Measurement of Projectile Energy and Velocity
Requirements for the Disruption of Unexploded
Ordnance

by

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Submitted to the Department of Mechanical Engineering
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Abstract

This paper details the design and fabrication of a disrupting test rig for measuring the energy required to separate the fuze from the casing of unexploded ordnance (UXO), also called disrupting the device. Preliminary tests were conducted using an explosive disrupting tool and the energy for disruption relative to input kinetic energy was estimated and used to design a test rig with suitable energy to ensure disruption. The disrupting test rig operates on the same principle as a Charpy Notch testing machine, and can deliver up to 3kJ of kinetic energy with its 3m long and up to 137kg mass pendulum arm. A sliding fixture mechanism provides kinematic constraints to allow the fuze body to be pulled out of the casing by the projectile. Measurements taken with the disrupting rig show that disruption can be achieved with as little as 1.5kJ of kinetic energy, assuming the casing is rigidly fixed to ground during disruption. This work will inform further development of a non-explosive tool to replace existing explosive disrupting tools.

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Chapter 1

Introduction

Landmines and unexploded ordinance are dangerous left-overs from past conflicts in many countries around the world. Cambodia in particular carries a large burden of infected lands, restricting access to farmland, grazing land, and water resources [4]. One particular issue in solving this problem is defuzing or disrupting UXOs (i.e., separating the fuze from the high-explosive material) once they are identified. One primary technique exists for accomplishing this task, which employs a high-power rifle cartridge to precisely fire either a metal slug or a slug of water at the joint between the two components, mechanically separating them. Humanitarian demining organizations would prefer to work with a device which can perform the same task without the use of the rifle cartridge, in order to minimize the safety and security risks of handling energetic materials in their operations. This thesis describes an investigation into the functional requirements for a non-explosive version of the disruptor tool. The researcher spent more than three months in Cambodia over the course of the project, working alongside Cambodian engineers and technicians to design, fabricate, and utilize a disrupting test rig to determine these functional requirements.

Chapter two describes some background of the problem of explosive remnants of war (ERWs) around the world, and existing techniques for de-arming UXOs.

Chapter three discusses demonstrations and a theoretical analysis of the current technique for disrupting UXOs and calculations of the kinetic energy required for the
de-arming function. The role of velocity vs. mass of the projectile and expectations of the experiment as conducted in Cambodia are also discussed.

Chapter four describes the design, construction, and use of the disrupting test rig, including some of the challenges inherent in doing work in Cambodia and, more generally, the developing world.

Chapter five describes the results from the operation of the test rig and compares them to the original analysis described in Chapter 3.

Chapter six offers conclusions and directions for future work.

1.1 Unexploded Ordnance

"Explosive remnants of war" (ERW) is the term used to describe any explosive piece of hardware left behind after an armed conflict. Landmines, in use since the American Civil War, are the most well-known ERW as well as the most costly. This is in particular due to their initial design intent: to deny use by the enemy of a piece of land, and to remain hidden until the enemy approaches[10]. Unexploded Ordnance (UXO), on the other hand, are relatively easier to identify, yet still a large threat in post-conflict areas. McGrath defines UXO as 'any object containing explosive of any kind which has been deployed and failed to detonate, or has only partly detonated, or such objects which have been abandoned in any condition' [10]. They can be in the form of any type of ordnance: from artillery shells to large bombs dropped from airplanes. The existence of a UXO implies that something went wrong in the arming sequence, firing, or dropping of the device. This also leads to their inherent danger: only the failure (almost never identifiable from the outside of the device) need be overcome to cause the explosives inside to detonate. The intactness of a UXO also causes those who discover it to assume its safety, suggesting that "if it's been lying here all this time and not detonated, then it must be safe to handle."

To a humanitarian demining team, UXO offer a different set of challenges compared to anti-personnel and anti-tank mines. UXO are much easier to detect, since they typically consist of large amounts of steel (easily identified using metal detec-
tors), but since different ordnance which look similar from the outside may have significantly different internal designs and therefore failure modes, special care must be taken in identifying UXO and deciding on a neutralization method.

If a UXO can be successfully identified, and a benign failure mode is the accepted standard for that particular UXO, then the device can be moved to a safe location for neutralization. If, however, the identified model of ordnance is known to fail in an unsafe manner, or if the deminer is uncertain of the ID of the UXO, then it must be treated as if the slightest disturbance will set off the explosives in the UXO. In this case, the UXO must be neutralized in the field. The simplest course of action is to detonate the device from a safe distance, typically by setting up a small explosive charge next to the UXO and triggering it remotely. This is not always practical, as UXO are often discovered near settlements or within in the scope of an ongoing humanitarian demining operation. Setting off a UXO inside an uncleared minefield risks the detonation of other hidden munitions nearby, and will send steel fragments into both cleared and uncleared sections of the minefield, further complicating clearance efforts.

In such cases, where a UXO must be neutralized in the field without detonating it, the goal is to mechanically separate the fuze of the UXO from its explosive payload. The tool most often used for this task is called a disruptor or de-armer, and is discussed below. Once the fuze of the UXO is clear of the device, then the explosives are considered safe to move and can be relocated for a controlled disposal.

### 1.1.1 Casing and Fuze

The UXO used for this project is a 105mm-diameter artillery shell, the body of which is roughly 400mm long and made of thick-walled steel. The front of the shell contains 50mm threads to accommodate the fuze, which is screwed into the casing in the final step of assembly of the weapon. Thus the fuze may appear as a nosecone on the front of the ordnance, as in Figure 1-1.

A large number of fuzes fit this particular shell opening and can be used to trigger whatever explosives are inside the casing. Fuzes vary significantly in their intent (e.g.,
Figure 1-1: 105mm Artillery. 3 examples of 105mm artillery shells with different fuzes and payloads. From L to R: timed fuze with bomblet payload; M565 timed fuze with flare and parachute payload; M557 impact fuze with single-charge explosive payload.

timed vs. impact), complexity, and quality of manufacture. In all cases, however, the first priority of a fuze is to not detonate when it is not intended. Thus most artillery fuzes will require multiple arming steps before they are ready to detonate. The complexity introduced by these multiple arming steps makes it more difficult to predict exactly how a particular fuze design might fail once it has been fired.

For this project, fuzes with the identifiers M557 and M565 were used at the suggestion of Explosive Ordnance Technicians (EODs) from Golden West Humanitarian Foundation. The M565 is a mechanical timed fuze consisting of a timing mechanism inside a brass housing, and was chosen due to its relative mechanical complexity and sensitivity to vibration in its failed form. The M557 fuze has a steel body, and was chosen because it is one of the more difficult fuzes to disrupt. More M557 fuzes were available during the course of testing than any other, so the bulk of data were
collected with this fuze design.

1.1.2 De-armer

A de-armer is essentially a small cannon which uses a .50-caliber or 12.7mm rifle cartridge to fire a 25mm-diameter steel slug. In the disruption of UXO, the de-armer is aimed at the fuze, just above the seam between the fuze and the steel casing. The goal is to either break the fuze body in two, or to rip the fuze out of the casing at the threads. This is accomplished through the significant kinetic energy imparted to the steel slug by the rifle cartridge. Based on experiments in the field, the slug travels as fast as 400m/s as it exits the muzzle of the disruptor. Taking into account the dimensions of the slug, this translates to 21kJ of kinetic energy just before the slug impacts the fuze.

Figure 1-2: De-armer being loaded in the field with steel slug.

Limitations

Use of high-powered rifle cartridges in UXO disruptions and other humanitarian demining operations brings with it complications in regards to availability and transportation of these cartridges. In many countries where humanitarian demining teams work, good connections with the militaries of those countries can provide a ready supply of the correct ammunition to support de-armer use. The situation becomes more
complicated, however, when the military presence of the host country is either less welcoming or less well supplied.

Situations in which a civilian demining team wishes to respond quickly to clear potential UXOs directly after a conflict, for example, would necessitate travel on a commercial airline with all of their tools. Rifle cartridges, not allowed on commercial flights, would have to be sourced at the destination (generally not an easy prospect).

Transporting rifle cartridges also bring with it security concerns, given their initial intended use and obvious appeal to other parties in a conflict or post-conflict area.

1.2 Project

Note: while the terms “de-armer” and “disruptor” are nominally interchangeable, in the interest of clarity in this report “de-armer” is used to describe the tool which uses a high-powered rifle cartridge. “Non-explosive disruptor” is used to describe a tool with the same function, but which does not use an explosive charge. “Disruptor” is used when discussing any tool which performs the function of disrupting a UXO or landmine.

1.2.1 Non-explosive Disruptor

These limitations point to the need for a non-explosive tool for UXO disruption. Based on the speed of the slug exiting the existing explosive de-armer, it is difficult to imagine what other power source could provide the same energy and portability. So the question is raised... is that level of kinetic energy really required to complete the disruption of a 105mm artillery shell? The design of a non-explosive disruptor is outside the scope of this thesis, but we venture to answer the question of feasibility, and to take initial steps towards defining the functional requirements of a non-explosive disruptor.
1.2.2 Disrupting Test Rig

To this end, a disrupting test rig (DTR) was designed and built at Development Technology Workshop (DTW) in Phnom Penh, Cambodia. The DTR was used to measure the energy required to disrupt M565 and M557 fuzes, and contributed to the analysis of disruption and creation of a list of functional requirements for a non-explosive disruptor.
Chapter 2

Background

2.1 Humanitarian Demining

The manufacture, stockpile, and use of landmines has been banned in 157 countries around the world through the Mine Ban Treaty.[4] Even so, anti-personnel mines and unexploded ordnance (UXOs) continue to injure and kill civilians in post-conflict areas. The task of clearing the infected land of these dangers during peacetime is called “humanitarian demining,” and includes detection, neutralization, removal, and destruction of mines and UXOs, as well as accident prevention through education and awareness programs, and support for victims of landmine accidents [9].

