Viability and Performance of Improvised Ammunition

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Abstract. Within the UK, ammunition is tightly controlled by the Firearms Act (1968) and, as such, not readily available for legal purchase by the general populous. The Metropolitan Police Service assess the threat picture within the UK and have highlighted open source designs and instructional material available online to construct improvised ammunition. This paper has two aims i. to investigate the viability and performance of improvised handgun ammunition ii. To assess the ability of such ammunition to defeat typical materials used in law enforcement protection schemes. This paper will initially review open-source material available online with a view to down selecting the most promising and investigating the viability and performance of each option. Finally, this study will consider modifications and alternative materials for the fabrication of improvised ammunition and, once again, its performance will be evaluated against typical materials used in law enforcement protection schemes.

1. INTRODUCTION

Within the UK, both firearms and ammunition are tightly controlled by the Firearms Act (1968) and, as such, not readily available for legal purchase by the general populous. The UK operates a firearms licensing structure, in which citizens can apply to hold firearms or shotguns; for this they require a 'good reason' for owning the firearm, as well as an assessment by the police to ensure they do not pose risk to public safety [1]. As of 31 March 2024 147,364 people hold firearms certificates and 495,798 hold shotgun certificates in the UK. There are 510,717 individuals who hold these due to dual certification [2]. Due to this strict firearms licensing, firearms offences in the UK are considered some of the lowest in the world with 6268 offences in England and Wales reported between April 2023 and March 2024 [3]. Although globally the UK has one of the lowest rate of firearm related violence, death and crime in the world, this annual figure has shown an upward trend since 2014, and in that time has risen by over 29% from 4856 cases in 2014 [3]. One possible cause for this increase in offences over the past decade is the introduction of the 3D printed firearm.

Although 3D printed firearms are not the first kind of improvised firearms in existence with published designs and assembly instructions, they have significantly reduced the fabrication skills and equipment needed to produce a functional semi-automatic weapon. The first 3D printed firearm design was published on the internet on the 7th May 2013. The Liberator was a single shot firearm almost entirely produced from plastic using a 3D printer. Since this there have been huge advancements in the field of homemade printed firearms. Models available for download on the internet vary in calibre, complexity, and construction materials. At the time of writing most downloaded and produced firearms are hybrid 3D printed firearms. These systems use both 3D printed components in conjunction with traditionally manufactured components such as barrels and firing pins. By using a hybrid approach these firearms are durable, powerful, and accurate. Currently the most downloaded 3D printed firearm is a pistol-calibre carbine known as the 'F**k Gun Control 9 mm' (FGC 9) which is used by hobbyists, insurgents, militia members, terrorists, and drug traffickers in at least 15 countries [4]. The FGC9 free download has an extremely comprehensive guide to its production, and is also distributed with a link to producing improvised ammunition for use in tightly controlled areas such as Europe [5]. The FGC9 and many similar hybrid 3D printed weapons are chambered in 9 mm, and will still require ammunition that cannot legally be obtained in the UK without a firearms licence. Data from the Metropolitan Police Service (MPS) shows that 12 3D printed guns were recovered in London between 2020 and 2024 [6]. Data from the National Crime Agency (NCA) show that nationally 17 3D printed firearms or components were recovered in 2022 and 25 recovered in 2023 [7]. In addition to the threat of 3D printed firearms, converted blank firing weapons pose a threat in the UK. Data from police figures show that in 2023 there were 64 discharges from converted blank firing weapons compared to 42 from real equivalent weapons [8]. Recently legislative changes have made owning certain types of blank firing weapons illegal in the UK [9].

Whether the threat is an illegal i) converted blank firing firearm, ii) 3D printed firearm or iii) factory produced firearm, without a firearms licence, criminals will not be able to legally obtain

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ammunition for any of these weapons in the UK. This leaves the criminal two available options; illegally obtain commercial off the shelf (COTS) ammunition, or the production of improvised ammunition.

2. OPEN-SOURCE INSTRUCTIONAL MATERIAL

A specialist team within the MPS assess the firearms threat picture within the UK and have highlighted open-source designs and instructional material available online to construct improvised ammunition. The team highlighted the documentation that had received high levels of traffic and downloads. In addition using MPS registered IT equipment and as part of their employed role, the author undertook an assessment of open source material provided by a popular search engine with relevant key terms.

Instructional material highlights techniques to produce improvised ammunition in a range of materials and calibres. From the material reviewed improvised handgun ammunition fell into three broad categories; 3D printed ammunition, reactivated ammunition, and modified ammunition.

2.1 3D printed ammunition

3D printed ammunition files are widely available on many 3D model file repository sites. Files are available in a variety of calibres and designs. The files are usually accompanied by suggested material type, most of which suggest Poly Lactic Acid (PLA+) as a build material as well as printer settings and instructions from the designer on how to achieve the best results. The files that are provided are usually in a Stereolithography (STL) file format, which can be edited and amended by the user to customize or enhance the print to their specification. Files are available for both projectiles and casings. Projectiles are available which are modelled on conventional ammunition including Full Metal Jacket (FMJ) and Jacketed Hollow Point (JHP) as well as custom models designed as sabots to carry ball bearings for additional mass. It should be noted that 3D models will not behave the same as the ammunition they are geometrically modelled on due to their different material properties. Some casing files are modelled on COTS ammunition and as such are dimensionally accurate to its brass counterpart, others are specifically designed with modified internal dimensions to help withstand the firing of the bullet in a weapon, or allow the seating of an alternative sized projectile. One such design, the '9mm Deep' is well documented and designed to fire a range of different sized projectiles from a 9mm chambered weapon using a custom designed case with external dimensions of a 9mm Lugar [10]. Videos are available on host platforms such as YouTube of 3D printed ammunition being successfully discharged from both 3D printed weapons and conventional handguns into a range of targets including paper targets, watermelons and gels.

