# Pre-Trial Assessment of Digger D2

Chris Leach
For and on behalf of the Canadian Centre for Mine Action Technology

October 2006

# Administration page

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# Executive Summary

This report details the results of a Pre-Trial Assessment (PTA) of the Digger D2 vegetation and ground-clearing flail. The PTA is an important part of the testing of a piece of equipment, allowing testing organisations such as those represented by ITEP (International Test and Evaluation Programme for Humanitarian Demining) to gather and verify basic data quickly and cost effectively before committing significant time and effort of a full test of the equipment. Although a PTA will not be able to give accurate information on the performance it has been designed to highlight trends and characteristics of the equipment in that can be explored further at a later stage.

The tests conducted demonstrated that the machine has the potential to clear mines, albeit with limitations. Due to lack of suitable available vegetation, evidence of Digger D2's ability to clear vegetation was gleaned from video taken of tests performed earlier this year in Sudan. The tests and the video footage along with observations made during the PTA highlighted a number of important characteristics of the machine, both positive and negative:

**Positive**

- Flails ground very effectively to a depth of ~15cm
- The possibility of using a number of different tools in place of the flail, providing good versatility
- It is compact and easily transportable using a truck or trailer with an 8 Tonne load capacity.
- Highly mobility due to ground clearance and tracks
- The Digger D2 appears to be built to a high quality and technical specification with an emphasis on ease of maintenance and robust components.

**Negative**

- In current configuration the Digger D2 is not able to flail much deeper than a maximum of ~20cm
- With the chains so short and the flail shaft so close to the ground there is potential for major damage if larger UXO is encountered and detonates.

The main recommendation to the manufacturer would be to experiment with a longer chain and hammer configuration in order to increase the clearance depth as well as mitigate the damage caused by the effects of detonating larger UXO.

Even if the above recommendation is not followed through, it is believed that the Digger D2 has the potential to be a valuable tool for the demining community and it is recommended that a prospective user consider it for further testing and/or field trials.

# List of contents

# 1 Introduction

## 1.1 Terms of Reference

The requirement for the trials is outlined in Contract Number W7702-06P263 – Pre-Trail Assessment of the Digger D2.

## 1.2 Background

The International Test and Evaluation Program (ITEP), of which Canada, through the Canadian Centre for Mine Action Technologies (CCMAT), is a member, has agreed that testing of mechanical equipment for humanitarian demining should be based on agreed standards wherever practicable. The European Committee for Standardisation (CEN) Workshop Agreement CWA 15044 provides the basis for this type of testing that has been adopted by ITEP.

Following the inspection of data from the manufacturer, the recommended first step in CWA15044 is a Pre-Trial Assessment (PTA). Normally conducted at or near the manufacturer's facilities, this stage is used as a filter to ensure that the machine in question is sufficiently capable, and the design sufficiently mature that it is worth proceeding to the next steps in CWA15044, which are much more expensive in terms of time, labour, and other resources.

The Digger D-2 flail is a machine that has been developed by Digger DTR, (a Swiss NGO) in Switzerland for the purpose of assisting in the process of humanitarian demining. Design and performance information has been reviewed, and CCMAT personnel made a visit to the factory. It was determined that a PTA was justified at this time.

## 1.3 Aim

The aim of the trial was to evaluate the performance and mobility of the Digger D2 under defined threat and terrain conditions.

## 1.4 Scope

The scope of the trial was to conduct a PTA in accordance with CWA15044 at an agreed location at or near the manufacturer's facility in Tavannes Switzerland.

The tests were to include an assessment of mobility to, in and from the minefield area. The equipment was also be evaluated on its ability to clear representative and live anti- personnel (AP) mines and other UXO, laid on the surface of, flush to the surface and buried in at least two different ground types. The operational running and maintenance costs shall be assessed as best as possible within this limited trial.

## 1.5 Trial Objectives

The key objective of this Pre-Trail Assessment shall be to perform tests and use best engineering judgement in order to present basic evidence to the customer (CCMAT) as to the maturity and applicability of the equipment in relation to current technology and methods used in Humanitarian Demining.

