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RESULTS: MINE AREA CLEARANCE VEHICLE (MACV) EXPLOSIVES EXPERIMENTS FINAL TEST REPORT

Kenneth J. Knox, PhD

Applied Research Associates
P.O. Box 40128
Tyndall AFB, FL 32403

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AIRBASE TECHNOLOGIES DIVISION
MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIAL COMMAND
139 BARNES DRIVE, SUITE 2
TYNDALL AIR FORCE BASE, FL 32403-5323

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//signature//
WALTER M. WALTZ
Work Unit Manager

//signature//
JOHN S. MASCELLI, Captain, USAF
Acting Chief, Force Protection Branch

//signature//
ALBERT N. RHODES, PhD
Acting Chief, Airbase Technologies Division

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Applied Research Associates
P.O. Box 40128
Tyndall Air Force Base, FL 32403

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14. ABSTRACT

The Hydrema 910 Mine Area Clearance Vehicle (MACV), a Danish mine clearing system, is being converted to teleremote operations by the Air Force Research Laboratory (AFRL) for the HQ Air Combat Command Civil Engineer (HQ ACC/CE). On 8 July 2005 AFRL conducted a series of experiments to evaluate and demonstrate the survivability of the robotic controls during simulated mine clearing operations. The MACV was exposed to a range of munitions detonated adjacent to the mine-clearing flail, ranging from antipersonnel weapons to antitank weapons. None of the weapons had an appreciable effect on the MACV or on the robotic controls contained in the operator's cab. The vehicle cab was exposed to approximately 5.5 psi incident pressures on the exterior, but the interior pressure increased less than 0.2 psi. The magnitude of shock experienced by the cab and the robotic controls was 8.7 g's or less, well within the proven capacity of the control systems of 19.5 g's. Overall, the MACV did a good job protecting the cab and the robotic controls in the experiment series.

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MACV, MACE, mine clearance, flail, teleremote, Hydrema, Perkins, sensors, robotic, ACC, vehicle cab, GPS, C-130

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1.0 Executive Summary

The Hydrema 910 Mine Area Clearance Vehicle (MACV), a Danish mine clearing system, is being converted to teleremote operations by the Air Force Research Laboratory (AFRL) for the HQ Air Combat Command Civil Engineer (HQ ACC/CE). On 8 July 2005 AFRL conducted a series of experiments to evaluate and demonstrate the survivability of the robotic controls during simulated mine clearing operations. The MACV was exposed to a range of munitions detonated adjacent to the mine-clearing flail, ranging from antipersonnel weapons to antitank weapons. None of the weapons had an appreciable effect on the MACV or on the robotic controls contained in the operator's cab. The vehicle cab was exposed to approximately 5.5 psi incident pressures on the exterior, but the interior pressure increased less than 0.2 psi. The magnitude of shock experienced by the cab and the robotic controls was 8.7 g's or less, well within the proven capacity of the control systems of 19.5 g's. Overall, the MACV did a good job protecting the cab and the robotic controls in the experiment series.

2.0 Background

2.1 The Hydrema 910 (Mine Clearance Vehicle) MCV-2 Flail System, hereafter referred to as the Mine Area Clearance Vehicle (MACV), is a commercially available mine clearing system designed by the Danish government to be manually operated. The HQ Air Combat Command Civil Engineer (HQ ACC/CE) has expressed strong interest in being able to remotely employ the vehicle system, thereby removing the man-in-the-seat during mass area clearance operations in an effort to improve personnel safety. The Air Force Research Laboratory's (AFRL's) MACV Developmental Test & Evaluation program supports the continuing developmental testing effort to establish the effectiveness (high degree of driving accuracy and positioning) of teleremote operations as a means of employing the mine clearing system.

2.2 Description. The MACV employs an articulated chassis so that all four wheels are in contact with the ground at all times. When being driven on roads the cab is to the front; during mine clearing operations, the vehicle is driven in reverse with the cab to the rear. The fully enclosed, all-welded steel armor cab protects the occupants from small arms fire up to 7.62 mm armor piercing rounds and the bullet-proof windows provide all around visibility. For increased crew comfort during travel and mine clearing operations, the cab is suspended in rubber elements to dampen vibration. The cab seats three people, although the vehicle can be operated by a single operator.

The vehicle is powered by two Perkins 1006-6TW 6-cylinder turbocharged diesel engines. One is used for driving the vehicle and is coupled to a six-speed semi-automatic transmission. The second diesel engine powers the mine clearing flails. Each engine has its own cooling, air filter, exhaust and hydraulic system. During mine clearing operations, a separate hydrostatic transmission is used which gives a continuously variable speed and considerable tractive force. The hydrostatic driving unit can be supplied from the hydraulic system of the powerpack and can be used in an emergency should the main engine stop, enabling the Hydrema 910 to move out of immediate danger under its own power.

The MACV can be manually driven on roads up to a maximum speed of 35 km/h. The vehicle is steered through a hydrostatic pivot steering system on all four wheels with an emergency backup in case of engine failure. The fuel tanks hold 300 liters and are integrated onto the chassis for maximum protection. When in the travel mode, the complete flail system and deflector, which is suspended on hydraulic systems, is raised clear of the ground and traversed through 90° using a hydraulically operated tilting/turning system so that it is in line with the chassis. In this configuration, it can be driven on public roads.

For mine clearing operations, the complete flail system is rapidly lowered into position at the rear of the vehicle. The system can clear a mine path 3.5 m wide. During mine clearing, the vehicle can be manually operated from the cab using a joystick or through the use of a computerized fully automatic pilot steering system. When being used in the latter configuration, the operator needs only to select a number of key parameters such as depth on the monitor. The depth control of the flail and the armored deflector plate, which is positioned to the immediate rear of the rotating flail, is then fully automatic using sensors. The chains rotate clockwise if mines are buried and counterclockwise if they are on the surface. The flail assembly consists of a rotating axle with 72 chains attached; the end of each of these is fitted with a hammer type head which weighs 0.9 kg. When these chains or heads are damaged, they can be easily and quickly replaced. The axle rotates at up to 400 rpm. Vehicle travel speed depends on the type of terrain. On cross-country terrain, for example, the MACV can travel about 1.4 km/h, while on a firm hard surface it could travel up to 12 km/h.

A robotized MACV will be postured at each of three active-duty USAF RED HORSE Squadrons in a ready-to-deploy status. RED HORSE engineers will be trained in mine/counter-mine clearance procedures and will be on-call to deploy with robotized MACVs anytime, any place. Robotized MACVs are C-130 air transportable and can be delivered to any C-130 capable airfield worldwide. The robotized MACV will give Combatant Commanders a viable option to rapidly clear large numbers of UXO from airfield surfaces anywhere, anytime.

Figure 1. Hydrema 910 Mine Area Clearance Vehicle

3.0 References

3.1 Air Force Research Laboratory Mission/ Project Plan for Trial Number 2005-07, "Mine Area Clearance Vehicle (MACV) Explosive Experiments," June 2005.

3.2 "Low Velocity Airdrop of the Modified All-Purpose Remote Transport System (ARTS-II)," HQ U.S. Army Operational Test Command, June 2005 (FOUO).

3.3 "ConWep 2.1.0.8," software developed by USAE Engineer Research and Development Center.

4.0 Objectives and Technical Approach

4.1. Objective. The objective of this experiment was to demonstrate the survivability of the robotic controls during a detonation. Explosive materials were detonated in close proximity to the flail assembly, and the effects on the robotic controls were measured and analyzed.