2.2 Reactivated ammunition

Within the UK and many other heavily regulated areas it is possible to obtain deactivated ammunition, as well as some component parts for the ammunition such as the projectile and casing. Various resources on the internet discuss how to re-activate this de-activated ammunition. Distributed alongside the FGC9 is the document *'But What About Ammo? V1.0'* [5] which documents using Hilti DX 6.8/11 cartridges for Hilti DX tools to provide the priming compound and propellant to re-activate them. The document is a comprehensive guide with high quality imagery for the user to follow. It provides details of all the required tooling, as well as links to 3D printed parts to assist in the process.

Following on from V1.0 *'But What About Ammo Volume 2'* [11] has also been published. This document focuses on casting and electroplating lead projectiles for use in 9mm ammunition. This document follows a similar format to V1.0 and equally has a high quality pictorial guide to the process. Since casting of lead projectiles has been a process followed by hobbyist shooters in the UK for a long time, and unjacketed lead projectiles can be purchased from some specialist ammunition suppliers and known to be less penetrative than its jacketed counterpart, this process was not explored further.

Various resources are available online for the creation of homemade primers. These typically use a spent primer and reactivate it with an alternative high explosive, making use of the existing anvil and primer cup. *'Homemade Primer Course'* [12] details three methods that can be used; Primers made from toy caps, primers made from strike-anywhere matches, and primers made with H-48 home made potassium chlorate priming compound. Strike anywhere matches are hard to obtain in the UK and have been banned from sale since 2018, the chemical components in H-48 are also restricted and hard to obtain, as such the toy cap method is the most viable.

2.3 Modified ammunition

Another method documented within the open-source literature focuses on the modification of blank ammunition. Blank ammunition can be purchased in the UK without the licensing restrictions other ammunition is subjected to. Blank ammunition is designed to generate a muzzle flash and explosive sound, for instance to start a race, rather than fire a projectile. A paper *'Modification Methods of Blank Pistols in Turkey in 2006'* [13] explores how both blank firing weapons of the time could be modified to discharge a projectile, as well as modification of blank cartridges by adding projectiles to them. The paper makes reference to how blank cartridges with buckshot projectiles can be lethal.

3. PRODUCTION OF IMPROVISED AMMUNITION

Assembly of improvised ammunition took place at a Ballistic Test Facility (BTF), under the supervision of the facilities range officer. Assembly was conducted using basic hand tools similar to those recommended in open-source material. Where appropriate some professional reloading tools were used, for example a primer seating tool and reloading press in the interest of efficiency and safety.

3.1 3D printed ammunition production

3D printing, which is otherwise known as additive manufacturing, is a process which has been available to hobbyists since 2009. Within the field of 3D printing there is a vast array of different 3D printers that are available for purchase, using different filament types and technologies. Prices for 3D printers for home use currently range from around £100 upwards. Most open source resources recommend PLA+ as a build material. For this study ammunition was produced in alternative materials. Ammunition was produced using two different 3D printers;

i. Form 3+ [1] Stereolithography (SLA) or resin 3D printer, which can produce very high quality prints using UV curing of resin. Components produced in; Black Resin V5, Durable Resin and Tough 2000 Resin. Unit price approximately £2250 [14].

ii. Bambu Lab P1S[2] Fused Deposition Modeling (FDM) 3D printer, which uses a more traditional filament spool to melt and fuse layers of material. This unit was used to produce Acrylonitrile Butadiene Styrene (ABS), PLA+ and Polyethylene terephthalate glycol (PETG) components. Unit price approximately £510 [15]

Utilizing the FDM printer ABS and PETG prints were evaluated. Compared to PLA+, PETG is a tougher but softer material, ABS is a tougher and more rigid material. Prints on the SLA printer use specialist resin. In addition to a standard resin (black Resin V5), using the Formlabs material database [16] resins design to withstand force were selected to produce prints from Durable resin and Tough 2000 resin.

3.1.1 3D printed projectiles

Figure 1 below shows a selection of 3D printed projectiles. Projectiles were produced in three different designs, and were sized to fit COTS 9mm x 19mm brass cartridge cases and loaded using COTS primers and propellant. The three designs of 9mm projectiles that were evaluated were:

i. Solid projectile,
ii. Projectile with opening for three 6mm ball bearings (BBs),
iii. Projectile with opening for single 4mm BB.

All projectile only designs were downloaded from freely available 3D printing file repositories and had a nominal diameter of 8.93mm.

