fabricate the middle bracket were also right angles without a radius, which contributed to the localized loading on the tank. An alternative would be to use tube steel, which typically has rounded edges, to minimize localized loading on the tank. Both these design changes were incorporated into the manufacture of the centre tank for the subsequent test.

3.4.5 DUMMY RESPONSE DATA

The response data from the 50th percentile Hybrid III dummy seated in the driver's seat of the pickup truck is summarized in Table 9. The graphical data is contained in PMG's test report RP 01-038 (Ref. 8).

Table 9: Response data for the 50th percentile Hybrid III truck driver and truck accelerations (test RP 01-038).

	Direction	**Min**	**Max**
Linear head accelerations (g)	X	-8.1	1.1
	Y	-22.8	6.0
	Z	-1.5	30.6
	Rslt	0.1	34.7
Upper neck loads (N)	X	-317.4	30.4
	Y	-907.7	199.8
	Z	-78.2	1355.3
	Rslt	0.0	1507.7
Upper neck moments (N-m)	X	-55.4	15.3
	Y	-6.6	10.0
	Z	-15.6	5.2
	Rslt	0.0	57.6
Linear chest accelerations (g)	X	-6.6	0.7
	Y	-16.4	1.1
	Z	-3.1	8.2
	Rslt	0.0	16.7
Linear pelvis accelerations (g)	X	-6.4	1.0
	Y	-19.2	2.9
	Z	-6.4	5.0
	Rslt	0.0	20.6
Belt Loads (N)	Lap	-6.5	2881.8
	Shoulder	-15.3	2255.5

Based on the response data, injury parameters were calculated and compared to allowable limits. The various injury criteria are summarized in Table 10. More details with regards to the calculations can also be found in PMG's report RP 01-038 (Ref. 8).

Table 10: Calculated injury criteria for the 50th percentile Hybrid III truck driver (test RP 01-038).

Injury Criteria	Requirement	Results
HIC unlimited	< 1000	194
HIC 15	< 1000	179
HIC 36	< 1000	94
Peak resultant head acceleration	< 80 g	34.68
Peak resultant chest acceleration	< 60 g	16.65
3 ms clip head acceleration	< 80 g	33.73
3 ms clip chest acceleration	< 60 g	16.24
Neck injury criteria Nij	< 1	0.3

As seen in Table 10 the injury criteria values calculated are all well below the allowable threshold limits, thereby suggesting that, from the perspective of the driver, this particular crash is not life threatening despite the apparent severity of the crash.

3.5 Test RP 01-039

3.5.1 Vehicle Configuration

Vehicle	1986 GMC Sierra 1500
Fuel Tank System #1	Custom fabricated, steel tank (16 gauge), centre-mounted between frame rail and drive shaft on the passenger's side of the vehicle. A radius was added to the lower edges of the tank.
	Check valve from G.T. Products Inc.
	Capacity: 19.0 gallons
Fuel Tank System #2	None
Driver Dummy	50th percentile Hybrid III without instrumentation
Passenger Dummy	None

3.5.2 Test Parameters

Impact Velocity (actual)	x-Impact Point Obtained	z-Impact Point Obtained
50.9 mph	0.9" towards the front	0.9" towards the top

3.5.3 Test Description

The bullet vehicle for this test was again a Chevrolet Caprice. Photographs of the truck and bullet vehicle are shown in Figure 50 to Figure 52.

Figure 50: The final resting position of the truck and bullet vehicle in test RP 01-039.

Figure 51: Pre and post test views of the GM pickup truck (test RP 01-039).

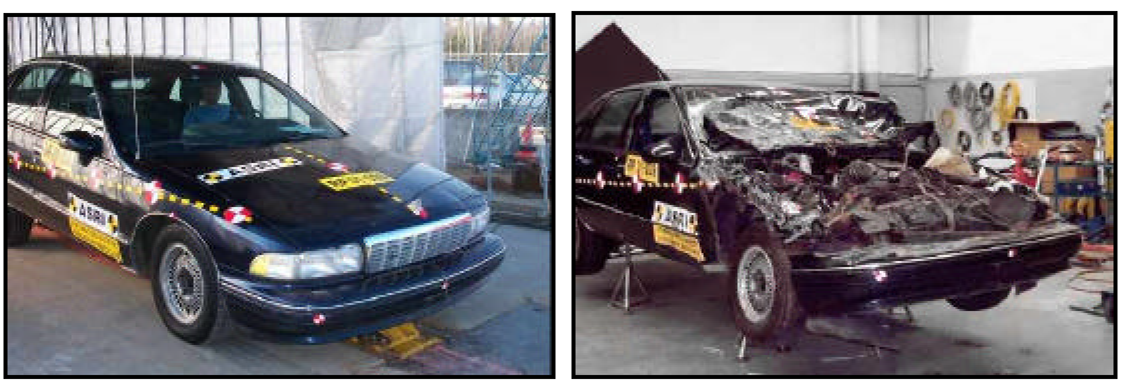


Figure 52: Pre and post test views of the Caprice bullet vehicle (test RP 01-039).

As with the previous three tests with the Caprice as the bullet vehicle, the truck was carried laterally with all four of its tires lifted completely off the ground during the initial phase of the impact. When both vehicles came to a rest the truck remained on top of the Caprice, similar to other tests. However, the right rear wheel remained noticeably higher of the ground thus more of the weight of the truck was been born by its under carriage including the centre tank (see Figure 53).

Figure 53: Post test view showing the right rear tire on the truck is noticeably off the ground (test RP 01-039).

During the collision, there was an initial spray of fluids, which could not be measured. It is believed that the fluids were forced out from the connection of the filler vent line and the filler cap assembly due to the overpressure in the fuel tank. After the event was over there was no indication of continued fluid leakage. An inversion test on the truck revealed a small amount of leaking from the carburettor but not from the tank components, thus confirming the integrity of the tank system as no additional leakage was observed (see Figure 54).

Figure 54: Inversion test of truck 9 (test RP 01-039).

3.5.4 POST CRASH OBSERVATIONS

The shield placed over the fuel lines, which ran along the inside of the frame rail, to prevent damage from the transmission housing, was deformed from contact with the transmission. Additionally, the exhaust manifold, which was not removed from the truck as it was in the previous test, impeded relative translation of the frame rail towards the transmission. The lower flange of the frame rail imprinted itself in the right manifold pipe indicating substantial loading of that component. The fuel lines, however, were not damaged. Figure 55 shows the deformed shield with the arrow highlighting the side of the transmission and the dented manifold pipe.

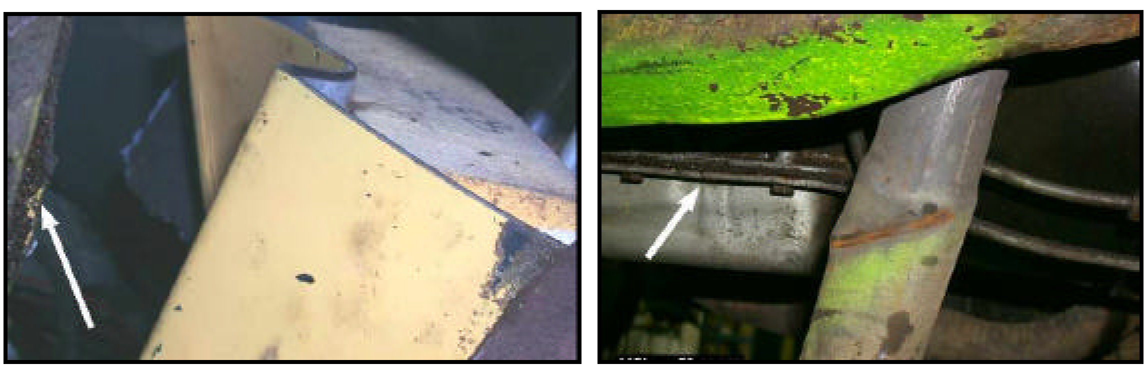


Figure 55: Damaged fuel line shield and exhaust manifold. The arrow is pointing to the edge of the transmission (test RP 01-039).

The tank sustained damage on both sides and along its length from various sources. The left front side of the tank contacted the drive shaft with minor denting while the flange of the frame rail indented the forward portion of the right side of the tank. During the collision the tank shifted inwards sufficiently to be deformed by the drive shaft bearing housing.

The middle struck side of the tank sustained the most deformation. The radius on the lower edge of the tank and the tubular middle bracket appeared to be effective at preventing twisting and folding of the tank material in this area, which in the previous test resulted in a hole in the tank.

Paint transfer marks on the drive shaft indicate that the middle tank bracket contacted the drive shaft and slid downwards. Although, not deliberate in this test, it may be preferable to design the middle tank bracket to ensure contact with the drive shaft thereby transferring the load of the displacing frame rail to the drive shaft and reducing contact between the tank and the drive shaft. The various deformations of the tank are shown in Figure 56 to Figure 58.

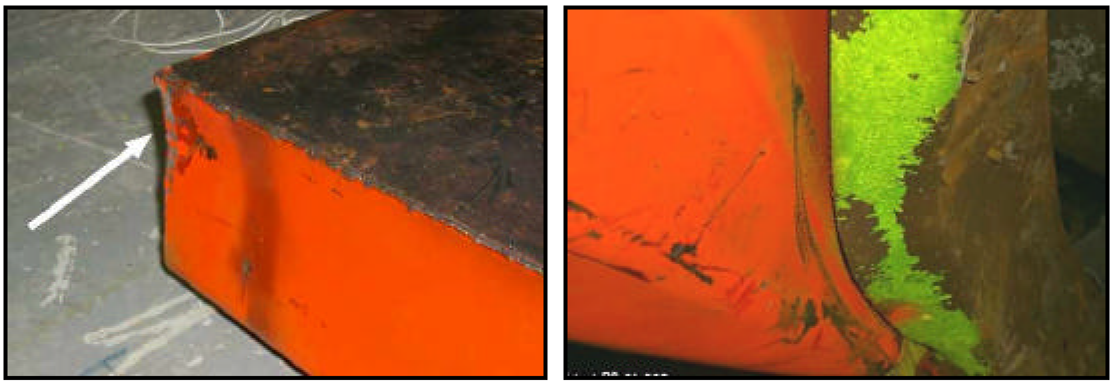


Figure 56: Damage tot the front of the tank was caused by the drive shaft on the left side and by the frame rail on the right of the tank (test RP 01-039).