4.2. Technical Approach. This experiment consisted of four detonations (Figure 2) to represent possible situations during clearance operations. All charges were located close to, but outside the rotating radius of the flail (approximately 3.5 ft horizontal distance from flail centerline). The first detonation consisted of a non-fragmenting explosive charge to measure blast pressures and effect on the flail assembly. The remaining series of charges consisted of fragmenting ordnance items positioned at various locations adjacent to the flail. These charges were:

1. Non-fragmenting 10-lb C-4 charge
2. M67 Frag Grenade
3. BLU-97 CEM (Combined Effects Munition)
4. M15 Mine

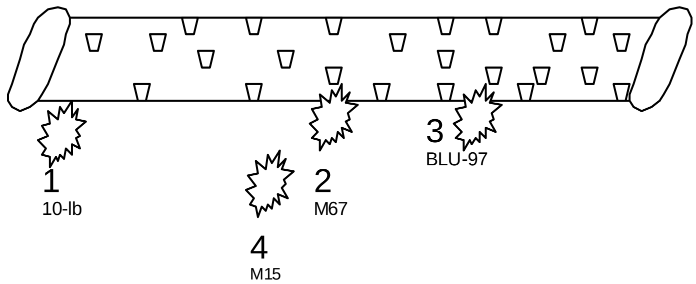


Figure 2. Explosive Placement

4.3. Data Collection. Data collection consisted of high-speed and still photography, accelerometers and pressure gauges. Details on the gauges are shown in Figure 3 and summarized below:

- Accelerometer #1: Range = 200g. Located on left (as you face the flail) wall panel of cab, where the robotic low level controls were located. Orientation was transverse to the vehicle axis (i.e., left to right axis). NOTE: This gauge malfunctioned during the experiments and produced no useful data.
- Accelerometer #2: Range = 200 g. Located on left panel inside cab, near the video controllers. Orientation was along vehicle axis (i.e., front to back axis).
- Accelerometer #3: Range = 200 g. Located on horizontal surface left side, at video controllers. Orientation was vertical.
- Accelerometer #4: Range = 100 g. Located on right side of cab on high level controller tray. Orientation was axial and redundant with Accelerometer #2 (i.e., front to back axis) for Experiments 1 and 2. Orientation was then changed to transverse to the vehicle axis (i.e., left to right axis) for Experiments 3 and 4 to compensate for malfunctioning Accelerometer #1.
- Free Field Pressure Gauge #1: Range = 10 psi. Located on operators seat inside cab.
- Free Field Pressure Gauge #2: Range = 10 psi. Located on floor behind operator's seat inside cab.
- Free Field Pressure Gauge #3: Range = 25 psi. Located in open test arena 31.5 feet from explosive device (same standoff as the MACV operator's cab).

5.0 Experimental Results

The four MACV experiments were conducted on 8 July 2005 at AFRL's Range 2, Tyndall AFB, FL. For each experiment, the vehicle was stationary with the flail operating at a height that just touched the ground surface. The explosive charges were placed 3.5 feet horizontal distance from the flail centerline, just beyond the radius of the flail hammers. Following the explosive detonation, the flail was stopped and the MACV inspected for damage.

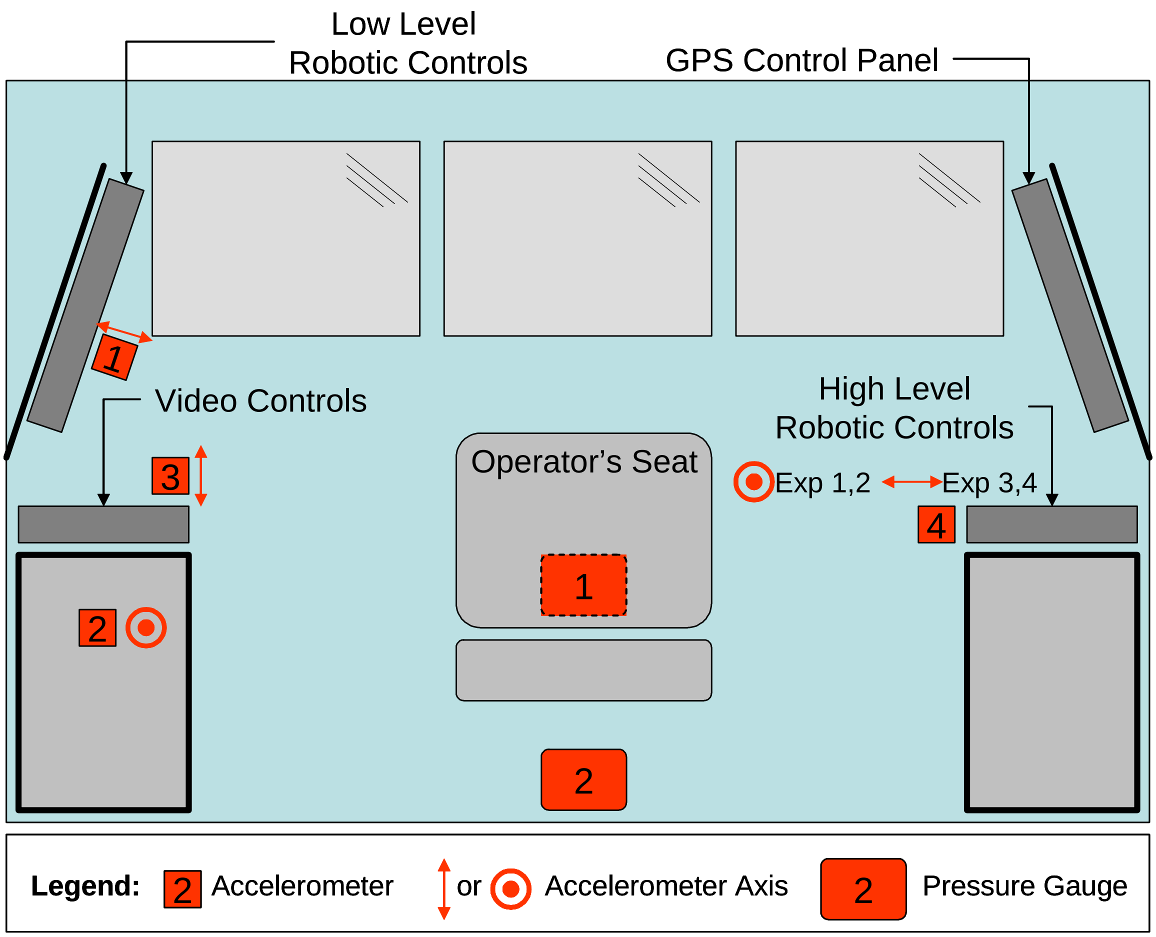


Figure 3. Instrumentation Inside Operator's Cab

5.1 Test 1: 10-lb C-4 Charge. A 10-lb block of C-4 military explosive was buried level with the ground and near the right end of the flail assembly (Figures 4 and 5). This non-fragmenting charge would expose the MACV to only shock and pressure loads. The incident pressure loads at the cab standoff (31.5 ft) were predicted by ConWep (Reference 3.3) to be approximately 5.6 psi. Table 1 summarizes the test results. The gauge plots are included in the Appendix. The robotics controls suffered no damage in Test 1.

Results: Mine Area Clearance Vehicle (MACV) Explosive Experiments

Figure 4. Pre-test: 10-lb C-4 Charge

Figure 5. Post-test: 10-lb C-4 Charge

Table 1. Test 1 Results

Gauge	Description	Measurement
Accelerometer #1	Transverse	No Data
Accelerometer #2	Axial	2.1 g @ 18 ms
Accelerometer #3	Vertical	3.0 g @ 18 ms
Accelerometer #4	Axial	2.1 g @ 13 ms
Free Field #1	Inside Cab	0.08 psi @ 31 ms
Free Field #2	Inside Cab	0.11 psi @ 26 ms
Free Field #3	Arena	4.7 psi @ 19 ms
ConWep Prediction	Arena Prediction	5.6 psi @ 16 ms
Crater	Diameter/Depth	6.5 ft diam / 14 in deep

5.2 Test 2: M67 Frag Grenade. The M67 grenade is a spherical steel grenade containing 0.13 lbs Comp B explosive. The grenade was buried level with the ground and near the center of the flail assembly (Figures 6 and 7). The incident pressure loads at the cab standoff (31.5 ft) were predicted by ConWep (Reference 3.3) to be approximately 0.7 psi. Table 2 summarizes the test results. The gauge plots are included in the Appendix. The robotics controls suffered no damage in Test 2.