The task of destruction of mines and UXOs has been one focus of technological development. One method, in use by the military since World War I, is to use what is called a “waterbomb disruptor” to separate the fuse of a mine or UXO from the main body of high explosive material [6]. The technique involves using a small round of explosives, whether in the form of a bullet-less rifle cartridge or a packing of plastic explosives inside a housing, to fire a slug of water at the joint between the fuse of a piece of ordnance and the high explosives. The water effectively splits the UXO in two, mechanically separating the two components and defusing the explosive. This basic concept, refined through specific innovations since its introduction, continues to be commonly used to neutralize mines, UXOs and improvised explosive devices (IEDs). The use of commercial explosives in this task, however, is expensive, and adds
danger and complexity to demining operations. Cambodia’s Mine Action Center, in collaboration with Golden West Humanitarian Foundation, has invested in the development of a process and tools to reclaim explosive materials from defused UXOs and reuse them in the disrupting of other UXOs, called the “Explosives Harvesting System” [7]. Despite the significant reduction in cost accomplished through this system, humanitarian demining organizations are interested in finding a method of disrupting UXOs without the use of energetic materials [7].

Humanitarian demining, as a research topic, lies in a grey zone in terms of technology development and intellectual property. Many groups, both commercial and academic, have shown interest in developing tools for humanitarian demining over the last 30 years, but competition amongst manufacturers can drive prices down, to the point of limiting R&D budgets and therefore innovation [13]. Explorations from robotic demining to statistical improvements of manual demining techniques and personal protective equipment continue in the academic realm, but implementation of these innovations is dependent upon the right links to industry and the right motivation for decision-makers in demining organizations [11, 12, 3]. Literature on the subject of humanitarian demining technology is spread across topics from mine detection to explosive reclamation and reuse, but recent disruptor innovation found by this researcher is limited to robot mounting methods and the incorporation of plastic explosives rather than a rifle cartridge. [5, 1]
Chapter 3

Disrupting: existing methods

The tool currently used to perform disruptions in the field, a de-armer, is essentially a small cannon, powered by a large rifle cartridge. This section describes the current tool, its use, and the results of a disruption by such a device. Analyses of both the device and the mechanisms of disruption are also discussed.

3.1 M557 Fuze

The M557 fuze design was chosen for the bulk of this research because of its relative difficulty to disrupt and its availability from the de-mining partner organization. The fuze, as shown in Figure 3-1, includes a thin steel cap over the main body, also made of steel, which houses part of the safety mechanism. The steel body is screwed into a lower aluminum shell, which supports the final detonator (which would set off the main explosive charge).

3.2 De-armer

Shown in Figure 3-2, de-armers are manufactured by or for de-mining teams in many countries, including Cambodia, and consist of a body with blast chamber, a short barrel, a breach plug, and assorted tools for assembly, disassembly, and maintenance. A bullet-less rifle cartridge, typically .50-caliber or 12.7mm (shown in Figure 3-3), is
Figure 3-1: The M557 fuze consists of a thin sheet-metal cap on top of a steel body, screwed into an aluminum insert, which is in turn screwed into the threads at the end of a 105mm casing.

used to propel a steel projectile out through the barrel. While some variation exists based on the manufacturer of the device, projectile dimensions are typically 25mm in diameter and approximately 70mm long. The cartridge is triggered either through a length of detonation cord or a small detonator placed directly behind the cartridge. In some cases, for example with plastic-bodied anti-personnel mines, the steel projectile is replaced with a small balloon filled with water.
Figure 3-2: A DE-ARMER uses a .50-caliber rifle cartridge to accelerate a steel projectile at the target UXO.

Figure 3-3: A bullet-less 12.7mm cartridge is used to power the de-armer. EOD technicians remove the bullet, repack the cartridge with explosive powder, then cap the end with cotton or gel to keep the powder in during handling.
3.3 Use

In normal use, a de-armer is loaded with the rifle cartridge, slug, and detonation method away from the target, so that the Explosive Ordnance Disposal (EOD) technician can minimize the length of time he or she spends within the blast range of the UXO. Sandbags are used to limit the motion of both the UXO and the de-armer, and to position the de-armer relative to the UXO. The de-armer is placed roughly one projectile-length away from the target, and aimed at the fuze just above the joint between the fuze and the casing (see Figure 3-4). A trigger system is connected to the de-armer, and all personnel retreat to a safe distance before detonation.

![Figure 3-4: The de-armer is positioned perpendicular to the UXO and aimed just above the line separating the fuze from the casing of the UXO.](image)

The force of the de-armer firing throws the de-armer, projectile, fuze, and UXO casing in different directions. The casing at a minimum rotates significantly, sometimes shoving sandbags around in the process; the fuze is often found buried tens of cm deep in a sandbag if one was placed directly behind it during setup; the de-armer body pushes itself backwards several meters as it accelerates the projectile; and the projectile can bounce off of the fuze and land tens of meters away in just about any direction. As long as the fuze mechanism has been removed from the UXO casing without the UXO exploding, it is judged to be a successful disruption.
3.4 Analysis

To better understand how disruptions are carried out and to inform design of the disrupting test rig, researchers observed multiple disruptions using de-armers by the EOD technicians at Golden West Humanitarian Foundation’s test facility in Kampong Chhnang province, Cambodia. Attempts were made to collect high-speed video of the disruptions, but they were unsuccessful due to the smoke from the de-armer occluding the view of the camera.

Observations of multiple attempted disruptions highlighted the variability of de-armer performance. A number of failed disruptions were attributed to causes such as moisture in the explosive powder in the cartridge, over-packing or under-packing of powder in the cartridge, non-ideal triggering mechanism (detonator cord rather than an electrical detonator), and insufficient seal between the projectile and the barrel of the de-armer. Variation was also noted in the precision with which EOD technicians set up the de-armer relative to the target UXO. All of these factors suggest that ease of use and robustness of energy delivery to be important in the design of a non-explosive disruptor.

3.4.1 Projectile kinetic energy

Projectile velocity was measured using two Chrony Chronographs. Dust and smoke from the de-armer caused some failed readings, but an average velocity was found of 385m/s. Given the mass of the projectile (approx 260g), this translates to an average projectile kinetic energy of 19.3kJ.

3.4.2 Disruption mechanism

Based on analysis of the UXO components after disruption, a few observations can be made regarding the mechanism by which the fuze was separated from the casing. First, the impact point of the slug on the face of the fuze shows significant plastic deformation in both the fuze and the slug, as in Figures 3-5 and 3-6. Second, the steel body of the fuze is pulled away from the aluminum insert, which remains inside the
Figure 3-5: After disruption, the M557 fuze shows significant plastic deformation at the point of contact with the slug in both the thin cap and the steel body.

casing. This separation is enabled by the shearing of the threads on roughly half the circumference of the aluminum insert. The threads which are torn by this motion are on the sides and back of the aluminum insert, as seen from the de-armer, suggesting that the fuze is pushed backwards in the casing (away from the de-armer) before sufficient force is built up in the axial direction to pull the steel body of the fuze from the aluminum insert. At the same time, this rear-ward force deforms the steel body of the fuze, as in Figure 3-7. This shortening and widening of the steel fuze body increases the contact of the steel body with the threads on the sides of the aluminum insert, leaving some of the threads at the back of the aluminum insert unbroken as the steel body separates from it. Only minimal deformation occurs in the annulus of the casing during disruption.

Taken together, these deformations suggest a particular sequence of events during the disruption, as outlined in Figure 3-8. First, the fuze body is pushed backwards in the aluminum fuze insert (away from the de-armer) by the projectile. At the same time, the casing begins to rotate away from the de-armer. This rotation causes the momentum vector of the projectile to more closely align with the axis of the casing and the threads in the fuze. As the fuze body meets the back of the rim of the casing, the force of the projectile produces a torque in the steel body, causing it to begin to rotate out of the aluminum insert. Because the fuze body has already shifted
backwards, the threads on the front edge of the fuze body are no longer engaged with those of the aluminum insert, so the threads cannot counteract the rotation of the fuze body out of the aluminum insert. However, compression of the steel fuze body in the longitudinal direction does cause a widening of the annulus of the fuze body in the transverse direction. This ensures that the threads on the sides of the fuze body stay engaged with those of the aluminum insert. Some resistance to rotation is felt by the steel body, but there is enough momentum in the projectile and fuze body that the aluminum threads on the sides are cleanly sheared off. By this point the casing has continued rotating, leaving the steel fuze body a relatively unobstructed exit from the aluminum fuze insert. In some cases the threads at the back of the aluminum insert were completely removed, and in some cases only the top half were stripped out, presumably because of the differing pivot points of the steel fuze body as it rotated out of the aluminum insert. From this point, each of the individual components are free to carry whatever momentum they have collected into open space. The fuze typically travels along roughly the same trajectory as that on which the projectile was originally fired. The casing spins and slides on the ground until it impacts at least a couple of sandbags. The projectile typically flies off in another direction which was difficult to observe due to safety precautions during the tests. Often the projectile would land tens of meters away from the test site after hitting at least one barrier.

Figure 3-6: The projectile shows significant deformation on impact, in part due to the angled face of the fuze.
Figure 3-7: The steel body of the fuze shows significant deformation due to the slug impact. The arrow indicates the approach of the projectile, and the black line indicates a perfectly round circle to more clearly show the distortion.