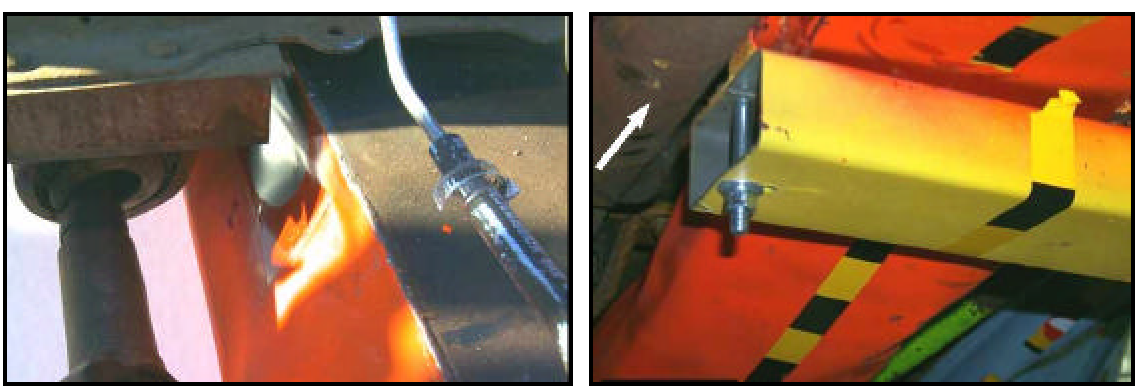


Figure 57: Deformation of the tank caused by the drive shaft bearing housing (left) and contact of middle bracket with the drive shaft (right) (test RP 01-039).

Figure 58: Deformations of the centre portion of the tank (test RP 01-039).

In addition to the large noticeable deformations of the tank, there were several scratches and minor gouges that could be associated with hard points on the bullet vehicle. Some of these hard points are shown in Figure 59.

Figure 59: Hard points on the bullet vehicle that caused minor scrapping and gouging to the tank (test RP 01-039).

4. DISCUSSION

4.1 PICKUP TRUCK ACCELERATIONS

Triaxial accelerometers were mounted at or near the centre of gravity of the pickup trucks and the three directional accelerations imparted to the pickup trucks during impact were measured in three of the tests and are summarized in Table 11.

Table 11: Summary of truck accelerations from three tests.

Direction	Measured Acceleration (g)					
	RP 01-0036		RP 01-037		RP 01-038	
	min	max	min	Max	Min	Max
X	-23.6	13.5	-10.2	19.2	-47.7	29.6
Y	-16.0	27.2	-23.3	68.5	-8.6	31.6
Z	-49.0	48.6	-21.1	32.7	-58.3	78.8
Resultant	0	49.6	0.0	69	0.2	83.6
Impact Velocity (mph)	50.9		40.1		50.9	

The speed of the collision in test RP 01-037 was 40.1 mph by a FMVSS 301 rigid moving barrier and therefore the truck accelerations from that test can not be compared to the other two tests. However, tests RP 01-036 and RP 01-038 appear to be similar. Their collision speeds were the same and their deformation patterns were similar although the truck from test RP 01-038 appears to be bent upwards slightly more than the truck in test RP 01-036 (see Figure 60 and Figure 61).

Figure 60: Crush patterns in test RP 01-036 (left) and RP 01-038 (right) – view 1.

Figure 61: Crush patterns in test RP 01-036 (left) and RP 01-038 (right) – view 2.

Despite being similar in appearance, the truck acceleration response of tests RP 01-036 and RP 01-038 do not correspond. The substantially higher accelerations of the truck in RP 01-038 were primarily due to the higher acceleration values in the fore-aft (X) and the vertical (Z) direction. The differences in the Z direction may have contribute to the slight differences in vertical deformation between the two trucks. It is unclear why the accelerations were so different considering the alignment of the vehicles and the impact speeds were the same. The acceleration traces contained in Appendix C do not offer any further insight.

4.2 General Test Reproducibility

In general the input parameters for the four side impact tests with the Chevrolet Caprices were similar. The vehicle alignment at impact was within 1.8 inches of the static pre-crash alignment and in fact it was within 1.0 inches for three of the tests. The impact speeds ranged from 50.9 mph to 51.0 mph. The tested weight of the of the trucks and bullet vehicles including the test dummies ranged from 4399.0 lbs to 4417.8 lbs for the trucks and between 3996.0 lbs and 4002.6 lbs for the bullet vehicles. Additionally the ride height for each of the trucks was within 0.5 inches of each other; the same is true for the bullet vehicles.

Considering the similarity in the test set-up and input conditions, it is not surprising that the kinematics of each test were very similar. Following contact with the truck the front end of the bullet vehicle was pushed downwards and as it travelled under the truck it lifted the truck up and carried it in the direction of impact. The resulting damage to the vehicles, from test to test, was, for all intents and purpose, similar. A comparison of the damage to the vehicles is shown in Figure 62.

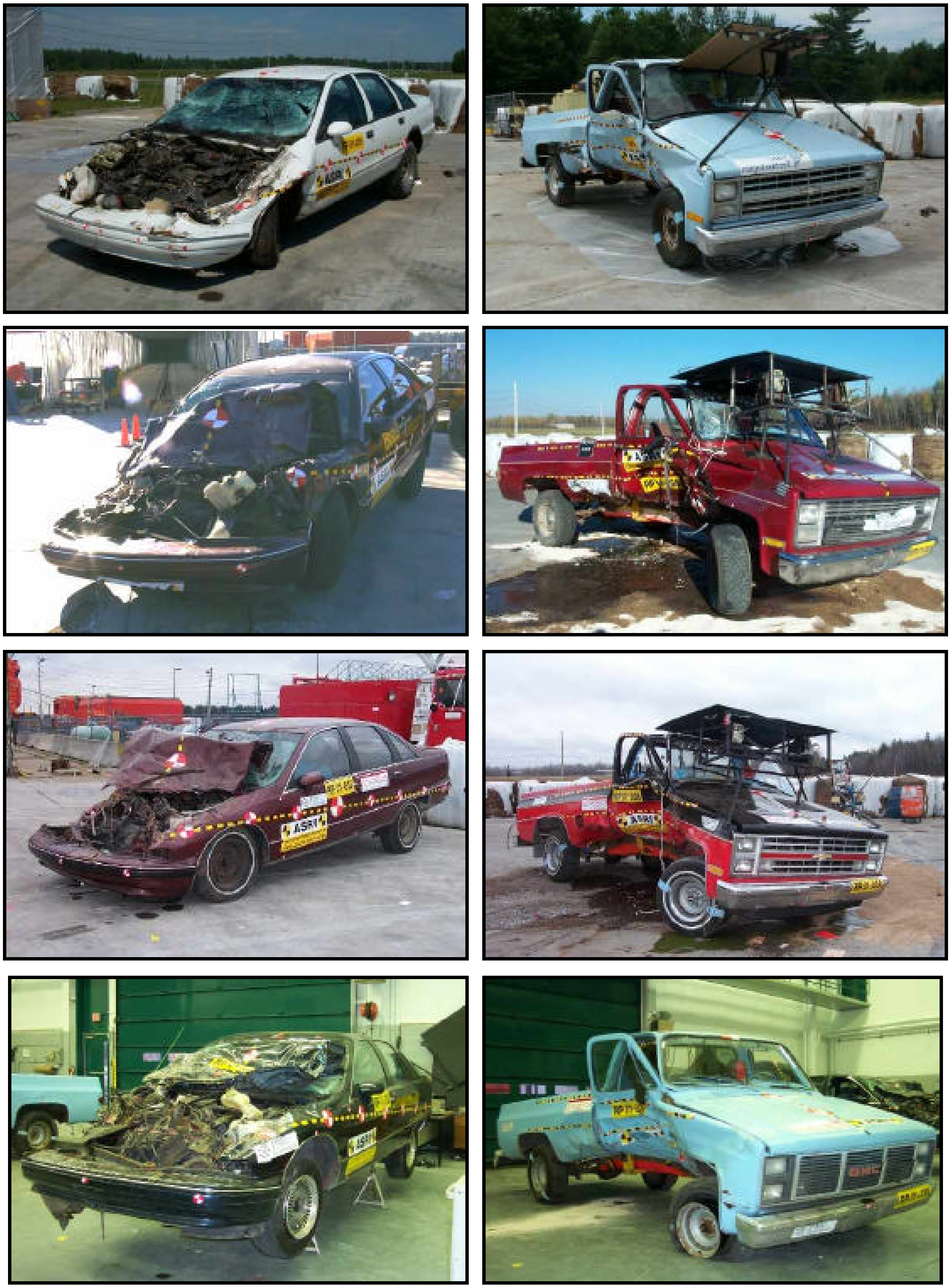


Figure 62: Comparison of damage to tested vehicles. From top to bottom: test RP 01-009, RP 01-036, RP 01-038 and test RP 01-039. (note the truck in RP 01-009 was impacted on the drivers side, the photo was reversed for ease of comparison.

4.3 Anti-rollover Bar

To protect the film equipment mounted on the hood of the pickup truck, an anti-rollover bar was installed on the side of the truck opposite the struck side of the vehicle. In the first test (test RP 01-009) the rollover bar failed and the truck rolled onto its passenger side. This raises an issue as to whether or not the anti-rollover bar can affect the severity and outcome of the impact and subsequently, the damage to the tank.

In each of the centre mounted fuel tank tests the bullet vehicle tended to submarine under the truck. In so doing it created an upward force on the underside of the truck, which was, applied closer to the struck side of the vehicle. The application of this force promoted rotation of the truck about its longitudinal axis (ie. rollover). If the truck rolled sufficiently, the anti-rollover bar would contact the ground creating a restoring moment to the truck. Without the anti-rollover bar, the trucks could rollover and possibly, allow the fuel system to be cleared of the advancing car. However, with the anti-roll bar in place, the truck is not able to move out of the way. As the bullet vehicle continues to penetrate under the truck it generates larger upward forces had the anti-rollover bar not been installed. This could increase the deformation of the centre mounted tank.