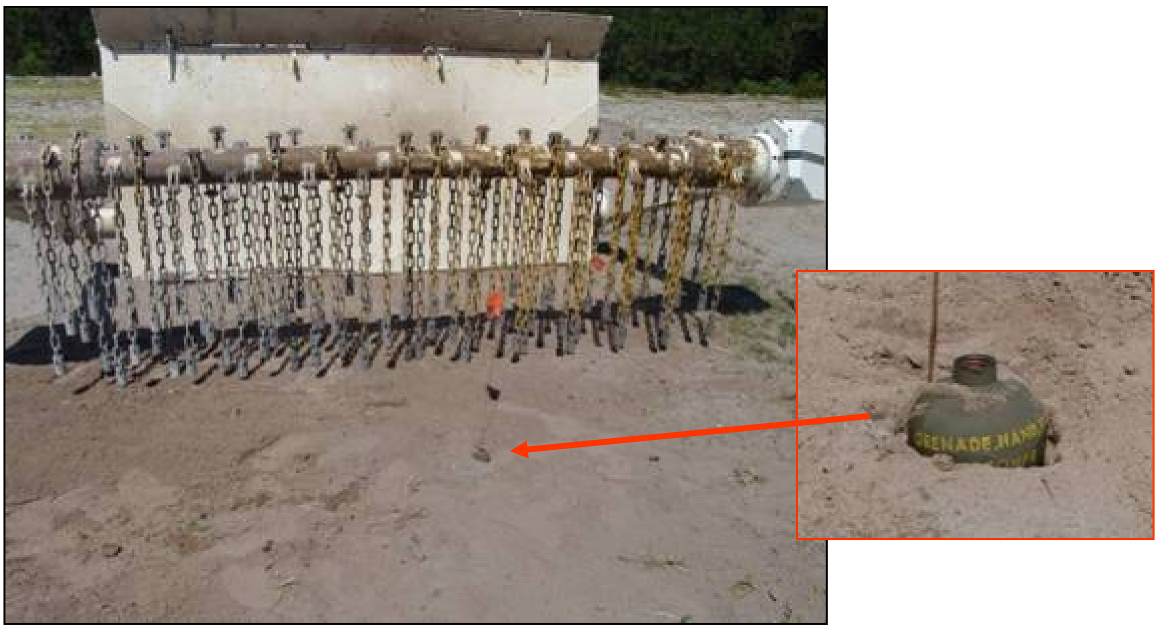


Figure 6. Pre-test: M67 Grenade

Figure 7. Post-test: M67 Grenade

Table 2. Test 2 Results

Gauge	Description	Measurement
Accelerometer #1	Transverse	No Data
Accelerometer #2	Axial	1.4 g @ 26 ms
Accelerometer #3	Vertical	1.7 g @ 17 ms
Accelerometer #4	Axial	0.5 g @ 19 ms
Free Field #1	Inside Cab	0.02 psi @ 29 ms
Free Field #2	Inside Cab	0.03 psi @ 31 ms
Free Field #3	Arena	0.7 psi @ 25 ms
ConWep Prediction	Arena Prediction	0.7 psi @ 25 ms
Crater	Diameter/Depth	28 in diam / 8 in deep

5.3 Test 3: BLU-97 CEM. The BLU-97 Combined Effects Munition (CEM) is a soda-can-sized bomblet submunition containing 0.64 lbs explosive that is dispensed in large numbers (approximately 150-200 bomblets per weapon) to attack "soft" area targets. The bomblet was placed on the ground and near the center of the flail assembly (Figures 8 and 9). The incident pressure loads at the cab standoff (31.5 ft) were predicted by ConWep (Reference 3.3) to be approximately 1.3 psi. Table 3 summarizes the test results. The gauge plots are included in the Appendix. The robotics controls suffered no damage in Test 3.

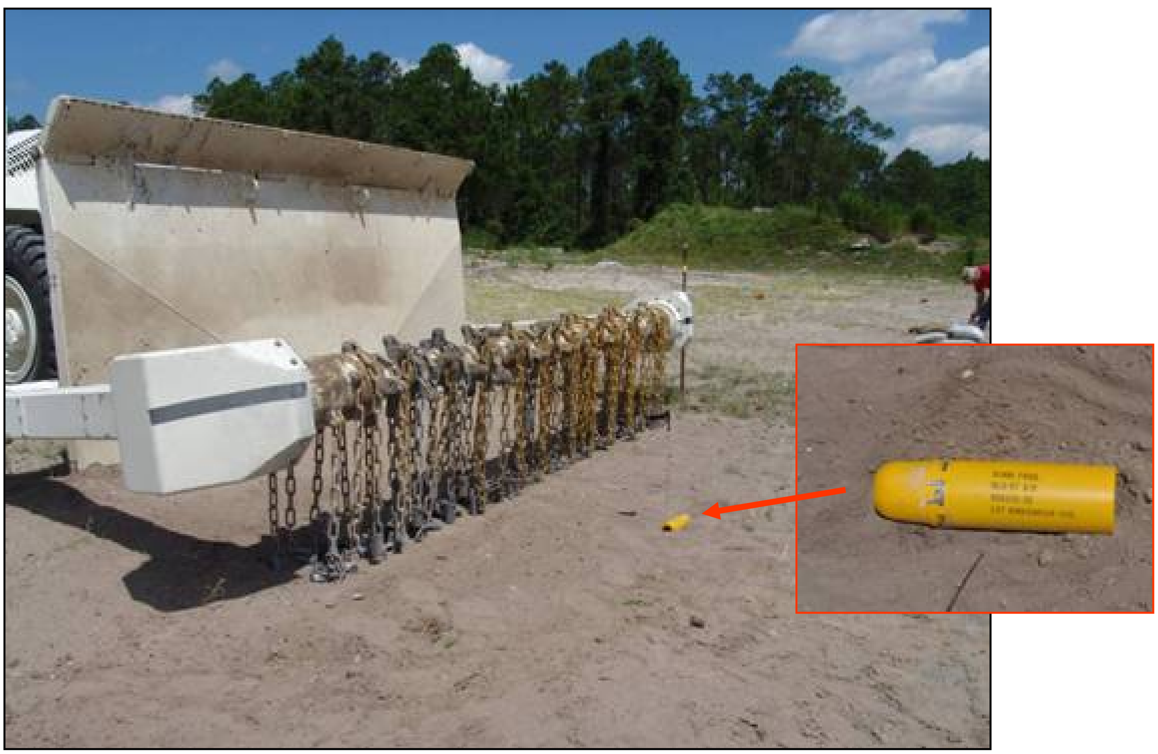


Figure 8. Pre-test: BLU-97 CEM

Figure 9. Post-test: BLU-97 CEM

Table 3. Test 3 Results

Gauge	Description	Measurement
Accelerometer #1	Transverse	No Data
Accelerometer #2	Axial	0.6 g @ 24 ms
Accelerometer #3	Vertical	0.6 g @ 17 ms
Accelerometer #4	Transverse	0.9 g @ 17 ms
Free Field #1	Inside Cab	0.02 psi @ 29 ms
Free Field #2	Inside Cab	0.03 psi @ 31 ms
Free Field #3	Arena	0.9 psi @ 23 ms
ConWep Prediction	Arena Prediction	1.3 psi @ 23 ms
Crater	Diameter/Depth	39 in diam / 15 in deep

5.4 Test 4: M15 Mine. The M15 Mine is an antitank mine that is contained in a round sheet-steel casing containing approximately 22.75 lbs Comp B explosive. The mine was buried level with the ground surface and near the center of the flail assembly (Figures 10 and 11). The incident pressure loads at the cab standoff (31.5 ft) were predicted by ConWep (Reference 3.3) to be approximately 9.1 psi. Table 4 summarizes the test results. The gauge plots are included in the Appendix. The robotics controls suffered no damage in Test 4.

