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Desktop Firearms:
Emergent Small Arms Craft Production Technologies

Edited by
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2023 Update

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Ivan T. is a firearms enthusiast with a particular interest in manufacturing technologies and techniques. They have worked to develop '3D-printable' magazines and receivers; electrochemical machining systems and methods; and other tools and techniques useful to the home gunsmith. In addition to working as a developer for Deterrence Dispensed, Ivan has conducted original research into the recent history of craft-produced firearms in both the United States and globally, with a particular focus on the application of advanced and emergent technologies to small-scale home production.

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About Armament Research Services

Armament Research Services (ARES) is a specialist technical intelligence consultancy, offering expertise and analysis to a range of government and non-government entities in the arms and munitions field. ARES fills a critical market gap, and offers unique technical support to other actors operating in the sector. Drawing on the extensive experience and broad-ranging skillsets of our staff and contractors, ARES delivers full-spectrum research & analysis, technical review, training, and project support services. Our services are often delivered in support of national, regional, and international initiatives, and can be conducted in both permissive and non-permissive environments.

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Safety Information

Remember, all arms and munitions are dangerous. Treat all firearms as if they are loaded, and all munitions as if they are live, until you have personally confirmed otherwise. If you do not have specialist knowledge, never assume that arms or munitions are safe to handle until they have been inspected by a subject matter specialist. You should not approach, handle, move, operate, or modify arms and munitions unless explicitly trained to do so. If you encounter any unexploded ordnance (UXO) or explosive remnants of war (ERW), always remember the 'ARMS' acronym:

AVOID the area
RECORD all relevant information
MARK the area to warn others
SEEK assistance from the relevant authorities

Disclaimer

***Cover image:** YouTuber Print Shoot Repeat with a FGC9 MKII (source: Print Shoot Repeat 3DPG Reuploads., 'The FGC9 MKII | Making Tyrants Afraid Again (Reupload)').*

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Abbreviations & Acronyms

ACP	Automatic Colt Pistol (cartridges)
AM	Additive manufacturing
AP	Armour-piercing
ATF	Bureau of Alcohol, Tobacco, Firearms and Explosives
BJP	Binder jet printing
CAD	Computer-aided design
CNC	Computer numerical control
CP Ti	Commercially pure Titanium
DD	Defense Distributed
det_disp	Deterrence Dispensed
DIAS	Drop-in auto[matic] sear
DIY	Do-it-yourself
DMLS	Direct metal laser sintering
EBF	Electron beam freeform fabrication
EBM	Electron beam melting
ECM	Electrochemical machining
ECR	Electrochemical rifling
EDM	Electrical discharge machining
F3DP	Fully 3D-printed
FCG	Fire control group
FDM	Fused deposition modelling (also 'fused deposition of material')
FFF	Fused filament fabrication
FGC-9	F**k Gun Control 9
Fosscad	Free Open Source Software – Computer Aided Design (also 'FOSSCAD')
IRC	Internet Relay Chat
ITAR	International Traffic in Arms Regulations
PKC	Parts kit conversion (also 'parts kit completion')
PLA	Polylactic acid polymer
SMG	Sub-machine gun
SLM	Selective laser melting
SLS	Selective laser sintering
STL	Stereolithography

Introduction

Fundamentally, firearms are a simple technology. In their most primitive form, a firearm may consist of no more than a tube sealed at one end and open at the other, with a small hole through which a charge of propellant is ignited. Historically, this was the same propellant which today is still packed into fireworks enjoyed every year around the world. Up until the Industrial Revolution—and its attendant advances such as the production line—firearms were made entirely by hand, usually by a single gunsmith, perhaps with the assistance of an assistant or apprentice. Today, individuals in much of the world have unfettered access to an extensive virtual library containing the accumulation of more than 700 years of gun-making knowledge. Whereas in the past a firearm's barrel had to be skilfully and laboriously forged around a mandrel from a solid piece of iron, for example, suitable thick-walled precision steel tubing—a ready-made barrel save for a breech/chamber or breech-plug—may now be purchased online or from a local hardware store. Early firearms makers were often forced to develop and produce their own specialised tooling, whereas today advanced tools can be readily acquired by individuals. Inevitably, the production of firearms has continued to incorporate new technologies, of which those found to be readily replicated with less demanding input from the maker have tended to prove successful (Hays & Jenzen-Jones, 2018). Whilst the firearms industry has historically tended toward conservatism, relatively new technologies such as 3D printing (also known as 'additive manufacturing'; AM) offer sufficient advantages to even major manufacturers such that they have found acceptance in commercial design and manufacture as well (Jenzen-Jones, 2015).

Craft-produced firearms are generally understood to be those which are fabricated primarily by hand in relatively small quantities. Often as simple as improvised 'zip guns'[1], they are recovered daily by police forces across the world, frequently in countries where local laws restrict the legal acquisition of firearms (Hays & Jenzen-Jones, 2018). In more recent years, there has been an uptick in the legal craft production or home-assembly of weapons in nations where firearms are more easily obtained, such as the United States (ARES, 2019). Partially homemade weapons assembled using un-serialised components are increasingly seized from criminal groups in other countries, such as Canada and Mexico. In cases of both legal and illegal acquisition, these weapons are often hybrid designs combining available firearm components with substituted non-firearms or craft-produced parts (ImproGuns, 2018a). The increasing affordability of hobbyist machines and tooling, such as small desktop lathes and computer numerical control (CNC) mills[2], as well as the proliferation of (and improvement in) consumer-grade 3D printers, has led to significant advances in home manufacturing techniques (Federico, 2019). These allow for greater ease in the production of certain otherwise-unavailable or regulated firearm components. Designs may be both created and shared by skilled individuals in the form of computer-aided design (CAD) files or in other digital formats. The process for producing fairly complex parts now requires significantly fewer skills and less experience on the part of an individual craft-producer than at any other time in history. Although not quite a case of hitting 'Ctrl-P', these new technologies do significantly reduce the barriers to entry for those wishing to attempt manufacture of a firearm. As such, they increasingly represent a realistic method by which an individual may easily acquire a firearm. Accordingly, such methods also represent a challenge to the governmental control and regulation of firearms manufacturing.

Increasingly, craft-produced small arms made by individuals are being referred to as 'privately made firearms' (PMFs), particularly in the United States. PMFs can be understood as firearms that have been produced (including those that have been 'completed' or 'assembled' from parts kits; see below) by any

1 Zip guns are generally understood to be improvised, single-shot, small-calibre firearms that lack a conventional trigger mechanism (Hays & Jenzen-Jones, 2018, p. 64; Koffler, 1969, pp. 520–521).

2 CNC mills are, in essence, the opposite approach to additive manufacturing and represents a modern take on earlier machining and hand-crafting methods. A piece of material is gradually machined away in a series of precise, computer-controlled operations until the final shape is achieved.

individual other than a licensed manufacturer. The U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) classifies PMFs according to their own system, which reflects U.S. legal norms but does not generally accord with specialist classification of arms and munitions.[3] The ATF writes that "PMFs are commonly referred to as "ghost guns" because it can be difficult to track them" and notes that "investigating crimes involving unserialized PMFs can create difficulty in tracing the origins of the firearm and linking them to related crimes" (ATF, 2023).[4]

The vanguard of 'home gunsmith' development has largely been located in the United States, although there have been a number of notable and active European contributors. Most designs continue to utilise 3D-printed components wherever possible, due to their low cost and ease of production, and supplement these with metal components obtained in varying ways. Whilst a range of new technologies may be employed to craft-produce firearms, the focus of this report will be on technologies that scale down to the individual level—that is, those technologies accessible to the average hobbyist in a developed country on the basis of legal status, commercial availability, price, and ease of use. As of early 2020, the entire receiver (or frame)[5] of certain semi-automatic firearms as well as their magazines may be produced on a commercial-grade 3D printer costing no more than 200 USD.[6] Furthermore, a firearm's barrel may be fashioned from a piece of steel tubing, chambered, and rifled using an electrochemical machining (ECM) method, with the aid of a 3D-printable jig (ImproGuns, 2017; 2019). Many of the remaining metal components such as the bolt, firing pin, and trigger mechanism may in some cases be produced by combining less-durable 3D-printed parts with off-the-shelf metal components for increased structural strength. Hybrid firearms designs—that is, those most often combining a combination of production technologies, such as 3D printing, desktop CNC mills, and ECM—are increasingly the norm for modern craft production in the developed world. These processes and the associated designs are being rapidly refined and improved by 'home gunsmiths' and enthusiasts, mostly in the United States. In the near future, it will be possible to assemble a semi-automatic or automatic pistol-calibre firearm—comparable to a factory-made weapon in all respects—from 90 per cent 3D-printed parts. The remaining metal components may be discreetly obtained either online or from a hardware store almost anywhere in the world, and finished in the home (Luke C., 2019).

A Brief History of 3D-printed Firearms

On 5 May 2013, Defense Distributed (DD)—a self-described "…private defense contractor in service of the general public", based in Austin, Texas—released the data for an almost entirely 3D-printed firearm (see Figure 5.1) (Defense Distributed, 2019). Christened the 'Liberator' after the small, disposable, single-shot .45 ACP pistol developed during the Second World War, it could be printed on a relatively inexpensive consumer-grade 3D printer, the only additional part being a nail to act as a firing pin.[7] A video released by the group showed spokesman Cody Wilson firing a single .380 ACP round using the pistol, proving the concept of an entirely plastic firearm as at least viable for a small number of shots (Defense Distributed, 2013; Greenberg, 2013a). The ensuing publicity leading up to and following the release resulted in a letter from the U.S. Department of State to the company, advising them of an apparent International Traffic in Arms Regulations (ITAR) violation and requesting that the company remove download links to the

3 See: <https://www.atf.gov/firearms/privately-made-firearms> cf. Jenzen-Jones, 2020.

4 In the U.S. context, the ATF notes that "from 2016 through 2021, there were approximately 45,240 suspected privately made firearms reported to ATF as having been recovered by law enforcement from potential crime scenes, including 692 homicides or attempted homicides. These issues have led to some states passing additional laws related to PMFs" (ATF, 2023).

5 The 'receiver' (frame in the case of handguns) is the main body of the firearm which accepts or 'receives' all other components.

6 See, for example, the 'Creality Ender 3' (Creality, n.d.).

7 Like its modern namesake, the original FP-45 Liberator was designed to make use of the then-state-of-the-art in expedient firearms manufacturing technology. In the 1940s, this was stamped, folded and welded sheet steel. See (Canfield, 2012, pp. 48–51; 83–84)

Liberator design files (Greenberg, 2013b). However, more than 100,000 people downloaded the Liberator stereolithography (STL) design files in the two days they were hosted on Defense Distributed's website (Neal, 2013). Prior to the release of the design, a lease between DD and Stratasys, the U.S.-based manufacture of the 3D printer used in producing many of DD's firearms designs, was cancelled by the latter company (Beckhusen, 2012). From this point onwards, and largely as a direct result of the publicity surrounding the work of Defense Distributed, 3D printing of firearms and firearm components began to proliferate (Fey, 2017, pp. 21–30).[8] Following the State Department's effective shutdown of Defense Distributed's freely available downloads, followers of DD re-hosted the restricted files via a variety of online hosting services. Some of those followers subsequently banded together under the name 'FOSSCAD' (Free Open Source Software Computer Aided Design; usually rendered in lower case as 'Fosscad'). Fosscad members made significant progress in furthering the use of 3D printing for firearms development, both in improving Defense Distributed's designs and in pioneering new designs. Printed AR-15 lower receivers were further perfected as seen in the 'V5.1' and 'Vanguard' lower receivers (amongst others) shared by Fosscad (ARES, 2019). One user who went by the pseudonym of 'Derwood' designed a platform known as the 'Shuty', named for (if not substantially derived from) the sub-machine gun design developed in the 1990s by Englishman Philip A. Luty. The Shuty uses a printed structure—comprised of upper and lower receivers, bolt housing, and receiver extension— paired with a bolt made from steel rods, a factory-made Glock 17 barrel, and an AR-15 lower parts kit (ARES, 2016). The platform was initially released in 2016 as the Shuty MP-1, and Derwood and further designers—among them Mussy and ZipDic[9]–developed it into more than ten distinct patterns of self-loading long arms chambered for pistol cartridges (often called 'pistol-calibre carbines'; PCC). The latest iteration in this family of firearms was released as the RTT 9 in April 2023 (DEFCAD, n.d.(b)).