In effect, testing with the anti-rollover bar in place is in fact testing to a worst case scenario.

4.4 Tank Penetration

It was found that the front of the bullet vehicle has many sharp edges, particularly underneath the hood, which gets peeled away during the test. These hard points have resulted in scrapping and minor gouging to the tanks. If required, protection from this kind of damage may be achieved by placing a shield over the steel centre tank similar to the plastic shield used in test RP 01-036 or similar to the plastic shield installed on “new” pickup trucks.

4.5 Check Valves and Tank Fill Times

The fuel filler hose is quite large in diameter and, if severed, could leak significant amounts of fuel. To prevent this from occurring, a check valve was added to the trucks’ fuel tanks in test RP 01-036 to test RP 01-039 to eliminate reverse flow of fuel. In each of the tests the check valve remained intact and functional following the test. However, it could not be ascertained if the valve mechanism was fully loaded by the build-up of pressure inside the tank during the impact.

A readily available, off the shelf check valve was installed in the tanks. Unfortunately, these valves are designed to be compatible with a 1 inch filler hose and not the 1 7/8 inch hose of the GM pickup trucks. Consequently, the flow restriction created by these valves resulted in a longer tank filling time.

To quantify the flow restriction caused by the check valve, a comparative test was performed. The basic test set-up consisted of a large, 26 gallon, plastic container with a hole cut in the bottom. Attached to the hole was the fuel tank filler system that was installed in the trucks. A picture of the set-up is shown in Figure 63.

Figure 63: Test apparatus for measuring flow restriction through the check valve.

The container was filled to approximately 95% of full capacity. The end of the supply system was plugged until the container was filled with water. The plug was removed to allow full flow of water. A stopwatch was used to measure the time it took for all of the water to drain from the contained. The same test was repeated for various fuel supply systems that are described in Appendix D. The results of the flow tests are summarized in Table 12.

Table 12: Summary of time to drain the container through various fuel supply systems.

Test No.	Description of Test	Time to Drain(sec)
1	Complete Fuel Supply System	85
2	Fuel Supply System without Check Valve	53
3	Fuel Supply System without Check Valve and Reducer/Elbow	38
4	Standard Short Fuel Supply System without Check Valve and Reducer/Elbow	38

It is clear from these results that both the check valve and diameter reducing fitting (1 7/8 inch to 1 inch) create a substantial flow restriction that could result in longer filling times at a service stations. Therefore, further revisions of the centre mounted tank system must consider alternative check valve systems that would not introduce significant flow restriction resulting in unusually long tank filling times.

5. SUMMARY

A centre mounted fuel tank system was installed into five GM 1500 series pickup trucks. Four of the trucks were impacted on the side by a Chevrolet Caprice angled at 60 degrees from the front of the truck and travelling at 50 mph. An additional truck was impacted by a FMVSS 301 rigid moving barrier travelling at 40 mph perpendicular to the longitudinal axis of the truck.

In one of the tests with a Caprice as the bullet vehicle, the centre tank leaked and exceeded the requirements of FMVSS 301. The leak stemmed from a crack that was created by inversion of a right angle bend, on the lower edge of the tank, in on itself. To prevent similar damage in a subsequent test, a radius was added to the tank and the middle mounting bracket was redesigned to also include radii along the edges contacting the tank. The other four tank installations passed the FMVSS 301 leakage requirements.

A comparison of test conditions, the vehicle preparation and the vehicle damage of the four tests involving the Caprice as the bullet vehicle showed good reproducibility. However, accelerometers installed on two of the trucks produced readings that differed by 40%.

In preventing rollover with the addition of the anti-roll bar on the truck, the tank may experience increased loading were the bars not present. A resistive moment created by the presence of the roll-bar to counteract the upward loading on the tank from the bullet vehicle travelling under the truck could possibly increase the magnitude of the load experienced by the tank. An anti-rollover bar was installed on the side of the truck opposite the struck side of the vehicle. If the truck rolled sufficiently as a result of the collision, the anti-rollover bar would contact the ground creating a restoring moment to the truck. As the bullet vehicle continues to penetrate under the truck it generates larger upward forces, compared to a truck without the anti-rollover bar installed, which could increase the deformation to the centre mounted tank. Therefore, testing with the anti-rollover bar in place is in fact testing to a worst case scenario.

The exhaust system, including the manifold, was removed in two of the tests in order to achieve the desired truck test weight. In so doing, protection of the fuel line was inadvertently diminished. The manifold, which runs down between the frame rail and the transmission housing, provides a rigid spacer that prevents the transmission housing from damaging the fuel lines that are routed along the inside of the frame rail. In one of these two tests the fuel line was severed. In the other test the truck was impacted by a rigid barrier, which does not penetrate as much as the Caprice and the fuel lines remained intact.

The front of the bullet vehicles had many sharp edges, particularly underneath the hood, which gets peeled away during the test. These hard points resulted in scrapping and gouging of the tanks. Protection from this kind of damage can be achieved by placing a shield over the centre tank similar to the plastic shields installed on “new” pickup trucks.

The check valve that was installed on four of the centre mounted tanks could create a flow restriction resulting in longer tank filling times. If a check valve is to be incorporated into the fuel tank system it must have a large enough diameter so as not to impede filling.

6. REFERENCES

Ref. 1: Arndt, Mark W., “Failure Modes of General Motors C\K Light Truck Outboard Frame, Side-Mounted Fuel Containment System”, Arndt & Associates, Ltd., Tempe, Arizona, March 24, 1994.

Ref. 2: Keown, M., Kot, J., Fournier, E., Shewchenko, N., “GM C/K Pickup Truck Fuel Tank Retrofit Evaluation – Phase 1”, Biokinetics and Associates Ltd. Report no. R99-13, December 7, 1999.

Ref. 3 Fournier, E., Keown, M., “Summary Report: Bed Mounted Tank System for the GM C/K 1500 Pickup Trucks”, Biokinetics and Associates Ltd. Report no. R01-03, March 2001.

Ref. 4: Markusic, C., "Final Report of 1991 Chevrolet Caprice into a1986 Chevrolet C10 Pickup Truck", Transportation Research Center Inc., Final Report, 930324, March-May 1993.

Ref. 5 “Test Report – 50 mph Side Impact”, PMG Technologies, Report no. RP 01-009, September, 2000.

Ref. 6 “Test Report – 50 mph Side Impact”, PMG Technologies, Report no. RP 01-036, November, 2000.

Ref. 7 “Test Report – 50 mph Side Impact”, PMG Technologies, Report no. RP 01-037, November, 2000.

Ref. 8 “Test Report – 50 mph Side Impact”, PMG Technologies, Report no. RP 01-038, December, 2000.

Ref. 9 “Test Report – 50 mph Side Impact”, PMG Technologies, Report no. RP 01-039, December, 2000.

APPENDIX A : SUMMARY OF TESTED PICKUP TRUCKS

	Truck Number				
Test	RP 01-009	RP 01-036	RP 01-037	RP 01-038	RP 01-039
Make	Chevrolet	Chevrolet	GMC	Chevrolet	GMC
Model	Custom Deluxe 1500	Custom Deluxe 1500	Sierra 1500	Wrangler 1500	Sierra 1500
Model Year	1987	1987	1987	1986	1986
Odometer (km)	92023	188277	200039	160390	328206
Vehicle Stock Throughout	Y	N	Y	Y	N
Prior Accident History	N	N	N	N	N
Vehicle Corrosion	Good	Excellent	Good	Good	Poor
Condition of Bumper and Frame	Good	Excellent	Good	Good	Fair

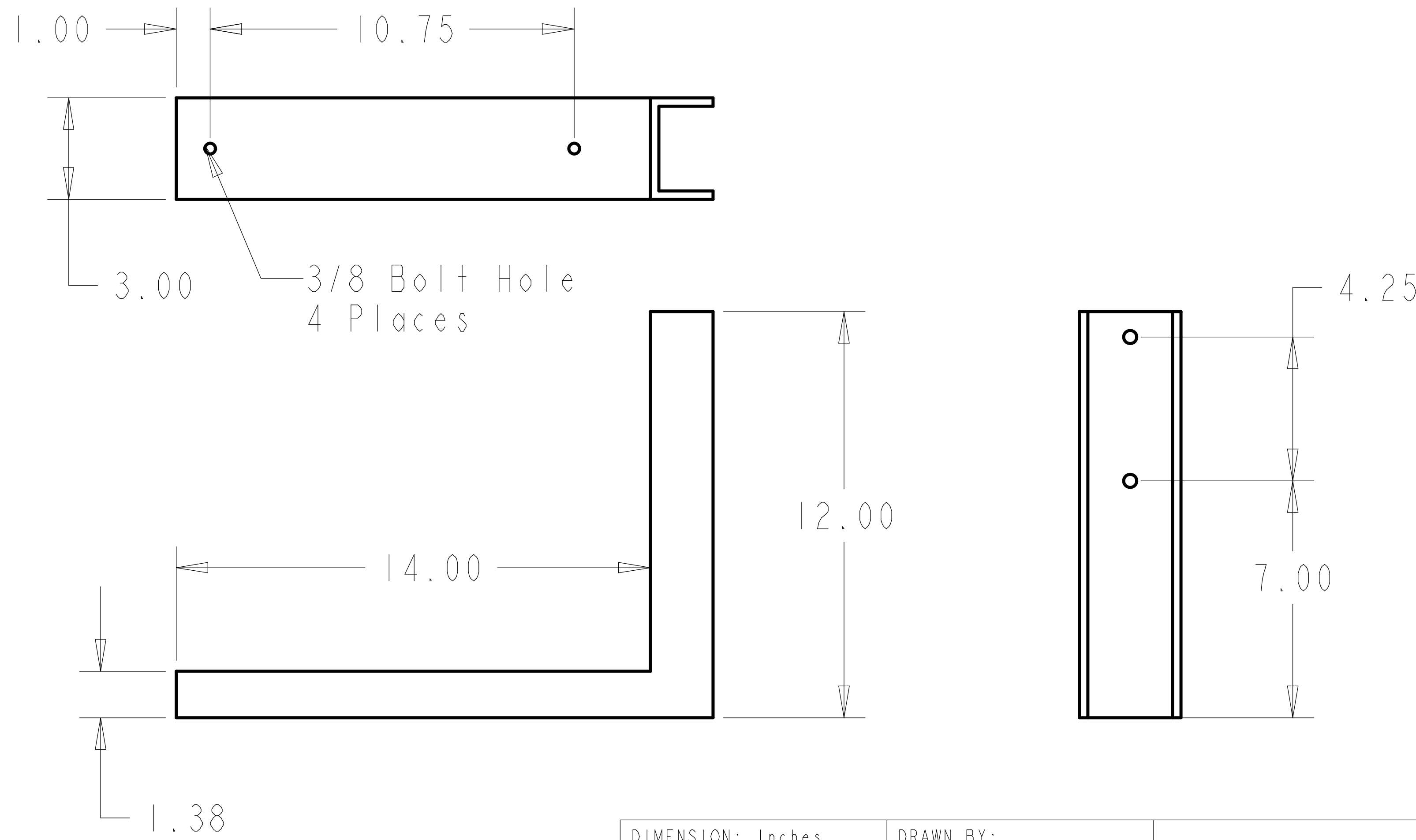
Note: The corrosion and condition are a relative comparison against an exemplar vehicle and are rated on a scale of poor / fair / good / excellent.