Results: Mine Area Clearance Vehicle (MACV) Explosive Experiments

Figure 10. Pre-test: M15 Mine

Figure 11. Post-test: M15 Mine

Table 4. Test 4 Results

Gauge	Description	Measurement
Accelerometer #1	Transverse	No Data
Accelerometer #2	Axial	2.7 g @ 17 ms
Accelerometer #3	Vertical	8.7 g @ 17 ms
Accelerometer #4	Transverse	6.3 g @ 18 ms
Free Field #1	Inside Cab	0.11 psi @ 29 ms
Free Field #2	Inside Cab	0.17 psi @ 26 ms
Free Field #3	Arena	5.5 psi @ 19 ms
ConWep Prediction	Arena Prediction	9.1 psi @ 14 ms
Crater	Diameter/Depth	9 ft diam / 28 in deep

6.0 Discussion

The Mine Area Clearance Vehicle was exposed to a range of munitions, including blast and fragment-producing weapons. The only damage noted from any of the four experiments was a vent cover knocked loose in the operator's cab, and a few fragment nicks on the deflector shield next to the flail mechanism. The vehicle remained fully operational, including the robotic controls, throughout the test series.

Figure 12 summarizes the blast pressures measured in the four experiments. Except for the M67 Grenade (Test 2), the measured free field (incident) pressures tended to be only 60 to 73% of predicted. Nevertheless, in all cases the increase in cab pressure was minimal, well below any pressure increase that would cause even temporary hearing problems for people or damage to equipment.

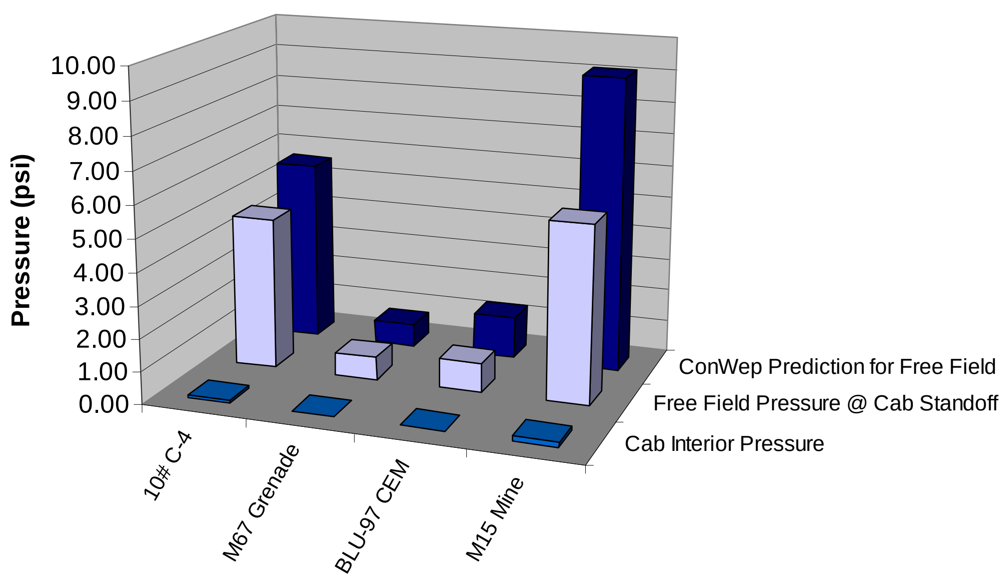


Figure 12. MACV Pressure Measurements

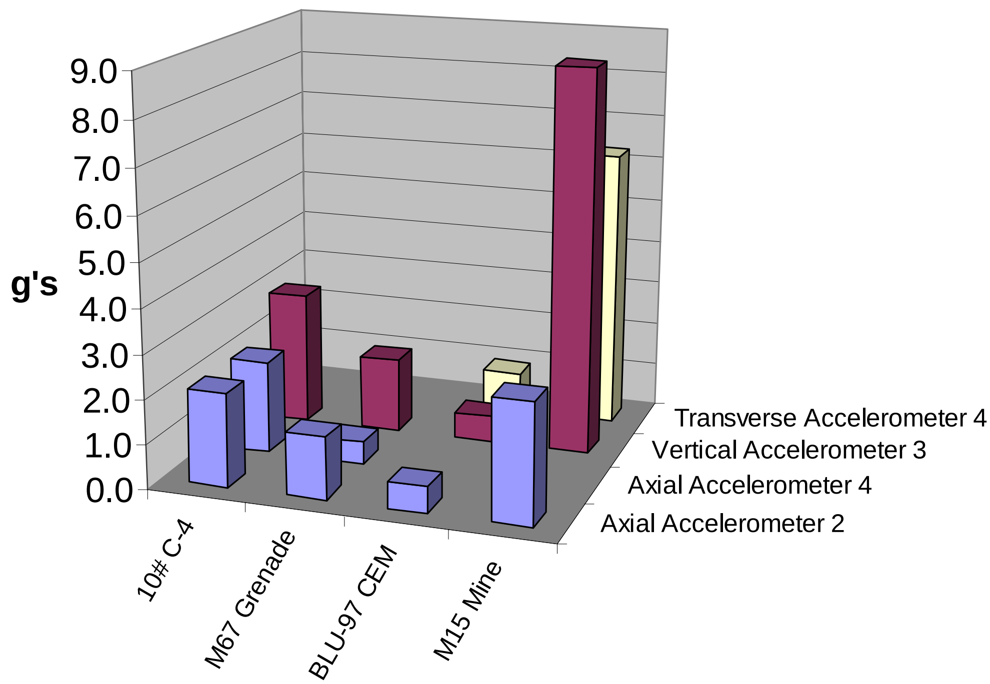


Figure 13. MACV Cab Accelerations

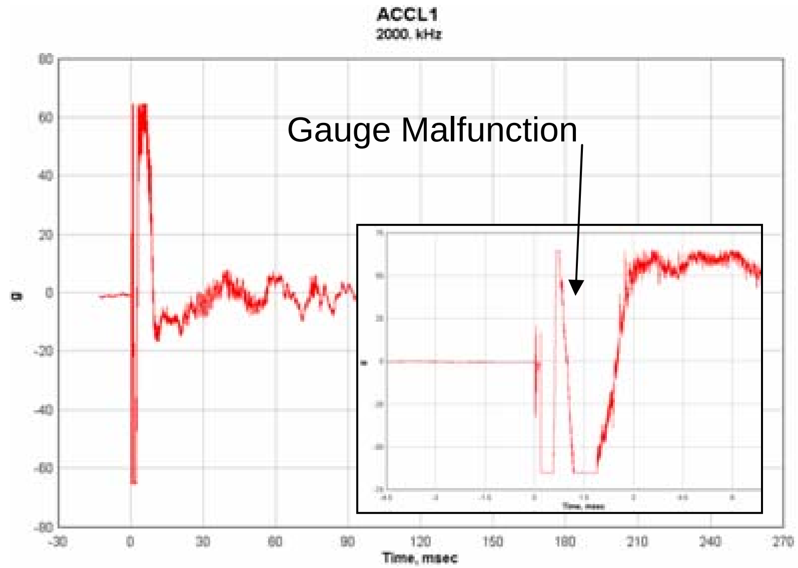
Figure 13 summarizes the accelerometer results from the four experiments. The magnitude of acceleration was taken as the maximum acceleration (either positive or negative) prior to the first "significant or obvious" spring back in the record. The pure accuracy of this data is always suspect due to the difficulty in interpreting accelerometer data (see Appendix). However, the general magnitudes are consistent with the blast pressures, and some reasonable conclusions can be drawn. The vertical accelerations usually had the largest magnitudes, and were close to the magnitude of the axial (front to back axis) acceleration, except for the M15 Mine experiment. Even the worst case, 8.7 g's vertical acceleration for the M15 Mine, was well below the 19.5 g's that similar robotic controls experienced in the airdrop testing of the All-Purpose Remote Transport System (ARTS) (Reference 2.2).