It is important to note that, in current practice, the UXO casing is only lightly restrained before the de- armer is fired. The casing is, however, heavy enough, and the projectile velocity high enough, that the casing’s rotational inertia prevents it from moving significantly before the fuze has been pulled out of it.
Figure 3-8: Proposed sequence of steps during the disruption of an M557 fuze in the field. The projectile first shifts the steel body of the fuze backwards, then pulls the fuze body out of the fuze insert as the casing begins to rotate. As the casing rotates, the momentum of the projectile becomes more closely aligned with the axis of the casing, allowing the projectile to pull the fuze body out of the fuze insert, stripping the threads of the aluminum fuze insert.
### 3.4.3 Disruption energy

In a disruption, the kinetic energy of the projectile is distributed amongst the various components of the UXO through the collision, as described in Table 3.1. Of the energy sinks as listed, it is clear that the kinetic energy of the UXO components after the collision will increase with increased input kinetic energy (i.e., increased velocity or mass of the projectile). Given the safety measures taken during testing and the smoke blocking the view of the high-speed camera, researchers were unable to collect meaningful empirical data on any of the post-collision kinetic energies.

To shed light on the range of energies around which to design the DTR, estimates were made on the residual strain energy in the M557 fuze components after disruption. Because materials generally exhibit more brittle behavior under high strain rates [8], we use quasi-static models to obtain an upper bound estimate for the energy of disruption.

#### Deformation

Wulff (1965) [14] describes the area under the stress-strain curve as indicative of the toughness of a material, with units of Energy/Volume. Using an idealized stress strain curve for an elastic perfectly plastic solid (see Fig. 3-9), the area under the curve

\[
U = \int \sigma \, d\varepsilon = \sigma_{\text{yield}} \cdot \varepsilon_{\text{deformed}},
\]

(3.1)

where \(\sigma\) is the engineering stress, \(\sigma_{\text{yield}}\) is the engineering stress at material yield, \(\varepsilon\) is the engineering strain, and \(\varepsilon_{\text{deformed}}\) is the plastic engineering strain of the material after the collision. This value multiplied by the volume of deformed material \(V_{\text{deformed}}\) gives an estimate of the energy used to deform the material:

\[
E_{\text{deformed}} = \sigma_{\text{yield}} \cdot \varepsilon_{\text{deformed}} \cdot V_{\text{deformed}}.
\]

(3.2)

These equations were used directly to estimate the residual strain energy in the projectile and the fuze at the point of contact with the projectile. The yield strength
Figure 3-9: Idealized engineering stress-strain curve for an elastic perfectly plastic solid. For a series of induced strains (indicated by arrows), the shaded area represents the strain energy per unit volume absorbed by the material over the course of the deformation.

for steel is $\sigma_{yield} = 870\, MPa$, and the deformation, $\delta$ of the $0.25\, mm \times 66.2\, mm$ slug is measured as $5.6\, mm$. For the steel fuze body where the slug contacts, the indent covers a volume of roughly $30\, mm$ in diameter and is $2\, mm$ deep.

Figure 3-10: Comparison of disrupted fuze (A) to CAD model with 10-degree hinge 'deformation' (B).

A slight variation was used to estimate the residual strain energy of the annulus of the fuze body. In this case, the annulus was modeled as four segments connected by hinges, as illustrated in Figure 3-10. Impact from the slug on the hinge facing the
de-armer causes two hinges to close down and two to expand, leaving the material segments between them undeformed. The same formula as above applies, and the original length $L_0$ of each "hinge" is taken to be one wall thickness $t$ in a circumferential direction ($L_0 = t$). The strain profile through the thickness at each hinge is then

$$\varepsilon = y \times \tan\left(\frac{\theta}{2}\right) \times \frac{1}{L_0},$$  \hspace{1cm} (3.3)$$

where $y$ is the distance from the neutral axis and $\theta$ is the angle by which each hinge either opens or closes. $\varepsilon_{\text{deformed}}$ is then found as the strain which, as a constant through the wall thickness, would have the same area under the curve as $\varepsilon$. Thus

$$\varepsilon_{\text{deformed}} = \frac{\tan\left(\frac{\theta}{2}\right)}{2}. \hspace{1cm} (3.4)$$

Segment length and angle of hinge deflection $\theta$ were chosen based on the CAD model shown in Fig. 3-10. The 10 degree angle shown, with wall thickness $t = 3.3mm$ and depth $d = 9mm$, produce a strain energy for a single hinge of 3.7J and 15J for the four hinges together.

Finally, to estimate the strain energy of the sheared threads on the ID of the aluminum fuze insert, the energy release rate, $G$ is used according to Anderson (1995) [2].

$$G = \frac{K_{IC}^2}{E},$$  \hspace{1cm} (3.5)$$

where $K_{IC}$ is the critical stress intensity factor, given in the literature for Aluminum, and $E$ is Young's Modulus.

These estimates are listed in Table 3.1, and are dominated by the distortions at the point of contact between the projectile and the fuze body. The total quantity of residual strain energy in the material components, 3.6kJ, is also much less than the kinetic energy of the slug upon exit from the de-armer, which was estimated at 19.3kJ (based on measured mass and velocity of the projectile).
Table 3.1: Residual strain energy post-collision (de-armer)

<table>
<thead>
<tr>
<th>Energy Sink</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation of slug</td>
<td>2400J</td>
</tr>
<tr>
<td>Deformation of fuze at slug contact point</td>
<td>1200J</td>
</tr>
<tr>
<td>Deformation of steel fuze body in annulus</td>
<td>15J</td>
</tr>
<tr>
<td>Sheared surface of threads in aluminum fuze insert</td>
<td>7J</td>
</tr>
</tbody>
</table>

**Kinetic**

Kinetic energies of the fuze body, casing, and slug are difficult to judge empirically, due to the safety procedures of operating with explosives in the field. The qualitative observations described in Section 3.3 above suggest that the fuze body and casing both exhibit a large amount of kinetic energy immediately after the disruption. Subtracting the sum of the deformation energies discussed above (3.6kJ) from the original projectile kinetic energy of 19.3kJ gives 15.7kJ yet to be accounted for. This is a not insignificant amount of energy, but when one considers the sandbags surrounding the tests and the masses of the components involved, it is not surprising that the post-collision energy caused significant movement in the tests, yet was contained primarily within the test area.

**3.5 Summary**

This chapter provided an overview of the current most-used method for disrupting UXOs: the explosive de-armer. We described their use and the effects of a slug from an explosive de-armer on a typical UXO fuze, the M557 impact fuze. An analysis of the kinetic energy from the slug and post-mortem analysis of the material deformations in disrupted fuses revealed an estimate for the amount of energy required to perform a disruption.
Chapter 4

Disrupting Test Rig

To measure the amount of kinetic energy required to disrupt a UXO, a disrupting test rig (DTR) was designed and constructed in Phnom Penh, Cambodia from June to August of 2012. Significant technical and administrative assistance was provided by the staff of Development Technology Workshop (DTW), a British charity, engineering consultancy, and manufacturer in Phnom Penh.

This chapter describes the design, fabrication, and use of the different components of the DTR. Challenges throughout the process included material availability and communication with the manufacturing technicians, discussed briefly in a later section.

4.1 Design

Design of the DTR includes multiple components. The test rig itself, as described below and illustrated in Figure 4-1, is of a pendulum design. In addition, the fuzes for testing had to also be designed. A limited number of real M577 fuzes were available from the de-mining partner, and so a surrogate fuze was designed and a number manufactured in order to increase the sample size for the experiments. The surrogate fuzes failed in a manner nearly identical to the real fuzes, except for a slight reduction in the energy required for disruption.
4.1.1 Test Rig

The primary task of the test rig is to deliver a projectile of known kinetic energy and velocity to the fuze. An ideal test rig would allow researchers to choose any energy from 0-20kJ and any velocity from 0-400m/s. Physical, time, and logistical limitations, however, led to a much more modest goal: 0-3kJ and 0-7m/s.

Determination of the functional parameters for the DTR and design of each component are described below. To both assist in the design process and to help communicate with the workshop technicians, a small-scale prototype of each subsystem was constructed before the full-scale design was finalized. Particular points of departure from an exact replication of the conditions of the explosive de-armer tests are in velocity/mass of the projectile and in the restraining of the casing to enable disruption...
at the lower velocities.

**Rig Architecture**

As mentioned above, an ideal test rig would be able to deliver a projectile with any kinetic energy up to 20kJ to a target fuze. Practical limitations meant that only a scaled-down set of projectile energies and velocities was possible. Energy storage/release mechanisms including explosives, pneumatics, flywheels, gasoline, springs, and gravity were all considered. For the sake of simplicity, repeatability, ease and speed of manufacture, and cost, it was decided to pursue a gravity-powered design.

From the analysis of the de-armer test in Chapter 3, material deformation accounts for approximately 3.7kJ of energy. This number, however, is dominated by the plastic deformations at the contact point between the projectile and the fuze. Given the much lower velocities of a gravity-powered disrupting test rig, it can be safely assumed that the deformations at the point of contact between the projectile and the fuze will be only a fraction of that in an explosive de-armer disruption. To ensure an effective disrupting test rig, the target energy for the design was set at 3kJ.

Among gravity-powered options, the simplicity of a Charpy Notch Tester pendulum mechanism lent itself to the DTR design. Illustrated in Figure 4-2, a pendulum is released twice from the same angle ($\theta_{\text{start}}$): once without a sample, and once with a sample present in the path of the pendulum. The difference between the maximum height reached by the pendulum in its first swing after each release is proportional to the energy required to break the sample. Most Charpy Notch Testers, however, are designed to measure energies on the order of tens or hundreds of Joules, not thousands. To reach the desired maximum kinetic energy of 3kJ, the pendulum of the DTR was designed to have a 3m swing and 137kg mass.