APPENDIX B : DRAWING OF THE CENTRE MOUNTED TANK AND BRACKETS

The centre mounted fuel tanks that were installed in GM 1500 series pickup trucks were fabricated according the following list of drawings.

Drawing No.	Description
6905-002	Centre Support
6905-003	Centre Strap
6905-004	Front Support
6905-005	Front Strap
6905-006	Rear Strap
6905-CR002V02	Centre Support for test RP 01-039
6905-CR010V01	Centre tank for test RP 01-009
6905-CR010V02	Centre tank for test RP 01-036, RP 01-037 and RP 01-038
6905-CR010V03	Centre tank for test RP 01-039
6905-CR011	Fuel Line Shield

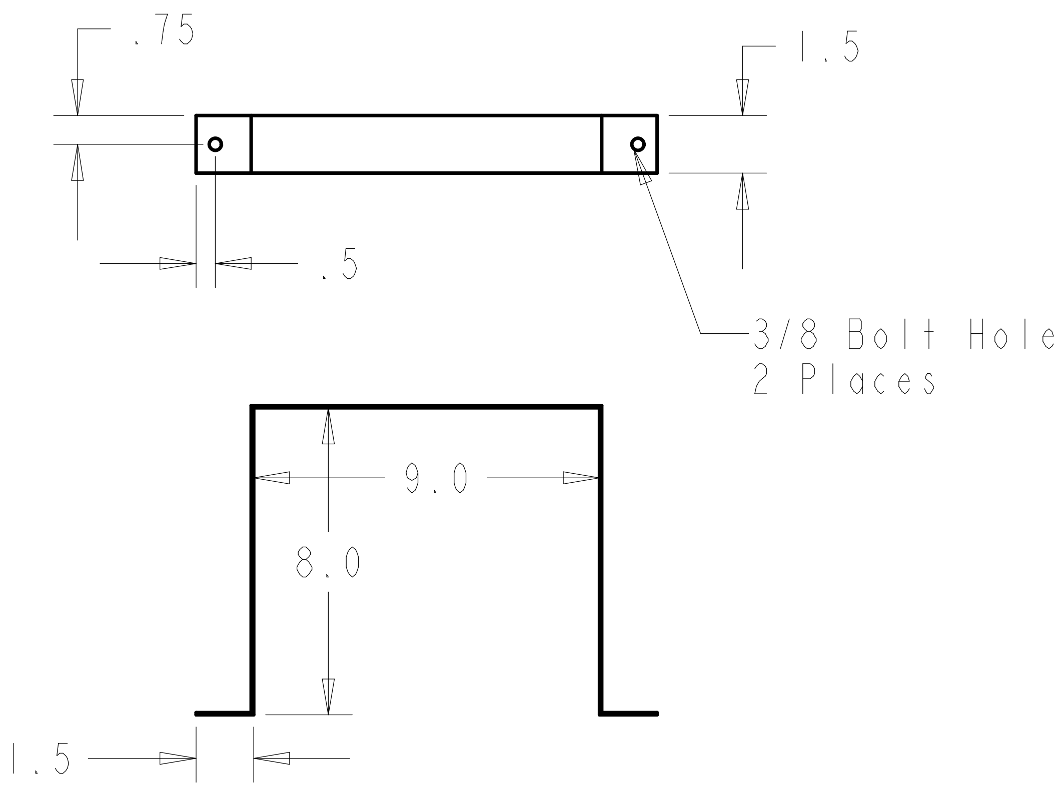
REV.	DESCRIPTION	DATE	APP.
A	Original		



SCALE 0.200

DIMENSION: Inches SCALE: 0.2	DRAWN BY: MK	BIOKINETICS and Associates Ltd.
TOLERANCES DEC. .X± 0.1 DEC. .XX± 0.01 DEC. .XXX± 0.001 ANGLES° 0.5	CHECKED: CHECKED_BY DATE: 5 September 2000 QTY QTY	Centre Support Centre Tank
	MATERIAL: Steel, 1/4"	FINISH FINISH
	DO NOT SCALE DRAWING	1/1 DRAWING NO. 6905-CR002

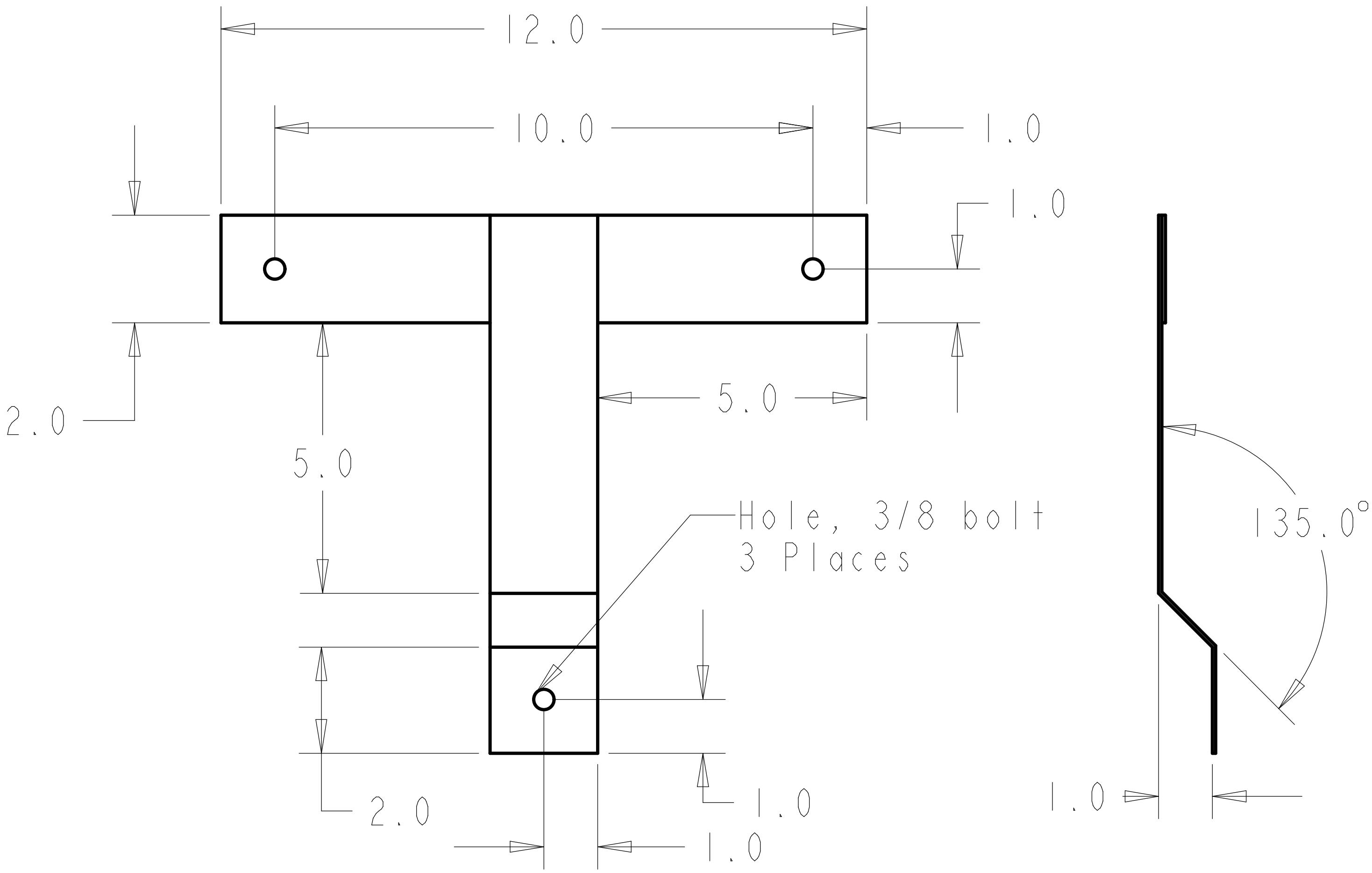
REV.	DESCRIPTION	DATE	APP.