As Defense Distributed remained entangled in multiple legal battles over the years, several people active in online discussion forums decided to band together under the banner of 'Deterrence Dispensed' (a not-so-subtle nod to Defense Distributed) in February 2019 (Deterrence Dispensed, n.d.). Like Fosscad, the group (known as sometimes by the shorthand 'det_disp') operates as a decentralised collective of designers and publishers who use a variety of platforms to communicate and to improve upon designs, often sharing pre-release (or 'beta') files for peer review and testing to ensure quality upon final release (of which more later). Since 2021, the Deterrence Dispensed website has redirected visitors to a website titled 'The Gatalog'—reportedly to prevent confusion with the company Defense Distributed. Since then, the group has organised their file releases via this latter website, but is still commonly referred to as 'Deterrence Dispensed'. So far, the group has released close to 100 original files for the creation of 'printable' receivers, magazines, suppressors, accessories, and complete firearms (The Gatalog, 2023). They remain at the forefront in the development of 3D-printable firearm designs and adoption of emergent manufacturing technologies (ARES, 2019).

Besides Deterrence Dispensed, two other prominent groups design and release 3D-printable firearm parts and components. These groups are 'The Black Lotus Coalition' (founded in 2021; see *Black Lotus Coalition*, n.d.) and 'Are We Cool Yet?' (active since July 2020). The Black Lotus Coalition (BLC) was founded in 2021 by a person going by the username 'Moderator Gage'. The group describes itself as "talented group of professionals who mix their passion of firearms with pro-freedom of speech ideals to create truly unique pieces of digital art work" (*Black Lotus Coalition*, n.d.). The BLC is most well known for their Harlet family of .22 calibre Derringer-type pistols, but has also released designs for magazines, 3D-printed receivers, and accessories (ModeratorGage, 2023).

8 For a wider assessment of the viability and potential security risks associated with 3D printing and other consumer-level additive manufacturing technologies see Jenzen-Jones, 2015; Shaw et al, 2017.

9 See *Print2a Wiki*, n.d.

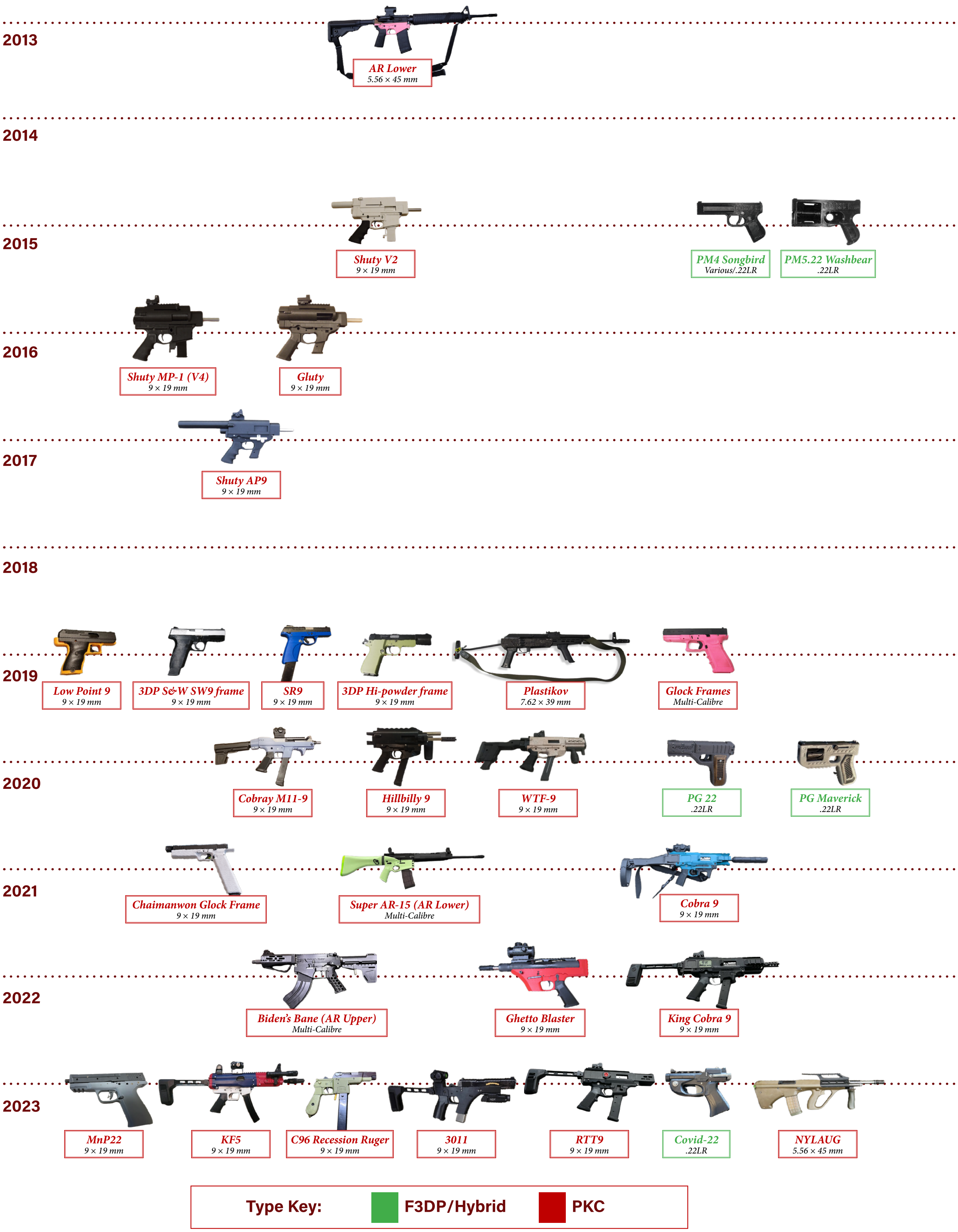
'Are We Cool Yet?' (usually rendered as 'AWCY?') describes itself as a "decentralized group of individual's [sic] who's [sic] core believe is Art is Not Meant to be Contained. […] Advancements in desktop manufacturing has opened new possibilities for everyone" (*Are We Cool Yet?*, n.d.). The group's name is apparently inspired by the international avant-garde artistic movement by the same name (SCP Foundation, 2023). To date, this 3D printing group has released close to 60 designs, mostly of 3D-printed receivers, magazines, and accessories (*DEFCAD*, n.d.(a)). Outside of gun design, AWCY? has gained prominence by co-organizing an annual shooting tournament specifically for 3D-printed and privately made firearms, known as the 'Gun Maker's Match' (Hamilton, 2021).

AWCY?

BLC

COME AND TAKE IT

TIMELINE OF SELECTED 3D-PRINTED FIREARMS




2013
Liberator
Various, .380ACP
Reprringer
.22LR
Grizzly
.22LR
2014
Zig Zag
.380ACP
2015
2016
2017
2018
Hybrid Square Tube SMG
9 × 19 mm
Liberator12k
12 ga
2019
WTF-9 w. ECM Barrel
9 × 19 mm
FGC-9 Mk. I
9 × 19 mm
Cheetah-9
9 × 19 mm
2020
FGC-9 Mk. II
9 × 19 mm
CF 2000
13 mm
Harlot
.22LR
2021
FMGC-01
9 × 19 mm
FGC-9 Mk II Stingray
9 × 19 mm
EZ22
.22LR
YEET22V.1
.22LR
YEET22 C
.22LR
2022
Urutau
9 × 19 mm
Nutty 9
9 × 19 mm
Partisan 9
9 × 19 mm
Partisan 9 Mk II
9 × 19 mm
HD22
.22LR
YEET22V.2
.22LR
YEET22 Hammer
.22LR
2023
Type Key:
F3DP
Hybrid

Obtaining a Craft-produced Firearm

Concepts and requirements

Craft-produced firearms are most often made by individuals for personal use, usually the result of experimentation as part of a hobby. This is, of course, either licit or illicit activity depending upon the jurisdiction. For example, it is quite legal in the United States for an individual to manufacture a firearm provided they do not then sell it, whereas any successful manufacture of a 'component part' under English or Scottish law represents a serious crime (ATF, 2020; CPS, 2019). Although many makers have no intention of profiting from their activities, adequately skilled individuals may be incentivised to manufacture and supply craft-produced or modified firearms for profit both on a small or large scale. Again, this activity can be legal or illegal, depending on where it occurs. Skilled individuals employed in relevant trades may be approached by criminals or criminal groups to produce firearms for them, being supplied either blueprints or an original weapon to reverse-engineer. In other cases, the traditional craft is passed on by family within local communities where the trade often provides necessary income (Hays & Jenzen-Jones, 2018; Hills, 2017).

Craft-produced firearms have long been produced by hand, using traditional manufacturing techniques and technologies. Increasingly, these may be augmented or supplanted by emergent methods, such as 3D printing, miniaturised ('desktop') CNC machines, and small-scale ECM. The production of entirely 3D-printed or hybrid firearms—and even the assembly of 'parts kit' firearms, depending on jurisdiction—offers an easy way for an individual assemble a viable firearm which is difficult for law enforcement to trace through conventional means.

Figure 4.1 *The Liberator 12K featured at the Serbu Firearms booth at SHOT Show 2020 in Las Vegas (source: Jeff Rodriguez).*

There are a variety of reasons an individual may choose to produce a firearm, which may range from the simple enjoyment gained in completing a technical challenge, to an urgent need for a self-defence tool, or even for criminal or warfighting purposes. In some cases, the choice to attempt craft-production may be influenced by an inability to acquire firearms legally or through conventional black-market routes. Some criminal elements may be attracted to the low cost and disposability of craft-produced weapons, something reflected in the success of the early zip guns of 1950s and 1960s America and the tumberas of modern Latin American street gangs (Koffler, 1969; Hays & Jenzen- Jones, 2018). At SHOTShow 2020, the annual U.S. firearms and outdoor industry trade show held in Las Vegas, the Liberator 12K was featured at the Serbu Firearms booth, highlighting a growing interest in 3D-printed firearms technology from both consumers and manufacturers (see Figure 4.1).

As with traditional craft production, the primary 'barrier to entry' for a prospective craft-producer of 3D-printed firearms is their level of interest and determination. The largely automated nature of 3D printing has significantly lowered this barrier when compared to traditional craft production methods—the layperson with access to a 3D printer is now able to print out the receiver for an AR-15 rifle or Glock pistol at home, with relatively little manual work involved, in less than a day of printing time,[10]representing a huge shift in the nature of craft production. For example, according to one active developer, a new user to the det_disp Keybase group went from purchasing a 3D printer online to printing a Glock frame within just one week (ARES, 2019).

Table 4.1 — Users and producers of improvised and craft-produced weapons, their motivations, and associated risks.

USERS AND PRODUCERS	PRIMARY MOTIVATIONS FOR ACQUISITION OR PRODUCTION	ASSOCIATED RISKS
Tribal groups and families	Cultural reasons, limited availability of conventional firearms, hunting, deterrence, self-defence	A decline in access to or production of craft weapons may lead to an increased use of commercial weapons. Craft weapons may be used in conflict.
Hobbyists and collectors	Interest	Minimal direct threat to others, although the sharing of know-how online may facilitate production by and proliferation among criminals and non-state armed groups. If poorly designed, the weapons may harm users if fired.
Gunsmiths and engravers	Livelihood or supplemental income (see Section III)	Production is unregulated and contributes to illicit proliferation, including of semi-professional copies of commercially-available weapons.
Subsistence poachers	Limited availability of conventional firearms, livelihood	Possession facilitates crime. Safety issues may threaten users and bystanders.
Traffickers	Limited availability of conventional firearms, profit (see Box 3)	Trafficking exacerbates illicit proliferation and the arming of non-state armed groups.
Individual criminals	Limited availability of conventional firearms, low cost, limited traceability, easy concealment	Possession facilitates crime. Safety issues may threaten users and bystanders
Criminal organizations	Limited availability of conventional firearms, low cost, limited traceability, easy concealment	Possession facilitates crime. Safety issues may threaten users and bystanders
Insurgent groups and militias	Limited availability of conventional firearms, filling capability gaps, supplementing holdings or facilitating capture of industriallyproduced weapons	Acquisition facilitates armed conflict, including attacks on civilians and security and military personnel.
States	Limited availability of conventional firearms, circumventing sanctions or embargoes	Acquisition or production may entail the misuse of international aid and can facilitate armed conflict.

Source: *Hays & Jenzen-Jones, 2018*

10 For example, the stated print time for one AR-15 lower receiver in 2019 was 17 hours (Potatosociety, 2019).

Categorising 3D-printed Firearms

While some 3D-printed firearm designs such as the famed 'Liberator' are indeed almost entirely constructed from polymers (and therefore subject to some unforgiving material limitations), recent developments have involved the integration of critical metal components such as steel barrels and breech faces. Just as in factory-made designs, these components are able to adequately contain the pressures subjected upon them from the rapid deflagration of propellant that takes place inside a modern cartridge.[11] The reliance on printed parts and incorporation of typically regulated components is perhaps the best determining factor when categorising 3D-printed firearms. All 3D-printed firearm designs in circulation fall into one of the three categories outlined below, which are summarised in *Table 5.1*.