In doing so it shall be necessary to:

- To assess the mobility of the equipment using the facilities available.
- To make a “rule of thumb” assessment of the performance of the equipment under prescribed conditions and to estimate clearance rates of both mined and vegetated areas.

## 1.6 Authority

Mr Chris Leach, an independent Consultant Engineer, has been tasked to carry out the trials on behalf of the Canadian Centre for Mine Action Technology (CCMAT).

# 2 Equipment under test

Digger DTR, a Swiss charity, has developed Digger D2. The Digger D-2 is a lightweight, remote controlled demining and vegetation clearance vehicle for mine clearance assistance work. It replaces the Digger D-1, which was also developed by Digger DTR.

The primary tool is a vegetation/mine clearance flail however since it uses a Caterpillar® quick coupler theoretically other Caterpillar® compatible front-end attachments could be used.

*Figure 2-1 Digger D2*

In addition to the front end tools described above, the Digger DTR team are also developing a magnetic object sifting device to fit on to the rear of the vehicle. Currently, Digger DTR have a concept demonstrator model making it worthy of note here, however it was not possible to test or assess the capability of this device during the Pre-Trial Assessment.

The general specifications of the machine, as provided in the manufacturer's literature are as follows:

**ENGINE**

- John Deere 4.5ltr, 4-cylinder turbocharged diesel.
- The D-2 has a 3 stage filtration system, with one cyclone pre-filter, one oil bath air filter and one dry type air filter.
- Engine protection for oil, coolant temp etc. Hydraulic fluid protection for level & temp.
- Maximum power rating (ISO-3046, 2534): 104kW (140 hp) @2200rpm
- Maximum torque rating (ISO-3046, 2534): 540Nm @ 1400rpm
- Average fuel consumption: 22l/h

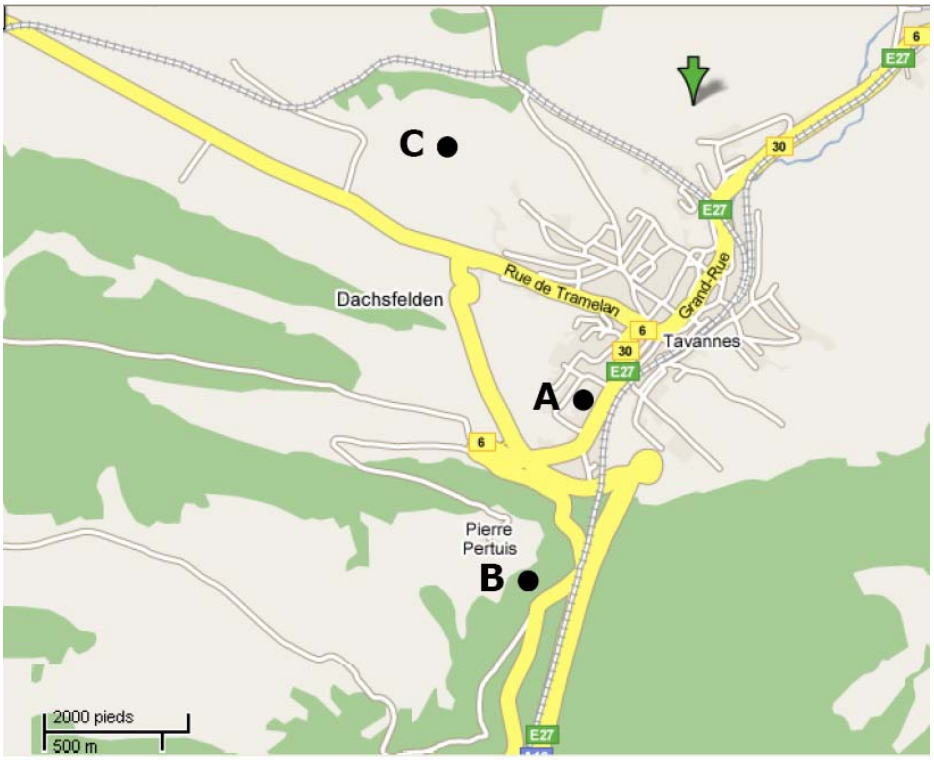
**CHASSIS**

- Body, arms and flail rotor made from Hardox anti-fragmentation steel.