Compared to a Charpy Notch Tester, the DTR required a more complicated mechanism to hold the test samples, outlined below. A rigid frame was designed to support the pendulum axis, as was a tower from which to raise and release the hammer. Available space for building and operating the DTR required it to be broken down into more easily moved components, thus the two upright towers were designed to separate
Figure 4-2: Similar to a Charpy Notch Tester, the difference in heights between a free swing (without a target) and a swing including a collision with the fuze is used to calculate the energy lost by the pendulum in the collision.

To aid in side-to-side rigidity, the pendulum was designed to begin its swing no higher than 90 degrees from vertical. This allows the bearing support structure to span the width of the frame without interfering with the swing of the pendulum. A schematic of the DTR is shown in Figure 4-3.

Materials

The available composition and form of materials in Phnom Penh for a project of this small size is rather limited. Large-scale projects can import any material as needed by the container load, but researchers on this project were limited to what was already available for purchase in the market. Timing is also a critical factor, as supplies vary significantly due to the limited demand for many engineering materials.
and shopkeepers' reluctance to maintain large stocks.

Some materials choices (such as a thinner-walled square tube to support the lifting/release mechanism) would have made little difference to the final product. Other preferred (but not available) materials might have reduced the variation in collected data. For example, a thinner and lighter tube in the material of the pendulum arm would have placed the center of mass of the pendulum closer to the point of impact with the fuze, leading to smaller percussive vibrations along the pendulum arm.

**Pendulum Arm**

Design of the pendulum arm emphasized stiffness from side-to-side, in torsion, and along the radius of the swing. The pivot was designed to be removable and adjustable from side to side for alignment, and is supported by two standard bearings (available in the local market) mounted in cast iron pillow blocks.

Some considerations were made of a cable- or chain-derived pendulum arm, offering little or no resistance to upward or rotating motion of the pendulum head at the bottom of the swing. It was decided, however, that these motions would drastically
and inconsistently affect the height the pendulum reaches after impact, making the collected energy data less precise. Because of the limited number of fuzes available for testing, as discussed below, precision of data was an important consideration.

**Pendulum Hammer**

The pendulum hammer, shown in Figure 4-4, is mounted to the bottom of the pendulum arm using four bolts through an adapter plate. This configuration allows different head geometries to be attached in the future without changes to the pendulum arm.

![Pendulum hammer configurations](image)

Figure 4-4: The pendulum and hammer can be configured to obtain four different total masses: 71kg (A), 90kg (B), 114kg (C), and 137kg (D). (E) shows the finished hammer.

The main base plate connects via a short adapter to the pendulum arm; holds the dowel pins; offers mounting points for the striker bar at the front of the plate; and includes a hook at the back for attachment of the trigger mechanism. Additional masses are added above or below the main plate, fastened using M10 machine screws to threaded holes in the main base plate. Impact force is transmitted from the masses to the base plate via two 30mm dowel pins passing through the base plate and each
mass with a light press fit.

To approximate the dynamics of an unconstrained projectile and avoid excessive percussive effects, the center of mass of the pendulum should be aligned with the height of the target. Given the mass, space, and fixturing constraints of the DTR, however, this was not possible. To keep the center of mass of the pendulum as low as possible, the hammer masses below the main plate are positioned to pass on either side of the disrupted fuze after impact. While six mass configurations are technically possible, it is recommended to mount these lower masses before any other masses, which reduces the number of configurations to four.

The striker bar on the front of the hammer base plate is heat treated to increase hardness. The bar is 30mm square, and 100mm long, allowing space for four mount screws and approximately 50mm of contact area between the innermost screw heads. Because each test produces a small plastic deformation in the striker bar, the bar is rotated after each test. Each bar is used for four tests and then replaced. See Figure 4-5.

Figure 4-5: The striker is the only part of the hammer which contacts the fuze. The square bar is rotated after each test to present an un-deformed contact surface to the fuze.
Casing/Fuze Fixture

The lower velocities of the DTR projectile (i.e., the pendulum hammer) require a different fixturing method than seen in field tests. The projectile velocity of current de-armers is such that the inertia of the casing effectively keeps the UXO stationary while the projectile pushes the fuze out of it. In the case of the DTR, leaving the casing unconstrained at impact will not lead to disruption because, at the lower projectile velocities (7m/s vs. 385m/s with the de-armer), the casing does not have sufficient inertia to remain stationary while the fuze is separated. Thus the first requirement to ensure effective disruption of the fuze in the DTR is to hold the casing in a very stiff manner in the direction of travel of the projectile.

For consistency and because of a limited supply of real UXO casings, substitute casings were manufactured out of 75mm diameter x 17mm wall thickness steel tube and used exclusively in the DTR. Threads matching those of the UXO casings were machined in the ends to accept the sample fuzes.

Experimentation with the small-scale prototype pendulum highlighted another requirement of the casing fixture. The failure mode of the fuze/casing connection, as demonstrated by the de-armer tests described in Section 3.4, includes an effective lengthening of the fuze/casing body pair as the fuze is pulled out of the threads at the top of the casing. In the DTR, if the casing is held rigidly and not allowed to rotate or move upon impact, then a different failure mode will result, if the hammer is able to complete the disruption at all. To allow for a more realistic failure mode, a prismatic joint was designed to hold the casing rigidly along the projectile axis yet allow the casing to move downwards (perpendicular to the projectile axis) during and after impact. Two sleds were constructed: one holds the casing vertically, and the other holds the casing tilted away from the projectile by 10° (see Figure 4-6). This second sled was built as insurance, just in case the DTR was not able to disrupt a fuze with the casing in the vertical position. Early tests indicated that this was not an issue, so the 10° sled was used for only one experiment, then set aside.

Early tests were conducted with the casing welded into the fixture sleds. The
Figure 4-6: Two sliding carriages were built to support the casings and fuzes during DTR tests. One oriented perpendicular to the projectile’s path (A), and one angled back by 10 degrees (B).

failure mode produced by the DTR included significant deformation of the casing wall, which meant that the casings could not be reused from one test to the next. The design was changed for later tests such that the casing rests inside the sled without clamping or welding, allowing for much faster sample changes between experiment runs.

**Lifting/Release Mechanism**

Lifting of the hammer and pendulum to the starting position is accomplished via a second tower at the rear of the DTR. A cable winch is attached to a cable which runs over two pulleys at the top of the tower, then to a carabiner which is attached to the pendulum arm for lifting and removed before release.

To release the 137kg pendulum consistently, an over-center release mechanism was designed, as shown in Figure 4-7. A four-bar over-center mechanism was chosen to avoid the wear common to sliding release mechanisms and to provide a consistent release motion. A loop at the rear of the hammer rests in the V-shaped groove of the release mechanism, and rotates in the groove as the mechanism operates. This
Figure 4-7: Steps of the over-center trigger mechanism are illustrated: (A) start position, (B) pulling in the direction indicated raises the hammer to "center", (C) the loop on the back of the hammer rotates within the V-shaped cradle of the trigger mechanism, (D) as the mechanism rotates, gravity takes over and the hammer hook pushes the trigger mechanism out of the way, until (E) the hammer is completely free of the trigger. (F) is the trigger as constructed.

Joint, plus two small pivots and the main pendulum axle, make up the four pivots of a four-bar mechanism. Once the mechanism has progressed past the "center" point at which the force vector of the hammer loop is aligned with the line passing between the V-groove and the next small pivot, gravity and the mass of the hammer push the release mechanism out of the way and the hammer is free to fall.

In the DTR’s maximum-energy configuration, the over-center mechanism is attached with a pivot to the underside of the top bar of the lifting tower, as shown in Figure 4-8. When a lower starting height is required, a webbing with ratchet strap is stretched between the anchor point on the lifting tower and the pivot of the over-center mechanism. This allows a continuously adjustable release height for the pendulum.
Figure 4-8: (A and B) The over-center trigger mechanism allows a smooth release of the pendulum hammer with minimum wear on parts. (C) To achieve lower release heights, the trigger mechanism is suspended from the lifting tower by an adjustable-length strap.

**Data Collection**

Data from the DTR tests were collected in three different ways: through a dial indicator mounted on the side of the test rig, a rotary encoder taking data from the pivot of the pendulum, and high-speed video of some of the tests.

Similar to conventional Charpy Notch testing machines, the DTR design includes a gauge showing the maximum height of the pendulum swing, shown in Figure 4-9. A small pusher arm is mounted on the end of the main pendulum axle, which pushes only on the rear-ward side of the indicator needle. The axis of the needle is tightened to maintain just enough friction to keep it from moving unless pushed. Thus the pendulum’s motion will push the needle forward through the first swing, and the needle will stop at the pendulum’s furthest reach. Vertical (zero), start angle, and maximum swing angle indicated by the needle were recorded for each test.

A small rotary encoder is fixed to the end of the pendulum shaft opposite the dial indicator. Encoder position is calculated by an Arduino micro controller via an
Figure 4-9: The indicator dial served as a backup to the digital encoder. A pusher arm on the end of the pendulum’s main shaft moves the needle only in one direction.

interrupt trigger, and transmitted in real time to a laptop via XBee wireless serial transmitter. This configuration offers a rotational sensing resolution of 0.09 degrees.

High-speed video of some tests was taken using a Nikon J1 digital camera. The camera records at 1200 frames per second with a resolution of 320 x 120 pixels. Playback of the video allows analysis of the disruption failure mode and estimates of pre- and post-collision velocities of each component.