SCALE 0.200

DIMENSIONS: Inches	DRAWN BY:	BIOKINETICS and Associates Ltd.	
SCALE: 0.2	MK		
TOLERANCES	CHECKED:	Centre Strap	
	CHECKED_BY	Centre Tank	
DEC. .X± 0.1	DATE:		
DEC. .XX± 0.01	5 Septermber 2000		
DEC. .XXX± 0.001	QTY QTY		
ANGLES° 0.5	MATERIAL:	FINISH	1/1
	Steel, 1/8"	FINISH	DRAWING NO.
	DO NOT SCALE DRAWING		6905-CR003

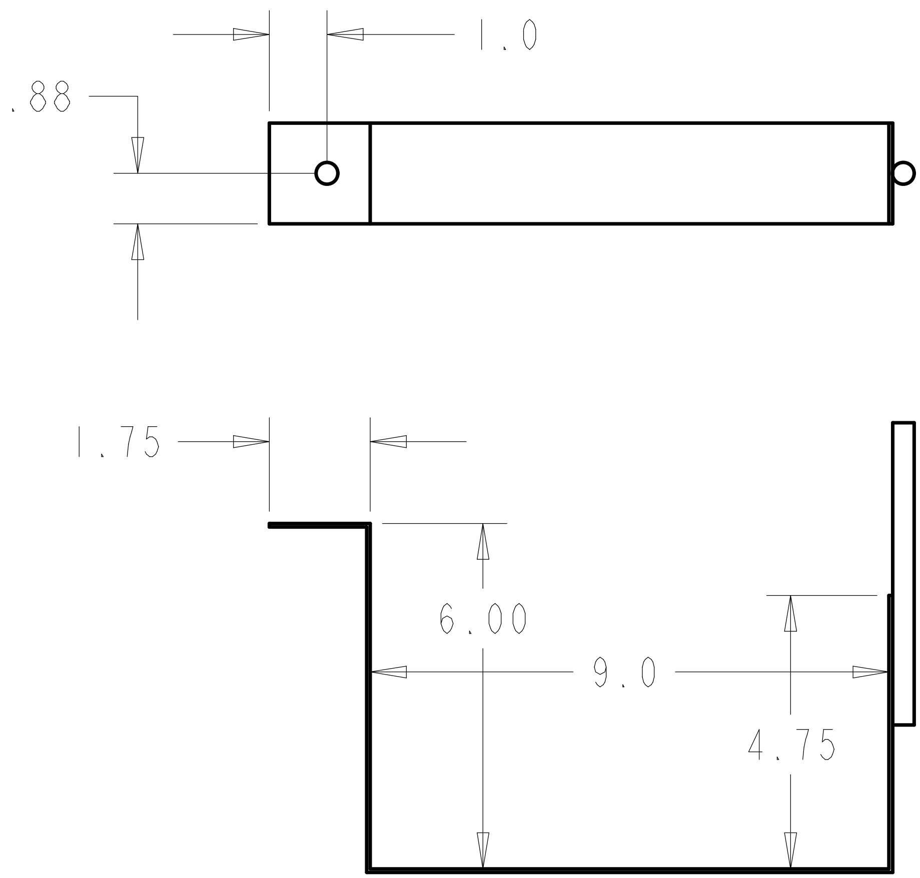
REV.	DESCRIPTION	DATE	APP.
A	Original	5 September 2000	



SCALE 0.300

DIMENSIONS: Inches.	DRAWN BY:	BIOKINETICS and Associates Ltd.	
SCALE: 0.3	MK		
TOLERANCES	CHECKED:	Front Support Centre Tank	
	CHECKED_BY		
DEC. .X± 0.1	DATE:		
DEC. .XX± 0.01	5 Septermber 2000		
DEC. .XXX± 0.001	QTY QTY		
ANGLES° 0.5	MATERIAL:	FINISH	1/1
	Steel, 1/8"	FINISH	DRAWING NO.
	DO NOT SCALE DRAWING		6905-CR004

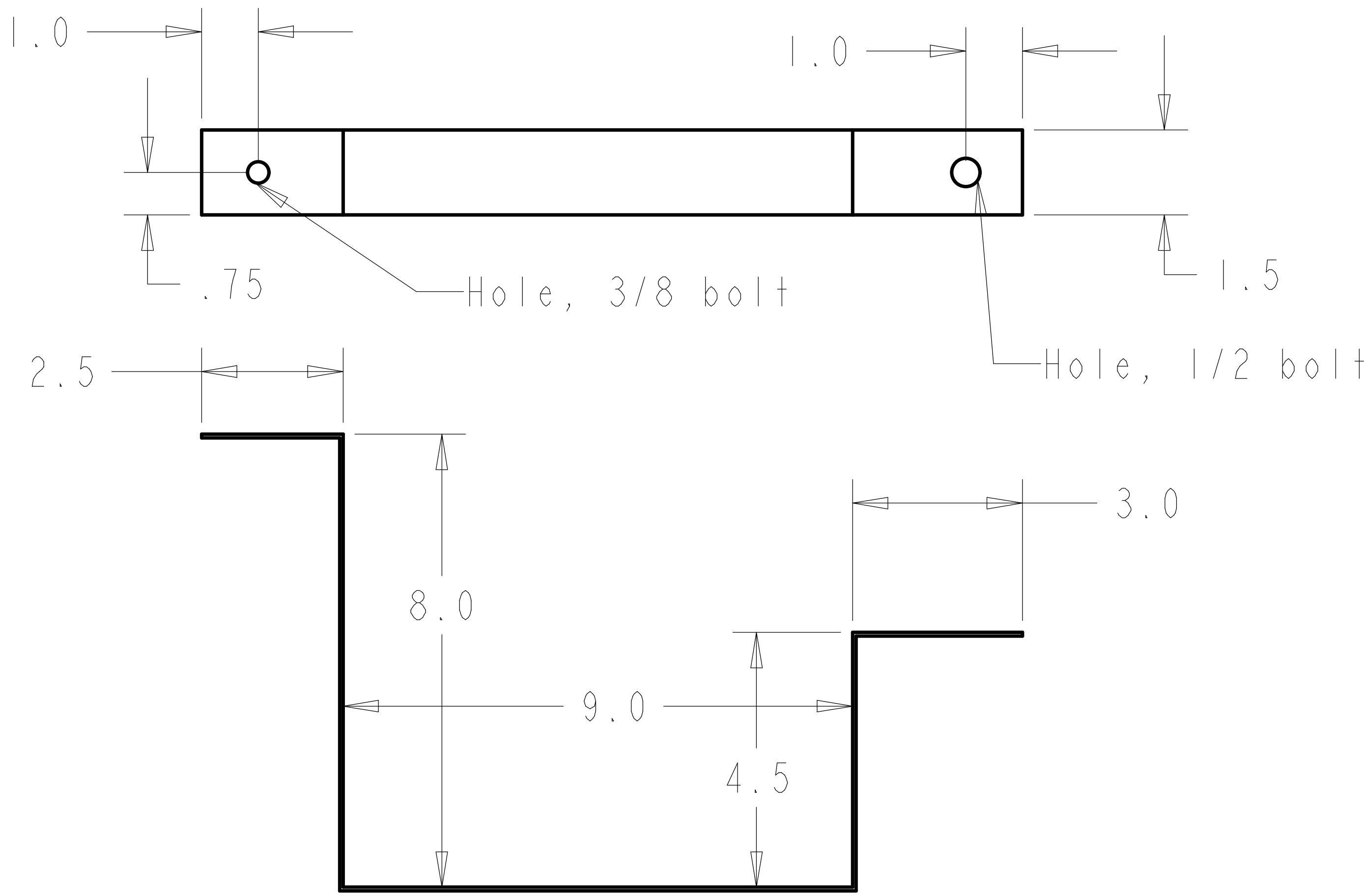
REV.	DESCRIPTION	DATE	APP.
A	Original	5 September 2000	



SCALE 0.300

DIMENSIONS: Inches	DRAWN BY:	BIOKINETICS and Associates Ltd.	
SCALE: 0.3	MK		
TOLERANCES	CHECKED:		
	CHECKED_BY	Front Strap	
DEC. .X± 0.1	DATE:	Centre Tank	
DEC. .XX± 0.01	5 September 2000		
DEC. .XXX± 0.001	QTY QTY		
ANGLES° 0.5	MATERIAL:	FINISH	1/1
	Strap	FINISH	DRAWING NO.
	DO NOT SCALE DRAWING		6905-CR005

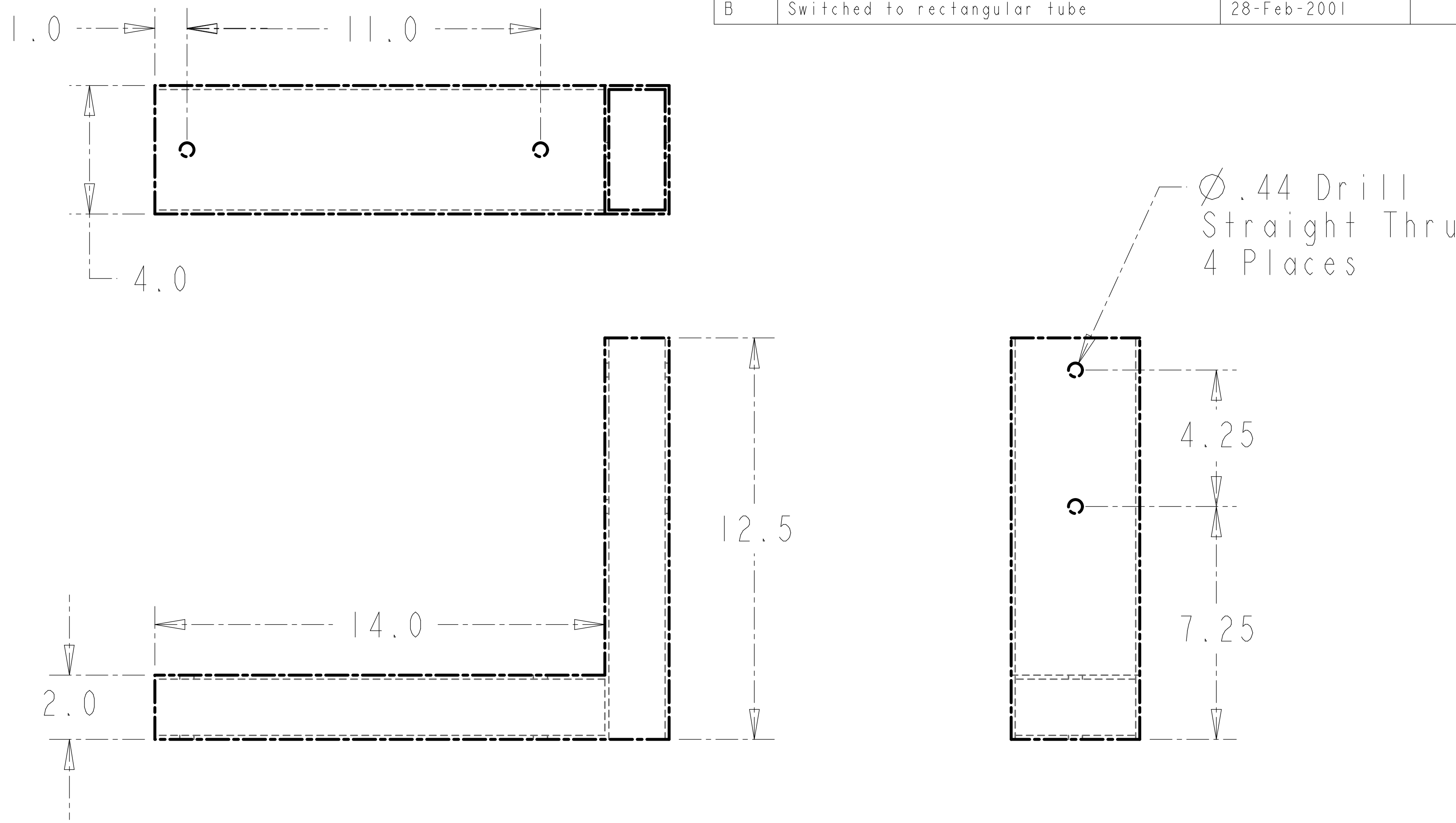
REV.	DESCRIPTION	DATE	APP.
A	Original	5 September 2000	