Table 5.1 — Relative characteristics of the three categories of 3D-printed firearms

	F3DP	HYBRID	PKC
Durability	Low to Moderate	Moderate to High	Moderate to High
Capability	Low	Moderate to High	High
Ease of Production	Moderate to High	Moderate	Moderate
Accessibility of Parts	High	Moderate	Low to Moderate
Cost of Production	Low	Low to Moderate	Low to High

Notes: *These are necessarily generalisations, and depend on numerous factors. See more detailed descriptions below. There are edge cases which could be considered either Hybrid or PKC designs. The assumptions regarding durability and capability depend largely on the builder's ability to follow the specifications and instructions that accompany the CAD files. When the these are not followed, the firearms produced can be significantly less capable or less durable, and may be more dangerous to operate.*

Fully 3D-printed Firearms

3D-printed small arms in this category require no pressure-bearing non-printed components, but may contain minor non-printed parts, such as a nail to act as a firing pin or an elastic band to power a hammer. Because of the near-total absence of metal components, F3DP such as these have become the focus of many sensationalist media reports.

Any discussion of fully 3D-printed (F3DP) firearms must be prefaced with a discussion on the degree to which these weapons actually incorporate non-3D-printed parts. To date, there are no 3D-printed firearm designs in which 100 per cent of the components are exclusively 3D printed. As such, they are sometimes referred to as 'primarily printed' (PP) designs. Some examples of 3D-printed firearms are comprised almost entirely of 3D-printed parts, however. The most prominent such example is the Liberator—which includes only one non-printed part (two if following the nominal advice regarding the inclusion of a metal block for legal purposes)—but no entirely printed examples have been shown to exist. While it would be possible to use a metal 3D-printing technique to print the firing pin for a Liberator, this would mean reproducing a roofing nail costing less than a $0.01 USD for more than $10 USD. Additionally, the metal printed part would exhibit the same characteristics as a commercial nail—especially relevant in regard to its potential for detection by magnetometers and other security scanners. In the case of the Songbird (see p. 18), the

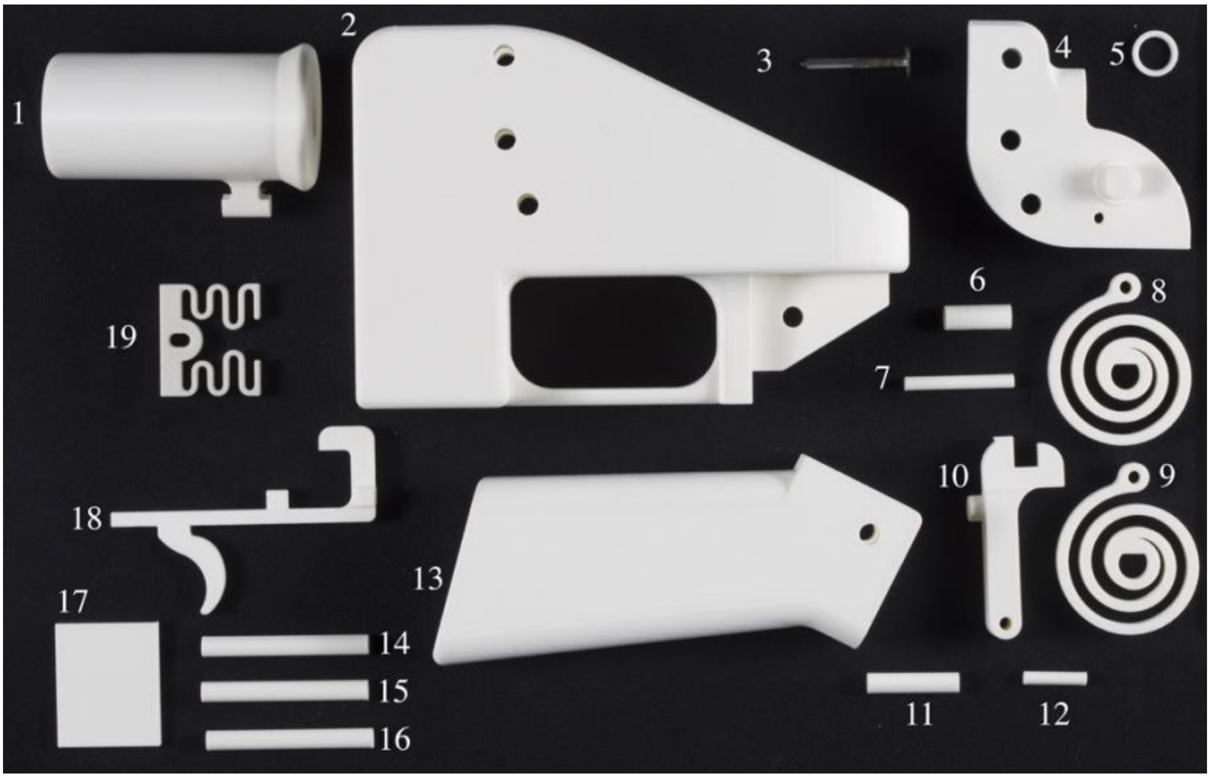
11 These pressure- or stress-bearing components include the barrel, slide or bolt, and the trigger mechanism (as opposed to the lower receiver or housing that contains it). In many jurisdictions around the world, all or most pressure-bearing components are legally controlled.

inclusion of rubber bands to replace common springs for the fire control parts makes for a cheaper and more expedient solution. Whilst these rubber bands are not 3D printed, they are likely to work better than 3D-printed springs and are of course not regulated. Nevertheless, just entirely 3D-printed firearms are not yet viable does not mean that this category of 3D-printed firearms is irrelevant or that these weapons are not capable of being used to lethal effect.

The Liberator

Figure 5.1 *The Liberator single-shot pistol released by Defense Distributed in 2013 (source: Wikimedia).*

As noted above (see ***A Brief History of 3D-printed Firearms)***, the Liberator pistol was introduced by Defense Distributed in May 2013. It is a hammer-fired, single-shot handgun. To load the Liberator, the barrel must be removed from the receiver, loaded with a cartridge from the breech end, and reattached to the frame. Once loaded, the gun can be fired by pulling back the hammer and releasing the trigger. This allows the hammer to move forward under spring pressure, striking the firing pin (in the Liberator's case, a regular store-bought nail) and firing the cartridge. The Liberator uses 3D-printed springs to function: two coiled springs and one linear compression spring (which resembles an accordion). The coiled springs cock the trigger into position; when released, the linear compression spring functions as the hammer spring, pushing the hammer forward with enough force initiate the cartridge (Atherton, 2013). Defense Distributed reportedly tried to design a firing pin from hardened plastic rather than using a nail; if successful, this would have created a 100 per cent 3D-printed firearm. However, this proved impossible with the commercial printer used to make the rest of the Liberator. Thus, the Liberator relies on one non-3D-printed functional component—a nail for the firing pin.



1: Barrel; **2:** Frame; **3:** Nail **4:** Hammer body; **5:** Firing Pin Bushing; **6:** Spring Connecting Rod Bushing; **7:** Spring Connecting Rod; **8** and **9:** Spring; **10:** Hammer; **11:** Frame Pin; **12:** Hammer Pin; **13:** Grip; **14**, **15**, and **16:** Frame Pin; **17:** Bottom Cover; **18:** Trigger; **19:** Trigger Spring.

Figure 5.2 *The 19 components of a Liberator (source: Honsberger, et al.).*

The Songbird

Figure 5.3 *A PM422 Songbird 3D-printed single-shot pistol seized during an August 2020 raid in the western suburbs of Sydney, Australia (source: NSW Police Force).*

The PM422 Songbird design was published in 2015 by developer James R. Patrick using the screenname "Guy in a Garage". The Songbird is a single-shot pistol with an internal hammer powered by elastic bands rather than 3D-printed springs, which uses a nail or screw to act as a firing pin (Hays, 2020). Like the Liberator, the Songbird uses a removable barrel block. In the Songbird's case, this block is designed to be printed from Bridge Nylon, a material manufactured made by Taulman (Luke C., 2020), which reportedly combines the superior strength of Nylon 645 and the comparatively lower price of ABS and PLA plastics (Taulman, n.d.). The frame as well as the rest of the 3D-printed parts, including the trigger pins, trigger assembly, and grip, are all made from regular ABS filament.

The Songbird was originally designed to be chambered for .22 LR cartridges. In this configuration—using a barrel made from Bridge Nylon without metal support—the gun reportedly managed to fire ten shots without catastrophic failure (Watkin, 2016). However, the nylon barrel does not stabilize the bullet.

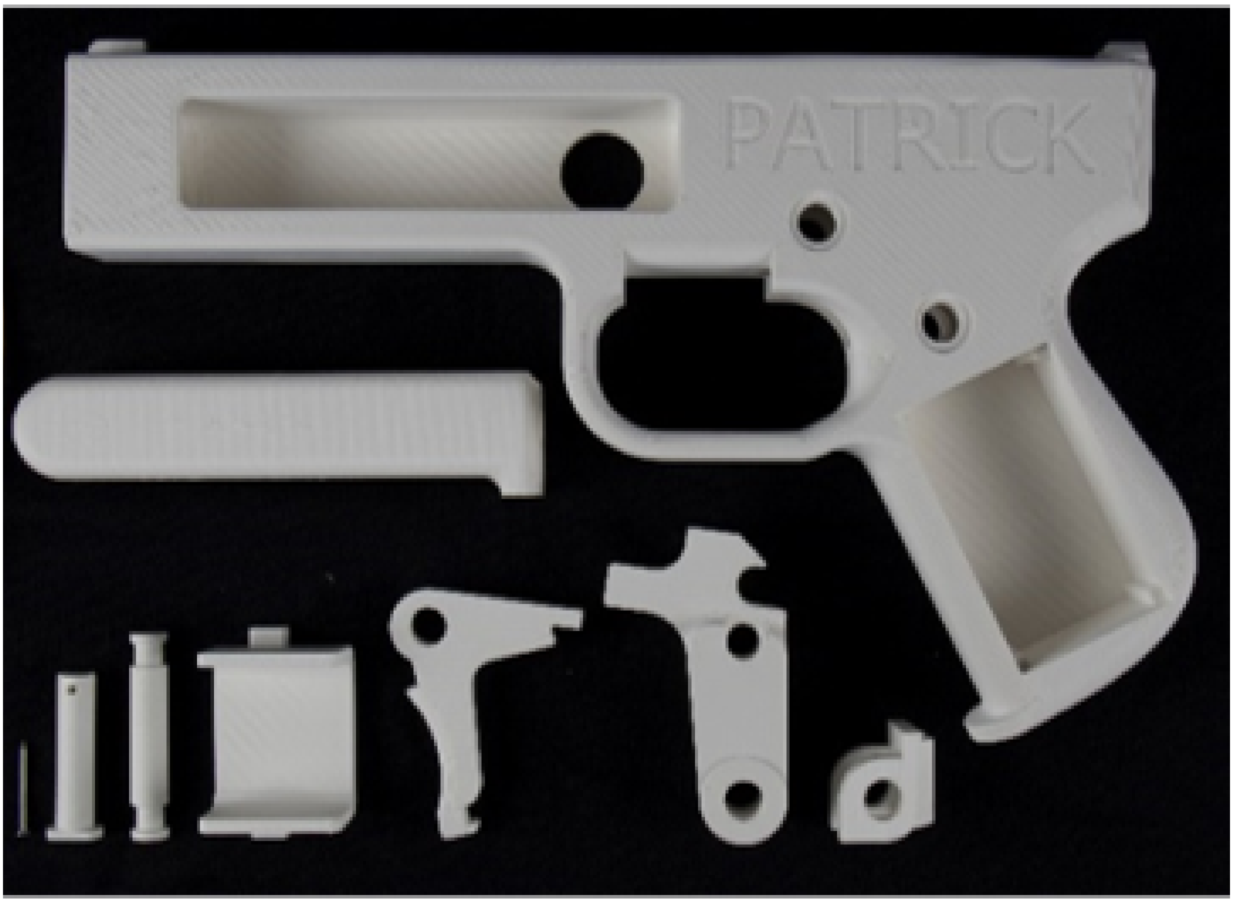


Figure 5.4 *Physical components of a Songbird. Note the space in the grip intended for hexnuts to make it compliant with the United States Undetectable Firearms Act of 1988—they serve no other function (source: Honsberger, et al.).*

The Washbear

Figure 5.5 *A PM522 Washbear (source:Metropolitan Police).*

Like the Songbird, the PM522 Washbear design was published in 2015 by developer James R. Patrick. The Washbear is a manually operated handgun with a fixed barrel that features a rotating cylinder with multiple parallel chambers. The cylinder is aligned and rotated by zig-zag grooves on the outside of the cylinder's round body. Whilst often described simply as a revolver, the Washbear is more specifically a revolving pepperbox—each of the chambers is connected to its own barrel.