4.1.2 Surrogate Fuzes

Real UXO fuses are carefully controlled once removed from UXOs during demining operations, and so are not readily available in large quantities. In addition, before they can be handed over to uncertified operators (such as the graduate student researcher on this project), the fuzes must have all explosive material removed from them. This ‘sanitizing’ process is not trivial, and so only a limited number of fuzes were available for testing. This led to a need for the design and manufacture of surrogate fuzes for use in testing with the DTR.
Design

As described in Section 3.1, the M557 fuze consists of three main components. Only two of these are structural, so the thin sheet metal nose cone was omitted from the surrogate fuze design (designated M557D for “dummy fuze”). The main body of the M557 fuze, made of steel, includes a narrow ridge across the top which requires the use of a milling machine for manufacture. Because de-armers of this fuze design in the field are placed along the axis of this ridge, rotational orientation of the fuze in the DTR is important. To avoid this orientation issue for the surrogate fuzes, and to simplify and speed their manufacture, M557D fuzes were designed to be axially symmetric. The real and surrogate fuzes are depicted for comparison in Figure 4-10.

![Figure 4-10: A real M557 fuze and the simplified design of the surrogate M557D.](image)

Both components were manufactured from materials available in the market in Phnom Penh. Steel rod of the required diameter (61mm or greater) was available in only one material composition, presumably mild steel. Suitable aluminum was found only in cast rods.

Testing with De-armer

Before use in the DTR, surrogate M557D fuzes were tested in the field using an explosive de-armer. The goal was to confirm that the surrogate fuzes fail in the same
way as the real fuzes. Figure 4-11 shows the primary difference between the two failure modes: the aluminum insert of the M557 fuze remained intact except for the stripped threads, whereas the aluminum insert of the M557D surrogate fuze failed through its thickness in addition to at the threads. This difference suggests that the aluminum material available in Phnom Penh is softer than the aluminum used in the original M557 fuzes.

![Image of aluminum inserts](image)

Figure 4-11: Comparison of the aluminum insert from the original M557 fuze (A) and that of a surrogate M557D fuze. The fracture through the wall thickness of the surrogate fuze component suggests that the material used may be softer than in the original fuzes.

### 4.2 Fabrication

Construction of the DTR occurred at Development Technology Workshop (DTW), a British charity and local engineering consulting and manufacturing organization in Phnom Penh, Cambodia. DTW provided use of its assembly area and machine tools, full time of two student technicians and one technician, and part time of their workshop manager, visiting engineer, and driver. Standard machine tools were available, including lathes, mills, stick-welders, and powered hand tools.
4.3 Use

The Disrupting Test Rig requires a minimum of two people for safe operation. See Appendix A for safety guidelines on operation of the DTR, assembled by Peter Sharpe and the graduate student researcher. This section describes the procedures used for each round of testing with the DTR and an overview of the design of the experiment as a whole.

4.3.1 Testing Procedures

Pre-trial

Before every other test with an actual fuze, a calibration swing is performed. The pendulum is raised to the starting height for the coming trials and released. The maximum height that the pendulum reaches on its first swing is recorded as the baseline for the trials.

Trial

For each trial, the measurements are recorded at the corresponding step as listed in Table 4.1.

Post-Trial

Because of the quality of the concrete floor in the space available for erecting the DTR, it is not feasible to mechanically anchor the frame of the device. This means that some of the kinetic energy from each disrupting test goes into sliding the 780kg rig on its footings. Galvanized steel sheets are used to adjust the height of each foot to ensure the rig is level on the uneven floor, so it is between two galvanized sheets that the sliding motion happens. This rig displacement is measured after each trial. After every other disrupting test, the rig is moved back into a centered position on each of its feet and re-leveled.
Table 4.1: Data collection steps during use of the DTR

<table>
<thead>
<tr>
<th>Action</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjust fuze height relative to striker edge</td>
<td>note indicator dial position</td>
</tr>
<tr>
<td>raise pendulum to start position</td>
<td>begin encoder data logging</td>
</tr>
<tr>
<td>release pendulum</td>
<td>note indicator dial position</td>
</tr>
<tr>
<td>allow pendulum to hang vertically</td>
<td>record high-speed video</td>
</tr>
<tr>
<td>move pendulum to storage position</td>
<td>note max indicator dial position</td>
</tr>
<tr>
<td></td>
<td>stop encoder data logging</td>
</tr>
<tr>
<td></td>
<td>measure the following dimensions</td>
</tr>
<tr>
<td></td>
<td>- fuze width front-to-back</td>
</tr>
<tr>
<td></td>
<td>- fuze width side-to-side</td>
</tr>
<tr>
<td></td>
<td>- perimeter of fuze body</td>
</tr>
<tr>
<td></td>
<td>- depth of impact mark on fuze</td>
</tr>
<tr>
<td></td>
<td>- height of impact on fuze</td>
</tr>
<tr>
<td></td>
<td>- internal diameter of fuze insert shear marks</td>
</tr>
<tr>
<td></td>
<td>- casing width front-to-back</td>
</tr>
<tr>
<td></td>
<td>- casing width side-to-side</td>
</tr>
<tr>
<td></td>
<td>- casing perimeter at top of distortion</td>
</tr>
<tr>
<td></td>
<td>- height of distortion in casing wall</td>
</tr>
<tr>
<td></td>
<td>- rig displacement distance</td>
</tr>
</tbody>
</table>

4.3.2 Design of Experiment

Our initial goal in operation of the DTR is to characterize the kinetic energy required to disrupt a UXO, which suggests two dependent variables, as listed in Table 4.2.

Table 4.2: Dependent Variables in DTR testing

<table>
<thead>
<tr>
<th>Variable name</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful disruption</td>
<td>binary</td>
</tr>
<tr>
<td>&quot;Projectile Energy Lost&quot; (PEL)</td>
<td>Joules</td>
</tr>
</tbody>
</table>

The PEL value is the amount of energy lost by the pendulum to the different components of the disrupted target and the DTR itself.
Sample Size

Sample size is a severely limiting element of this experimental design. In all, 31 trials were run with the DTR. Of these, 16 trials were conducted with real M557 fuzes, and 12 trials used the M557D surrogate fuzes. The remainder used surrogate M565D fuzes, but were discarded due to lack of supply of real M565 fuzes for comparison.

Other factors of interest

Repeatability of the test is of significant interest, given the complexity of the mechanical interactions and myriad sources of variation.

Also of interest is the performance of surrogate, or “dummy”, fuzes relative to real fuzes in the test, and how best to integrate them into the experimental design. Comparable failure modes in an explosive de-armer disruption qualitatively confirmed the dummy fuzes to be effective surrogates of the real fuzes in these tests. The next step will be to confirm their effectiveness quantitatively.

4.4 Summary

A disrupting test rig (DTR) for measuring the energy necessary to disrupt UXO fuzes is described in its design, fabrication, and theory of use. Testing procedures are described, as well as the experimental approach to use of the machine.
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Chapter 5

Results

31 trials were run with the DTR. Of these, 16 trials were conducted with real M557 fuzes, and 12 trials used the M557D surrogate fuzes. The remainder used surrogate M565D fuzes, but were discarded due to lack of supply of real M565 fuzes for comparison.

5.1 Mechanism of Disruption

Fuze fragment damage from DTR trials differed slightly from the de-armer tests described in Chapter 3, but in a predictable manner. The fixture of the casing, in particular requiring that the casing remain in a vertical orientation, caused greater deformation in the casing wall in the DTR trials. Shown in the frames of high-speed video in Figure 5-1, the sequence of events are relatively clear.

First, upon contact between the striker and the fuze, the casing is bent backwards slightly, storing elastic energy. Almost simultaneously, the fuze pushes on the rear wall of the casing, causing it to deform rearwards. Because the striker contacts the fuze slightly above the line of contact between the fuze and the casing, there is a vertical component to the force on the fuze. This leads to a pivoting motion between the rearmost point of the fuze and the inside of the casing annulus, and pushes the casing downwards. This motion effectively lifts the fuze body out of the aluminum fuze insert, which remains in the casing. Further motion of the hammer accelerates
the casing down further, and rolls the fuze body the remainder of the way out of the aluminum fuze insert. As the stored elastic energy in the components is released, the contact points separate. Thus the fuze pushes ahead of the still-moving hammer, but primarily in a rotating manner because of the reaction force from the rear wall of the casing. The casing continues down and out of the way, eventually impacting the floor and bouncing up slightly. The fuze spins in the air and falls on the floor or is caught in the rear basin of the rig. The hammer is slowed, and the arm vibrates from the percussive effects of the impact as it continues on its swing path.
Figure 5-1: Time lapse of an M557 fuze in a DTR trial. In sequence, the striker contacts the fuze, the casing is bent backwards, the fuze is lifted out of the aluminum fuze insert (inside the casing), and the casing is pushed downwards.
5.1.1 Comparison to De-armer Disruptions

Plastic deformations in fuze and projectile components used in the DTR trials differed only slightly to those from the de-armer disruptions. The shape of the deformation at the point of contact between the hammer's striker and the fuze body was flat, rather than round. It was also much shallower, as shown in Figure 5-2, which is to be expected given the lower speed and lower energy of the DTR projectile.

![Figure 5-2:](image)

Figure 5-2: Compared to fuzes from the de-armer tests (B), the deformation of the fuze seen in DTR tests (A) was much smaller.

The projectile itself, or in the case of the DTR tests the hammer's striker bar, also experienced plastic deformation. The striker bar is heat treated for hardness (as is the de-armer's projectile), and was deformed less overall than the fuze body. However, because the striker bar contacted only at its corner and it could not rotate to orient itself perpendicular to the surface of the fuze body, the corner experienced significant deformation during the collision. See Figure 5-3 for details.