SCALE 0.300

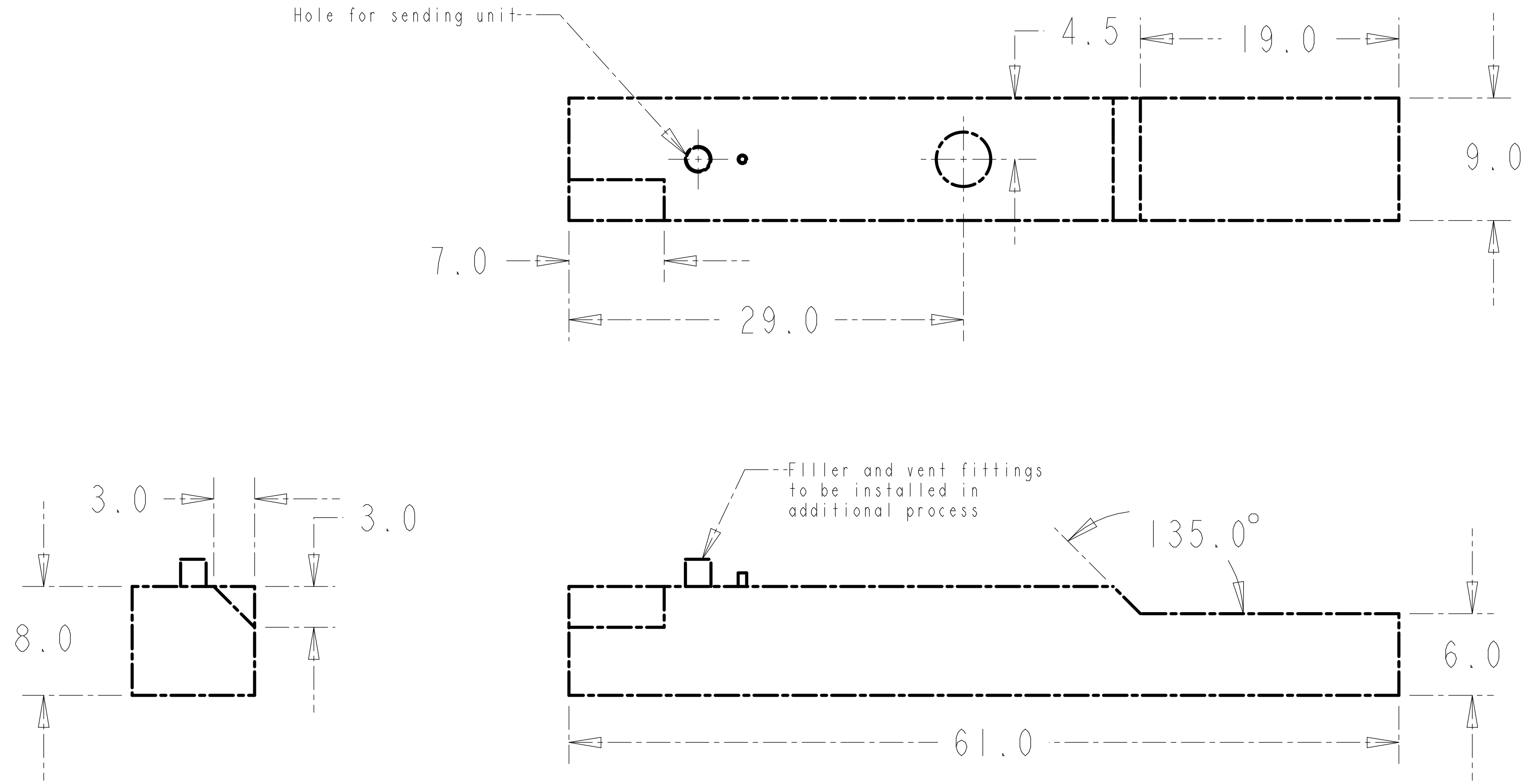
DIMENSIONS: Inches	DRAWN BY:	BIOKINETICS and Associates Ltd.	
SCALE: 0.3	MK		
TOLERANCES	CHECKED:	Rear Strap Centre Tank	
	CHECKED_BY		
DEC. .X± 0.1	DATE:		
DEC. .XX± 0.01	5 September 2000		
DEC. .XXX± 0.001	QTY QTY		
ANGLES° 0.5	MATERIAL:	FINISH	1/1
	Steel, 1/8"	FINISH	DRAWING NO.
	DO NOT SCALE DRAWING		6905-CR006

REV.	DESCRIPTION	DATE	APP.
A	Original	5-Sept-2000	
B	Switched to rectangular tube	28-Feb-2001	



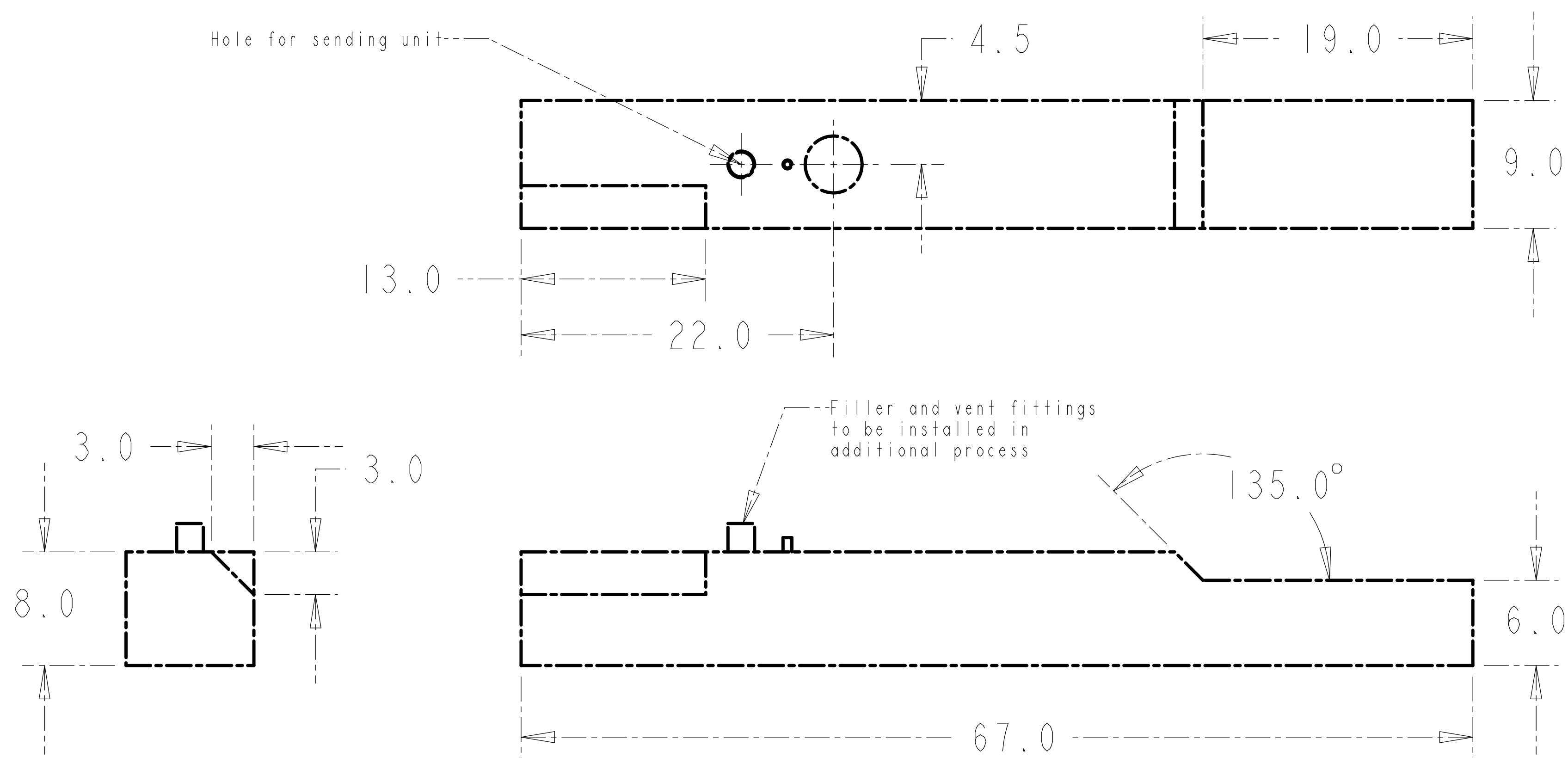
DIMENSIONS: Inches	DRAWN BY:	BIOKINETICS
SCALE:	M. Keown	and Associates Ltd.
TOLERANCES	CHECKED:	CENTREV02
	E. Fournier	
DEC. .X± 0.1	DATE:	PART
DEC. .XX± 0.01	2001-02-28	
DEC. .XXX± 0.001	QTY 1	
ANGLES° 0.5	MATERIAL:	FINISH / 1/1
	Steel	N/A / DRAWING NO.
	DO NOT SCALE DRAWING	6905-CR002V02