The frame of the PM522 Washbear was designed to hold either six or eight shots. However, the six-shot design is intended to be printed in more durable nylon material, while the eight-shot is designed to consist of ABS with steel chamber liners for extra strength. Both barrels will fit in the same gun frame, so they are interchangeable. All of the .stl files have been orientated by the designer to maximize the strength of the material and minimize failure. For instance, the gun frame is printed flat on its side while the cylinder is printed standing up. By putting them together, the frame is reportedly strong enough to contain the pressure of firing and keep the cylinder layers from splitting (Pete, 2017).

Like the Songbird, the Washbear uses elastic bands instead of springs to power the firing mechanism. The designer suggests ¼-inch orthodontic elastic rubber bands. A modified roofing nail with the tip ground flat is used as the firing pin, and the cylinder is designed so that when the trigger is at rest, the firing pin would not be in line with the bullet cartridge, apparently making the gun drop-safe (Grunewald, 2015).

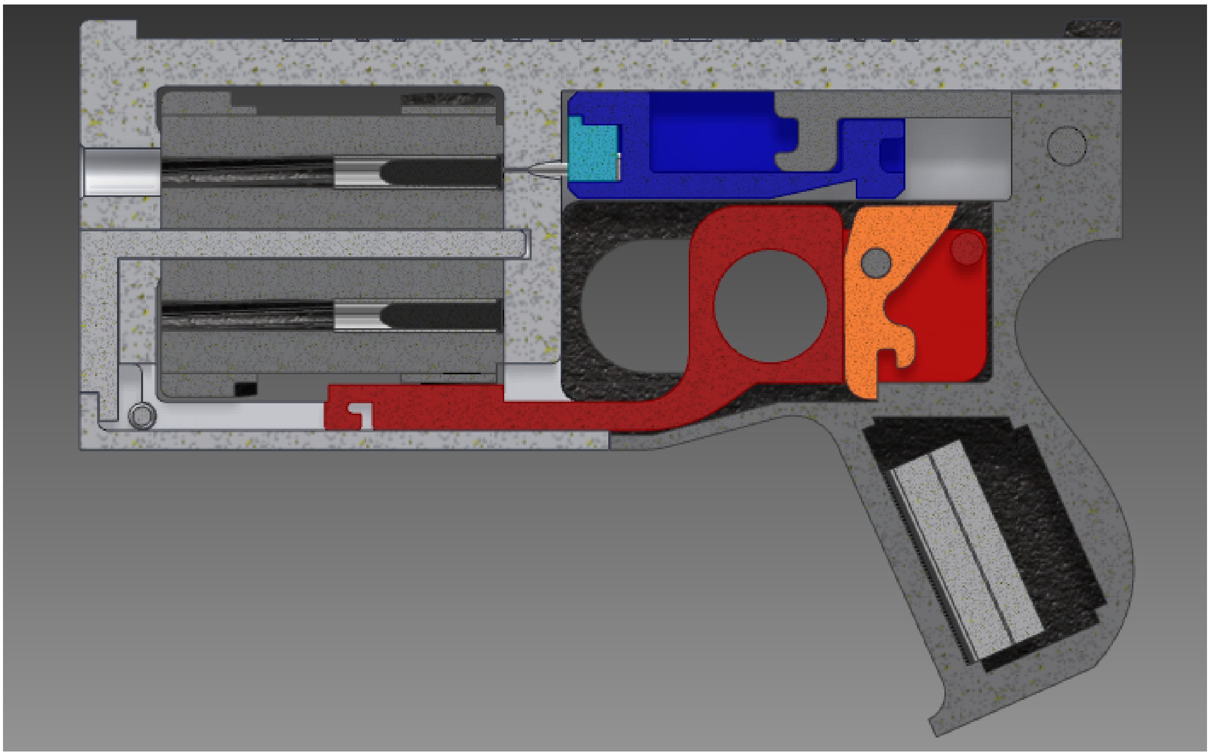


Figure 5.6 *A 3D rendering of the PM522 Washbear (source: James R. Patrick).*

Limitations of fully 3D-printed Firearms

In the case of fully printed guns, reliability and durability are major concerns – while many designs exist, those described above are the most relevant insofar as they have received sufficient testing of their capabilities. While more than three designs in this same vein do exist, their testing and associated documentation are either very sparse or leave so much up to the individual builder's interpretation that it is difficult to coherently classify the designs. With any of these, the builder must be incredibly thorough to make sure their 3D printing equipment is entirely sound, as even a small defect could cause a 3D-printed barrel to fail in short order. Additionally, regardless of the skill of the builder, printed polymer rifling tends to be unable to stabilize bullets, so accuracy is rather poor. An example of six liberators being tested for accuracy can be seen below, demonstrating this.

Figure 5.7 Vertical and Lateral trajectories of the six projectiles fired from six Liberators with a shot from an industrially made CZ45 as comparison (source: Honsberger, et al.).

Fully 3D-printed Firearms with Metal Inserts

To increase longevity, sections of steel tubing are sometimes inserted into the barrels and/or chambers of fully 3D-printed firearms, providing a level of capability and robustness that is at least equal to, and frequently better than, traditional craft-produced firearms in the zip gun category. In many cases, these constitute hybrid designs as outlined below, although there is some blurring of the line between the two categories. Even though this reinforcement may technically make guns hybrid 3D-printed designs, it is worth noting that in terms of build complexity, the addition of a metal liner to a barrel is often trivial while greatly increasing the viability of a fully 3D-printed design. In the case of the Songbird, examples have been printed in .357 Magnum using the aid of a metal barrel inserted to the printed barrel housing that the design is based around. In the case of .22 LR builds of the Liberator, Songbird, and Washbear, a common size brake line can be inserted into the printed barrel housing to reinforce it—effectively making the barrel a permanent part instead of one with a very short lifespan. Some designs have been based around this type of metal reinforcement in a very simple, easy-to-build format, such as the BLC Harlot—a compact .22 LR Derringer-style firearm which relies on a metal liner in the barrel to safely handle .22 LR. cartridges. In any of these cases of metal liners being used, it is possible for rifling to be cut into the liner (using ECM, pre-rifled tubes, or any other method) to attain adequate levels of accuracy.

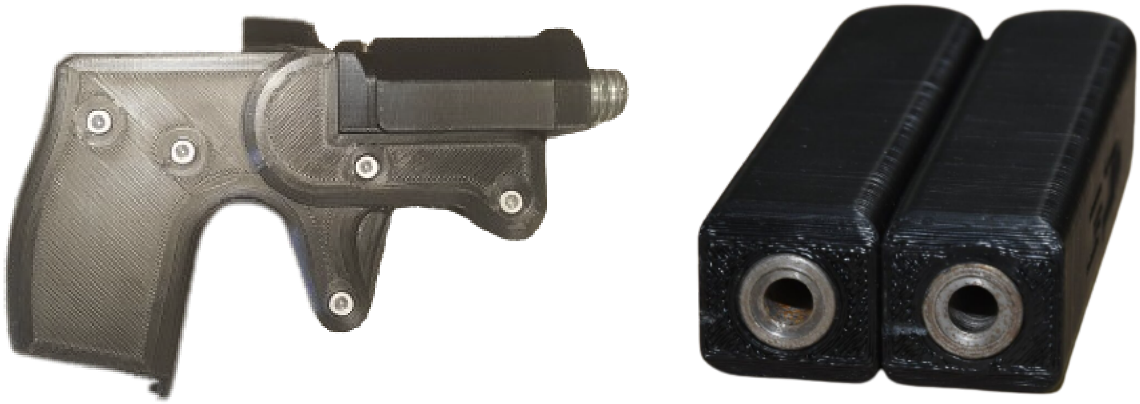


Figure 5.8 *Left: A Harlot pistol with a threaded metal barrel protruding (source: Black Lotus Coalition). Right: Removable barrel units for PM422 Songbird 3D-printed single-shot pistols seized during an August 2020 raid in the western suburbs of Sydney, Australia. Note the reinforcing steel tubes sleeved into the printed barrel bodies (source: NSW Police Force).*

Hybrid 3D-printed Firearms

Hybrid 3D-printed firearm designs rely on readily available components that are globally unregulated, such as steel tubing, metal bar stock, and springs. Such designs are primarily 3D-printed but utilise these non-restricted metal parts primarily for strengthening major assemblies or to serve as barrels and chambers. Most of these parts are so innocuous as to ordinarily attract little attention from law enforcement or intelligence agencies upon purchase. Despite not using purpose-made firearms parts, hybrid designs can still offer broadly comparable performance to some types of conventional weapons. Where available, unregulated firearms components (such as magazines) may be incorporated.

FGC-9 Family of Firearms

Arguably the most well-known and most often used hybrid 3D-printed firearm available today is the FGC-9 Mk II ('F**k Gun Control 9 mm Mark 2'). Variants of this firearm have appeared in the hands of enthusiasts and individual users, as well as fighters of the Myanmar People's Defence Forces (Eydoux, 2022), Irish dissident groups (Mooney, 2022), and on the black markets of many countries. As the weapon's name suggests, the FCG-9 Mk II is an improved version of the FGC-9 Mk I.

FGC-9 Mk I

The FGC-9 was designed by a Deterrence Dispensed team led by user 'JStark1809' and released in March 2020. The design is broadly based on the Shuty-series of 3D-printed firearms by the user Derwood, but the concept was developed further, improving mechanics, ergonomics, and assembly processes. The main driver for the design of the FGC-9 was the goal of circumventing European gun regulations, according to an ARES interview with JStark1809.

Figure 5.9 *Left- and Right-hand side view of the FGC-9 Mk I (source: JStark1809).*

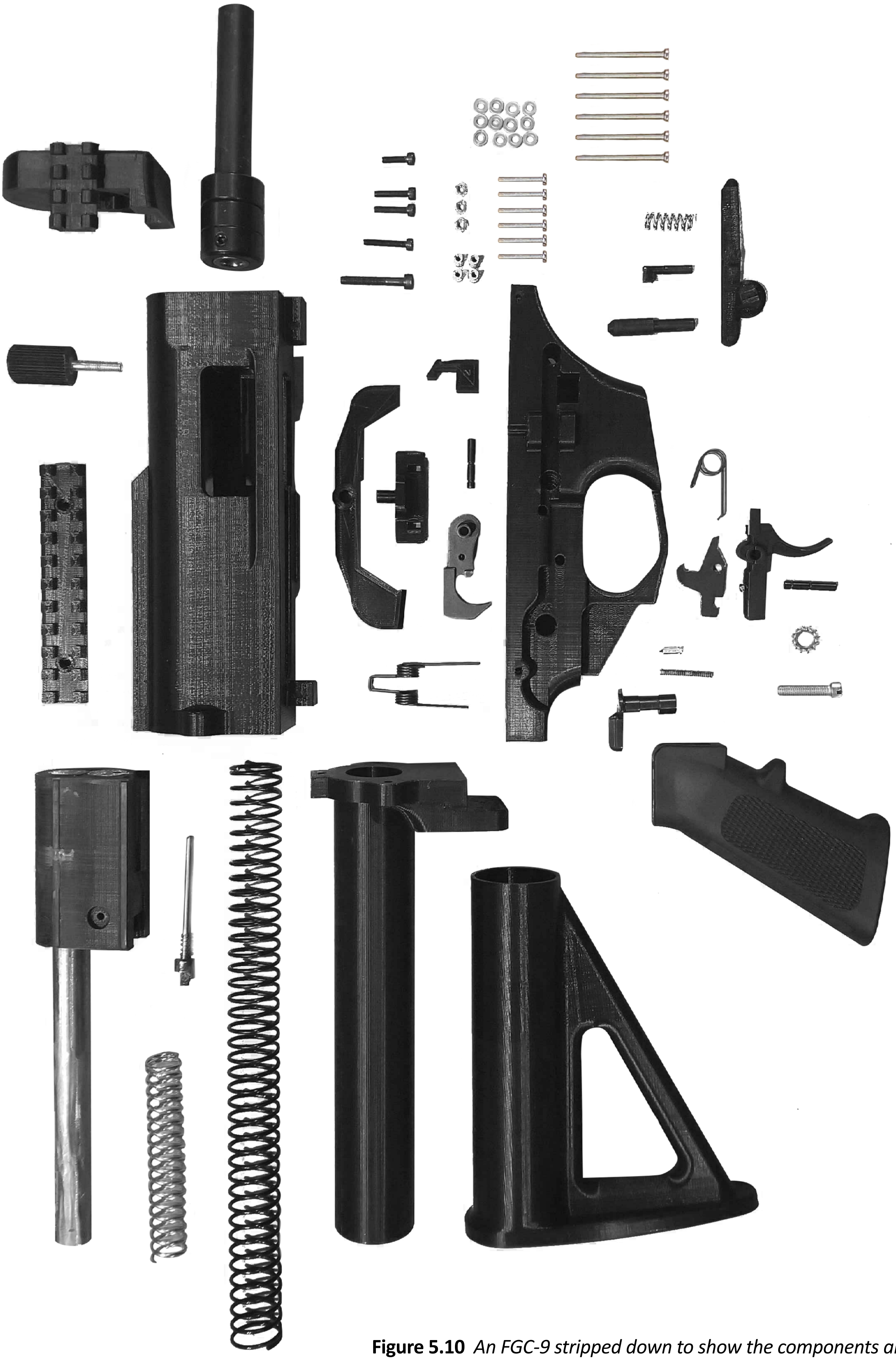


Figure 5.10 *An FGC-9 stripped down to show the components and general construction (source: JStark1809).*

Most significantly, the FGC-9 incorporates a homemade barrel made from commercially available pre-hardened 16 mm O.D. hydraulic tubing. The FGC-9 files also include building instructions to rifle the barrel using electrochemical machining (ECM) (Hays, Ivan T. & Jenzen-Jones, 2020). This is a critical improvement for lowering the bar of acquisition of an international audience to a 'usable'–namely, accurate and reliable—firearm. In addition to the homemade barrel, the FGC-9 also stands out in its use of European-based DIN parts (e.g., machine screws). One of the stated aims of the lead designer was to develop a design that could be readily produced by individuals in the European Union, where gun controls are generally strict (JStark1809, 2020).