In the same way that the threads of the aluminum fuze insert were stripped out during de-armer tests, the threads of the fuze inserts in the DTR testing also failed. In many tests, however, the aluminum insert also failed through the wall thickness, as shown in Figure 5-4. Due to their rigid fixture, casings used in DTR
Figure 5-3: The hardened steel of the striker bar maintained a flat surface despite impact with the round shape of the fuze body, but the corner did deform because of relatively little material to support it.

Trials underwent significant deformation as the fuze body was pushed backwards by the pendulum hammer. In addition to the elastic deformation visible in Figure 5-1, plastic deformation in the upper portion of the casing wall remained after the disruption.

**Strain Energy Analysis**

Techniques similar to those described in Section 3.4 can be used to estimate the plastic strain energy lost to each of the components during the DTR trials. In addition, analysis of the high-speed video from DTR tests offers a method of estimating the kinetic energy of each component immediately after the collision, and data recording from the trials included a measurement of the kinetic energy imparted to the rig itself. Average values for the maximum-energy trials are listed in Table 5.1.
Figure 5-4: Results of an M557R (real fuze) disruption with the DTR. Similar to the de-armer tests, threads of the aluminum fuze insert were torn out in the course of the disruption. However, in DTR tests the wall of the aluminum insert often broke through the wall thickness, in addition to its threads being stripped out by the departing fuze body. Also note the significant casing deformation in the bottom of the image.

Table 5.1: Residual energy post-collision (DTR - maximum energy trials)

<table>
<thead>
<tr>
<th>Energy Sink</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation of striker</td>
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</tr>
<tr>
<td>Deformation of fuze at slug contact point</td>
<td>160J</td>
</tr>
<tr>
<td>Deformation of steel fuze body in annulus</td>
<td>12J</td>
</tr>
<tr>
<td>Sheared surface of threads in aluminum fuze insert</td>
<td>7J</td>
</tr>
<tr>
<td>Deformation of casing annulus</td>
<td>230J</td>
</tr>
<tr>
<td>Rotational kinetic energy of fuze body</td>
<td>1J</td>
</tr>
<tr>
<td>Linear kinetic energy of fuze body</td>
<td>12J</td>
</tr>
<tr>
<td>Kinetic energy of casing sled</td>
<td>260J</td>
</tr>
<tr>
<td>Sliding kinetic energy of rig</td>
<td>140J</td>
</tr>
</tbody>
</table>
5.2 DTR Data

Data were collected from the DTR trials using three methods: a digital rotary encoder, the built-in dial indicator on the DTR, and high-speed video.

5.2.1 Encoder Data

Raw encoder data were collected for each trial, as shown in Figure 5-5. Start, finish, and offset angles were extracted from the data, confirmed with indicator measurement and high-speed video capture when available, and used to compare results amongst the trials.

In Figure 5-5, data collection starts with the pendulum hanging vertically at rest and the encoder value set to zero. The pendulum is raised to the starting height and the trigger is set, where it stays while other preparations are made. When the pendulum is released, it strikes the target on the first swing, then is allowed to slow down under its own friction until it can be safely stopped by the operators (typically 10 to 20 cycles). Once stopped, the pendulum is allowed to settle back to vertical, then raised to its storage position.

![Encoder Data Diagram](image)

Figure 5-5: Encoder output from a single trial (#12), with the pendulum at 137kg, released from maximum height.

Each collision of the DTR causes a slight offset in the rotary encoder data, po-
tentially from slip in the connection between the encoder shaft and the pendulum shaft. To measure this offset, the pendulum is allowed to settle back to vertical after each test, and that settling angle in the encoder is compared to the starting angle. Figure 5-6 shows the encoder data used to determine the settling angle. The difference between the settling angle and the zero angle (when data collection starts), both measured while the pendulum is hanging vertically, is added to the angle that the pendulum reaches on the back end of its first swing (i.e., $\theta_{\text{finish}}$ as discussed in Chapter 4).

![Figure 5-6: Encoder output from the settling phase of a single trial (#12). The red-colored data are averaged to determine the zero offset for the swing.](image)

Figure 5-7 shows an example of the section of encoder data which is of the greatest interest: the initial swing from starting angle to the max finish angle, including collision with the fuze. Zero on the vertical axis indicates the pendulum is hanging vertically. The collision occurs directly after this point, and is characterized by vibrations in the arm and encoder reading.
Figure 5-7: Encoder output from the first swing of a single trial (#12). Collision with the fuze is shown by the vibratory response of the encoder. Start and finish angles were taken from plots like this of each trial to populate the graphs shown below.
5.2.2 Dial Indicator Data

For each trial, readings were taken from the dial indicator built onto the side of the DTR as described in Chapter 4.

5.3 Energy of Pendulum

Results for the energy of the pendulum before and after the disrupting collision are shown in Figure 5-8 relative to the velocity of the hammer directly before striking the fuze.

Figure 5-8: Energy of the pendulum before (diamonds) and after (squares) collision with a real M557R fuze at maximum pendulum mass, and the difference between them (triangles). The X’s represent unsuccessful disruptions.

The start energies follow an $x^2$ curve as expected from the relationship between kinetic energy and linear velocity. Finish energies also increase with respect to striker velocity, as does the variation found between trials. The difference between the start
and finish energies, called Pendulum Energy Lost, appears to increase linearly with pendulum velocity. Averaging the results for each velocity input shows this trend more clearly (see Figure 5-9).

The successful disruption with the lowest initial energy drew 1500J from the kinetic energy of the pendulum.

![Figure 5-9: Energy of the pendulum before (diamonds) and after (squares) collision with a real M557R fuze at maximum pendulum mass, and the difference between them (triangles). Results averaged for each velocity input level.](image)

5.4 Surrogate Fuzes

The difference between the real and surrogate fuzes can be seen in Figure 5-10. Real fuzes (shown in the plot by triangular markers) consistently took 9 to 15 percent more energy to disrupt than the surrogate M557D fuzes, given the same approximate pendulum starting energy. Within the data for each type of fuze, however, the variation is somewhat smaller.
Figure 5-10: Pendulum energy lost vs. striker velocity for real and surrogate fuzes.

5.5 Unconstrained Casings

Two DTR trials were conducted in order to test one of the hypotheses described in Chapter 3, namely, that the projectile velocities achieved with the DTR were too slow to effectively disrupt a UXO fuze without restraining the casing. In the first trial, a single DTR casing was mounted behind the normal fixture setup, such that the casing leaned forward against one part of the DTR frame and would be perpendicular to the striker at the point of contact (see Figure 5-11). This allowed the casing to move freely backwards as it was struck by the pendulum. As expected, the casing was simply thrown backwards by the force of pendulum, and no plastic deformation could be identified on the fuze, casing, or striker surfaces.

In a second test a heavier casing was used, which was designed to have a moment of inertia comparable to that of a 105mm UXO casing (see Figure 5-12). In both tests the maximum pendulum release height and pendulum mass were used, resulting in over 3kJ of kinetic energy at the bottom of the swing. The second test resulted
in a slight deformation in the surface of the fuze body, but the fuze unscrewed easily from the fuse inwert, suggesting no damage to the threads.

Figure 5-11: In the DTR trials using unconstrained casings, the casing is leaned against the DTR frame and aligned with the pendulum.

Figure 5-12: A second "free" casing was built to approximate the rotational inertia of a 105mm UXO casing, but showed only a very small fuze deformation at the point of contact with the striker.
Chapter 6

Discussion

After investigating a current, widely used method for disrupting unexploded ordnance (UXO), researchers designed and constructed a Disrupting Test Rig (DTR) to determine the minimum amount of kinetic energy required to perform a disruption. The DTR was built in Phnom Penh, Cambodia and used to measure the energy required to disrupt 31 sample fuzes.

Results show that the quantity of energy required to disrupt a UXO increases as the projectile energy increases, but the desired mechanical separation between fuze and casing can be achieved with as little as 1.5kJ of input energy. This presumes that the casing is held rigidly to ground relative to the moving projectile.

6.1 Role of Velocity

The kinetic energy of the projectile plays a large role in the effectiveness of a disrupting tool. Finding the energy required of the disruption operation is the task of the disrupting test rig, described in Chapter 4. The velocity of the projectile also plays a crucial role, as was shown by DTR tests of unconstrained casings.

In de-armer tests, the mass and rotational inertia of the casing effectively hold the casing steady while the fuze is impacted by the projectile. Only if the projectile is moving fast enough does the casing not simply accelerate with the fuze and spin both out of the way of the projectile.
The question remains of the minimum velocity of a projectile to carry out a disruption, and offers a direction for further research.

6.2 Use of Surrogates

In the design of the surrogate fuzes, it was hypothesized that the solid, axi-symmetric fuze body design would, if anything, require more energy to disrupt than the original fuzes. This proved to not be the case, presumably because of the softness of the cast aluminum used in the fuze insert.

A number of things were learned from the use of surrogates for this test. When test performance of surrogates vs. original samples should be monitored during the experiment, in case divergence can be corrected through a re-design of the surrogates. In the case of the DTR, sourcing alternative aluminum stock for the fuze insert components was not practical, but additional experiments to confirm that the fuze insert was indeed the source of the variation in the results would have been helpful.

The additional variability that surrogates can add to an experiment must be weighed against the cost (in financial, time, or logistical terms) of additional original samples. In a related note, because of the requirement of additional information from the dataset to confirm the validity of surrogates and understand their performance relative to original samples, the sample size including surrogates should be increased slightly over the desired sample size of all original samples.

