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THE HYBRID THERMAL LANCE: A PROMISING NEW TECHNIQUE FOR THE DESTRUCTION OF LANDMINES AND UXO BY DEFLAGRATION

by Donald Pratt [Messiah College] and Nicolas Torbet [The HALO Trust]

Explosive ordnance can be destroyed by a variety of methods. Destruction in-situ using an explosive charge is generally the preferred means; it is reliable, technically straightforward, and often the safest option. Other techniques include thermite-based tools or low-explosive powered disruptors. However, in a number of current humanitarian mine action (HMA) operating environments, clearance organizations are faced with restrictions on explosive use and/or importation of other energetic materials such as thermite. This may be due to the legitimate security concerns of mine-affected states, or legislative frameworks that do not account for non-military use of explosive ordnance disposal (EOD) tools. This takes place against a broadening range of explosive ordnance, particularly given the proliferation of improvised explosive based hazards in the Middle East.¹

This article presents an alternative method for destroying landmines and other thin-cased ordnance by burning through the case and deflagrating the explosive inside so that it is consumed without detonating. The device, referred to herein as the Hybrid Thermal Lance (HTL), is made from low-cost parts readily available in almost all countries, none of which are prohibited from carry-on baggage or likely to be subject to dual-use import restrictions. Single-use fuel tubes and locally-sourced gaseous oxygen make the HTL simple and inexpensive to use. While at a relatively early stage of testing, the authors felt sharing the results thus far (and making the concept open-source) would best meet the urgent needs of the HMA community, allowing other individuals or organizations to develop the concept further as they see fit.

Following a meeting in Cambodia between Donald Pratt and staff from The HALO Trust, there developed a research and development partnership between HALO and the Messiah College Collaboratory for Strategic Partnerships and Applied Research. The Collaboratory is an interdisciplinary undergraduate research initiative of Messiah College that connects students and faculty mentors from many different disciplines with real-world projects involving clients from around the world. HALO's need for a method to destroy ordnance in locations where explosives are highly regulated prompted an investigation into the idea that a modified hybrid rocket motor might be a suitable solution.

SIMILAR METHODS FOR THE DISPOSAL OF EXPLOSIVE ORDNANCE

Techniques using heat to enable the disposal of explosive

ordnance are well established.² They are often employed as they can allow for mass disposal of ordnance, with a significantly reduced chance of a high-order explosion, or as an alternative to explosives where licensing issues do not permit the use of high explosives:

- ♦ **Thermite EOD tools.** Thermite is an energetic material composition in which a metal-based powder, incorporating a fuel and an oxidizer, upon ignition undergoes an exothermic process producing significant amounts of heat in a focused area for short periods. For EOD purposes, aluminum powder is commonly used as the base fuel and, along with an oxidant mix, is initiated electrically using a magnesium-based (or similar) ignitor. The heat is focused onto the ordnance by either a crucible, flare, or direct placement system. Producing a high-quality thermite delivery system is relatively challenging, but a number of commercial products are available and have been employed by the HMA community with some notable successes. However, thermite-based EOD tools are often subject to licensing and import restrictions as, while comparatively safe to transport, they are considered to have potential military applications.³ Moreover, the price per demolition is often relatively high.
- ♦ **Gas-combination torches.** Torches that combine oxygen with liquid gas (or other similar fuel) have also been developed. These tools use principles similar to oxy-fuel welding/cutting torches to produce focused heat and flame. These have often been found to be overly complex to set up and challenging to reliably deploy in the field.
- ♦ **Incinerators and open-pit burning.** Although generally used for different purposes, this technique is mentioned for completeness. Large quantities of unfuzed, safe-to-move munitions can be destroyed using incinerators or burning of stacks in the open. In this case, wooden fuel is normally stacked among or under the munitions and ignited, often supplemented by a diesel mixture. This has the benefit of disposing of large quantities of munitions over time without detonating them. Disposing of mines or fuzed munitions using this technique is normally impractical or unsafe, although grill burners have been used successfully to destroy smaller anti-personnel mines in some instances.