Figure 5.11 *A craft produced FGC-9 Mk I barrel (source: JStark1809).*

The FGC-9's bolt is the most complex part of the weapon to produce. The bolt consists of two metal bars that are welded or glued together in a 3D-printed housing. Welding the metal pieces together results in a stronger overall construction, whereas gluing offers an easier—yet more labour intensive—way to construct the FGC-9's bolt. Nevertheless, either construction method is not trivial and a well-functioning bolt requires the confident use of metal working tools and a certain level of precision work by the person assembling it.

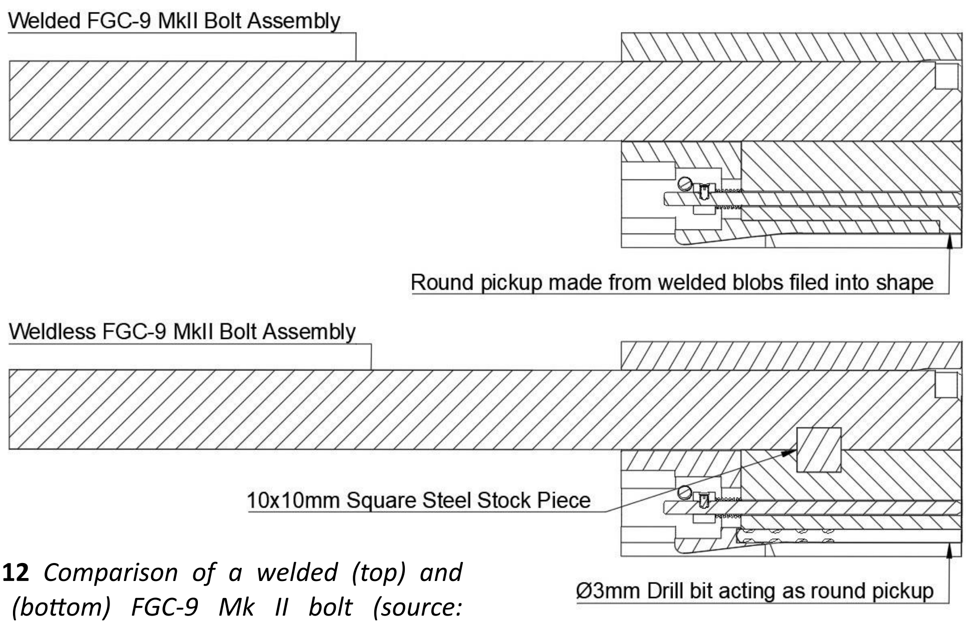


Figure 5.12 *Comparison of a welded (top) and a glued (bottom) FGC-9 Mk II bolt (source: JStark1809, IvanTheTroll, and 3socksandcrocs).*

The FGC-9—as most other hybrid 3D-printed firearms—uses a commercial AR-15 trigger group, which provides a reliable set of components that are unregulated in the United States and cheap to acquire. In order to make the design accessible in more restrictive environments such as the European Union, the FGC-9 can also use a slightly modified trigger group contained in gas-powered toy 'airsoft' guns of the same general design as a commercial AR-15 trigger group. Alternatively, AR-15 trigger groups can also be 3D-printed and equipped with craft-produced or repurposed springs (Ivan T., 2021).

This design choice means that the FGC-9 features a robust safety as the hammer is held back within the factory produced—or well tested craft produced—trigger group. However, this also means that the FGC-9, in its original configuration, only fires semi-automatically (the trigger has to be pulled for every shot). Commercially available AR-15 trigger groups do not feature an auto-sear and so only allow for semi-automatic fire. An AR-15 trigger group can be modified to fire automatic (firing until the trigger is released) by including an auto-sear or by using an automatic fire control group such as the FMGC-01 (see below).

FGC-9 Mk II

The FGC-9 Mk II was also designed by the Deterrence Dispensed team comprised of Jstark1809 in conjunction with users 'IvanTheTroll' and '3socksandcrocs'. Like the Mk I, the FGC-9 Mk II is made entirely out of unregulated commercial off-the-shelf (COTS) components using EU law as a compliance benchmark. The FGC-9 Mk II was released in April 2021 (JStark1809, IvanTheTroll & 3socksandcrocs, 2021).

Figure 5.13 *Right- and left-hand side view of the FGC-9 Mk II (source: JStark1809, IvanTheTroll, 3socksandcrocs).*

The main functional changes from the Mk I to the Mk II consist of a Heckler & Koch-style nonreciprocating charging handle and bolt hold-open, as well as a newly designed enclosed ejector for improved reliability. Further, primarily cosmetic changes include a full-length Picatinny top rail, a handguard with M-LOK slots for mounting accessories, an H&K-style sling mount, and an improved stock.

FGC-9 Mk II Stingray

The FGC-9 Mk II Stingray, designed by a user known as ‘hotsauce’, was released in June 2022 as a longer version of the FGC-9 Mk II. Mechanically, the FGC-9 Mk II Stingray functions like the FGC-9 Mk II but features a longer (16 inch) barrel, extended front grip, and collapsible stock. The longer barrel is likely to increase the velocity—and consequently the terminal ballistic effect—of a fired projectile compared to the shorter barrel on an FGC-9 Mk II. Usually, a longer barrel on a firearm is also equated with an increase in precision, but, in this case the longer barrel also means more stress on the Stingray’s 3D-printed housing. Thus, it is not clear if or by how much the Stingray is more accurate than the standard FGC-9 Mk II.

Figure 5.14 *Left side view of an FGC-9 Mk II Stingray (source: hotsauce)*

One reason for these changes is to avoid the FGC-9 Mk II Stingray falling under the United States’ National Firearms Act—which requires, among other features, a 16-inch rifled barrel. Broadly speaking, not being designated as a ‘short-barrelled rifle’ allows the FGC-9 Mk II Stingray to be more freely equipped with accessories such as vertical foregrips and shoulder stocks and avoids the legal necessity to register the firearm.

Partisan 9

In September 2022, a user known as ImmortalRevolt released the Partisan 9. Prior to this, the Partisan 9 had undergone beta-testing with the Deterrence Dispensed community. Functionally, this gun is largely based on the FGC-9 Mk II and retains many of its design choices, if not outright parts interchangeability. Most notably, the Partisan 9 retains the welded bolt construction. What sets the Partisan 9 apart from its FGC-9 roots, however, is its folding stock. Both FGC-9 models rely on a buffer tube that protrudes from the gun's housing (like on an AR-15) and adds to its overall length. The Partisan 9, on the other hand, features an interrupted side-folding buffer tube in its stock. However, the gun cannot be fired with a folded stock as the buffer tube in it is needed to absorb the recoil and cycle the gun.

Figure 5.15 *Top: The Partisan 9 with its unfolded stock. Bottom: The Partisan 9 with its folded stock. Both lacking a barrel (source: The_Real_Br0letariat)*

Notably, the Partisan 9 is designed to be equipped with a craft-produced ported barrel and an integral telescopic reflex suppressor that is specifically designed to reduce 124 gr supersonic 9 × 19 mm ammunition to subsonic velocity (ImmortalRevolt, 2022). Alternatively, the Partisan 9 can also be built without the integral suppressor using a standard, non-ported, barrel. As the Partisan 9's name implies, its designer sees the gun as especially attractive to asymmetrically operating forces and insurgents—partisans—due to the Partisan 9's short overall length (especially when the stock is folded) and low noise signature (when suppressed).[12]

Figure 5.16 *A rendering of a Partisan 9 equipped with a ported barrel and suppressor. Note the holes indicated roughly mid-way in the rifled barrel (source: The_Real_Br0letariat).*

Nutty 9

The Nutty 9 was designed by a user known as 'Joe Dirt' with the intention of lowering the bar of entry to build a hybrid 3D-printed PCC. The Nutty 9 is based on the FGC-9 but features a redesigned bolt which can be build with little to no metalworking experience. It is currently being beta-tested by both the Deterrence Dispensed community and the Black Lotus Coalition.

Figure 5.17 *A Nutty 9 hybrid 3D-printed PCC (source: The Black Lotus Coaliiton).*

12 Author's correspondence with an anonymous source.

As noted, the FGC-9's bolt requires some metalwork to construct it—which requires special tools and skills to complete. The Nutty 9 alleviates problem by using a bold build formed of hex nuts and 3D-printed components.

Figure 5.18 *Top: The partially assembled bolt from an FGC-9. Note the necessary welding (source: Parts Dispensed). Bottom, the bolt for the Nutty 9 consisting of Hex Nuts and a 3D-printed shell (source: BLC)*

Urutau

The Urutau is a firearm based on FGC-9 Mk II designed by the reportedly Brazilian-based designer known online as 'Zé Carioca', similar to the FGC-9 Mk II Stingray. However, unlike the Stingray, the Urutau's uses a bullpup design—that is, a firearm with its firing grip located in front of the breech (Ferguson, 2020)—and uses several non-FGC-9 parts. The Urutau's testing has been announced as early as September 2022 but, at the time of writing, the Urutau appears to be still in beta-tasting with no manufacture instructions having been publicly released. Notably, the Urutau is undergoing beta-testing with the Deterrence Dispensed and Are We Cool Yet? community (DrDeath1776, 2022).

Figure 5.19 *An assembled Urutau hybrid 3D-printed firearm (source: Zé Carioca).*

Reportedly, the Urutau is capable of semi-automatic, automatic, and 3-round burst fire using a specially designed 3D-printed fire control group. Like the FGC-9, the design is intended to be easily made anywhere in the world by using a mixture 3D-printed parts combined with COTS components. Notably, unlike the FGC-9, the Urutau's bolt is assembled by screwing it together and does not require welding, lowering the bar for construction ability significantly (Global Ghost Gun Policy Institute, 2022).[13] Additionally, the Urutau relies on magazines for the CZ Scorpion submachine gun instead of the Glock-pattern magazines the FGC-9 uses, supposedly for reliability reasons. Both pattern of magazines can reliably be 3D-printed (Global Ghost Gun Policy Institute, 2023).

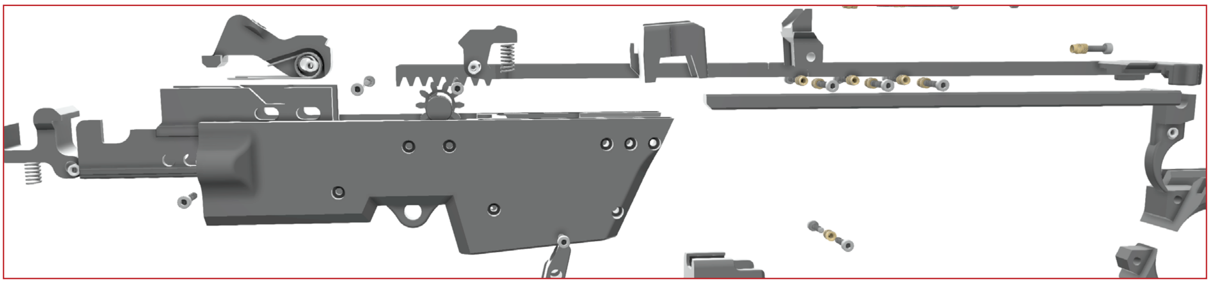


Figure 5.20 *A 'blown up' 3D rendering of an Urutau. Note the gear tooth used to connect the trigger to the firing mechanism (source: Zé Carioca)*

FMGC-01

A noteworthy 'unofficial' member of the FGC-9 family is the FMGC-01 ('Fuck Machine Gun Control 01'). Outwardly, the FMGC-01 looks similar to the FGC-9 Mk II but lacks the buffer tube and features a collapsible wire stock instead. The FGMC-01 was designed by a user known online as 'Sasà' and was released some time in 2022.