*Figure 2-2 Three-stage filtration unit*

## 2.1 Location and personnel

The trial took place between 19th and 20th September 2006 at or near the Digger DTR offices and workshop in Tavannes, Switzerland.




Tests were conducted in three different locations:

- A – Digger DTR Facility
- B – A nearby stone quarry
- C – An agricultural field

## 2.2 Records

A trials plan [1] and Risk Assessment [2] were prepared in advance of the trial. All trial activities were recorded on video and still photographs. Results of each test were recorded on trial performance sheets, which have been retained by Mr. C Leach and are available on request.

## 2.3 Test Procedure

Test procedure sheets were issued for each test, a summary of the tests is shown in the table below. A description, summary of results and comments/observations of each test are detailed on the following pages.

| Day | | Activity | Place |
|---|---|---|---|
| Monday 18th September | a.m. | • Arrive, Set up, Familiarisation of equipment and surroundings<br>• General Dimensions<br>• Turning Circle<br>• Remote Control<br>1. Failsafe<br>2. Controlled Shutdown<br>3. Range (if not enough distance available, can be made on next day)<br>4. Operational Control<br>• Weights (D-2 taken to a weighbridge) | A |
| | p.m. | • Slopes & Gradients<br>• Obstacles & Rough Terrain | B |
| Tuesday 19th September | a.m. & p.m. | • Straight Line speed & Braking<br>• Horizontal Ground Flailing<br>• Speed versus Depth<br>• Pack up & Debrief | C |

*Table 2-1 Schedule of planned tests*

# 3 Results

## 3.1 Weights and Dimensions

### 3.1.1 General Dimensions

The following measurements were taken using a tape measure and a straight edge:

| **Measurement** | | **Length/Angle** |
|---|---|---|
| Height: | Top of air filter | 1.89m |
| | Top of flail unit (skids on the floor) | 1.67m |
| | Flail & air filter removed | 1.59m |
| Overall length | | 4.80m |
| Wheelbase | Length between front & rear drive wheels | 1.89m |
| | Length between front & rear road wheels | 2.16m |
| Width between the external faces of the tracks | | 1.65m |
| Width of flail header | | 2.17m |
| Width of cut made by flail | | 1.76m |
| Ground clearance under belly of tractor | | 0.23m |
| Approach angle | | 60.1° * |
| Departure angle | | 48.2° |
| * The approach angle is effectively 90° since with the flail-arm raised, the front wheels are the first part of the vehicle to hit an obstacle | | |

*Table 3-1 Digger D2 general dimensions*

Some of these dimensions are slightly different to those stated in the manufacturer's information pact. This can be put down to modifications and changes made after the original Digger D2 went through development trials in Sudan.

*Figure 3-1 Digger D2 with flail raised*

### 3.1.2 Weights

The Digger D2 was loaded onto a truck and taken to a local recycling centre where both the truck and Digger D2 were weighed using a weighbridge. It was not possible to unload the Digger D2 there so only the gross vehicle mass was measured.

The following results were obtained. All measurements are in kilograms.

| | **Mass** |
|---|---|
| Truck plus Digger D2 | 18349kg |
| Truck | 10980kg |
| Digger D2 (with half a tank of fuel) | 7360kg |

*Table 3-2 Digger D2 weights*

*Figure 3-2 Digger D2 and truck -on the weighbridge*


*Figure 3-3 Weighbridge printout*

## 3.2 Handling and Mobility

### 3.2.1 Turning Circle

The Digger D2 was parked on an area of level ground. A container of cooking oil was attached to the front left corner of the flail header, positioned so that oil would drip onto the ground directly beneath the outermost corner of the vehicle as it turned to the right. The vehicle was then driven slowly through 360° to the right using its maximum turning using skid-steer.

The diameter of the circle was measured at three different points and the average taken to be ~6m (± 0.05m)

### 3.2.2 Straight Line Speed and Braking

From a rolling start the machine was timed over a 26.75m run on a flat and level surface (the maximum practicable distance available). It was driven at the maximum safe speed, and at the end of the run it was brought to a halt in the minimum distance possible, which was also recorded.