[1] Form 3+, Formlabs®, Massachusetts, USA, Catalogue #PKG-F3-WSVC-BASIC

[2] P1S, Bambu Lab®, Shenzhen, China

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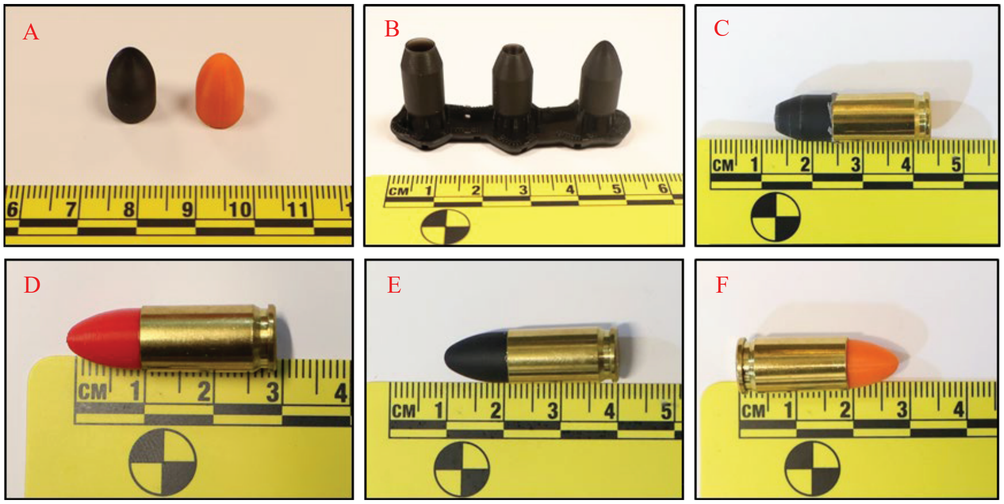

Figure 1. A) Black Resin V5 and orange ABS projectile. B) Black Resin V5 projectiles of three designs on a raft C) Black Resin V5 with 4mm BB projectile in brass case D) Red PETG projectile in brass case. E) Black Resin V5 projectile in brass case. F) Orange ABS projectile in brass case.

3.1.2 3D printed cartridge cases

Figure 2 below shows 3D printed cartridge cases, with projectiles assembled as complete rounds. The projectiles were the same as described above. Although cartridge cases were downloaded from the internet, to achieve the desired fitment custom case STL files were created. Cases were initially modeled on the 9 x 19mm brass NATO cartridge design using freely available CAD software. After initial trials it was found that 3D printed cartridge cases offered insufficient support to hold the primer in place, and it moved axially towards the neck of the case when struck with the firing hammer and pin. Hence the primer pocket was modified to offer more support to the primer in this area these cases are referred to in the results section as ‘enhanced (1)’ with an extra 1mm of support around the primer pocket, and ‘enhanced (2)’ with an extra 2mm support around the primer pocket. Cartridge cases of this design were produced on the SLA printer, capable of producing high tolerance and thin prints. A further custom design projectile and cartridge case combination was then created to be printed in PLA+ on the FDM printer. Due to the capability of the printer, and material characteristics this had a thicker walled case and projectile of only 8mm diameter. As such this projectile would not engage the rifling of the 9mm barrel.

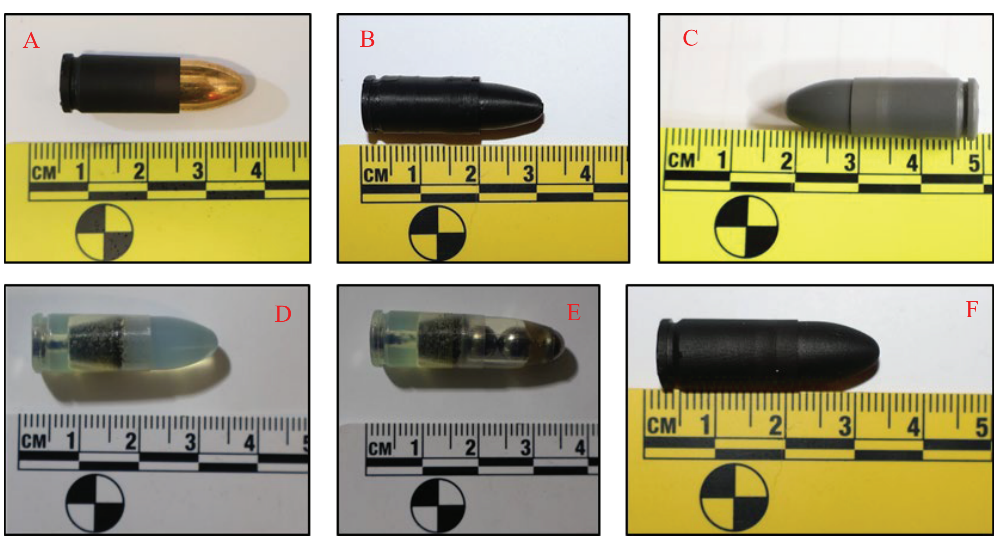

Figure 2. A) Black Resin V5 case and 124gn RUAG projectile. B) PLA+ ‘thick print’ case and ‘thick print’ projectile. C) Tough 2000 Resin case and projectile. D) Durable Resin case and projectile. E) Durable Resin case and projectile with 3 x 6mm BB. F) Black Resin V5 case and projectile.

3.2 Reactivated ammunition

Reactivated ammunition was produced using two different methods, one which produced both a reactivated primer and the propellant for the round, the other to produce just the primer. Following the process described in *'But what about AMMO?'* [5] A Hilti 6.8/11 cartridge was disassembled, and propellant and priming compounds were harvested. The priming compound was added to a previously fired primer and this was inserted into a new brass case with a new projectile. It should be noted that all of the above materials described in *'But what about AMMO?'* can be legally obtained in the UK with a license. Figure 3 below show the Hilti cartridge and one of the rounds produced.