Figure 5.21 *A FMGC-01 (source: Impro Guns).*

13 https://homemadeguns.wordpress.com/2022/12/20/urutau-9mm-carbine/

The most significant difference between the FGC-9 Mk II and the FMGC-01 is the latter's select-fire capability (being able to fire semi-automatic and automatic modes). This is achieved by a redesigned 3D-printed fire control group with metal inserts, which features a three-position safety switch (safe, semi-automatic, and automatic fire modes). Like the Urutau, this gun part has not undergone beta-testing with Deterrence Dispensed but seems to have been tested by individuals not associated with the group—at least one of these testers is an online user known as 'Shit_On_Wheels', who is believed to be operating from continental Europe.

EZ-22 and HD-22

Besides self-loading hybrid designs based on the FGC-9, there are some that rely on different operating mechanisms. These are the EZ-22 and the HD-22, both chambered for .22 LR cartridges and designed by an individual known as 'Plastic Blasters'. The EZ-22 was release in 2022, while the HD-22 was released in 2023. While construction files for both guns are available online, neither seems to have undergone formal beta-testing and both guns' construction files seem to require hand fitting by the individual builder to ensure their correct functioning.

Figure 5.22 *Left: an EZ-22 hybrid 3D-printed firearm (source: Plastic Blaster). Right: an HD-22 hybrid 3D-printed firearm (source: Plastic Blaster).*

Both the EZ-22 and the more compact HD-22 consist of a 3D-printed AR-15 lower receiver and a custom designed and 3D-printed upper receiver with a barrel shroud holding a metal tube that serves as the barrel. As noted above, the designs are chambered for the comparatively low powered .22 LR cartridge and do not enjoy the same level of publicity as the FGC-9. Nevertheless, HD-22's has been documented in police seizures in the US (PIX11 News, 2023) and Scandinavian gun design forums (Füredi, 2023).

Hybrid Self-loading Pistols

Besides hybrid 3D-printed pistol calibre carbines and sub-machine guns, there is a handful of hybrid self-loading pistols designs worth noting. Most relevant is the so-called 'Yeet' family of pistols designed by a user known as Shit_On_Wheels. All Yeet pistols are chambered in .22 LR, use an ECM rifled barrel, 3D-printed and COTS parts, and use a simple blowback operating system (Shit_On_Wheels, 2023). At the time of writing, five Yeet pistols by Shit_On_Wheels are known to exist. These are:

Figure 5.23 *The 'Yeet' family of hybrid 3D-printed self-loading pistols. Top left: The Yeet22 Hammer; Top right: The Yeet22 Auto; Middle: The Yeet22 C; Bottom left: The Yeet22 V.2; Bottom right: The Yeet22 V.1 (source: Shit_On_Wheels).*

Firearms with 3D-printed Receivers

The final category of 3D-printed firearms includes those that have been assembled using a 3D-printed receiver (or frame), but in which most or all of the pressure-bearing components (e.g. the barrel, slide, and bolt) are commercial, factory-made parts. These designs, sometimes referred to broadly as 'parts kit conversions' or 'parts kit completions' (PKC), are generally the most reliable of firearms that utilise 3D-printed parts, and are often just as capable as factory-made guns. However, these designs typically incur the highest material cost and may be more difficult to build if certain components are restricted by law, as in Europe and some U.S. states. By sheer number of designs, this is also by far the largest category. In the U.S. context, and in jurisdictions with similar firearms laws, these designs are often assembled around legally obtained firearms parts supplied as complete kits, save for a receiver or frame (or part thereof) due to the legal control of that component. In some cases, parts may be acquired very cheaply.

Firearms with 3D-printed receivers can broadly be divided into three subcategories, based on how closely they function like and resemble a factory produced design. 'True' parts kit completions are those firearms that copy an existing industrially produced design by replacing only its polymer parts with 3D-printed frames that are near-identical in dimensions and function. A 'true' parts kit completion retains all or most metal parts from the firearm and results in a weapon that is very similar in appearance and capability to the original firearm. An example of such would be a 3D-printed lower receiver for a Glock pistol, such as the Spaceman GOTY 17 by the user 'Charimanwon'.

Figure 5.24 *The 3D-printed Spaceman GOTY 17 lower receiver for a Glock 17 action and slide (source Chairmanwon).*

Besides ‘true’ parts kits completions, there are the so-called ‘parts kit *conversions*’. These firearms also consist primarily of firearm parts from the original factory-produced gun; however, their 3D-printed receiver no longer mimics that of the original firearm. This results in firearm actions being used in a 3D-printed chassis that may not resemble—and perhaps even function differently—than their donor firearm. An example of a conversion in this style is the Recession Ruger, designed by users ‘UberClay’ and ‘Kukitan’ (both associated with Deterrence Dispensed). This design uses the slide, barrel, springs, and pins from Ruger P95, P85, and P89 pistols and combines it with a 3D-printed lower receiver with an AR-15 fire control group. This lower receiver allows the Recession Ruger to accept Glock magazines, mount a fixed optic over the line of sight of the slide, and a accept a should stock—turning the pistol’s action into a PCC (UberClay & Kukitan, 2022).

Figure 5.25 *A Regression Rugar with a 3D-printed side-folding stock and a picatinny rail to mount an optic (source: DrDeath1776).*

Finally, there are 3D-printed firearm with firearm parts. This kind of firearm relies on comparatively few factory-produced firearm parts—usually only the barrel—and uses 3D-printed and other metal components to build most of the gun. In some cases, complex parts like the bolt may be a proprietary design of a firearm and require CNC machining to be built. These firearms differ from the other categories discussed because they do not mirror an already existing firearm and often use a new design or operating mechanism not related to established firearm designs. One example is the King Cobra 9, designed by users Derwood and Mussy.[14] The King Cobra 9 uses few firearm parts—only a Glock barrel—and a custom-designed bolt that is also manufactured and sold by the company 3DDefense. The operating mechanism of the PCC can best be described as a magnetic-delayed blowback system, that is, a simple blowback system with a set of magnets in the gun’s upper receiver to slow the bolt.

14 In collaboration with ZipDic, Sg2020, Memphistopheles, Treeman, V555, Lulzgoat and Mr.Snow

Figure 5.26 King Cobra 9 with a foldable brace (source: AWCY?).

Development, Peer-testing of Designs & Information Accessibility

Much of the popularity of 3D-printed firearms today can be traced back to vast improvements in their development.[15] Early on, very little testing and documentation went into a design. The Liberator, which was released in 2013, exemplifies this point well (even if it is not exactly the first 3D-printed firearm design). After a string of unsuccessful tests, a single successful one led to the design being hurriedly released to the internet. The documentation provided along with it consisted of the bare minimum level of information, lacking any useful troubleshooting or safety checks to be performed prior to firing the weapon. This was of course particularly important with early 3D-printed firearms, which, if used improperly, could easily injure their user.

This general method, whereby designs that were at best poorly tested were released with little documentation, was the standard until late 2018–early 2019. While some exceptions exist, most designs were released after either never having been tested or being tested only by one person using one printer to make the firearm. As the price of printers decreased and interest in printed guns grew, the need for designs that saw extended testing became apparent. Thorough documentation that covered as many aspects of the build process as possible (usually with an accompanying build video) became standard for releases.

While each 3D-printed firearm design has unique aspects that require differing levels of testing and documentation, most design processes now follow a basic procedure. This is very similar to that found in the traditional gun industry and engineering design in general, though the rate at which a dedicated developer can play the role of designer, fabricator, tester, and documentarian is often much quicker than the pace found in standard industry. This is usually due a result of the gun designer's tendency to rely on readily available parts and supplies, rather than having to shop out several runs of expensive prototype parts to arrive at something that works.

15 This section is adapted from a background report prepared by Ivan T. More information is available to selected clients.

The design process, of course, begins with an idea—this can take the shape of many things, from “wouldn’t it be cool if you could do X but with Y” to “it looks like X parts are cheap, if you did Y with them it might just work” to the classic “I want to make a gun out of zero gun parts”. Considering the popularity of 3D-printed guns in the United States and the relative ease of acquiring firearms/firearm parts there, most ideas run along the lines of the first two examples. The third example, common in the United Kingdom and mainland Europe (among other places), gave rise to guns such as the FGC-9 and Luty SMG, and represent one of the hardest sets of design challenges. While the first two examples can rely on factory-made barrels, bolts, and other parts to reach their end goal, the third is unique in its reliance on handmade or common hardware store supplies for these parts. As one might conclude, the documentation burden is also much higher on designs responding to the third challenge—with the first two, documentation need only cover printing of the required parts, assembly, and troubleshooting, and does not concern itself with the fabrication of bolts, barrels, and other components.

Once an idea is formed, the first drafts of a design are created. This is usually done in CAD software, where the designer lays out the gun’s basic design and functioning in 3D space. For some builds, only one or two parts need to be modeled in CAD, while other builds require many more. These initial designs are informed by measurements taken from existing physical parts, be they from a parts kit or hardware store stock material. Following the completion of the first draft design, parts are often printed to test fitting, such as by making sure that parts which should fit tight are indeed tight, and that parts which should move freely are not restricted in their movement.

Some first draft prototypesare capable of being test fired, though in most cases they need at least one round of revision to get to test-ready condition. These revisions usually consist of adjusting design geometry to ensure parts fit together correctly and that proper function of the gun is possible.

Once a design has been assembled and is ready to test, for safety reasons some designers opt to test the prototype remotely (such as by using an apparatus to hold the gun and a string to pull the trigger), while others choose to test it in a more traditional fashion. The nature of the design can inform this decision—a design chambered for .22 LR would be much safer to do initial test firing by hand than something chambered for .308 Winchester. Initial firing tests provide feedback on the reliability of the design’s relevant mechanism, as well as information on the durability of the design. Weak points that represent safety issues generally surface in short order, and part breakages can be taken back to the drawing board to be reinforced.

From here, projects can take one of many routes: from multiple iterations of testing and redesign by one tester, to a sort of ‘beta’ test where multiple testers follow the designer’s instructions to subject the prototype to more rigorous and widespread testing. Some projects end up going to beta testing after first shots are made on the initial prototype(s), but other projects feature significant refinement before beta testing begins. This sort of beta testing is crucial to the release of a good project, as third-party verification and validation of a design is the best indicator of how the project will fare when released publicly. In general, for a design to be accepted into a beta-testing program by major 3D-printing groups, it needs to be easy to make for the average person. This means that building the design should not require extensive machining, exotic materials, or expensive tools. From there, the design needs to have been built and fired safely. The safety of the testers is of course paramount, as their participation is what advances a 3D-printed design past the beta testing stage. Thus, many designs are rejected during beta-testing, which has likely prevented the numerous injuries that would have occurred as a result of unsafe designs being released to consumers. Being careful about which designs are accepted for testing also serves to weed out lazy or uncommitted designers from the community.

While benchmarks vary from one project to another, generally beta testing can be considered concluded after a certain number of rounds have been successfully fired by a certain number of testers who all used different printers. Documentation and design can and should be updated during the beta testing process to ensure that common errors and flaws in the project are remedied prior to release. At this point, finishing touches are put on the project and files sent off to various release platforms to host them. Oftentimes, the larger reach of the public can spur further improvements, spelling/grammar fixes in documentation, and even new features—meaning that even released projects continue to be updated and improved after their initial publication.

Information Accessibility

One common misconception is that the development and publication of 3D-printed firearms is something that occurs in dark corners of the internet (or even on the so-called 'dark web'). In reality, construction plans, original machinist's drawings, video tutorials, and detailed CAD models for craft-produced firearms have been widely available—in both amateur and professional formats—for decades (see *Figure 6.2*) (Colvin, 1917; Luty, 1998; Hays & Jenzen-Jones, 2018). The development of 3D-printed firearms is widely broadcasted across sites like X (formerly Twitter), Reddit, Instagram, and others, as making and testing firearms is legal in the United States. File downloads do not require any sort of knowledge of torrents or cybernautic talent, contrary to the insistence of some opponents of 3D-printed firearms. The information and files are published into the public domain and are easily accessible, being widely protected under free speech laws of many countries.

The platforms associated with development and dissemination of files can vary. Many developers choose to release their projects through a single website, such as Odysee, and allow it to be rehosted through other platforms by the broader community. Other developers put their work behind a paywall on sites like Cults3D or Defcad, where file downloaders have to pay for access and the host takes a cut of the payment. Due to the open-source ethos that defines the 3D-printed firearms community, many designs that are uploaded behind a paywall find their way to Odysee to be downloaded for free. Indeed, to many in the community, paying for files is contrary to the whole purpose of 3D-printed firearms. Other developers simply rely on email and direct download links using sites like Mega.nz. During development, any number of platforms are used, from self-hosted chat servers like Matrix or Rocketchat to more common platforms like Discord. Some developers have even utilized email to accomplish beta testing; any avenue that allows people to communicate ideas would work to fulfil this end.