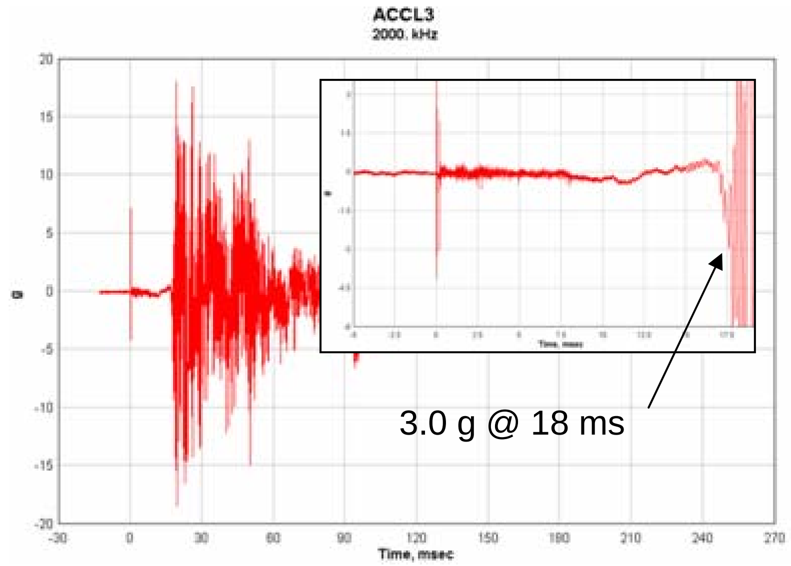
7.0 Conclusions

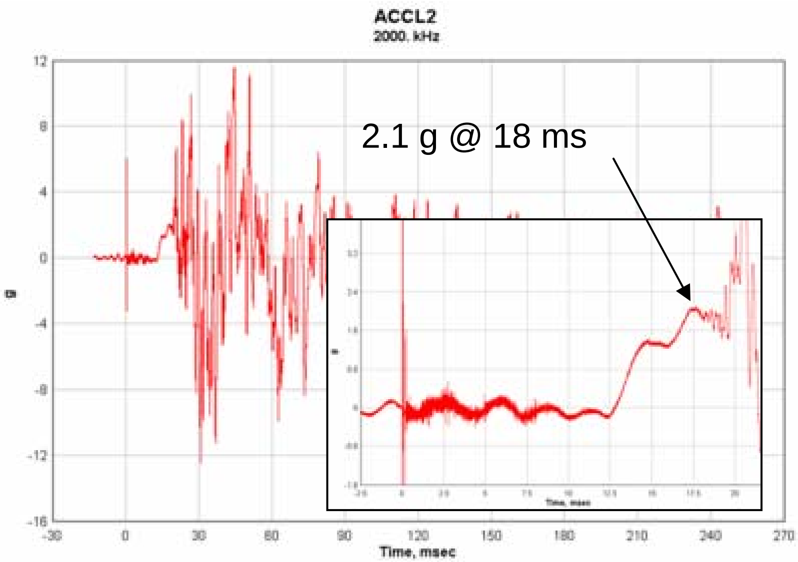
The robotically-controlled Mine Area Clearance Vehicle (MACV) was exposed to a range of munitions detonated adjacent to the mine-clearing flail, ranging from antipersonnel weapons to antitank weapons. None of the weapons had an appreciable effect on the MACV or on the robotic controls contained in the operator's cab. The vehicle cab was exposed to approximately 5.5 psi incident pressures on the exterior, but the interior pressure increased less than 0.2 psi. The magnitude of shock experienced by the cab and the robotic controls was 8.7 g's or less, well within the proven capacity of the control systems of 19.5 g's. Overall, the MACV did a good job protecting the cab and the robotic controls in the experiment series.