The conditions were a wet muddy clay soil in which the tracks sunk ~20mm at standstill.

The following results were obtained:

| | |
|---|---|
| Time for 26.75m | 31 seconds |
| Maximum speed | 0.86m/s = 3.1km/h = 1.92mph |
| Stopping distance from max speed | 0.35m |

*Table 3-3 Maximum speed and braking results*

***Manufacturer's comment:***

*The maximum speed seems to be much lower than what we expected and measured.*

*The design of the hydraulic system was made in order to achieve a 5.5km/h max speed, and the indication on the RC Unit gives a maximum speed of about 5-5.8 km/h. In addition, when D-2 is moved at its maximum speed, the operator has to walk fast in order to follow it, so the value of 3.1 km/h is surprising.*

### 3.2.3 Slopes and Gradients

Using the various slopes encountered at a local stone quarry (marked as 'B' in section 3.1) it was possible to attain a crude idea of Digger D2's gradeablity (or ability to climb slopes).

The Digger D2 was required to drive up a selection of slopes of increasing gradient, come to a complete stop halfway up the slope and then continue to the top of slope.

Driving Digger D2 up an access slope with on track in the adjacent gully assessed side slope.

The following results were obtained:

| Gradient | Direction | Terrain | Result |
|---|---|---|---|
| 24° | Forward (Stop & Restart) | Loosely compacted spoil from quarry | Lost traction due to lack of cohesion in the soil, brakes OK |
| 28° | Reverse (Stop & Restart) | Loosely compacted spoil from quarry | Ascended about half way, stopped, insufficient torque to continue. Descended satisfactorily forward, brakes OK. |
| 22° | Side Slope | Loamy Soil, light vegetation (Off-road) | Satisfactory (down only), brakes OK. |

*Table 3-4 Results of the slope test*

Measurements were taken using a digital spirit level and rounded to the nearest whole degree.

Unfortunately, the slopes available on the day were not sufficiently steep to challenge the Digger D2.

*Figure 3-4 Climbing 24° slope*


*Figure 3-5 Measuring side slope*

### 3.2.4 Obstacles & Rough Terrain

Whilst at the quarry site (site B) the Digger D2 was driven over a number of obstacles (rocks and tree trunks) in various orientations. On most occasions the machine merely pushed the obstacle out of the way but on the few occasions where it did mount the obstacle it crossed it easily (see pictures below).

It was during this test that a rough estimate of the front-to-rear balance point (and therefore the weight distribution) was made. This is useful to know since it will be an indication of any mobility and stability issues a machine will have during loading and transportation and also operations in soft terrain. In the case of the Digger D2, it appears to have a good weigh distribution with the balance point occurring just behind the third road wheel (see figure 4-7).

*Figure 3-6 Crossing improvised obstacles*

*Figure 3-7 Finding balance point of Digger D2*

## 3.3 Remote Control

### 3.3.1 General Description

The remote control system has two-way communication between the operator and the machine allowing for monitoring of certain critical factors such as engine temperature, fuel and hydraulic oil status. Fully charged the unit can operate for ~20 hours. The remote control can be charged from the machine or using a separate battery charger. All components have be tested to work from -10°C to 70°C and are sealed against water ingression and humidity such as that found in tropical climates.

### 3.3.2 Failsafe

Prior to evaluating the performance of the system under remote control, a basic check of its safety was carried out. This was done by performing basic manoeuvres with the Digger D2 (moving forwards, backwards and turning around) and then cutting the power from the remote control unit.

On switching off the remote control unit the engine kept running for no more than 10 seconds. For safety reasons – the test was being conducted in a relatively small courtyard – the Digger D2 was stationary, however it was explained that without a signal from the unit the machine would not move. Thus it was felt safe to proceed with further tests.

### 3.3.3 Controlled Shutdown

The next test of the remote control system was to ensure that the vehicle could be brought to a rapid and controlled shutdown. This was satisfactorily demonstrated, with no apparent delay between the operator's commands and the vehicle responding.