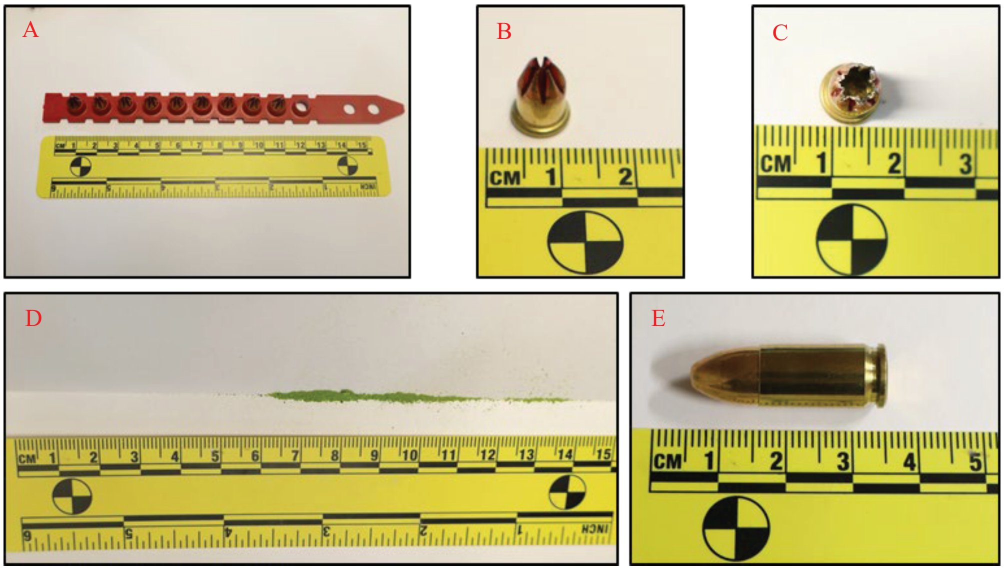

Figure 3. A) Hilti DX 6.8/11 red cartridge on strip. B) Single Hilti DX 6.8/11 red cartridge. C) Opened Hilti DX 6.8/11 with propellant and priming compound removed. D) Priming compound recovered from 2 Hilti DX 6.8/11 Cartridges. E) Assembled reactivated bullet.

Following the process described in 'Homemade Primer Course' [12] three improvised primers were produced, see Figure 4 below. By utilizing a cap gun ring, designed to create a loud sound and smoke simulating a gunshot when used in conjunction with a cap gun, the charge was removed from the ring and in conjunction with a small amount of fast pistol propellant an improvised primer created. The improvised primer was created from a previously discharged COTS primer, which can be obtained from 'deactivated ammunition' without license in the UK.

Figure 4. A) Cap gun ring. B) 8 recovered caps. C) 2 assembled cap gun activated primers.

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3.3 Modified ammunition

Figure 5 below shows some of the modified ammunition produced during this study. Modified ammunition were created in a similar method to that as documented in *'Modification Methods of Blank Pistols in Turkey in 2006'* [13] by affixing BBs to the end of blank ammunition. BBs were affixed with either microcrystalline wax, superglue, or melted plastic to the top of the blank. In this study stainless steel BBs were used. A crimp was applied to the neck of the 9mm x 21mm blank to reduce the neck diameter and allow it to chamber into a 9mm x 19mm barrel.

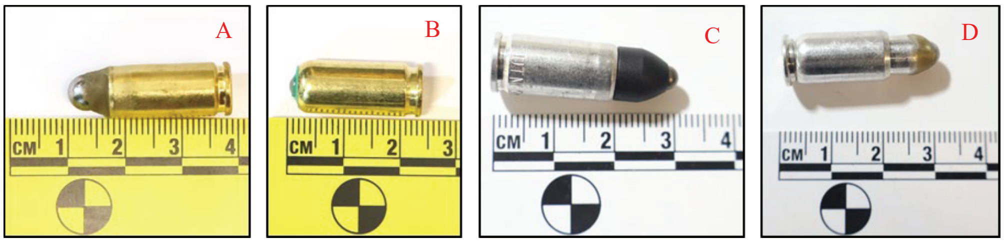

Figure 5. A) 9mm x 21mm blank with 8mm BB held in place with wax. B) 9mm x 19mm blank with 4.2mm BB melted into top. C) 9mm x19mm blank with 2 x 3.8mm BB glued in. D) Blank with 4.2mm BB held in place with wax.

4. BALLISTIC TESTING

A series of trials were conducted to determine the performance of the improvised handgun ammunition, constructed as described in section 3. In this study the performance of generic materials used within police protection schemes were evaluated. Figure 7 below shows the following materials which were evaluated;

i. 3mm Polycarbonate sheet 400mm x 400mm
ii. 0.9mm mild steel galvanized sheet 500mm x 500mm
iii. 20 layers of 200g/m^2 Aramid. Aerial density of target 4.0kg/m^2

The Rheinisch-Westfälischen Sprengstoff-Fabrike (RWS) DM11A1B2 (produced by RUAG since 2002) FMJ 124gn, as identified in the UK Home Office body armour (2007) standard [17] was used as a benchmark for testing, referred to as the RUAG DM11 in this report.

4.1 Method

Throughout this study a 9mm barrel (length 254mm) was coupled to a universal receiver. The improvised ammunition was loaded by the BTF range officer. Velocity was recorded using a chronograph system positioned 2.0 meters in front of the target. The aramid target was mounted on a microcrystalline wax block (nominally 420mm x 350mm x 100 mm), which was affixed into a steel frame. The polycarbonate and steel targets were affixed directly to the steel frame with no backing support. Figure 6 below shows a diagram of the experimental set up. Aramid and polycarbonate targets were held in place with elasticated hooked straps, and steel targets were affixed using clamps. High speed photography was captured a sample of the impacts and flight paths during the study.