It is beneficial to enter upon the use of surrogate samples in an experiment with defined hypotheses about the surrogates’ properties relative to those of the original samples. Resulting data should provide confirmation or rebuttal of these hypotheses.

6.3 Future Work

The variation in the post-collision energy data suggest a few possible improvements to the DTR and directions for further research. Closer alignment between the center
of mass of the hammer/pendulum assembly and the point of contact with the fuze would reduce the percussive effects of the impact. Direct measurement of hammer position would reduce some of the variation introduced by the long pendulum arm. Anchoring the DTR to the floor would reduce variation caused by the sliding of the rig at impact. More closely matching the materials of the surrogate fuzes to those of the real fuzes would also lead to more consistency between the results obtained with the original and surrogate fuzes.

Implementation of a force sensor in the pendulum hammer would provide valuable data for measuring the duration of contact between the projectile and the fuze, giving further insight into the dynamics of the collision. More testing with the 10° offset casing holder would allow a closer simulation of the de-armer failure mode and less casing deformation during disruption. Changing the shape of the striker bar on the front of the hammer might reduce deformation of the striker bar, allow its reuse, and simplify deformation calculations.

Testing of more fuzes within the existing velocity range of the DTR would be useful to some extent, but higher velocity tests would give a clearer picture of the relative shape of these two curves.

More testing of the original fuzes relative to the surrogates is also in order, to better understand the differences between them. One option not previously explored would be to combine the fuze components differently. For example, to mount an original fuze body with a surrogate aluminum fuze insert and vice versa. This would provide more concrete evidence as to which component (either the steel body or the aluminum insert) causes the variation seen between the original and surrogate fuzes.

In terms of the design of a non-explosive disruptor, better understanding of the disruptive effects at higher projectile velocities is required. This analysis has shown that energy is not the only important measure of a disruptor, and projectile velocity plays a critical role. In particular, if the UXO is unconstrained relative to the disrupting projectile, then the projectile velocity must be high enough to perform the disruption before the casing turns out of the way due to the force of the projectile impact.
Appendix A

DTR Safety and Operating Procedures

Revision: 01/08/12

A.1 Description

The rig comprises a hammer, suspended on an arm which is pivoted about an axis, allowing the hammer to swing in an arc. A target is positioned such that the hammer strikes it at the low point of the swing arc.

The arm bearings are mounted on a frame, which also locates and supports the target. The frame is fitted with a release mechanism, safety blocks, a lifting winch, and an indicator to measure the swing angle after impact. The hammer mass is adjustable by adding additional masses to the hammer base.

The rig rests on the floor on eight feet, fitted with rubber pads.

The hammer is held in the ‘primed’ position by a latch mechanism, which is released remotely by a pull-cord.

Two safety blocks are provided, designated lower and upper blocks. The blocks are removable bars which locate securely on frame members. Facilities are provided to lock the lower block in place when the rig is not in use.
A.2 Construction and Installation

The frame base should be positioned on a smooth floor, with the feet away from obvious defects and weak areas. Rubber pads are fitted under each foot, and shims used to give approximately equal loading on each foot.

Before use the additional mass (sandbags) must be added to the wells provided.

The area around the rig should be kept clean and free of obstruction.

Before operation, barriers and signs must be positioned so that personnel are warned not to enter the operation zone.

A.3 Test rig inspection

This inspection must be carried out before use and between tests.

1. Check the following locations for damage, distortion, cracks and loose fasteners:
   (a) Target mount, target platen, and frame in platen area
   (b) Hammer base, arm, masses, cutter
   (c) Main legs and end attachments
   (d) Arm bearings
   (e) Lifting legs and attachments
   (f) Latch mechanism
   (g) Winch, cable and pulleys

2. Check the sliding target mount for free and smooth operation

3. Check the latch operation

4. Check that the foot pads and shims are correctly located and no pads are loose.

5. Check the arc described by the cutter is in the correct relation (vertical and transverse) to the target
A.4 Hammer Location

1. When the rig is not in use the lower block should be locked, with the hammer above the block.

2. During maintenance and when setting the target the lower block must be in place with the hammer above the block.

3. Raising of the hammer above the lower block position should only be carried out immediately before a test.

4. No setting or maintenance should be carried out with the hammer at the upper block position.

A.5 Test Procedure

Note: two operators are required for this procedure.

1. Carry out pre-test checks:

   (a) Carry out a test rig inspection as described above

   (b) Check that the target is installed and the sliding mount (if used) is at the correct height

   (c) Clear the area of personnel and set the barriers & signs forbidding access

2. Set the indicator to zero

3. Attach the winch line to the arm

4. Raise the hammer above the upper block

5. Fit the upper block

6. Check the latch pull-line is unobstructed.
7. Raise the hammer to engage the latch. Check it is fully engaged

8. Disconnect the winch line

9. Remove the upper block

10. Remove the lower block

11. Both operators go to the release handle location

12. Check for signs of approaching personnel

13. Release the hammer

14. Allow the hammer to come to rest before approaching the rig

15. Read the indicator

16. Check the target and debris, photograph as required.

17. Clear the debris and remove the target base. Bag and mark it as required.

18. Inspect the rig for damage
Figure A-1: Rig General Arrangement, shown with one lifting leg removed for clarity.
Figure A-2: Platen and Sliding Mount

Figure A-3: Hammer and Latch, shown with one lifting leg removed for clarity
Appendix B

DTR Technical Drawings
# Drawing List (master)

**Product:** Disrupting Test Rig

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<td>tub support rib</td>
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<td>encoder mount</td>
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Number of required per machine - 1

Manufacturing time

DATE MODIFICATION NAME

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

DTW
PO Box1244
Phnom Penh

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Title: Tower Assembly

Sub: DTR
Dwg No. DTR_assembly

Date: 31.07.12
Check: Samnang

Material:
mild steel

All dimensions ± 1mm, all angles ± 0.5° except where stated

DO NOT SCALE DRAWING
SECTION C-C
SCALE 1:1

Manufacturing time
Dwg. Revision 0
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

<table>
<thead>
<tr>
<th>DATE</th>
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<th>NAME</th>
<th>DWG No.</th>
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<td>added wrench holes</td>
<td>Mark</td>
<td>DTR-009-P</td>
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Number of required per machine - 1

DATE MODIFICATION NAME NAME DATE Form No.: F039
10/08 added wrench holes Mark 25/06/12 DWG No.

 material: 6061 Alloy

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING
Number of required per machine -

NAME | DATE
--- | ---
PS | 15/07/12

Manufacturer: PS
Date: 15/07/12

Date: 23/11/04

Title: Mounting unit base plate, sliding

Template Rev: 2

Material: Mild steel

All dimensions in mm, all angles ± 0.5° except where stated.

Do not scale drawing

Note: Machine after fabrication.
Weld prep. 3mm at 45 deg. (2 places)

Weld prep. 3mm at 45 deg. (2 places)
**Slide rail, right**

**MATERIAL:** Mild steel

**ALL DIMENSIONS in mm**

**ALL ANGLES ± 0.5° EXCEPT WHERE STATED**

**DO NOT SCALE DRAWING**

**DWG No.:** DTR-031-P

**Form No.:** F039

**R. Date:** 23/11/04

**Template Rev:** 2

**Manufacturing time**

<table>
<thead>
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<th>DATE</th>
<th>MODIFICATION</th>
<th>NAME</th>
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</table>

**Chamfer all holes 1mm x 45°**

**De-burr all sharp edges 0.5mm x 45°**

**Number of required per machine -**

- Chamfer all holes 1mm x 45°
- De-burr all sharp edges 0.5mm x 45°

**DIMENSIONS ± 1mm**

- **SIDE A:**
  - 10 ± 0.50
  - 30°
  - 10
  - 10

- **SIDE B:**
  - 20 ± 0.50
  - 45 ± 0.50
  - 175.50 ± 0.50
  - 197.50 ± 0.50
  - 220 ± 0.50

- **SIDE C:**
  - 28
  - 240

**SIDE D:**

- **TOP:**
  - 10 ± 0.50
  - 14.0

- **BOTTOM:**
  - 10 ± 0.50

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**DTW Cambodia**
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine:

MATERIAL: Mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ±0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

TITLE: Arm stub

Form No.: F039
R. Date: 23/11/04
Template Rev: 2

DTW
PO Box 244
Cambodia
### Title
Mass, lower, right

### DWG No.
DTR-042-P

### Material
Mild steel

### Dimensions
- **350 mm**
- **100 ± 0.50 mm**
- **150 ± 0.50 mm**
- **45°**

### Chamfering
- Chamfer all holes 1 mm x 45°
- De-burr all sharp edges 0.5 mm x 45°

### De-burring
- De-burr all sharp edges 0.5 mm x 45°

### Notes
- All dimensions in mm
- All angles ± 0.5° except where stated
- Do not scale drawing

### Drawing Instructions
- **Date Mod:** 23/11/04
- **Checked by:** R.
- **Drawn by:** PS 20/07/12

### Manufacturing
- **Date:**
- **Modification:**
- **Name:**

### Notes
- **Number of required per machine:**
- **Date:**
- **Modification:**
- **Name:**
Mass, lower, left

Manufacturing time Dwg. Revision 0
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine:

<table>
<thead>
<tr>
<th>NAME</th>
<th>DATE</th>
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</thead>
<tbody>
<tr>
<td>PS</td>
<td>20/07/12</td>
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</tbody>
</table>

MATERIAL: Mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

DWG No. DTR-047-P
Material to be in annealed state for drilling and forming. Harden and temper before use.