REV.	DESCRIPTION	DATE	APP.
A	Original	4-Sept-2000	



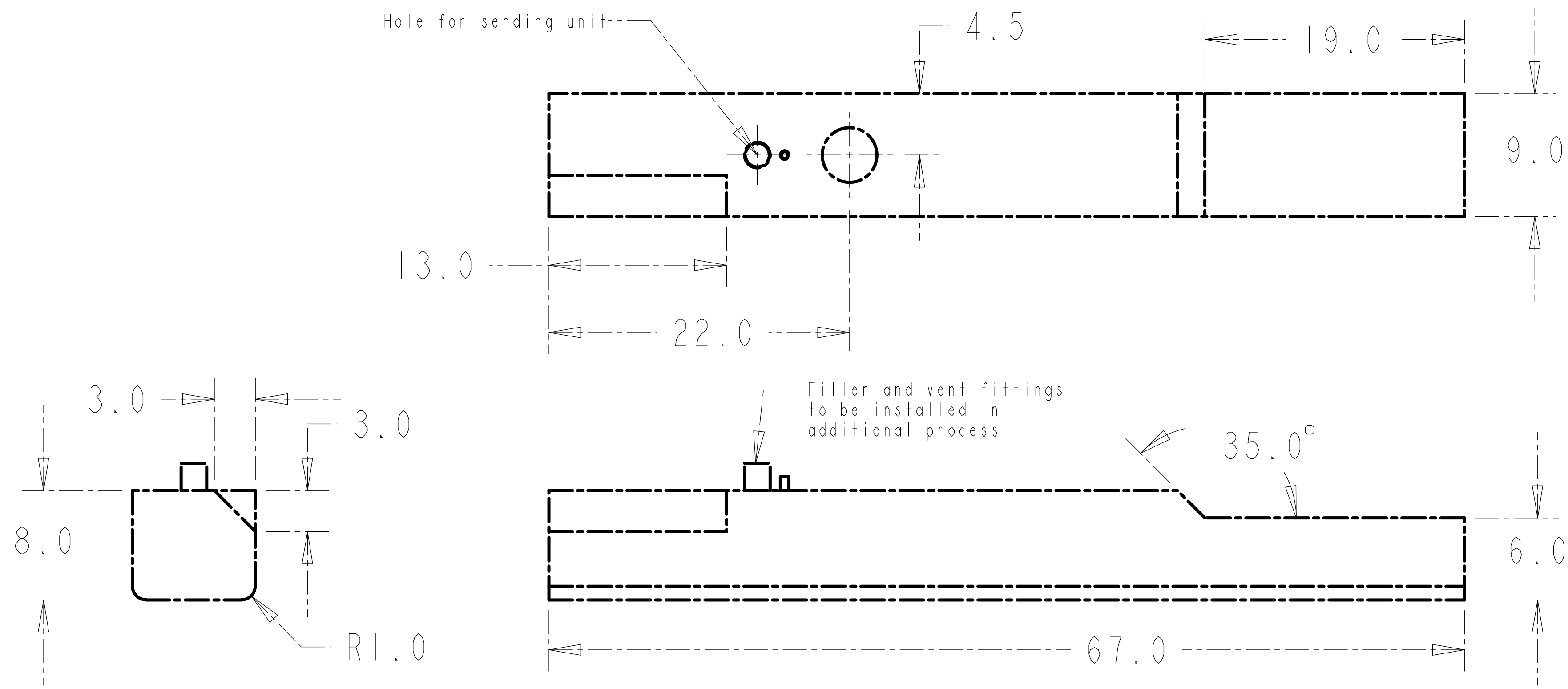
DIMENSIONS: Inches	DRAWN BY:	BIOKINETICS	
SCALE:	M. Keown	and Associates Ltd.	
TOLERANCES	CHECKED:	TANKV01	
	E. Fournier		
DEC. .X± 0.1	DATE:	PART	
DEC. .XX± 0.01	2001-02-27		
DEC. .XXX± 0.001	QTY 1		
ANGLES° 0.5	MATERIAL:	FINISH	1/1
	Steel, 0.060"	N/A	DRAWING NO.
	DO NOT SCALE DRAWING		6905-CR010V01

REV.	DESCRIPTION	DATE	APP.
A	Original	6-Sept-2000	
B	Increased length of tank	16-Nov-2000	

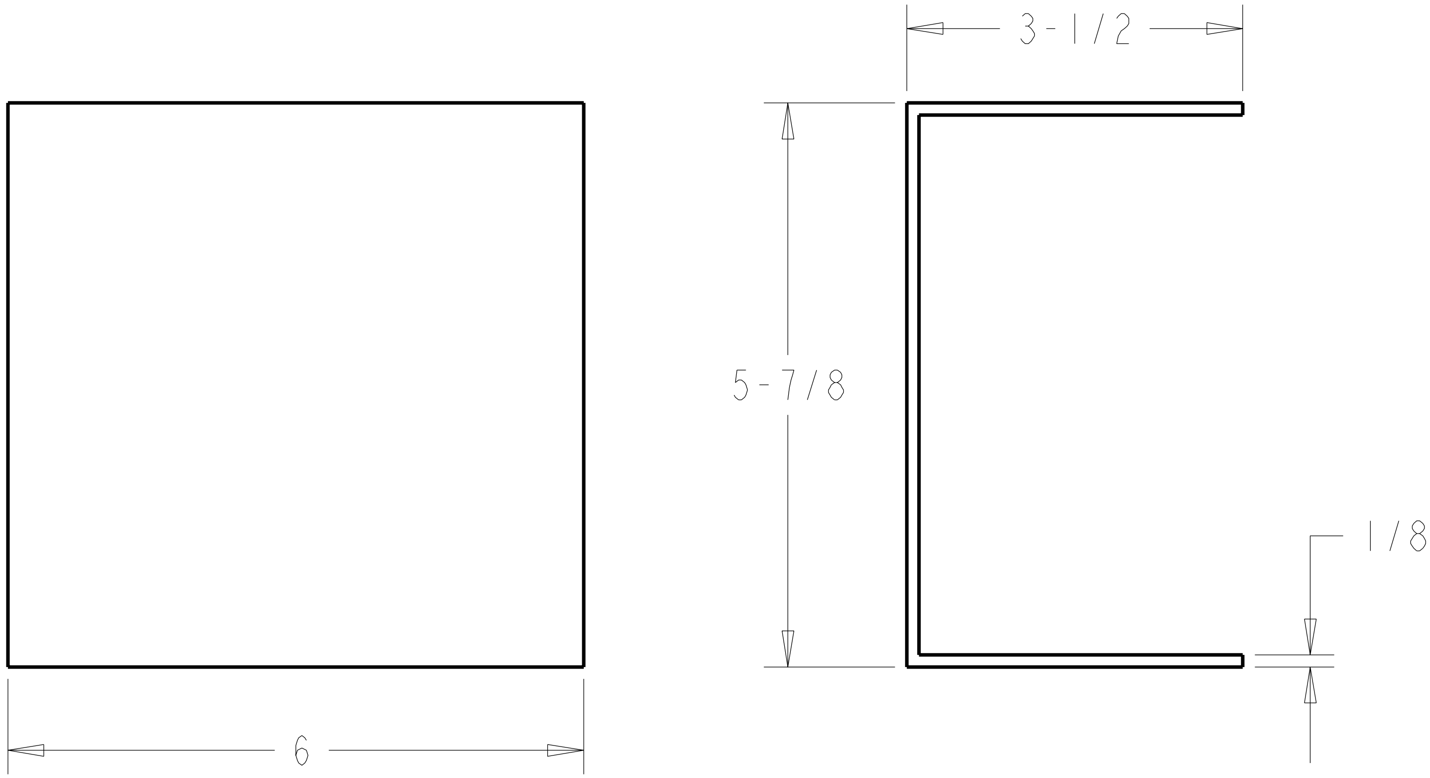


DIMENSIONS: Inches	DRAWN BY:	**BIOKINETICS**	
SCALE:	M. Keown	and Associates Ltd.	
TOLERANCES	CHECKED:	TANKV02	
	E. Fournier		
DEC. .X± 0.1	DATE:		
DEC. .XX± 0.01	2001-02-27	PART	
DEC. .XXX± 0.001	QTY 1		
ANGLES° 0.5	MATERIAL:	FINISH	1/1
	Steel, 0.060"	N/A	DRAWING NO.
	DO NOT SCALE DRAWING		6905-CR010V02

REV.	DESCRIPTION	DATE	APP.
A	Original	6-Sept-2000	
B	Increased length of tank	16-Nov-2000	
C	Added rounded edges on base	25-Jan-2001	



DIMENSIONS: Inches	DRAWN BY:	BIOKINETICS
SCALE:	M. Keown	and Associates Ltd.
TOLERANCES	CHECKED:	
	E. Fournier	TANKV03
DEC. .X± 0.1	DATE:	
DEC. .XX± 0.01	2001-02-27	PART
DEC. .XXX± 0.001	QTY 1	
ANGLES° 0.5	MATERIAL:	FINISH / 1/1
	Steel, 0.060"	N/A / DRAWING NO.
	DO NOT SCALE DRAWING	6905-CR010V03



DIMENSIONS: Inches	DRAWN BY: M. Keown	**BIOKINETICS** and Associates Ltd.
SCALE:	CHECKED: E. Fournier	Fuel Line Bracket
TOLERANCES DEC. .X± 0.1 DEC. .XX± 0.01 DEC. .XXX± 0.001 ANGLES° 0.5	DATE: 2001-03-01 QTY 1	PART
	MATERIAL: Steel	FINISH N/A / 1/1 / DRAWING NO. 6905-CR011
	DO NOT SCALE DRAWING	

APPENDIX C : PICKUP TRUCK ACCELERATION TRACES FOR TEST RP 01-036 AND TEST RP 01-038.