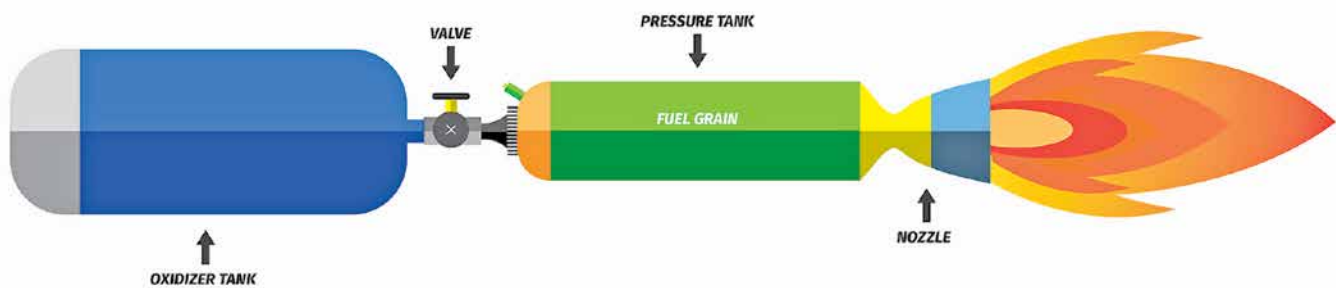


Figure 1. Schematic view of the basic component of a Hybrid Rocket Motor.
Figure courtesy of Emily Bean Design.

CHARACTERISTICS OF HYBRID ROCKET MOTORS

Hybrid rocket motors, consisting of a solid-fuel and liquid or gaseous oxidizer, have been around for a long time. Figure 1 shows the basic components of a typical hybrid rocket motor. A recent notable example is the liquid nitrous oxide/hydroxyl-terminated polybutadiene (a type of polyurethane elastomer) motor used in the suborbital Space Ship One developed by Mojave Space Ventures, which won the X-Prize in 2004. In contrast to solid rocket motors, having the oxidizer in liquid or gaseous form allows the reaction to be throttled, stopped, and restarted easily, without the complexity of mixing and metering required of rockets using liquid/gas fuel and liquid/gas oxidizer. Hybrid rocket motors are also safer than solid rocket motors, since mixing of the fuel and oxidizer in a hybrid does not take place until the point of combustion. In addition, many different types of materials can make effective fuels, including commonly available plastics, like polyvinyl chloride (PVC), acrylic, and polyethylene.⁴ Nitrous oxide is commonly used as an oxidizer, primarily because it's easier to concentrate in liquid form than pure oxygen.

Small hybrid rocket motors gained popularity with large-scale model rocket enthusiasts in the United States after 9/11 when shipping solid rocket motors for large-scale models became

increasingly difficult. Early versions used PVC as the fuel and liquid nitrous oxide in aluminum or composite tanks small enough to fit within the rocket tube. Modelers experimented with a variety of different fuels, including cast rubber and machined and/or 3D printed polymers. Polymethyl methacrylate (PMMA) became a popular option due to its availability, low cost, ease of ignition, high combustion temperature, and minimal production of harmful byproducts during combustion. Typical model rocket engines produce an impulse lasting from 0.5 to 4.0 seconds, with thrust levels ranging from about 20 to 100 Newtons.⁵

APPLICATION TO THE DESTRUCTION OF UNEXPLODED ORDNANCE (UXO) BY DEFLAGRATION

A hybrid rocket motor is intended to produce high pressures in a confined chamber to eject gases at high velocity to create thrust, usually for a relatively short duration. A suitable torch for burning explosives need not produce thrust but does need to run for a longer period of time. Ideally, it would also be able to be throttled, and so easily started and stopped. The HTL, shown in Figure 2, meets all of these requirements. It produces a focused flame that exits the fuel tube at a relatively low pressure, producing a very minimal thrust reaction, and burns for a much longer time than