Both open and closed groups dedicated to 'home gunsmithing'[16] exist on large sites such as Facebook with hundreds of members. Other platforms, such as the Russian-based social media site VK, also host many active groups. High profile platforms such as Reddit and Facebook have attempted to restrict this activity. In 2018, Facebook amended its policy to prohibit the sharing of files and instructions for gun-making, but exempted 'legitimate' gun shops and online vendors from marketing said files and instructions (Garcia, 2018). Reddit followed suit in 2019 with a ban on "…3D printed files to produce firearms…[including]… torrent links" (Reddit.com, 2020) and most firearms-related subreddits have attempted to follow this guidance. Users are nevertheless still link to other sites with this information and share the results of their 3D printing efforts, growing and enabling interest in the technology as it pertains to firearms. Since 2018, YouTube policy ('community guidelines') on firearm-related content has prohibited videos which are "intended to sell firearms, instruct viewers on how to make firearms, ammunition, and certain accessories, or instruct viewers on how to install those accessories". Specifically prohibited are "accessories that convert a firearm to automatic fire, such as: bump stocks, gatling triggers, drop-in auto sears, or conversion kits"

16 It is important to note that a variety of groups, pages, and other fora intended for professional gunsmiths are available online, and there is significant overlap between amateur and professional outlets.

(YouTube, n.d.). A large number of firearms and history channels have reported that their videos have been ‘demonetised’ (making them ineligible to earn advertising revenue for creators, and making them less likely to be returned in search results), or have suffered harsher consequences, such as ‘community guideline strikes’ (essentially written warnings), being marked ‘not family friendly’ (all but eliminating advertising revenue), and even channel suspension or deletion. Several of these channels reported not publishing any content that, to the best of their knowledge, violated YouTube’s guidelines. The opaque nature of YouTube’s enforcement mechanism and a perceived lack of accountability led the popular channel InRangeTV to say that YouTube’s “vague and one-sided firearms policy makes it abundantly clear that YouTube cannot be counted upon to be a safe harbor for a wide variety of views and subject matter” (InRange TV, 2018). According to a VICE News interview InRange TV “view[s] these new rules as a dangerous slippery slope away from freedom of speech on the internet’s largest public square of video content” (Turton, 2018).

Figure 6.1 *A .22 LR calibre revolver, made using traditional craft production techniques and based upon widely available construction plans. The skill level required to produce this sort of craft-produced firearm is higher than for some 3D-printed designs (source: ImproGuns).*

The 3D-printed firearms community is united by its shared hobby of designing and building firearms and the libertarian belief that it is part of an individual's freedom to own firearms. Beyond these commonalities, the 3D-printed firearms community is rather diverse—featuring many members of LGBTQ backgrounds—and generally discourages extremism. Taking Deterrence Dispensed as an example, significant efforts have been undertaken to exclude individuals with an extreme or violent ideologies from the 3D-printed firearm community. These measures are taken to both keep people safe and prevent division and infighting, which could jeopardize the productivity of the community. Individuals that express a radical or violent ideology are regularly banned from the group.[17] Nonetheless, there are indications that, as with almost any largely anonymous online community, some members have harboured extremist or violent perspectives (Basra, 2023).

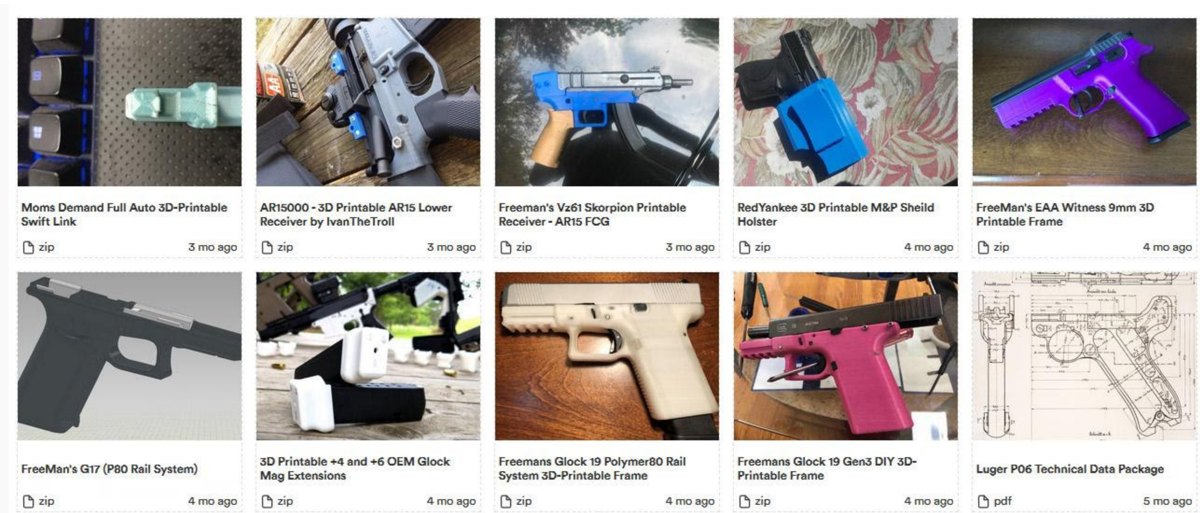


Figure 6.2 *A snapshot from January 2020 showing part of a new generation of 3D-printable DIY firearm files hosted in an extensive file repository maintained by det_disp (source: Deterrence Dispensed).*

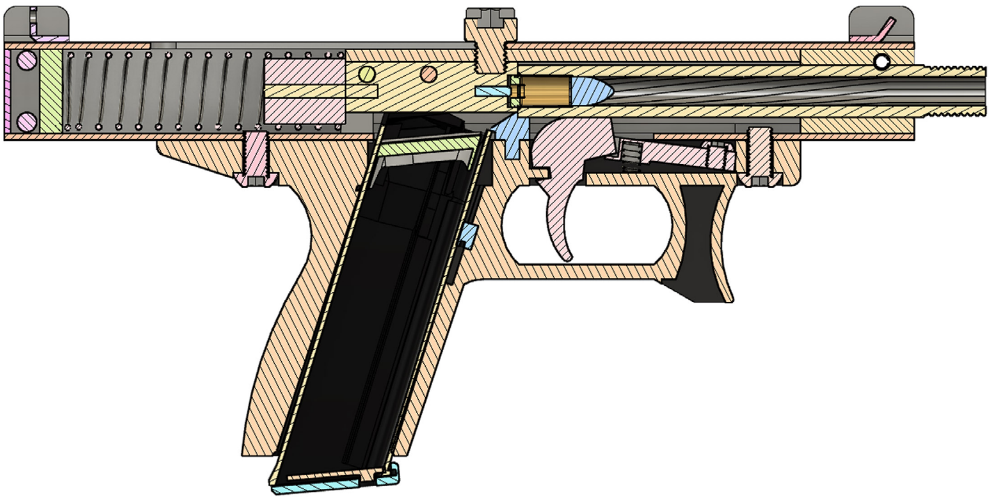


Figure 6.3 *A cutaway of the Cheetah-9 sub-machine gun (source: ProfessorParabellum).*

17 Authors' corresponded with members and moderators

Emergent Firearms Craft-production Technologies

Additive Manufacturing

Additive manufacturing (AM), otherwise known as '3D printing', is a computer-controlled process by which a physical object is created from a virtual 3D computer model in the form of a CAD file. This file provides information to a 3D printer which creates the item through a physical process most often involving the depositing and fusing together of layers of material (Jenzen-Jones, 2015). The term '3D Printer' alludes to the creation of 2D images on paper by means of ink deposition in the traditional desktop printer. Additive manufacturing first emerged in the 1980s when a technique known as Stereolithography (SLA)—which used an ultraviolet beam to selectively cure photosensitive polymer layer by layer—was developed by Chuck Hull (Bártolo 2011; Jenzen-Jones, 2015). One of the most valuable characteristics of 3D printers for firearms developers (both craft producers and commercial manufacturers) is their ability to rapidly produce prototypes. As useful as CAD models and digital assets are, a cheap physical model of a part can provide exceptional tactile and visual feedback for gunsmiths and enthusiasts alike. Prototype parts can often be reused in dry-fire or live-fire testing, cutting down on total tooling costs and development time, and reducing the number of complex parts that must be made. 3D printers are also increasingly easy to operate, and learning to use a 3D printer is significantly more straightforward than learning to run a manual mill. The lower machine and tooling cost and reduced skill requirements make one-off projects more feasible—should someone want to dabble in home gunsmithing in their spare time, they can do so by making an FGC-9 or Songbird with a significantly reduced investment in time and money when compared with conventional craft-production methods. The most popular process for consumer-level additive manufacturing today is known as fused deposition modelling (FDM),[18] where the CAD file is built through depositing and fusing together melted layers of thermoplastic material through a heated nozzle (Jenzen-Jones, 2015). Selective laser sintering (SLS), selective laser melting (SLM), and direct metal laser sintering (DMLS) fuse together polymer or metal powders, and are much more advanced than almost all FDM processes. This is reflected in a considerably higher price per printer, which are often orders of magnitude more expensive than consumer-grade FDM machines. Other technologies, such as binder jet printing (BJP), electron beam freeform fabrication (EBF), and electron beam melting (EBM), also exist (Jenzen-Jones, 2015). FDM is the most recognisable 3D printing technology to the layperson, and is the primary technology used by craft-producers of 3D-printed firearms (ARES, 2019). Perhaps the most prevalent printer in the DIY gun community in 2020 is the Creality Ender 3, a 200 USD printer made in China (see Figure 7.1) (Pete, 2019). This lacks many features of commercial-grade printers such as automatic bed levelling, a heated build chamber, and high-temperature polymer capability. Despite these limitations, this model is able to produce a range of different parts for firearms, ranging from frames for Glock handguns to AR-15 lower receivers, and from barrel rifling jigs to suppressor baffles. FDM printers can be used to work with a variety of polymers, which are typically fed from a spool of filament (see Figure 7.1) and vary by printer model (see Table 7.1). Certain polymers may also be more suitable for the application of other production techniques, such as conventional machining or chemical welding.[19] Whilst the Creality Ender 3 is somewhat limited in terms of the polymers it can print, another popular printer—the Prusa i3 family—can handle higher temperature nylons and comes with automatic bed levelling to ensure printing is performed on a level surface. Automatic levelling aids accuracy, which becomes significant when printing more complex components (ARES, 2019).

18 Also known as fused filament fabrication (FFF) and fused deposition of material (also FDM).

19 Chemical welding involves coating the mating surfaces of two or more parts you wish to join together in a chemical that dissolves a layer of polymer on each surface, and then pressing those parts together. Once the chemical binder evaporates or solidifies, the two parts have been welded together as one contiguous part.

Table 7.1 — *Physical Properties of Selected 3D-printer polymers (source: Patrick Senft; IvanTheTroll).*

Polymer	Rigidity	Strength	Failure Mode	Ease of Printing	Cost (USD)	Chemically welded easily?
PLA/PLA+ (eSun's PLA+)	Very High	Low	Shatter	Very Easy	Very Low ($20/kg)	Yes
PETG (Polymaker)	High	Low	Shatter	Easy	Low ($30/kg)	Yes
ABS (IC3D's ABS)	Moderate	Moderate	Gradual/crack	Hard	Low ($30/kg)	Yes
Nylon alloy (Taulman 910)	Low	High	Gradual/crack	Moderate	Medium ($35/kg)	No
DuPont Zytel	Very Low	High	Gradual/crack	Easy	High ($100/kg)	No
DuPont Zytel (33% glass fill)	Very High	Very High	Gradual/crack	Very Easy	Very High ($100/kg)	No

Source: *Patrick Senft; IvanTheTroll.*

Notes: *Suitability for a given application will depend on a wide range of factors, such as the mechanical and thermal stresses a part may be subject to, the operating conditions of the finished component, and any weight, flexibility, or thickness requirements.*

On the surface, the applications of FDM printing seem limited for gunsmithing. The polymer used by cheap printers is much weaker than aluminium, and FDM parts are weaker than injection-moulded polymer parts (Agarwala et al., 1996). However, if the craft-producer takes full advantage of an FDM printer, it can become a tool just as valuable as a lathe or mill. FDM printers are capable of producing a wide range of gun parts not required to bear extreme pressure, including the receivers of certain firearms (such as the lower receiver of an AR-15), magazines, grips, stocks, receiver extensions, and accessory rails. Whilst the strength of these parts is not high in comparative terms, the low cost of FDM printers and the relative ease of adding reinforcing elements to polymer components allow users to produce parts which will still function reliably over extended use, but at a fraction of the tooling cost of conventional manufacturing set-ups or more advanced 3D-printing technologies. FDM printers are also able to produce specialised tooling and workholding aids (for holding components in place during work) for use with traditional machine and hand tools. As maker 'JStark' puts it:

> *One can 3D-print the parts that are not directly impacted by the forces of the discharge of the cartridge. Complex shaped parts of firearms such as the main receiver or other secondary parts and assemblies of a firearm can be made by a 3D printer as well. By increasing the proportion of parts on a firearm design that can be 3D-printed one needs less labor and less specialized tools"((ARES, 2019).*

Depending on a range of factors including printer, polymer, and design, some 3D-printed components may be formed with more porosity than desired. Whilst metal reinforcements are preferred for many applications, plastic components can be strengthened in other ways. Parts printed in thermoplastics can be re-melted with a soldering iron to better fuse together the layers within the part, greatly increasing their lifespan. Another method of strengthening involving re-melting printed polymers is fiberglass patch reinforcement, a technique in which a sheet of fiberglass is held against the printed part and melted 'into' it by a soldering iron. Because the heat is localised, components are unlikely to warp, and will gain the stiffness of fiberglass over the applied area. Yet another re-melting technique used on PLA is referred to as 'annealing', although this is not a technically accurate term in this context. In PLA 'annealing', a part printed in PLA is left in a conventional oven for a period of time (usually around an hour) at a temperature which is held just above PLA's glass transition temperature (around 60–65° C). This causes individual layers of PLA to better fuse together. However, because heat is applied to the whole part, it will often warp as it cools (ARES, 2019). A variety of different parts and components can be produced using FDM printers, but these do have their limitations. It can be challenging to print pressure-bearing components such as bolts and barrels, or parts that need to be harder than cartridge cases, such as firing pins. Printing such components is difficult whilst maintaining cost-effectiveness and/or the ergonomics and function of the firearm. As a result, hybrid and PKC builds have become increasingly popular; frames, receivers, and magazines are now believed to be the most-printed firearms-related objects (ARES, 2019).