### 3.3.4 Range

The operator started at a distance of 300m from the Digger D2 and was able to perform all manoeuvres required satisfactorily. He then moved further away and out of the line of sight of the machine to a position 390m away and was, again, able to perform all manoeuvres required satisfactorily (start, move forward and back). At this distance it would be impracticable to operate the Digger D2 with any degree of accuracy due to the operator's ability to see.

## 3.4 Ground Flailing

### 3.4.1 Speed versus depth

Four test lanes of 6.6m were marked out for flailing on flat ground. The ground available fro this set of tests could be described as heavy, wet loamy clay. Each area had four hardboard sheets buried in it, 2.5m long by 0.3m wide (deep), buried on edge flush with the surface, orientated across the direction of travel of the machine. In the last two lanes electronic surrogate mines (WORMs) that transmit a signal when they are activated were also dug in at depths ranging from flush buried to 15cm deep. Six WORMs were placed a line along the centreline of each of the last two lanes. The WORMs were buried at the following depths (measured to the top of the main body of the mine):

- Flush buried
- 5cm deep
- 5cm deep
- 10cm deep
- 10cm deep
- 15cm deep

The intention of these tests was to flail each area at a constant depth (around 15cm) and to increase the forward speed of the machine with each test until the hardboard sheets indicated that forward speed was too high and hence obtain maximum forward flailing speed for the machine at that flailing depth.

*Figure 3-8 WORM mine surrogate as used in runs 4 and 5.*

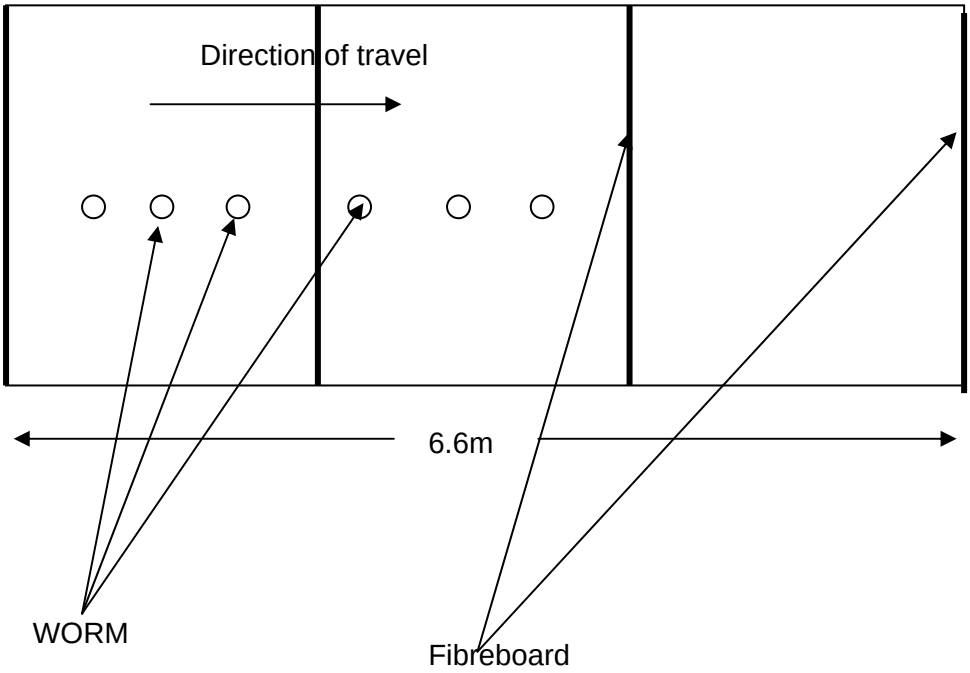



*Figure 3-9 Sketch of test lane (WORMs only used in runs 4 and 5)*

The boards were numbered 1 to 4 for the first test lane, 5 to 8 for the second lane and so on. Pictures of the board can be seen below.

The boards provided a clear indication of how deep the flail chains were cutting and whether they were achieving consistent cutting across the width of the flail. Previous tests had indicated that if flailing depth is too large or forward speed too high or flail rotational speed too low, uneven flailing will occur and sections of the hardboard strips will remain intact, whereas correct flailing will cut away an even depth of the boards across the entire width.