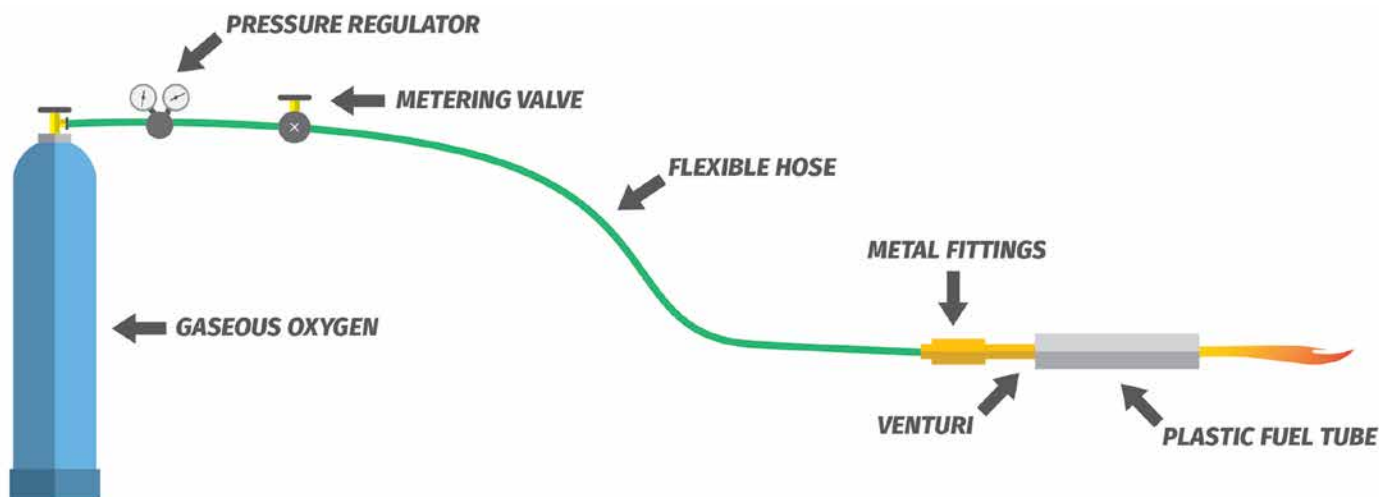


Figure 2. Basic components of the Hybrid Thermal Lance.
Figure courtesy of Emily Bean Design.



Figure 3. Fireproof test chamber used for initial prototype testing in the laboratory.
Figure courtesy of Donald Pratt.

a similarly sized hybrid rocket motor. Also, since the HTL is stationary while functioning and need not be light enough to fly, the use of gaseous oxygen is practical. Gaseous oxygen used for oxy-acetylene welding is very suitable and readily available virtually anywhere in the world. Medical oxygen can be used but high purity oxygen is not required. The HTL is fueled by a consumable plastic tube, which can be easily machined from stock, cast, or 3-D printed plastic shapes. PMMA (more commonly known as acrylic), was chosen for the initial laboratory tests and also the first field trials of the HTL, and found to be practical and effective. The HTL requires very little energy to ignite, and remote ignition can be achieved with a small electric arc or similar methods. The field tests described on the next page used an electric match for the ignition source, operated from the firing point by standard demolition equipment.

During early development, simple tests conducted by Pratt and his students in the Collaboratory using plastic tubing and gaseous oxygen were encouraging enough to warrant the construction of a fireproof test chamber equipped with high-impact glass observation ports, shown in Figure 3. Simple prototype fuel tubes were machined from 1" diameter acrylic rod stock cut in 4" lengths. A $\frac{1}{4}$ " diameter hole was drilled down the center of each rod, and one end was threaded for $\frac{1}{8}$ " national pipe threads (NPT). Figure 4



Figure 4. Prototype HTL fuel tubes made of 1" diameter 4" long PMMA before and after testing.
Figure courtesy of Donald Pratt.



Figure 5. 3" diameter wood test sample after 20 second exposure to the HTL.
Figure courtesy of Donald Pratt.

shows an unused fuel tube alongside one that has been subjected to four 30-second burns. A 3" long brass nipple was threaded into a bulkhead fitting that passed through the end plate on the test box. The oxygen was delivered through a rubber hose connected to an oxy-acetylene torch oxygen tank, using a stock regulator. Noting that the hose could potentially become a fuel source if the flame were allowed to propagate back through the tube, an aluminum plug was pressed into the outlet end of the brass nipple, with a 0.05" diameter hole drilled through the center to create a venturi to block propagation of the flame front. An emergency shutoff valve and an adjustable metering valve were attached to the brass tube to provide precise control of the oxygen flow to the test sample.