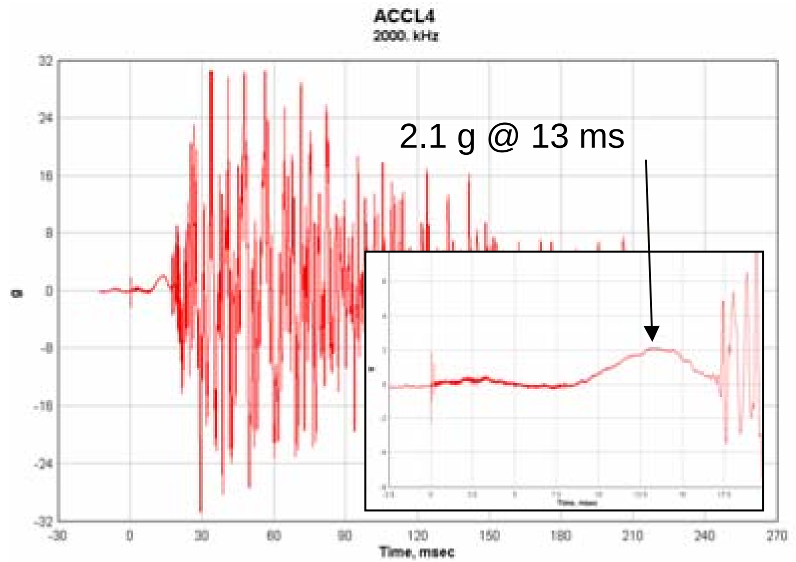
Appendix: Data Graphs

MACV – Experiment 1

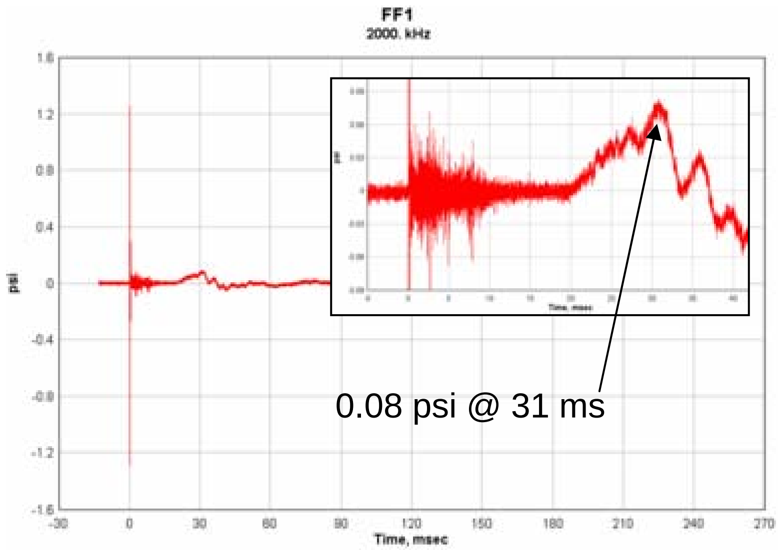


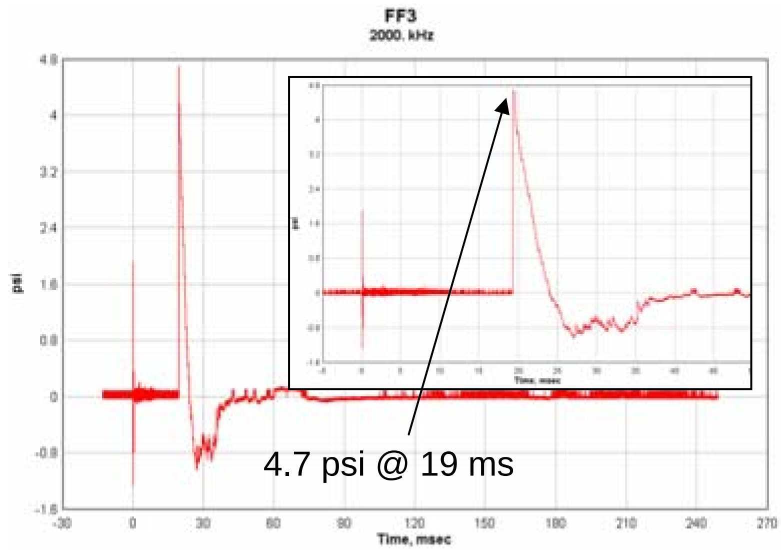


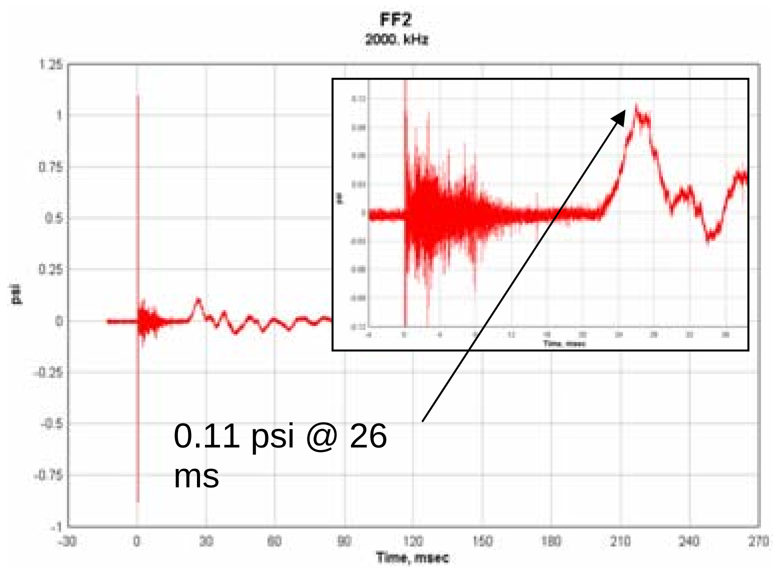




MACV – Experiment 1







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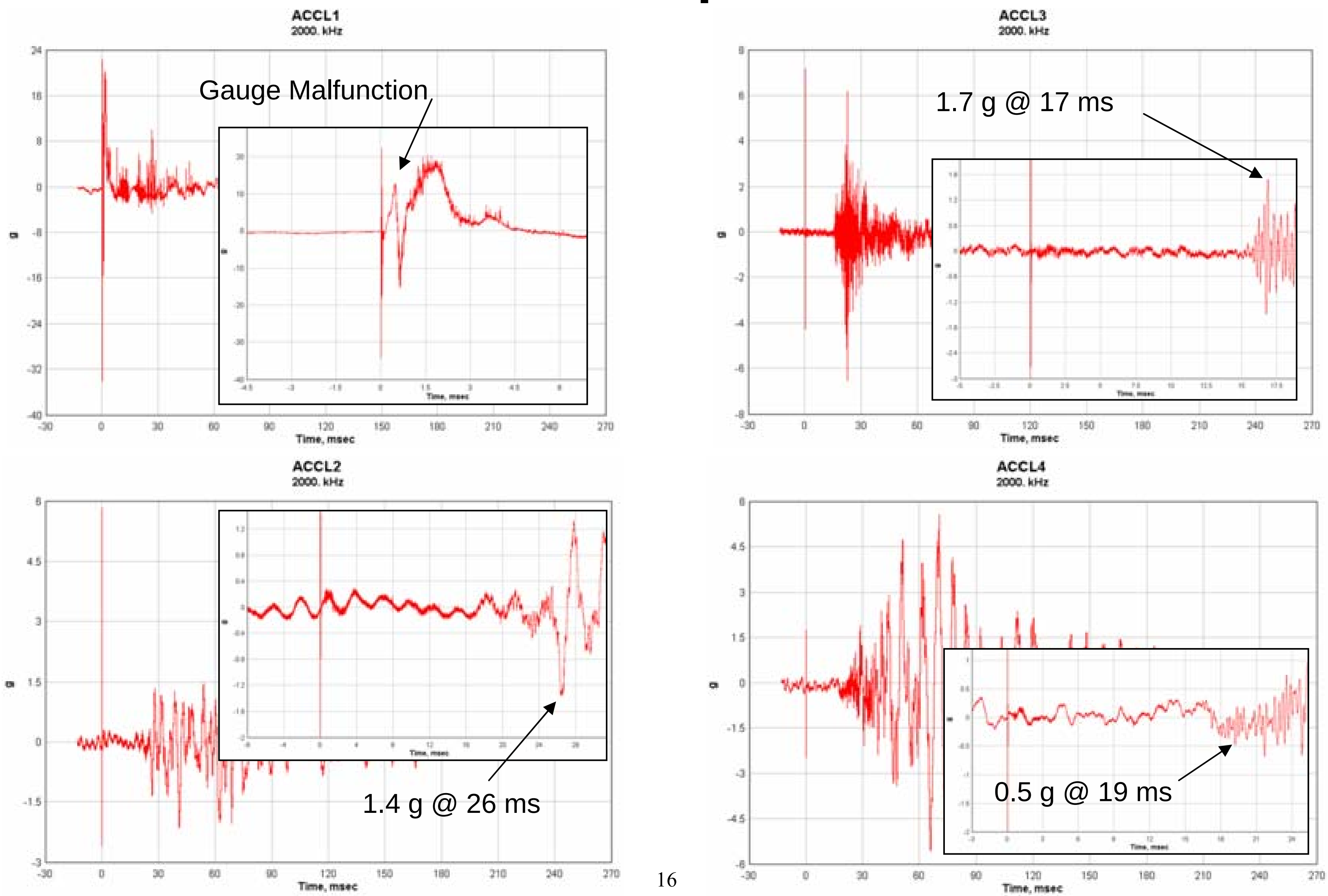

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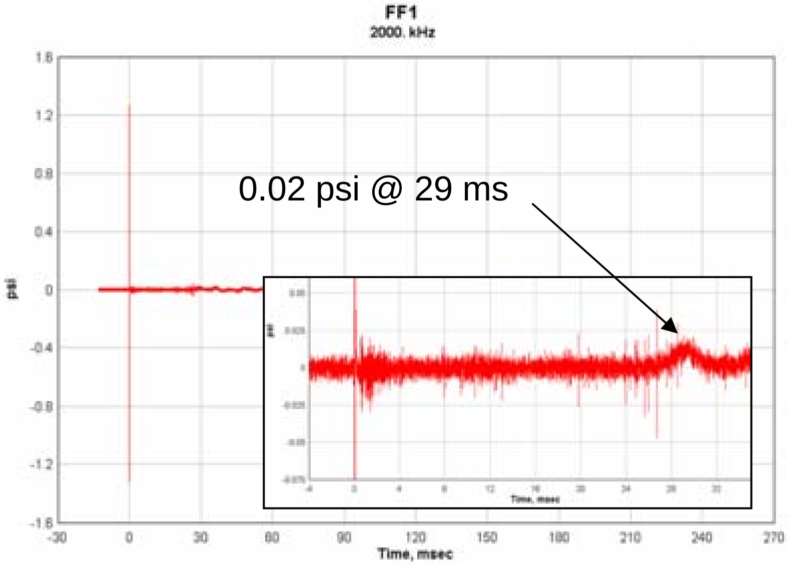