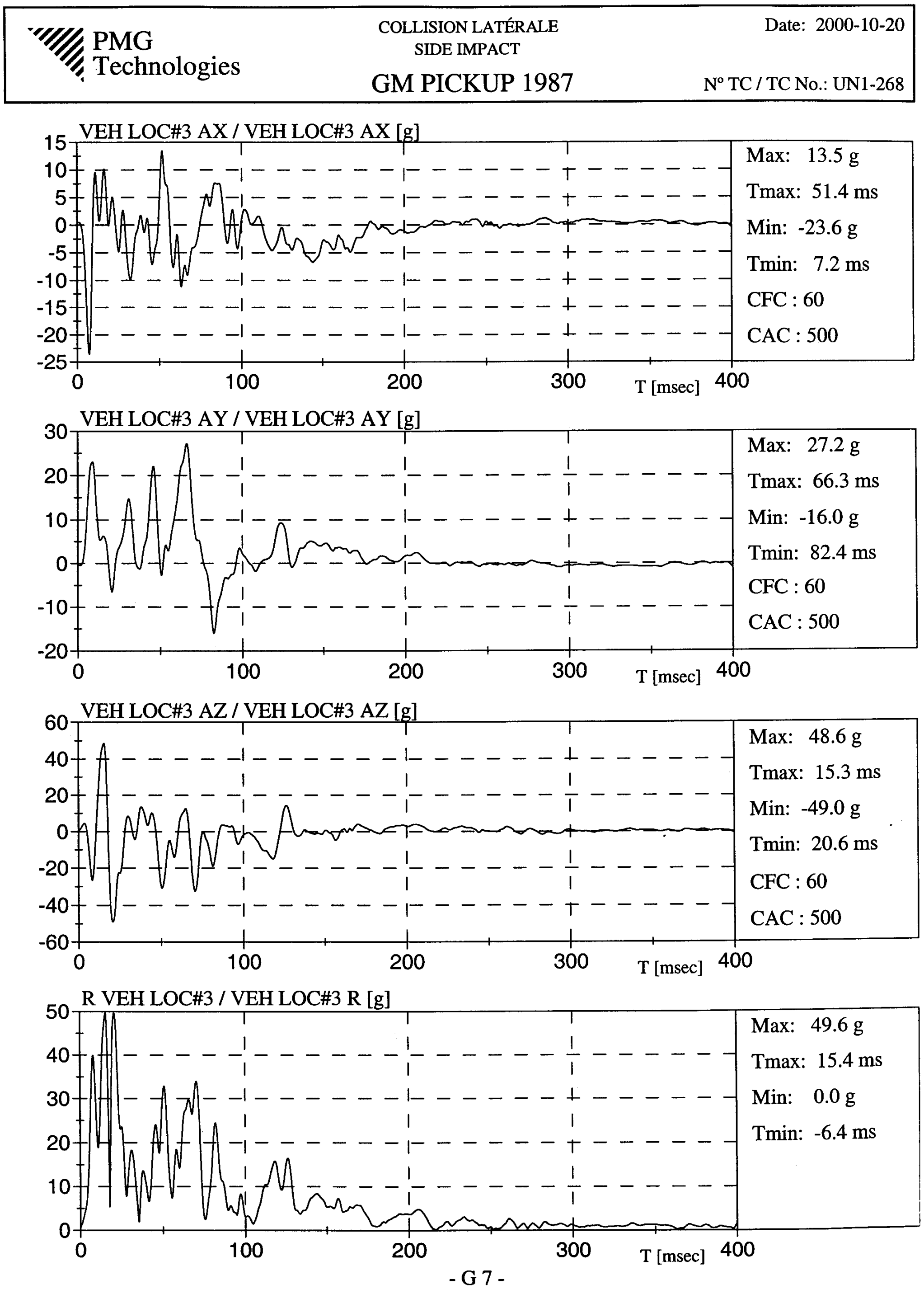


Figure 64: Truck acceleration in test RP 01-036.

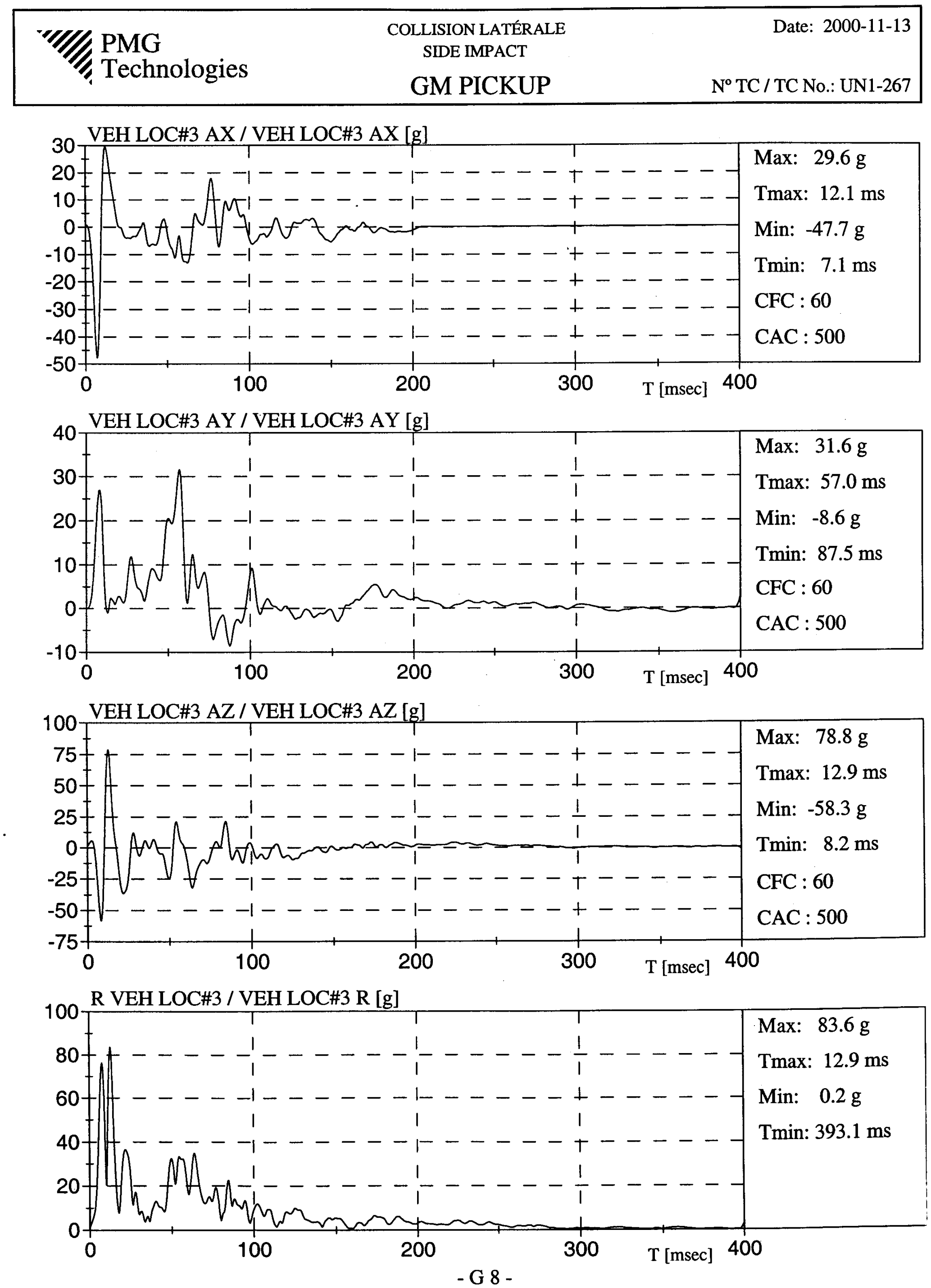


Figure 65: Truck acceleration in test RP 01-038.

APPENDIX D : FLOW TESTS OF FOUR TANK FILLER TUBE CONFIGURATIONS

<u>Complete Fuel Supply System</u>

The complete fuel supply system comprised of the filler throat, the horizontal supply hose, the reducer/elbow and the check valve (see Figure 66). A detailed shot of the check valve and the reducer/elbow can be seen in Figure 67. A view of the water draining through the check valve is shown in Figure 68. The time required to drain the container was measured to be 85 seconds.

Figure 66: Horizontal filler tube with reducer elbow and check valve.

Figure 67: Close-up of the reducer elbow and the check valve

Fig. 3

Figure 68: Water draining through the check valve.

Fuel Supply System without Check Valve

This system is identical to the one above with the exception that there is no check valve at the end of the supply system (see Figure 69). A close-up view of the reducer/elbow without the check valve can be seen in Figure 70. The time required to drain the container was measured to be 53 seconds.

Figure 69: Horizontal filler tube with reducer elbow (NO check valve).

Figure 70: Close-up of the reducer / elbow without the check valve.

<u>Fuel Supply System without Check Valve and Reducer / Elbow</u>

This system is identical to the one above with the exception that there is no check valve or reducer / elbow at the end of the supply system (see Figure 71). A close-up view of the filler tube without the reducer elbow or the check valve is shown in Figure 72. The time required to drain the container was measured to be 38 seconds.

Figure 71: Fuel supply tube without reducer elbow or check valve.

Figure 72: Close-up of the fuel supply tube without reducer elbow or check valve.

Standard Short Fuel Supply System without Check Valve and Reducer/Elbow

This system consists of a supply system that would be found on a GM pickup truck with a standard fuel tank (see Figure 73). The time required to drain the container was measured to be 38 seconds.

Figure 73: Standard GM pickup truck fuel filler tube.