Tests confirmed that the HTL was easily ignited and controlled by adjusting the flow of oxygen. Even at relatively low flow rates of under 0.5 cubic feet per minute, the HTL proved capable of producing an intense flame, which was easily throttled and quickly extinguished by simply cutting off the oxygen supply. While the ignition temperature of PMMA is only about 450°C, the

combustion temperature is considerably higher. PMMA burns in the presence of oxygen and produces monomer methyl methacrylate (MMA), which decomposes to generate methane, methanol, propylene, formaldehyde, acetone, acetylene, etc. These molecule products undergo combustion and produce carbon monoxide (CO), carbon dioxide (CO₂), water vapors, and other gases with the generation of high temperatures. For purposes of comparison, thermite burns at temperatures between 2,200° and 2,500° C, and a properly adjusted oxy-acetylene torch can reach temperatures close to 3,500° C. During initial tests in the laboratory, the destructive power of the HTL was evaluated by placing a 3" cylindrical block of pine 1.5" diameter at a distance of about 2" from the outlet of the fuel tube.⁵ Significant removal of material from the wood block occurred after only 20 seconds of exposure to the HTL, as shown in Figure 5. A similar test on an identical block of wood using an oxy-acetylene torch did roughly the same amount of damage to the test block, and while precise measurement of the HTL flame temperature has yet to be confirmed, it would appear that it is comparable to an oxy-acetylene torch.



Figure 6: Test setup using the HTL to destroy a simulated IED explosive charge (loose-fill ammonium nitrate-based explosives).
Figure courtesy of Donald Pratt.



Figure 7: Complete destruction of the simulated IED explosive charge.
Figure courtesy of Donald Pratt.



Figure 8. Test setup using the HTL to destroy a Pakistani P3 Mk2 anti-tank mine.
Figure courtesy of Donald Pratt.



Figure 9. Nothing remained of the P3 Mk2 anti-tank mine after exposure to the HTL.
Figure courtesy of Donald Pratt.



Figure 10. Test setup using the HTL to destroy a PG-2 grenade.
Figure courtesy of Donald Pratt.



Figure 11. Penetration of the casing of the PG-2 grenade by the HTL.
Figure courtesy of Donald Pratt.



Figure 12. Test setup using the HTL to destroy a Soviet TM-62M anti-tank mine.
Figure courtesy of Donald Pratt.



Figure 13. Remnants of the TM-62M anti-tank mine after exposure to the HTL.
Figure courtesy of Donald Pratt.

FIELD TESTS IN AFGHANISTAN

After obtaining these initial results, it was decided that there was sufficient justification to go ahead with field trials where the HTL could be tested on real mines and UXO. After discussion with HALO staff, Afghanistan was selected as a suitable site for testing, as it supplied access to range facilities, availability of live ordnance, and access to a well-established local office, which provided expertise, technical assistance, and infrastructure. In April 2018, the prototype HTL was taken to Afghanistan, where Pratt, Torbet, and Afghan HALO staff performed tests on four different types of ordnance at the HALO explosives range north of Kabul.

The first test was conducted using a variety of loose ammonium nitrate-based explosive materials placed in a plastic container, simulating an improvised explosive device's (IED) main charge, shown in Figure 6.⁷ An acrylic fuel tube was installed and the HTL was connected to a tank of compressed oxygen through a two-stage regulator and a metering valve. The regulator was adjusted to 5 psi. The HTL was placed approximately 2" from the plastic container and an electric match, locally sourced in Kabul, was inserted in the end of the fuel tube. Oxygen flow was established, and the electric match ignited. The flow of oxygen was allowed to continue for about 30 seconds and then shut off. Observers at 500 meters communicating by radio reported smoke and flames,

which persisted for several minutes. After the requisite waiting period, the test site was examined, and it was quickly determined that the explosives had been completely consumed by burning, leaving only a small amount of residue from the plastic container, as shown in Figure 7. It was clear that the HTL had ignited the explosives and stimulated combustion to the point where they were sufficiently engaged so that when the HTL was extinguished, the burn continued until the explosives were fully consumed, without causing detonation.