For all the flail tests the flail shaft was rotating at ~700rpm.

*Figure 3-10 First run (without boards) showing the type of soil in the lane.*

| Run | Time for 6.6m (s) | Speed km/h (Miles/h) | Flail cut profile | Comments |
|---|---|---|---|---|
| 1* | 84 | 0.28 (0.18) | Clean, ~15cm deep | Familiarisation run – no boards |
| 2 | 114 | 0.21 (0.13) | Clean, ~16cm deep | |
| 3 | 120 | 0.20 (0.12) | Clean, ~15cm deep | Skid set to lowest (deepest) setting. |
| 4 | 93 | 0.26 (0.16) | Clean, ~15cm deep | All but the last WORM (@15cm) destroyed |
| 5 | 115 | 0.21 (0.13) | Clean, ~15cm deep | All WORMS destroyed |
| * - “Dry run” with no boards | | | | |

*Table 3-5 Times and speeds for 6.6m flailing runs*

Due to the length of the chains and the design of the skid, Digger D2 is able to penetrate the ground to a maximum depth of ~15cm although as shown by the evidence from the fibreboards it appears to be able to process the ground effectively up to that depth.

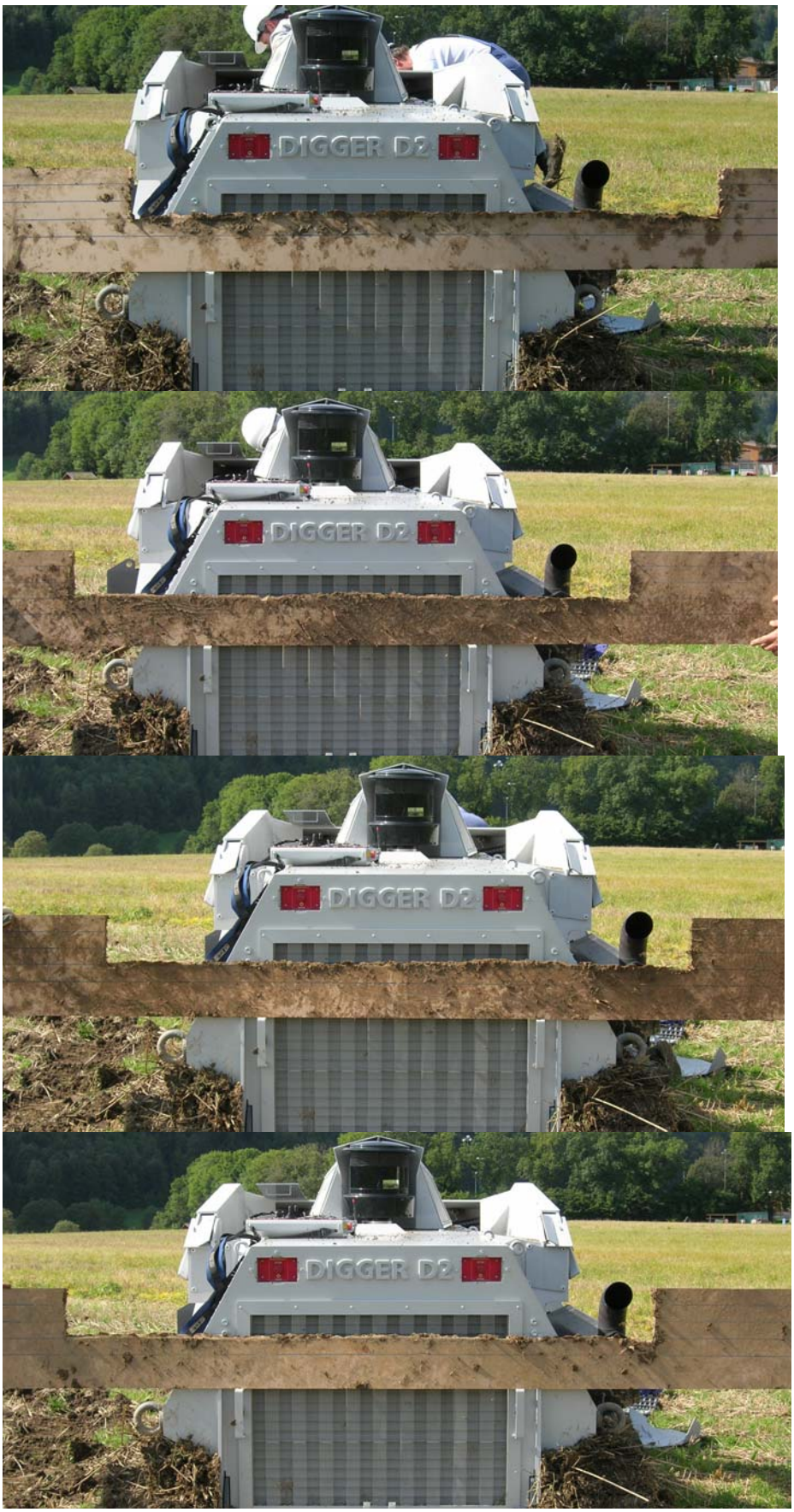



*Figure 3-11 Boards 1 to 4 (from run 2)*

*Figure 3-12 A board from run 3 still in situ*


*Figure 3-13 Board no. 7 (from run 3) showing a clean-cut profile at just over 15cm*

## 3.5 Vegetation clearance

Unfortunately it was not possible to test the Digger D2 for its ability to clear vegetation. It was decided that it would not be safe to use the area of vegetation available, at the base of the quarry face because of the risk of causing a rock fall.

A short film of the previous version of Digger D2 working in Sudan was submitted as evidence.

## 3.6 Logistics

With the trial only spanning two days very little could be gained from recording fuel consumption. However it was noted through observation and demonstration that a lot of thought had gone into making maintenance and repair of this machine easy.

For recovery the tracks can be made to freewheel by removing the extractable driveshafts.