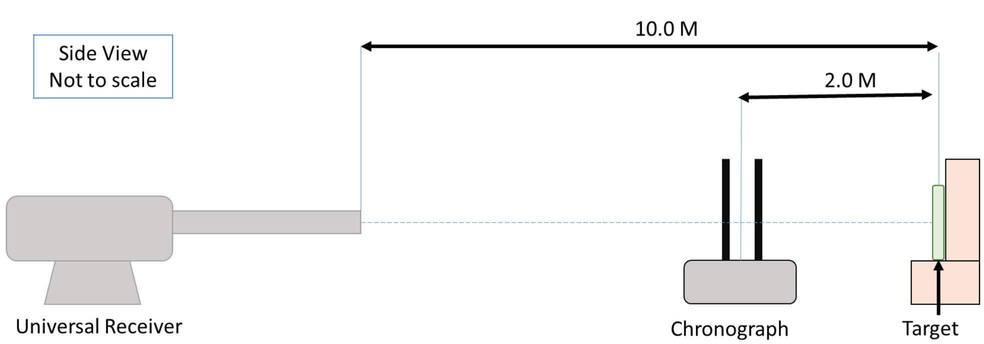

Figure 6. Diagram of experimental set up

Figure 7. A) Universal receiver fitted with 9mm barrel. B) Chronograph system. C) 3mm polycarbonate. D) 1mm galvanized steel plate. E) 20 layers of 200gsm aramid.

4.2 Results

Table 1 below summarized the results of the ballistic trial. Figure 8 plots velocity against mass of the three different types of improvised ammunition as described above, ammunition suffering a misfire and not recorded on the chronograph system has been omitted.