Figure 8 shows a plastic-encased, unfuzed P3 Mk2 anti-tank mine used for the second test.⁸ Setup of the HTL was very similar to that used for the first test, except that the oxygen flow was allowed to continue for about two minutes, long enough for the 1" diameter and 4" long acrylic fuel tube to be completely consumed. Observers reported a great deal of smoke and flame, which persisted for a longer period of time than during the first test. Figure 9 clearly shows results similar to that of the first test; the mine, including the case and all of the explosive material, was completely consumed. The photograph also shows that the intensity of the flames from the burning mine melted and separated the hose connecting the oxygen tank to the HTL. However, since the oxygen had been turned off two minutes into the test, the hose did not continue to burn. The metal parts of the HTL

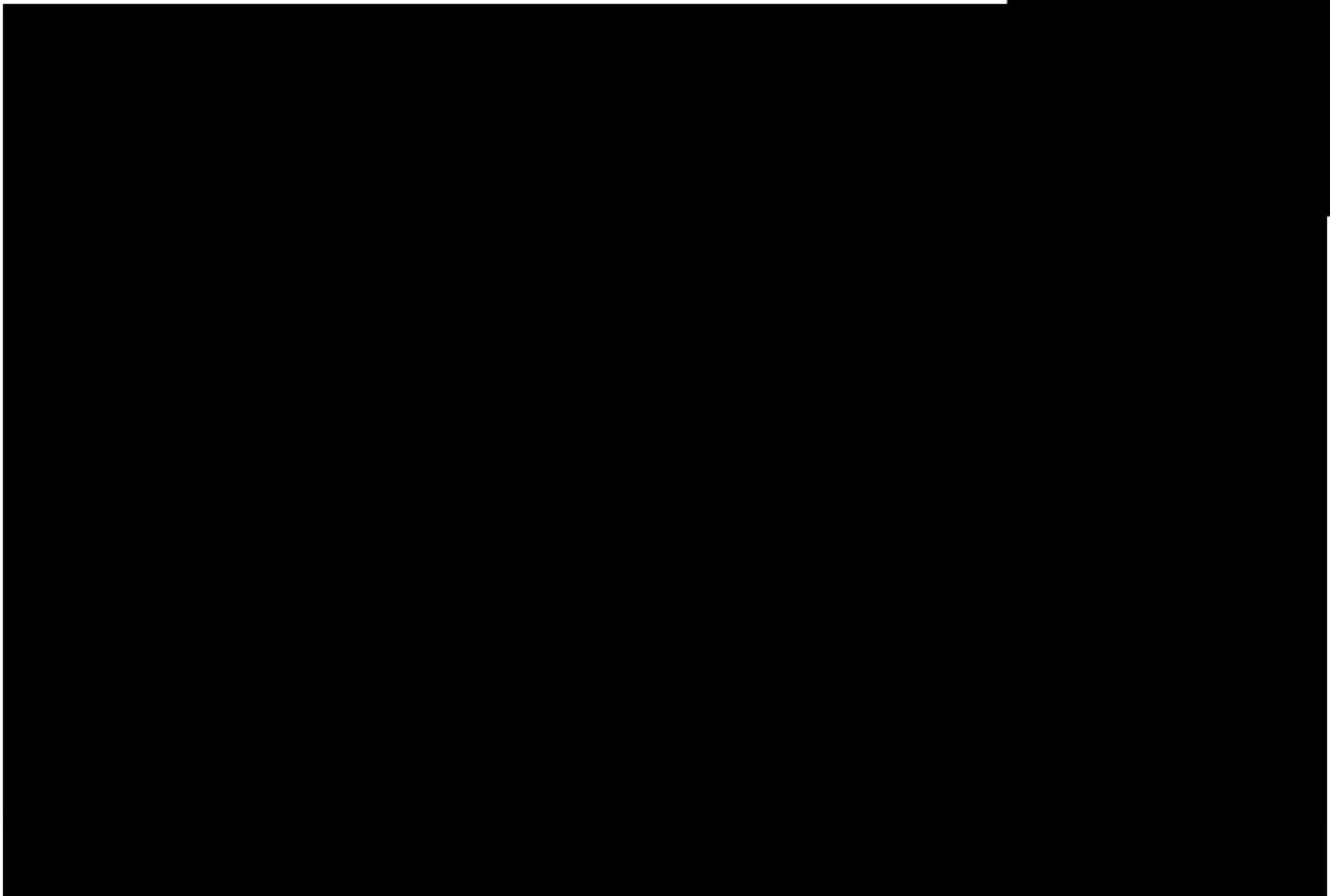
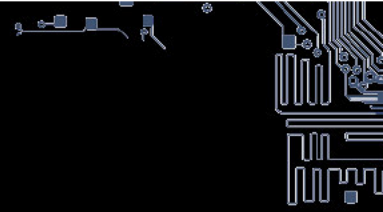


Figure 16. The HTL shortly after ignition burning through the plastic casing of a simulated IED explosive charge.
Figure courtesy of John Montgomery.

were slightly scorched, but otherwise undamaged. The hose was simply trimmed back and reattached to the HTL, after which testing continued.