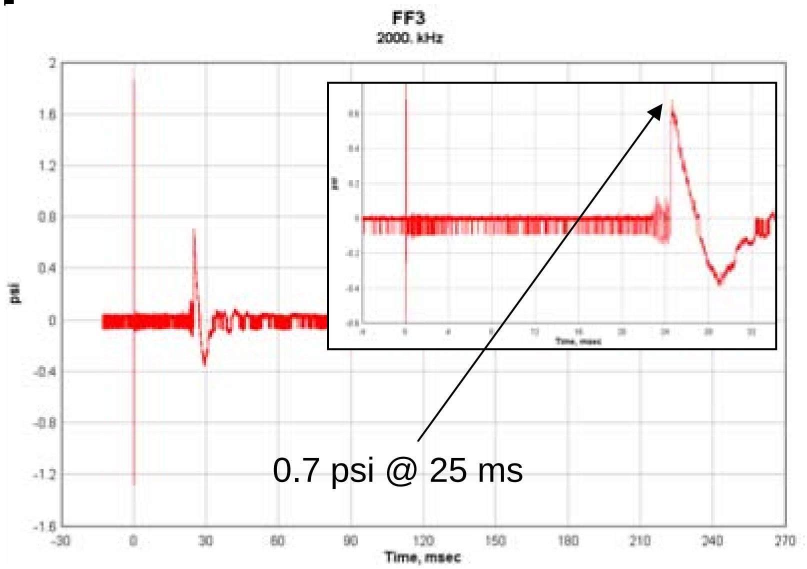

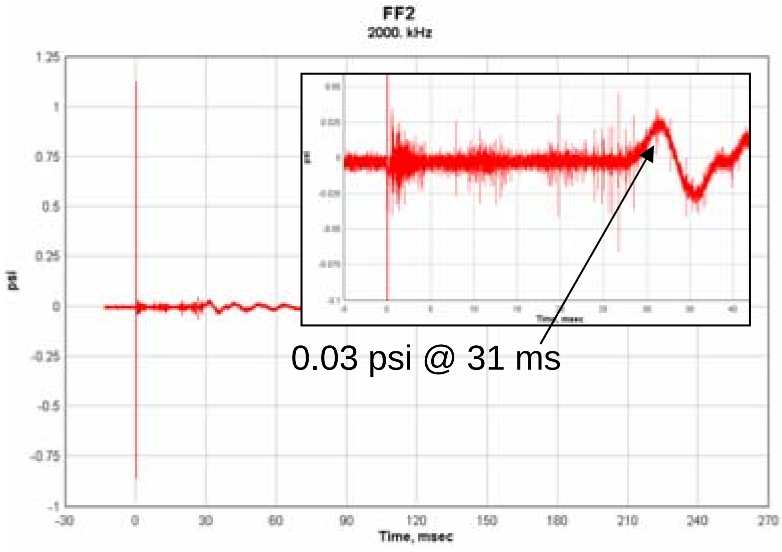

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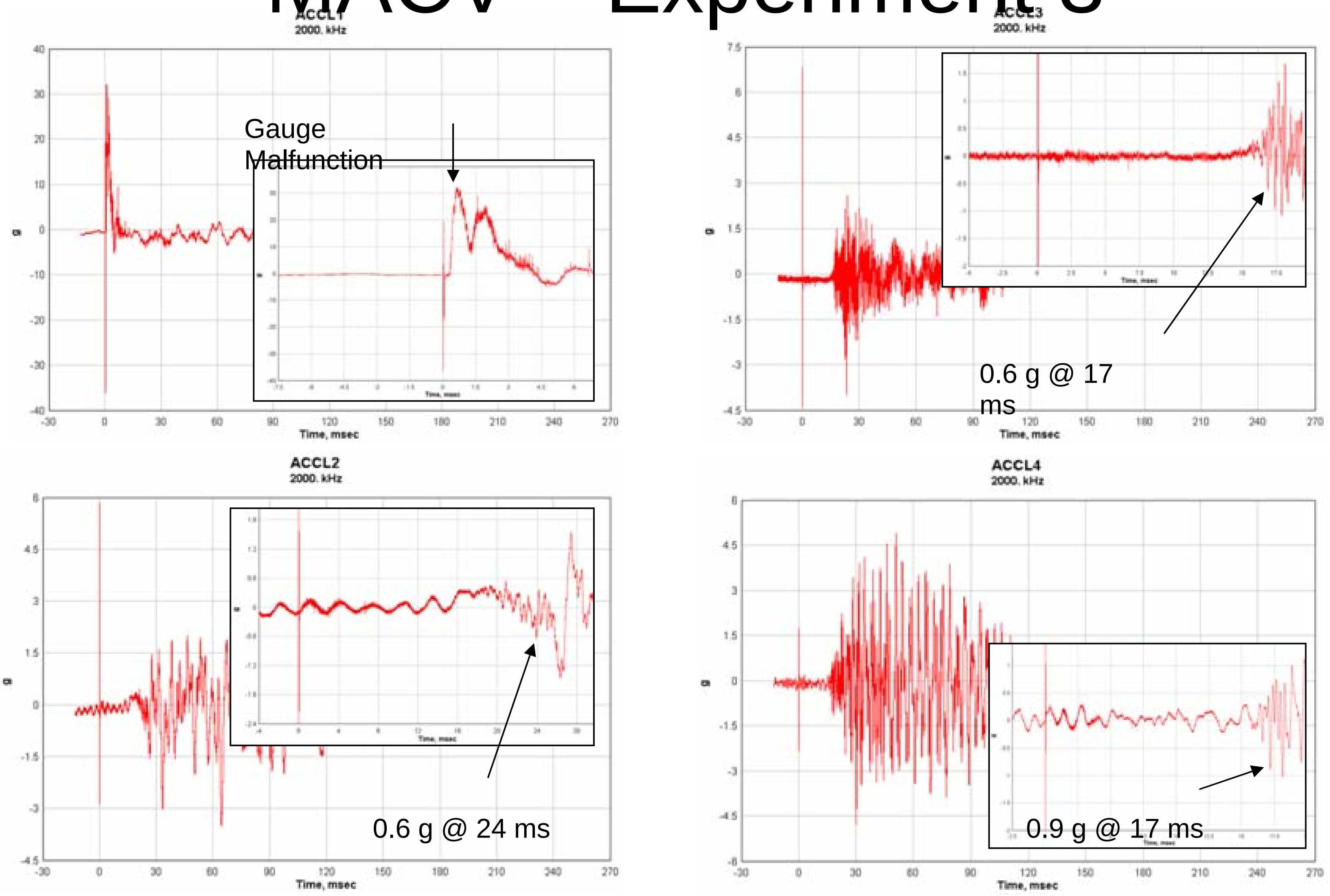