Table 1. Ballistic testing results

Shot reference	Type	Projectile	Mass (gn)	Cartridge case	Primer	Propellant	Propellant mass (gn)	Velocity (m/s)	Target type	Perforation
1	COTS	9mm RUAG DM11	124	9 x 19mm brass	CCI 500	APP	5.4	362	Polycarbonate	YES
2	COTS	9mm RUAG DM11	124	9 x 19mm brass	CCI 500	APP	5.4	365	Steel	YES
3	COTS	9mm RUAG DM11	124	9 x 19mm brass	CCI 500	APP	5.4	368	Aramid	NO
4	COTS	9mm RUAG DM11	124	9 x 19mm brass	CCI 500	Lovex DO36	3.5	156	Aramid	NO
5	Reactivated	9mm RUAG DM11	124	9 x 19mm brass	CCI 500	Hilti red	3.5	295	Steel	YES
6	Reactivated	9mm RUAG DM11	124	9 x 19mm brass	Improvised Hilti	Hilti red	4.1	Misfire	Steel	N/A
7	Reactivated	9mm RUAG DM11	124	9 x 19mm brass	Improvised Hilti	Hilti red	4.1	Misfire	Aramid	N/A
8	Reactivated	9mm RUAG DM11	124	9 x 19mm brass	Improvised Cap	APP	4.1	Misfire	Aramid	N/A
9	Reactivated	9mm RUAG DM11	124	9x19mm brass	Improvised Cap	APP	4.1	Misfire	Aramid	N/A
10	Reactivated	9mm RUAG DM11	124	9x19mm brass	Improvised Cap	APP	4.2	Misfire	Aramid	N/A
11	3D printed	9mm RUAG DM11	127	9 x 19mm black resin V5	CCI 500	APP	5.0	287	Aramid	NO
12	3D printed	9mm black resin V5	14.3	9 x 19mm black resin V5	CCI 500	APP	5.0	Misfire	Aramid	N/A
13	3D printed	9mm red PETG	13.7	9 x 19mm brass	CCI 500	APP	5.0	343	Aramid	NO
14	3D printed	9mm orange ABS	10.7	9 x 19mm brass	CCI 500	APP	5.0	367	Aramid	NO
15	3D printed	9mm black resin V5	14.3	9 x 19mm brass	CCI 500	APP	5.0	408	Polycarbonate	YES
16	3D printed	9mm red PETG	13.7	9 x 19mm brass	CCI 500	APP	5.0	361	Polycarbonate	NO
17	3D printed	9mm orange ABS	10.7	9 x 19mm brass	CCI 500	APP	5.0	404	Polycarbonate	NO
18	3D printed	9mm black resin V5	14.3	9 x 19mm brass	CCI 500	APP	5.0	387	Steel	NO
19	3D printed	9mm orange ABS with 1 x 4mm BB (friction)	17.5	9 x 19mm brass	CCI 500	APP	5.0	424	Steel	YES
20	3D printed	9mm orange ABS	10.7	9 x 19mm brass	CCI 500	APP	5.0	372	Steel	NO
21	3D printed	9mm red PETG HF	13.7	9 x 19mm brass	CCI 500	APP	5.0	398	Steel	NO
22	3D printed	9mm black resin V5	14.3	9 x 19mm brass	CCI 500	APP	5.0	329	Aramid	NO
23	3D printed	9mm black resin V5	14.3	9 x 19mm black resin V5	CCI 500	APP	5.0	Misfire	Aramid	N/A
24	3D printed	9mm black resin V5	14.3	9 x 19mm black resin	CCI 500	Red dot	5.0	Misfire	Aramid	N/A
25	3D printed	9mm black resin V5 with 2 x6mm BB (friction)	41.5	9 x 19mm black resin	CCI 500	Red dot	5.0	Misfire	Aramid	NO
26	3D printed	9mm tough 2000 resin	15.6	9 x 19mm tough 2000 resin	CCI 500	APP	4.1	Misfire	Polycarbonate	N/A
27	3D printed	9mm tough 2000 resin	15.6	9 x 19mm tough 2000 resin	CCI 500	APP	4.1	Misfire	Polycarbonate	N/A
28	3D printed	9mm tough 2000 resin	15.6	9 x 19mm tough 2000 resin	CCI 500	APP	4.1	125	Polycarbonate	NO
29	3D printed	9mm tough 2000 resin	15.6	9 x 19mm tough 2000 resin	CCI 500	APP	4.1	351	Steel	NO
30	3D printed	6mm BB (friction)	49.6	9 x 19mm tough 2000 resin	CCI 500	APP	4.1	N/R	Steel	NO
31	3D printed	9mm tough 2000 resin	15.6	9 x 19mm tough 2000 resin (1)	CCI 500	APP	4.2	Misfire	Aramid	N/A
32	3D printed	9mm tough 2000 resin	15.6	9 x 19mm tough 2000 resin (2)	CCI 500	APP	4.2	274	Aramid	NO
33	3D printed	9mm durable resin	14.6	9 x 19mm durable resin (2)	CCI 500	APP	4.2	313	Aramid	NO
34	3D printed	9mm durable resin	14.6	9 x 19mm durable resin (1)	CCI 500	APP	4.2	322	Aramid	NO
35	3D printed	9mm durable with 3 x 6mm BB (wax)	50.9	9 x 19mm durable resin (1)	CCI 500	APP	4.2	343	Aramid	NO
36	3D printed	9mm durable with 3 x 6mm BB (glued)	50.9	9 x 19mm durable enhanced (1)	CCI 500	APP	4.2	304	Aramid	NO
37	3D printed	9mm durable with 3 x 6mm BB (glued)	51.9	9 x 19mm tough resin	CCI 500	APP	4.2	Misfire	Aramid	NO
38	3D printed	9mm durable with 3 x 6mm BB (glued)	51.9	9 x 19mm tough resin	CCI 500	APP	4.2	N/R	Aramid	NO
39	3D printed	9mm durable resin	14.6	9 x 19mm durable enhanced (1)	CCI 500	APP	6.5	Misfire	Aramid	NO
40	3D printed	9mm durable resin	14.6	9 x 19mm durable enhanced (1)	CCI 500	APP	6.5	358	Steel	NO
41	3D printed	8mm PLA Thick Print	11.8	9 x 19mm Thick PLA 3d printed	CCI 500	APP	4.1	152	Polycarbonate	NO
42	3D printed	8mm PLA Thick Print	11.8	9 x 19mm Thick PLA 3d printed	CCI 500	APP	4.1	N/R	Steel	NO
43	Modified	8mm BB (wax)	32.3	9 x 21mm blank	Preloaded	Preloaded	Preloaded	279	Steel	YES
44	Modified	3 x 4.2mm BB (friction)	24	9 x 19mm Force n Force training blank	Preloaded	Preloaded	Preloaded	N/R	Steel	NO
45	Modified	6.34mm BB (wax)	16.2	9 x 21mm blank	Preloaded	Preloaded	Preloaded	32	Steel	NO
46	Modified	4.2mm BB (meltied in)	8	9 x 19mm blank	Preloaded	Preloaded	Preloaded	N/R	Steel	NO
47	Modified	4.2mm BB (melted in)	8	9 x 19mm blank	Preloaded	Preloaded	Preloaded	N/R	Polycarbonate	NO
48	Modified	8mm BB (wax)	32.3	9 x 21mm blank	Preloaded	Preloaded	Preloaded	298	Polycarbonate	YES
49	Modified	6.34mm BB (wax)	16.2	9 x 21mm blank	Preloaded	Preloaded	Preloaded	149	Polycarbonate	NO
50	Modified	8mm BB (wax)	32.3	9 x 21mm blank	Preloaded	Preloaded	Preloaded	295	Aramid	NO
51	Modified	2 x 3.8mm BB (glued)	8	9 x 19mm battlefield blank	Preloaded	preloaded	preloaded	N/R	Aramid	NO
52	Modified	4.2mm BB (wax)	8	9 x 19mm Force n Force training blank	Preloaded	preloaded	preloaded	N/R	Aramid	NO
53	Modified	8mm BB (wax)	32.3	9x19mm brass	CCI 500	APP	4.2	166	Aramid	NO

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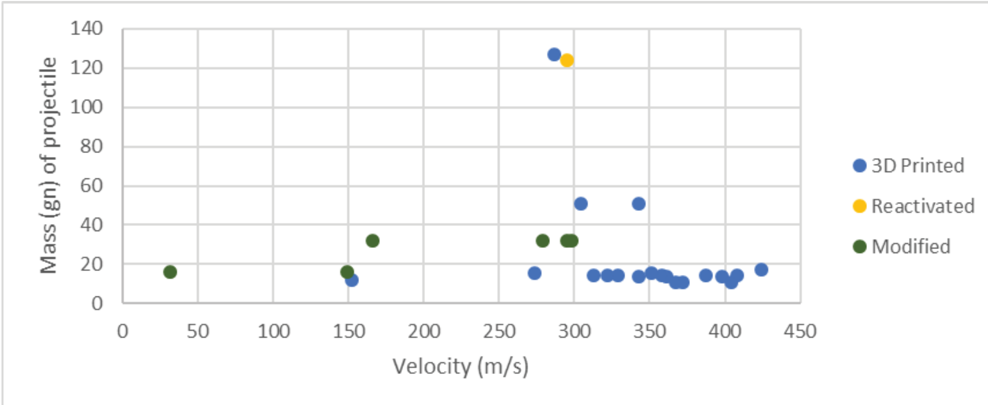

Figure 8. Chart showing velocity plotted against mass of the three categories of improvised ammunition.