The third test was performed on a Soviet-era PG-2, as shown in Figure 10.⁹ The HTL was aimed at the side of the case where the main charge was located, to try to avoid setting off either the fuse or the booster. As can be seen from Figure 11, the HTL made a hole in the case roughly 35 millimeters in diameter, and ignited the explosive material inside without detonation occurring. With no easy way to safely examine the inside of the grenade, it was difficult to assess the state of the main explosive fill, fuze, and booster, so the decision was made to ensure the complete destruction of the grenade using a small explosive charge. After examining the remnants, it appeared that the fuze and booster had been consumed by the burn initiated by the HTL, but this could not be established for certain. More testing on RPG-type ordnance is indicated.

The fourth test was made on an unfuzed TM-62M anti-tank mine, which has a metal case.¹⁰ Considering that the prototype HTL with 1" diameter and 4" long fuel tubes has a maximum burn time of only two minutes, the team were unsure of its ability to penetrate the case and fully deflagrate the explosive material. As shown in Figure 12 the HTL was placed at an angle to the case to reduce the possibility of the HTL flame reaching the booster charge before the outer HE explosive was fully engaged. Shortly after completing the HTL triggering sequence, the observation team reported smoke and flames, which continued and increased after the oxygen supply to the HTL was cut off. During this test, the mine emitted loud and varied roaring sounds. After examining the remnants, we surmised that these sounds were made by the hot gases from the burning explosive material exiting the case through the hole made by the HTL. Smoke, flames, and noises persisted for at least ten minutes after the HTL was extinguished. Subsequent examination of the remnants of the mine revealed complete destruction of the explosive material, as shown in Figure 13; all that remained was a tattered metal case filled with ashes.

With these encouraging results on targets containing live explosive fill, the question of how well the HTL could penetrate steel plate was briefly investigated at the HALO office in Kabul, shown in Figure 14, where the HTL was found to be capable of cutting a 10–15 millimeter hole through sheet steel several millimeters thick in under 20 seconds. Following these successful tests, the decision was made to take advantage of an opportunity for HALO EOD staff to be introduced to the HTL. A number of Afghanistan national staff were participating in an EOD training course at the same time that the HTL field trials were underway, and the HTL was somewhat hastily incorporated into that course and used during a number of training tasks against “dry targets” (i.e. non-explosive dummy devices), as shown in Figures 15 and 16. This provided an additional opportunity to uncover

operational challenges that might present in the field and to make a first pass at incorporation of the HTL into EOD task procedures. Back at the Collaboratory, testing is underway to further establish operational parameters, but it appears quite likely that the HTL will prove suitable for the penetration and destruction of thin-cased metal ordnance.

OPERATIONAL SAFETY CONSIDERATIONS AND STANDARD OPERATING PROCEDURES (SOP)

As well as being technically functional, a key concern for the end user is that the equipment is at least as safe as other EOD methods as well as being operationally practical. While the testing was conducted under the tight control of the Afghanistan program’s demolition range safety procedures, HALO is still establishing the SOPs for how the HTL will be deployed operationally once out of the prototype stage.

A primary safety consideration is that although a high order detonation is unlikely while using the HTL, it must still be considered as a possibility. Also, the HTL will require placement in close proximity to a potentially hazardous item of explosive ordnance. Any EOD operator must take both of these into account when deploying the equipment. Principles such as minimal time at target, initiation from a protected shelter or safe distance, personal protective equipment, safety distances, equipment emplacement, etc., must mirror those of conventional EOD techniques when a high order is expected. In addition, the HTL induces a burn the duration of which will depend on the nature of the target and environmental factors. A detonation could occur at any time during the burn, particularly if the explosive ordnance is fitted with a fuze or booster. As such an **igniferous soak** will be required following use of the HTL before the EOD operator can approach the target, confirm successful destruction, and collapse any cordon.¹¹