Figure 3-14 Digger DTR mechanic performing routine maintenance

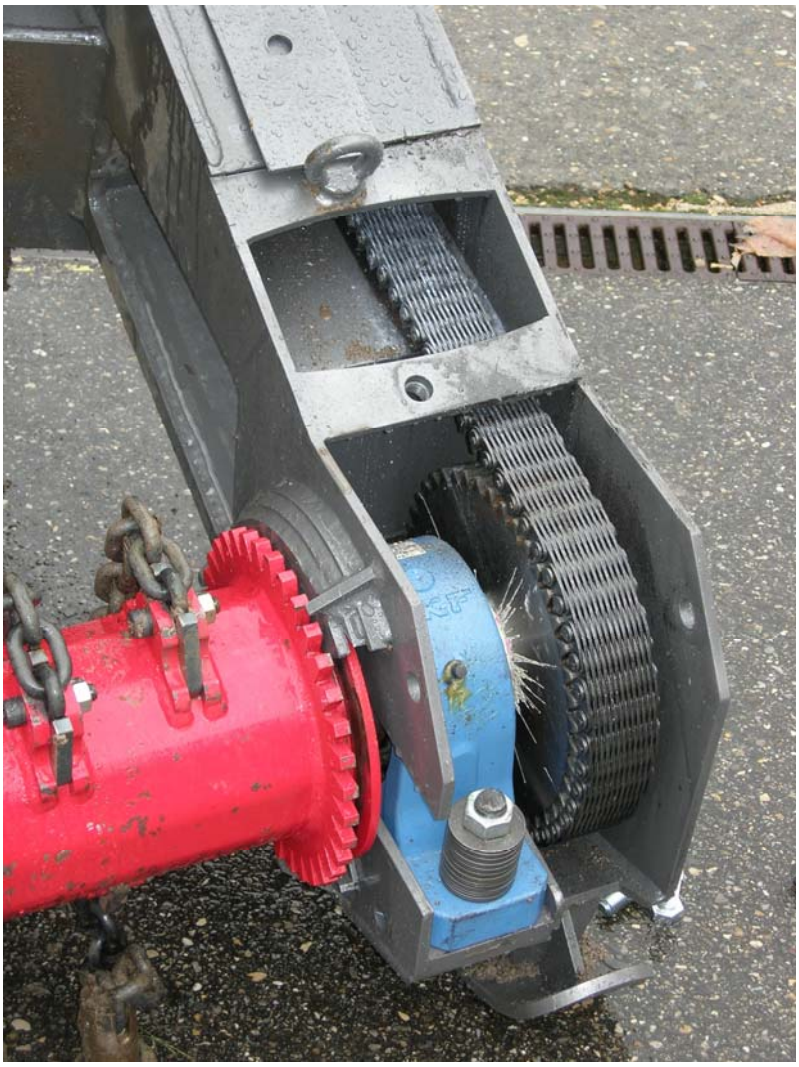


*Figure 3-15 Easy access for maintenance*

# 4 Conclusions

Overall the Digger D2 was considered to have the potential to be a useful tool for mechanically assisted demining. A number of particularly useful features and capabilities were recognised, but also a number of significant shortcomings. These are summarised below:

- Compact machine with a good approach and departure angle.
- Minor modifications have been made to the original Digger D2 plans possibly due to development trials in Sudan
- Relatively lightweight (7360kg) and easily transportable
- Due to its skid steer tracks the Digger D2 has and excellent turning circle – It is able to turn virtually on its own axis.
- The Digger D2 is well balanced with an even weight distribution between the front and rear.
- The tracks have no rubber pads presenting potential problems when driving on soft prepared surfaces such as tarmac.
- Although the Digger D2 is very manoeuvrable, it moves relatively slowly so would need to be transported to very near its place of work
- Digger D2 has good gradeablility with the potential to move safely over steep slopes and traverse side slopes.
- Digger D2 appears to have a stable and safe remote control system
- The operator is able to monitor the status of the machine via the screen on the remote control unit
- The range of the remote control system (>390m) is adequate for most operational situations. At this distance it would be impracticable to operate the Digger D2 with any degree of accuracy due to the operator's ability to see.
- Due to the length of the chains and the design of the skid, Digger D2 is able to penetrate the ground to a width of 1.8m and a maximum depth of ~15cm. As shown by the evidence from the fibreboards it appears to be able to process the ground very effectively up to that depth. Similar results were demonstrated on the DVD in the hard baked ground of Sudan.
- With an average clearance speed during the trial of over 0.2km/h Digger D2 is averagely fast. However, judging on how effectively it was cutting through the ground there is scope to run the machine quicker.