4.3 3D printed ammunition discharged using a handgun

Following the ballistic trials using the universal receiver system, three 3D printed rounds were assembled and inserted into the magazine of a Glock 17 pistol mounted in a Ransom Rest, as shown in Figure 9 below. The pistol was remotely fired using a draw string. Results of this trial are displayed in Table 2 below. It should be noted that although the pistol successfully discharged the rounds, the weapon did not successfully cycle, and required the slide to be manually drawn backwards to chamber the next round.

Figure 9. A) Glock 17 mounted in Ransom Rest. B) Glock 17 Magazine loaded with three rounds of 3D printed ammunition.

Table 2. Results from handgun discharge

Shot reference	Type	Projectile	Mass (gn)	Cartridge case	Primer	Propellant	Propellant mass (gn)	Velocity (m/s)	Target type	Perforation
54	3D printed	9mm durable resin	14.6	9 x 19mm durable enhanced 1	CCI 500	APP	4.2	339	Steel	NO
55	3D printed	9mm tough 2000 resin	15.6	9 x 19mm durable enhanced 1	CCI 500	APP	4	Misfire	Steel	N/A
56	3D printed	9mm durable resin	14.6	9 x 19mm durable enhanced 1	CCI 500	APP	4.2	365	Steel	NO

5. DISCUSSION

Of the 14 impacts on the aramid target, none perforated the target. Both polycarbonate and steel targets were perforated on one occasion by both the 3D printed and modified ammunition. Figure 10 below shows some impact sites from 3D printed ammunition.

In this trial all of the improvised primers lead to a misfire. The instructional material available online was followed as accurately as possible from the instructions given. As only two Hilti based primers were produced, and three cap gun primers, the process is at best difficult to successfully achieve for the layperson. It should be noted that spent primers that had previously been used had a heavy strike on their previous use with a universal receiver when compared to that normally left by a pistol. This may have impacted the primers ability to function for a second time. The propellant harvested from the Hilti DX 6.8/11 was able to be utilized in conjunction with a COTS primer, and performed in a very similar manner to the COTS Alliant Power pistol (APP) which was also used within this trial for 3D printed ammunition.

Of the 31 rounds of 3D printed ammunition that were loaded into the universal receiver system, nine resulted in a misfire. One perforation of steel and one perforation of polycarbonate were observed, both 3D printed projectiles using brass cartridge cases. On inspection of the misfired ammunition it was normally due to one of two causes; primer seated too deep into the primer pocket which lead to a light strike, or the cartridge case shattering on impact from the firing pin and again the primer not being struck as intended. Most 3D printed cartridge cases that had been successfully fired sustained some form of damage from the firing process, this was often a fracture around the primer pocket, or split to the neck of the case. Some cases split into two or more pieces in the firing process. Figure 11 below shows some of the recovered 3D printed casings and projectiles from the trial. Upon inspecting the impact on targets, as well as high speed photography, at least two of the 3D printed projectiles with BBs separated before reaching the target, leading to multiple impact locations. Accuracy of 3D printed ammunition with a 9mm projectile was very good, behaving in a similar manner to COTS ammunition. This is likely due to the ammunition engaging with barrel rifling. All fired shots impacted within 25mm of the intended location. The 'thick print' bullet was less accurate, impacting 90mm from the intended target in one instance, likely due to the projectile diameter being smaller than the barrel.

Of the 11 rounds of modified ammunition that were loaded into the universal receiver, none resulted in a misfire. Unfortunately due to the limitations of the chronograph system used it did not reliably detect projectiles less than 7mm in diameter passing through. As such no reading was attained for seven of the BBs discharged. It should be noted that accuracy for modified ammunition was poor, shots were up to 280mm from the intended impact location in one instance. This is likely due to the projectile diameter being smaller than the barrel.

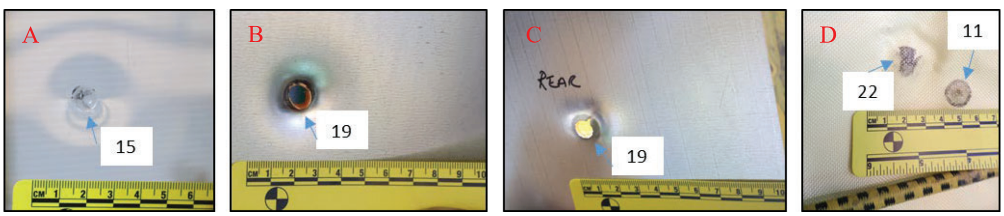

Figure 10. Numbers relate to shot reference in Table 1. A) Perforation in polycarbonate from 3D printed Black Resin V5 projectile. B) Perforation (front) in steel from 3D printed ABS projectile. C) Perforation (rear) in steel from 3D printed ABS projectile. D) Two non -perforations in aramid from 3D printed Black Resin projectile (22) and COTS projectile fired from 3D printed case (11).