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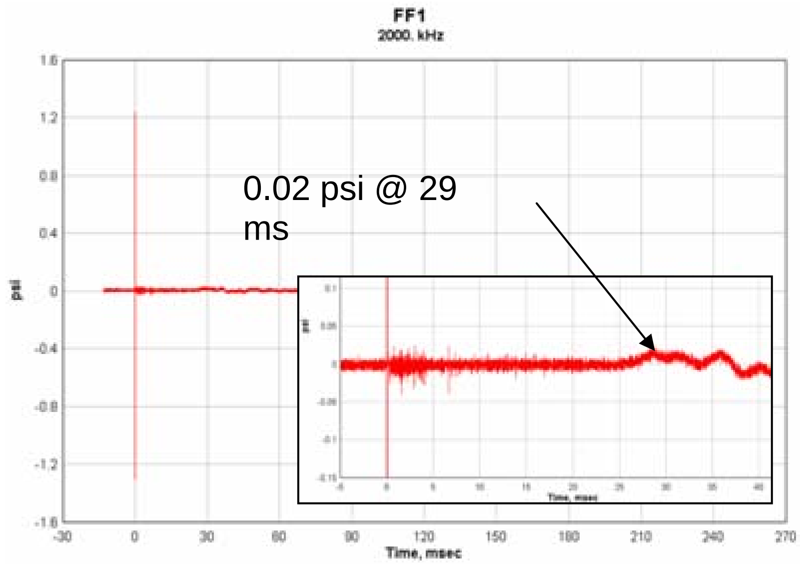
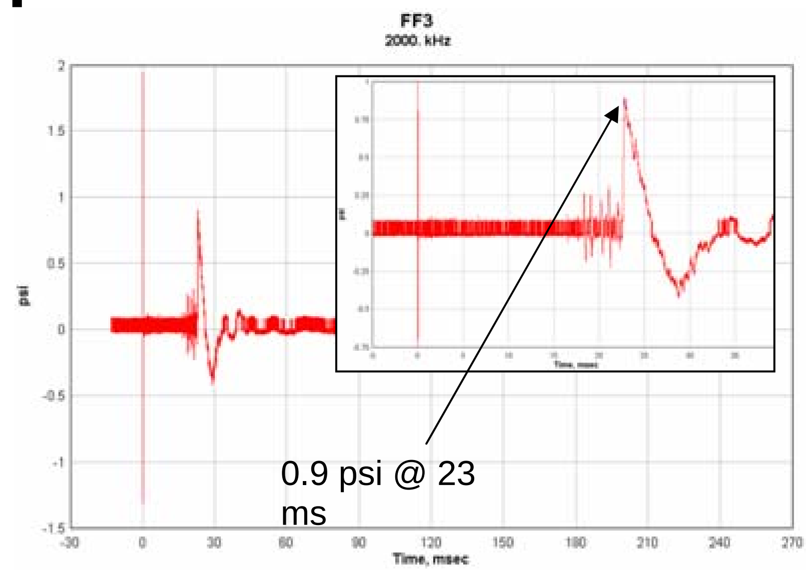
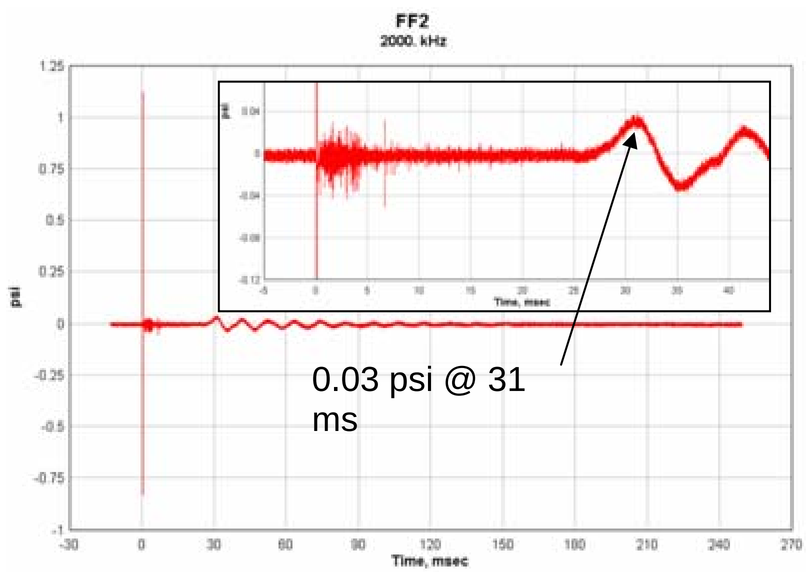
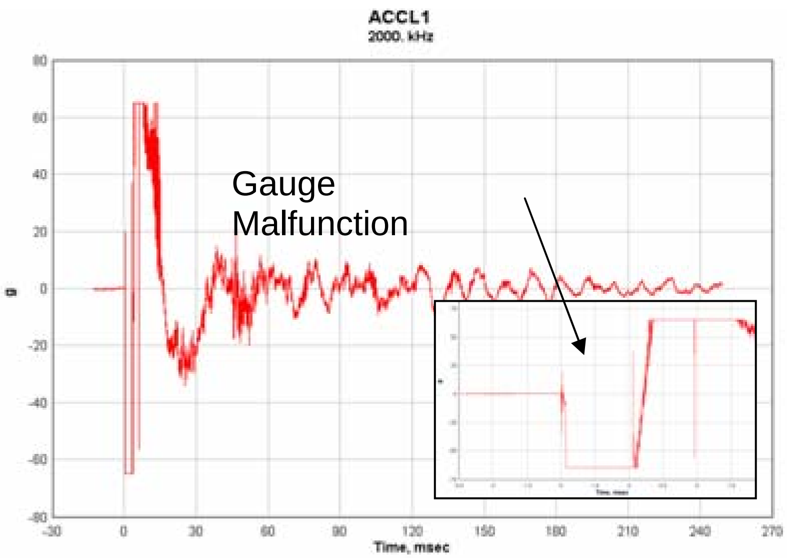
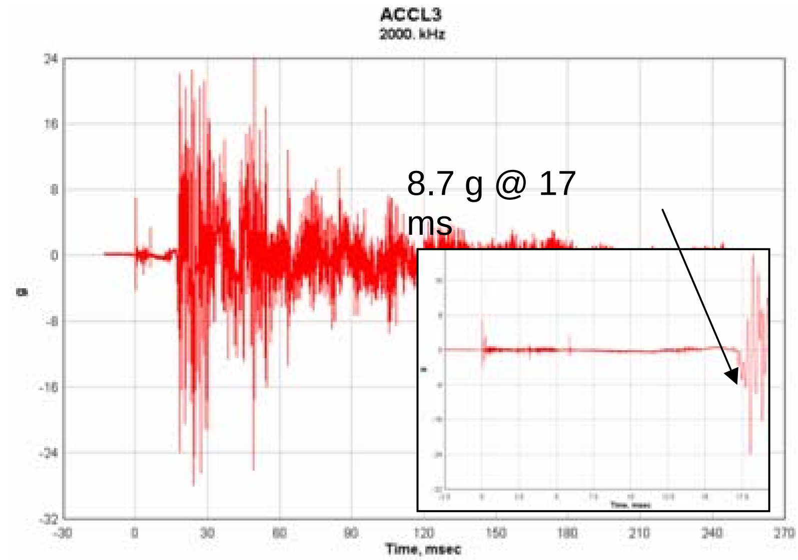


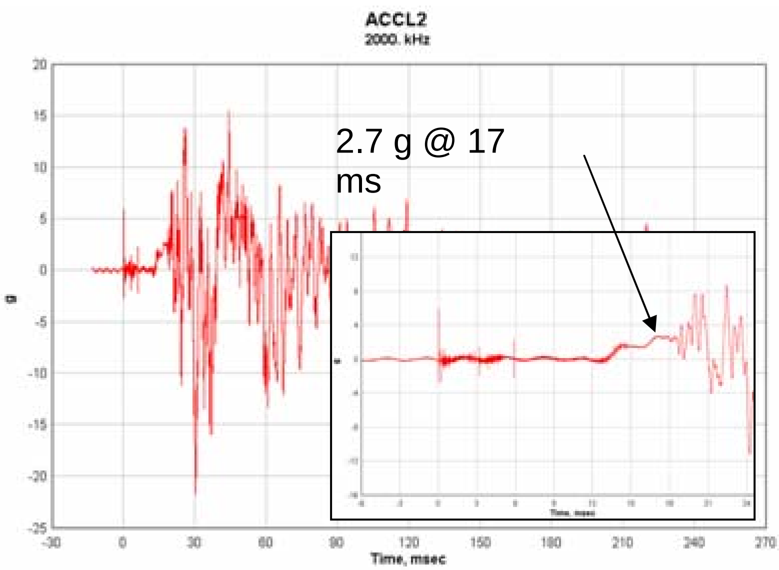


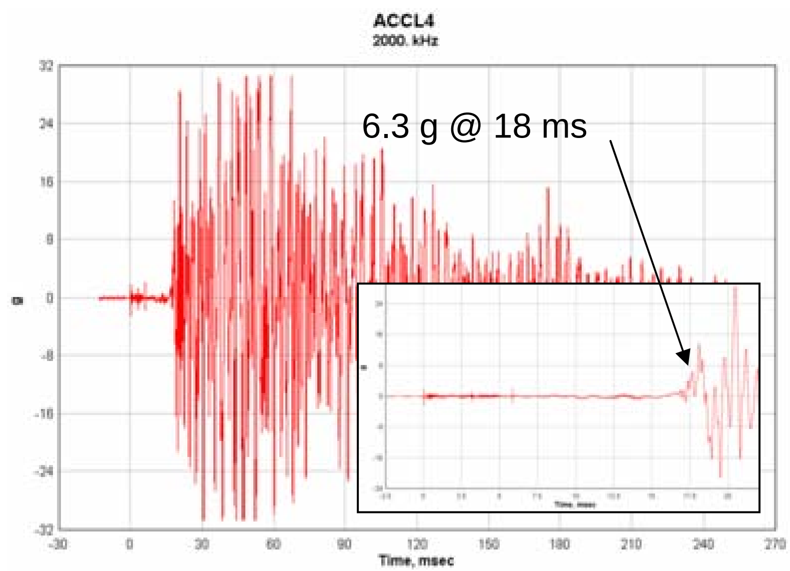


MACV – Experiment 4









MACV – Experiment 4