For field purposes the HTL will need to be initiated remotely to ensure no positive EOD action takes place while the operator is in the vicinity of the target area. During field testing of the initial prototype, two methods were employed to achieve this: placing the tank on a short hose near the target, leaving the oxygen running, returning to the firing point (protected bunker) and initiating the burn using an electric match on a length of firing cable, and alternatively, running a long hose (80+ meters) from the tank at the firing point to the fuel tube. In the latter case, both controlling the oxygen flow and initiating the burn were conducted from the firing point, which required two people. Clearly, neither of these methods would be particularly practical in the field as the setup is a relatively complex procedure and control of the oxygen flow is somewhat haphazard. Additionally, when the longer hose is employed, there is the potential for the hose itself to become a conduit for the propagation of flame back to the firing point, if a violent burn or high order should separate the venturi tube

and provide a source of ignition for the oxygen-filled hose. Thus, one of the key future developments will be a means of placing the equipment in its entirety in the vicinity of the target and initiating the procedure from the firing point. A longer venturi tube and protective stand will also assist with safe placement against more challenging targets. Work on this has already begun, and the next prototype will likely employ a smaller tank fitted with an electronic delay timer connected to a solenoid valve to control the flow of oxygen, all of which could be located near the target to simplify the procedure.

SUMMARY, CONCLUSIONS, AND POTENTIAL FOR FUTURE USE

After successful demonstration of the proof of concept in the laboratory, the prototype HTL has been tested under actual field conditions and found to be quite effective for consuming explosive material by deflagration. The ability of the HTL to quickly penetrate metal several millimeters thick makes it suitable for both plastic and metal encased ordnance. Apart from exposing a suitable target surface, using the HTL does not require contact with the ordnance that is to be destroyed, reducing the risk to the EOD operator during set up. If a device does function during the burning process, the parts of the HTL exposed to the explosion are inexpensive and easily replaced. The HTL is simple and inexpensive to make, and consists of parts and materials that are not regulated, and can be shipped without difficulty, and will pass easily through airport security. Pressurized gaseous oxygen of sufficient quality can be readily sourced virtually anywhere in the world. Thus the HTL has great potential for becoming an inexpensive, effective, and practical tool for the destruction of explosive ordnance in a variety of situations, particularly those where the use of secondary explosive charges is expensive or impractical.

In the short term, HALO anticipates that the HTL will be particularly suited for deployment against thin, plastic-cased IED main charges (especially following mechanical clearance operations), thin-cased cluster munitions, or smaller sensitive devices such as grenades on tripwires where explosive donor charge placement is more challenging.¹² In particular, the HTL is expected to be well suited for use in locations with security concerns such as Syria, Iraq, and Ukraine.

The HTL concept is not patented and is hereby released as open source, with the intent that it will be widely used to hasten the day when all people in all places may walk the earth in safety. Comments, questions, suggestions for improvement, and potential applications are invited.

FUTURE WORK

Parametric studies of fuel tube geometry are underway to determine the optimum size and shape for each category of ordnance to be destroyed. Precise measurement of the oxygen flow and tests

carried out at various flow rates are expected to lead to the development of an automated system for controlling the flow of oxygen. Continuing field testing on different types of live targets will yield a better understanding of the required flame characteristics and burn duration required to insure complete destruction of various types of target UXO and allow a detailed SOP to be written for each.

Based on the information obtained during the field trials described previously, a new prototype is being developed with a smaller oxygen tank that is placed closer to the device being destroyed. The flow of oxygen is regulated by a timer-controlled valve, allowing a set delay and precise burn time. Once the HTL is in position, the user simply starts the timer and returns to a safe position. After the set delay time, the user triggers the electric match and the rest of the sequence is carried out automatically. Depending on the size of the oxygen tank and the chosen burn duration, several burns can be carried out with a single fill and refilling the small tank in the field from a larger tank is quick and easy. Also, the decision was made to go with single-use fuel tubes on this second prototype, and a variety of diameters and lengths are being tested to determine the optimum tube size for each specific type of explosive ordnance to be destroyed. ©

See endnotes page 63

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Nick Torbet is responsible for setting up and developing new programs and technical projects as part of HALO's Capability Group, currently with a particular focus on the Middle East. He was previously HALO's Program Manager in Laos and Operations Manager in Ukraine. Before HALO he served as a British Army Officer for over ten years, specializing in explosive ordnance disposal.