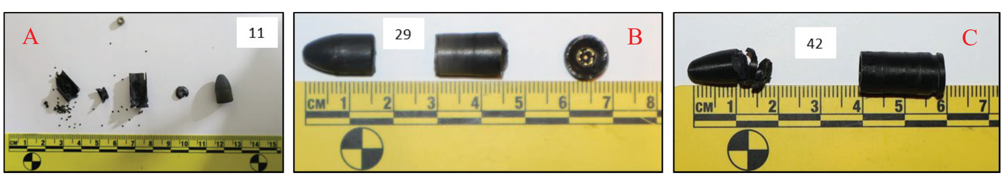

Figure 11. Numbers relate to shot reference in Table 1. A) Misfire, Suffered catastrophic casing failure upon strike from firing pin. B) Successfully fired at steel sheet, projectile recovered, case fracture at primer pocket. C) Successfully fired at steel sheet, projectile recovered showing impact damage.

6. CONCLUSION AND FURTHER WORK

The UK is subject to strict licensing laws which heavily restrict public access to firearms and ammunition. Because of this criminals looking to obtain ammunition for illegally held weapons are left with two options; illegally obtain COTS ammunition or produce improvised ammunition.

Instructional information is available open-source on the construction of improvised ammunition, which broadly falls under 3 categories;

i. Reactivated ammunition,
ii. 3D printed ammunition,
iii. Modified ammunition.

A significant amount of information is available, some techniques described require components that are not legally obtainable within the UK.

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Of the 14 impacts made on the aramid targets, none perforated. The simple, generic armour target of 20 layers of 200g/m^2 of aramid was able to stop all of the improvised ammunition tested at 10 meters. Many body armour schemes used in UK frontline policing have greater quantities of ballistic resistant materials in their construction, hence all improvised ammunition of these construction materials and types are unlikely to defeat such armours.

All improvised primers produced resulted in misfires. Both modified and 3D printed ammunition perforated steel and polycarbonate targets on one occasion each during the trials.

Finally the 3D printed element of this study focusses on plastic based materials, as is currently commonplace for hobbyist users due to the prohibitively expensive setup and material costs of other forms of 3D printers. As advancements are made in this area of manufacturing, alternative techniques such as metal 3D printing may become accessible to hobbyists, resulting in alternative projectile threats. Further consideration should be paid to assessing fiber reinforced materials which have recently become available for hobbyist use, and if they have merit in the improvised ammunition field.

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References

[1] Guide on firearm licensing law, UK Home Office https://www.gov.uk/government/publications/firearms-law-guidance-to-the-police-2012/guide-on-firearms-licensing-law-accessible-version#chapter-1-an-overview--frequently-asked-questions-about-firearms-licensing accessed 05/03/2025

[2] Accredited official statistics, Statistics on firearm and shotgun certificates, England and Wales: April 2023 to March 2024 https://www.gov.uk/government/statistics/firearm-and-shotgun-certificates-april-2023-to-march-2024/statistics-on-firearm-and-shotgun-certificates-england-and-wales-april-2023-to-march-2024 accessed 05/03/2025

[3] Dataset Crime in England and Wales: Office for National Statistics Centre for Crime and Justice https://www.ons.gov.uk/peoplepopulationandcommunity/crimeandjustice/datasets/crimeinenglandandwalesotherrelatedtables accessed 05/03/2025

[4] Dearden, Lizzie; Gibbons-Neff, Thomas (10 September 2024). "He's Known as 'Ivan the Troll.' His 3D-Printed Guns Have Gone Viral". New York Times.

[5] IvanTheTroll, Deterrence Dispensed presents – but what about AMMO v1.0 (2020)

[6] Metropolitan Police Service, Freedom of Information Request reference no: 01.FOI.24.041779 available at https://www.met.police.uk/foi-ai/metropolitan-police/disclosure-2025/january-2025/3d-printed-guns/ accessed 28/02/2025

[7] National Crime Agency, National Strategic Assessment 2024 Firearms https://www.nationalcrimeagency.gov.uk/threats/nsa-firearms-2024 accessed 07/03/2025

[8] Adrian Goldberg & Paul Grant, Converted handguns fired more than 'real' weapons in UK crimes (BBC News, UK, 2024) https://www.bbc.co.uk/news/uk-67895627 accessed 07/03/2025

[9] National Police Chiefs' Council, Firearms Amnesty available at https://news.npcc.police.uk/releases/over-1-000-top-venting-blank-firers-handed-in-with-less-than-10-days-remaining-of-national-gun-amnesty accessed 08/03/2025

[10] 9mm Deep Build instructions https://3dgunbuilder.com/accessories/9mm-deep/

[11] Cathode, But What About Ammo Volume 2 (2020)

[12] W. Marshall, Homemade Primer Course (2014)

[13] Aylin YalÅın Sarıbey, Modification Methods of Blank Pistols in Turkey in 2006 (J Forensic Sci, May 2009, Vol. 54, No. 3)

[14] Bambu Labs P1S 3D printer specification https://uk.store.bambulab.com/products/p1s?id=42280371159100 Accessed 08/03/2025

[15] Formlabs 3+ 3D printer specification https://formlabs.com/store/3d-printers/form-3-basic-package-without-service/#/ accessed 08/03/2025

[16] Formlabs material database available at: https://formlabs.com/uk/materials/ accessed 10/03/2025

[17] Croft J., and Longhurst D., HOSDB Body Armour Standards for UK Police (2007) Part 2: Ballistic Resistance Publication No. 39/07/B (2007) pp 12

[18] Hallrite Precision Engineering, Markham Works, Markham Road, Chesterfield, England, S40 1SU