Number of required per machine -

<table>
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<tbody>
<tr>
<td>PS</td>
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</tbody>
</table>

Title: Leaf spring, free state

Manufacturing time: Dwg. Revision 0

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°
Sliding mount stop pad

Number of required per machine -

- Chamfer all holes 1mm x 45°
- De-burr all sharp edges 0.5mm x 45°

MATERIAL: Rubber

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

DATE MODIFICATION NAME NAME DATE Form No.: F039

DAT DRAWN BY CHECKED BY R. Date: 23/11/04 Template Rev: 2

DWG No. DTR-057-P

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Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine -

TITLE: Arm joint plate

MATERIAL: Mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 8

Drawing by Mark
Checked by Samnang

MATERIAL: mild steel

ALL DIMENSIONS IN mm

DO NOT SCALE DRAWING
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 6

TITLE: TUB ANGLE
SUB: BASE
DWG No. DTR-067-P_base_TubAngle

MATERIAL: Mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

Manufacturing time
Dwg. Revision 0

DATE MODIFICATION NAME

DTW

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Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 1

DATE: TOP PLATE
SUB: BASE

DWG No. DTR-069-P_base_TopPlate

Form No.: F039
R. Date: 23/11/04
Template Rev: 2

MATERIAL: mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

DRAWN BY: Mark
DATE: 15.07.12

CHECKED BY: Samnang

Western Union: DTW Cambodia 006961211

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Chamfer all holes 1 mm x 45°
De-burr all sharp edges 0.5 mm x 45°

De-burr all sharp edges 0.5 mm x 45°

Number of required per machine - 2

SLEEVE CAP - BEFORE WELDING

DWG No. DTR-074-P_arm_SleeveCap
WELD FIRST, THEN MACHINE/DRILL/TAP

4x M6 UP TO NEXT

SECTION A-A
SCALE 1:3

360

4 3 2 1 8 7 6 5

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

MATERIAL:
mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

DATE MODIFICATION NAME NAME DATE
19.07.12

Form No.: F039
R. Date: 23/11/04
Template Rev: 2

TITLE: PIVOT ASSEMBLY

SUB: ARM

DWG No. DTR-075-A_arm_pivot
Number of required per machine - 1

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DTW
Development Technology Workshop
Cambodia

Manufacturing time
Dwg. Revision 0

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

ALL DIMENSIONS ± 1 mm,
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

DATE MODIFICATION NAME

NAME DATE
Mark 19.07.12

Material: mild steel

Title: NEEDLE PUSHER

Sub: ARM

Dwg. No.: DTR-076-P_arm_NeedlePusher

Form No.: F039
R. Date: 23/11/04
Template Rev: 2
Title: Hammer hook

Material: Mild steel

Dimensions:
- Chamfer all holes 1mm x 45°
- De-burr all sharp edges 0.5mm x 45°

Number of required per machine:

Drawing:
- Hammer hook

Date: 23/11/04

Check by: R.

Date: 23/07/12

Drawn by: PS

Template Rev: 2

Form No.: P039

Table:

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<th>NAME</th>
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 DWG No.: DTR-078-P

The drawing is for instructional use only.
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 1

Title: TOP BRACE

Sub: TOWER

Dwg. No.: DTR-083-P_tower_topbrace
Number of required per machine - 2

TITLE: ARCH BRACE

DRAWN BY: Mark
DRAWN DATE: 18.07.12

CHECKED BY: Samnang
CHECKED DATE: 23/11/04

MATERIAL: mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

Manufacturing time
Dwg. Revision 0
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 2
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 8

**TITLE:** LEG BRACE

**SUB:** TOWER

**DWG No.:** DTR-085-P_tower_legbrace
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 2

TITLE: LOCK SHELF
SUB: TOWER
DWG No. DTR-093-P_tower_lockshelf
Number of required per machine - 2

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°
TITLE: NEEDLE BRACKET

MATERIAL: mild steel

DIMENSIONS: ±0.5° (except where stated)

Number of required per machine: 1

Manufacturing time
Dwg. Revision
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

DATE MODIFICATION NAME NAME DATE

19.07.12

CHECKED BY: Samnang

R. Date: 23/11/04

Form No.: F039

TEMPLATE REV: 2

DO NOT SCALE DRAWING

DTW
PO Box #244
Siem Reap
Cambodia

DTW
PO Box #244
Siem Reap
Cambodia

SUB: INDICATOR

DWG No.
DTR-099-P_indicator_needlebracket
TITLE: NEEDLE

DRAWN BY: Mark
CHECKED BY: Samnang
MATERIAL: mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

Number of required per machine = 1

Manufacturing time
Date: 23/11/04

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

510
40
90
70
20

Dwell Revision
0

DATE MODIFICATION NAME

23/11/04

DATE

MARK

NAME

DTR-102-P_indicator_needle

DTW
PO Box 1244
Sihanoukville
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---

DATE
MODIFICATION
NAME

DRAWN BY

CHECKED BY

MATERIAL

DWG No.

Template Rev: 2

Form No.: F039

R. Date: 23/11/04

0

1
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<th>PART NUMBER</th>
<th>QTY.</th>
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<td>DTR-108-P_lifter_leg_front</td>
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**Chamfer all holes 1mm x 45°**

**De-burr all sharp edges 0.5mm x 45°**

**Number of required per machine - 2**

**TITLE: FRONT LEG ASSEMBLY**

**SUB: LIFTER**

**DWG No.:** DTR-109-A_lifter_leg_front
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 1

A DATE MODIFICATION NAME

MARK 26.07.12

MATERIAL: mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

TITLE: UPPER BLOCK - BAR
SUB: LIFTER
DWG No.
DTR-116-P_lifter_block_upper_bar
Number of required per machine - 2

CHAMFER ALL HOLES 1 mm x 45°
DE-BURR ALL SHARP EDGES 0.5 mm x 45°

MATERIAL: Mild steel

DRAWN BY: Mark  26.07.12
CHECKED BY: Samnang  23/11/04

TITLE: UPPER BLOCK - END
SUB: LIFTER

Form No.: F039
Template Rev: 2

DO NOT SCALE DRAWING
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Number of required per machine - 1

Manufacturing time: 0
Dwg. Revision: 0
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

DATE MODIFICATION NAME DATE MODIFICATION NAME DATE

DRAWN BY: Mark 26.07.12
CHECKED BY: Samnang

MATERIAL: mild steel

TITLE: UPPER BLOCK ASSEMBLY
SUB: LIFTER
DWG No. DTR-118-A_lifter_block_upper
ITEM NO. | PART NUMBER | DESCRIPTION | QTY.
---|---|---|---
1 | DTR-030-P | Fuze mount support platen | 1
2 | DTR-060-P | Platen rib | 1

Note: Machine item 1 as shown on part drawing after fabrication.
Manfacturing time
IDw.
Revision
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

DATE MODIFICATION NAME NAME DATE
FrmNo.: F039
TITLE: LOWER BLOCK - END
DRAWN BY Mark 26.07.12
CHECKED BY Samnang Template Rev: 2
MATERIAL: mild steel

Number of required per machine - 2

Number of required per machine - 2

All dimensions in mm
All angles ± 0.5° except where stated
Do not scale drawing

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<th>ITEM NO.</th>
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Number of required per machine - 1

MANUFACTURING TIME

Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

DE-BURR ALL SHARP EDGES 0.5MM X 45°

DATE MODIFICATION NAME NAME DATE

DRAWN BY         Mark                     26.07.12

CHECKED BY       Samnang                  23/11/04

MATERIAL         mild steel

Dwg. Revision  0

DWG No.          DTR-141-A_lifter_lower_block

TEMPLATE REV. 2

ALL DIMENSIONS IN MM
ALL ANGLES ± 0.5° EXCEPT WHERE STATED

DO NOT SCALE DRAWING

TITLE: LOWER BLOCK - ASSEMBLY

SUB: LIFTER

FORM NO.: F039

R. DATE: 23/11/04
TITLE: WINCHSTAND POST

DRAWN BY: Mark
CHECKED BY: Samnang

MATERIAL: mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ±0.5" EXCEPT WHERE STATED

DO NOT SCALE DRAWING

Number of required per machine: 1

Manufacturing time: Chamfer all holes 1mm x 45° De-burr all sharp edges 0.5mm x 45°
SECTION A-A
SCALE 1:7

ITEM NO. | PART NUMBER | QTY.
--- | --- | ---
1 | DTR-142-P_lifter_winchstand_plate | 2
2 | DTR-143-P_lifter_winchstand_post | 1

Number of required per machine - 1

Title: WINCH STAND ASSEMBLY

SUB: LIFTER

Dwg. Revision 0
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Manufacturing time

DATE MODIFICATION NAME
26.07.12
Mark

CHECKED BY
Samnang

DRAWN BY
Mark
R. Date: 23/11/04
Template Rev: 2

MATERIAL:
mild steel

ALL DIMENSIONS IN mm
ALL ANGLES ± 0.5° EXCEPT WHERE STATED
DO NOT SCALE DRAWING

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Manufacturing time
Dwg. Revision 0
Chamfer all holes 1mm x 45°
De-burr all sharp edges 0.5mm x 45°

Number of required per machine - 2

Title: Pivot Pin

Dwg. No.: DTR-145-P_trigger_pivotpin

Material: Mild steel

All dimensions in mm
All angles ± 0.5° except where stated

Do not scale drawing
<table>
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<th>Manufacturing time</th>
<th>Dwg. Revision</th>
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<th>DATE</th>
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<th>MATERIAL</th>
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<th>ALL ANGLES</th>
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**Number of required per machine: 1**

**TITLE: LIFTER PIN**

**SUB: ARM**

**DWG No.: DTR-146-P_arm_lifter_pin**
Bibliography