- The fact that it destroyed all but one of the WORMs reinforces the evidence from the fibreboards that Digger D2 is potentially very effective at clearing mines up to a depth of ~15cm. The missed mine, which was buried at 15cm, could be an indication that this is the limit of the clearance with the Digger D2 in its current configuration.
- With the chains so short and the flail shaft so close to the ground there is potential for major damage if larger UXO is encountered and detonates. This has been to some extent mitigated by manufacturing the flail unit arms and shaft from Hardox Anti-fragmentation steel and also setting the shaft bearing on an energy absorbing spring mounting.

- From what was seen on the video Digger D2 has the ability to perform most vegetation tasks
- A lot of thought had gone into making maintenance and repair of this machine easy.

# 5 Recommendations

Digger D2 appears to be very advanced in its development considering that it has not been used operationally except in a vegetation clearance role in Sudan.

The main recommendation to the manufacturer would be to experiment with a longer chain and hammer configuration in order to increase the clearance depth as well as mitigate the damage caused by the effects of detonating larger UXO.

Even if the above recommendation is not followed through, it is believed that the Digger D2 has the potential to be a valuable tool for the demining community and it is recommended that a prospective user consider it for further testing and/or field trials.

# Initial distribution list

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The PTA allows testing organisations such as those represented by ITEP (International Test and Evaluation Programme for Humanitarian Demining) to gather and verify basic data before undertaking costly and time consuming effectiveness trials. Although a PTA is not intended to definitively measure performance, it does indicate the general characteristics and potential performance issues of the equipment so that they can be explored further at a later stage.

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