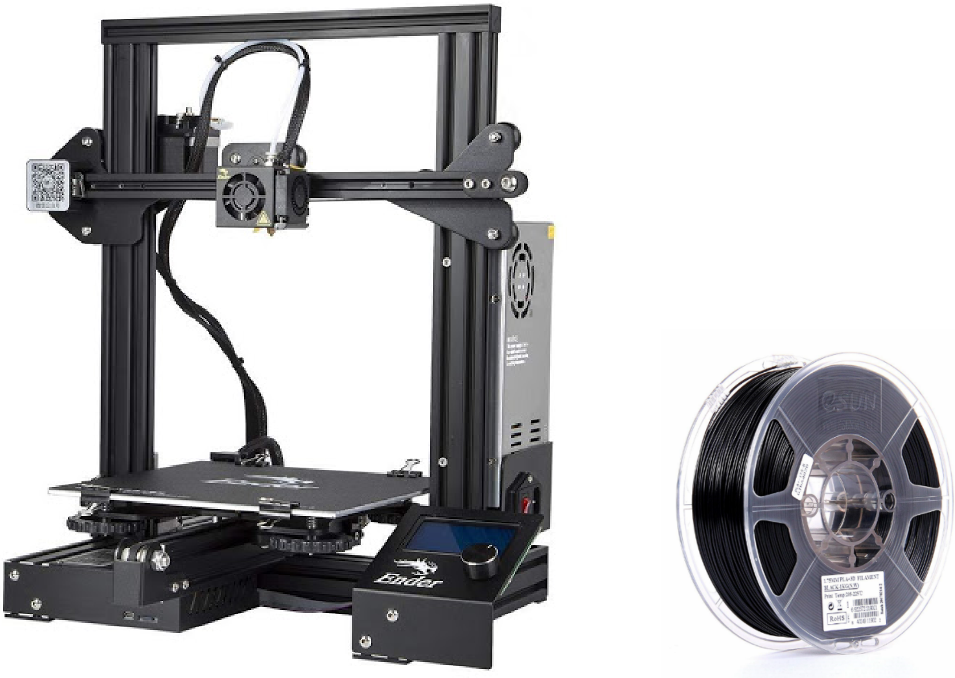


Figure 7.1 *A Creality Ender 3 desktop FDM 3D-printer; Right: a representative spool of polymer for an FDM 3D-printer, in this case eSun PLA+. Not to scale (sources: Amazon; eSun).*

Receivers & Frames

Perhaps the most prolific use of 3D printing in the craft production of firearms to date has been the design of 3D-printable lower receivers. The lower receiver or frame of some firearms designs—including most handguns and the ubiquitous AR-15 self-loading rifle—is not a component which is subject to significant stresses. Accordingly, receivers for these weapons, or portions thereof, may be made from non-metallic materials such as polylactic acid polymer (PLA), the standard filament type used in consumer-grade 3D printers. In many cases, the original design of a receiver is strengthened in printed models through increasing the thickness of material in certain areas. For example, the use of a polymer replacement receiver for the sheet steel AKM pattern weapon is believed to increase its overall resistance to mechanical stress (ARES, 2019). One reason makers have focused on the design and production of receivers and frames is their legal status within the United States. As previously discussed, these components may be the only legally controlled part of a firearm; as a result, an unregistered, difficult-to-trace firearm may be acquired in some jurisdictions by simply combining a 3D-printed receiver or frame with readily available components (see Figures 7.3 & 7.4).

Figure 7.2 *A 3D-printed AR receiver with reinforced rear section (source: Ivan T./ARES).*

Figure 7.3 *Commercially available FCG parts fitted to a 3D-printed AR-15 lower receiver (source: Ivan T./ARES).*

In some cases, 3D-printed polymer receivers may experience some wear from the reciprocating parts of the firearm (such as the bolt carrier on an AKM). In such cases, simple metal parts can be incorporated into the design to reduce wear. These are typically produced by using commercially available tube or bent angle stock, and provide a durable receiver with minimal additional effort (see Figures 7.4–7.6). This requires more skill than simply printing the polymer parts, but is easily achievable by anyone with basic craftworking experience or aptitude. Designers are increasingly simplifying this process for producers; for the Glock 17 receiver, for example, a series of 3D-printable jigs have been released to aid in the accurate removable of material where hand tools are to be used.

Figure 7.4 *A Glock 17 frame printed in DuPont 'Zytel' glass-filled nylon. Factory Glock pistols use a near-identical polyamide 66 type material. Note the visible metal rails at right (source: Ivan T./ARES).*

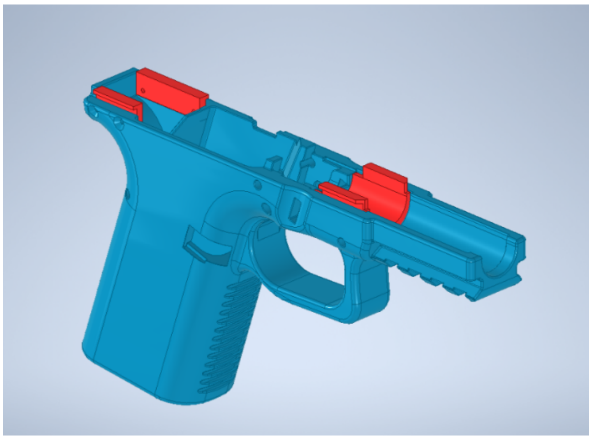


Figure 7.5 *CAD diagram showing the placement of metal rail inserts (red) in the 3D-printable Glock 17 receiver (source: Ivan T./ARES).*

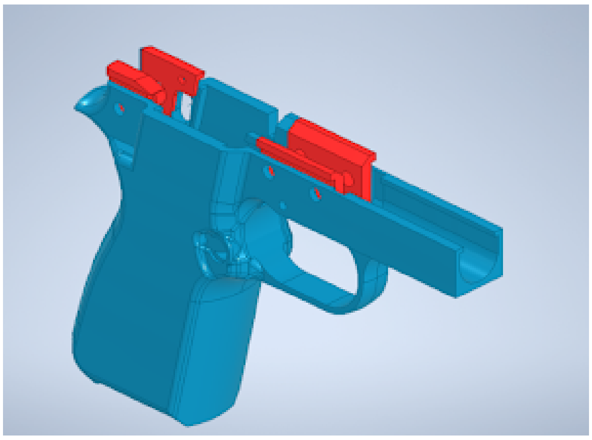


Figure 7.6 *CAD diagram showing placement of metal rail inserts (red) in the 3D-printable Browning Hi-Power receiver (source: Ivan T./ARES).*

Figure 7.7 *The 'Plastikov', a 3D-printable AKM pattern receiver recently developed by IvanTheTroll. The example pictured is assembled using Hungarian AMD parts (source: Ivan T./ARES).*

Figure 7.8 *Fibreglass-reinforced rear section of the Plastikov receiver (source: Ivan T./ARES)*

3D-printed receivers and frames have been developed for a wide range of commercially produced small arms, ranging from pistols and sub-machine guns to self-loading rifles (See *Figures 7.7–7.11*). At the time of publication, the frames and receivers compatible with commercial firearm part kits which have been successfully printed in PLA include:

- AR-15 self-loading rifle (.223 Remington/5.56 × 45 mm)
- AR9 self-loading rifle ('pistol') (9 × 19 mm)
- AKM ('Plastikov') self-loading rifle (7.62 × 39 mm)
- Ruger 10/22 rifle (.22 LR)
- VZ61 Škorpion sub-machine gun/pistol (7.65 × 17SR mm)
- TEC-9 (AB10 'Ghetto Blaster') self-loading pistol (9 × 19 mm)
- MAC Model 10 and 11 sub-machine guns ('Mac Daddy') (9 × 19 mm)
- Glock models 17, 19, and 26 self-loading pistols (9 × 19 mm)
- M&P Shield self-loading pistol (9 × 19 mm)
- Ruger SR9 self-loading pistol (9 × 19 mm)
- EAA SAR K2P self-loading pistol (9 × 19mm)
- EAA Witness self-loading pistol (9 × 19 mm)
- G43 SS80 self-loading pistol (9 × 19 mm)
- S&W SD9 self-loading pistol (9 × 19 mm)
- Diamondback DB380 self-loading pistol (.380 ACP)
- Hi-Point C9 ('Lo-Point') self-loading pistol (9 × 19 mm)
- Browning Hi-Power self-loading pistol (9 × 19 mm)

Figure 7.9 *A Browning Hi-Power self-loading pistol with a 3D-printed frame (source: Ivan T./ARES).*

Figure 7.10 *A vz. 61 Skorpion .32 ACP pistol (the civilian-legal semi-automatic version of the original sub-machine gun) with a 3D-printed receiver, based on a design developed by FreeMenDontAsk (source: Ivan T./ARES).*

Figure 7.11 *A 9 mm Tec-9 type (AB-10) pistol assembled using the 'Ghetto Blaster' 3D-printed receiver designed by FreeMenDontAsk (source: AustinQuemist).*

Magazines

Depending on a craft-producer's location, firearms magazines may also be regulated. This varies by jurisdiction, even within a country. In the United Kingdom, for example, magazines are unrestricted in England, Scotland, and Wales, but constitute a legally controlled 'component part' under Northern Irish law (Northern Ireland Office, 2005; PSNI, n.d.). This is partially due to their use in craft-produced designs, as producing reliable magazines has traditionally been difficult. (Jenzen-Jones, 2018). Being not much more than a box housing a spring, magazines were some of the first firearm parts to be produced using a 3D printer (Johnson, 2011). Early results proved less than adequate, however. Producing reliable magazines has always been a challenge for the craft-producer, as the geometry of the feed lips must be precise and strong enough to enable consistent reliable feeding of rounds from the magazine into the chamber. Designer IvanTheTroll recounts:

> *"3D-printed mags have been a valid concept since at least 2013, when Defense Distributed demoed a printed AR15 magazine. They employed SLA printing – a process more expensive than FDM. The DIY community never managed to match what Defense Distributed had shown in their promotional videos for their AR15 magazine – partly because of the lack of documentation from DD, partly because the printer DD used was superior to anything that the average DIY-er had access to. Users had issues with the lips on the top of the mag splitting, or the mags simply feeding poorly. This is where I came in, in the Summer of 2018. I took the DD AR15 mag, tweaked its internal geometry to better match a PMAG, and developed documentation on how to make a working magazine (detailing material and post-processing specs). I also developed a 3D-printable jig used to wind magazine springs into their rough shape – when using spring wire, the jig holds the spring in the shape needed for stress relief, which nets a spring in the proper shape without requiring a furnace, as an ordinary oven is able to stress relief spring wire. This made the AR15 30 round magazine an item that could be made entirely from scratch – body, peripherals, and spring." (ARES, 2019).*

With a reliable AR-15 magazine completed (see Figure 7.12), Ivan set his sights on what he considered the next-most widely-used magazine—that of the Glock 17 pistol (see Figure 7.13).

"My next project in this sphere was much more ambitious – at the very beginning of the FGC-9, it was realized that there were no proper models of Glock mags out there – even the outside dimensions of ones on Grabcad were wrong. I was asked to help by generating a new Glock mag model from scratch. I started by going for as close to a blueprint copy of a G17 mag as possible by reverse engineering a mag. This mag model was used to design the magwell of the FGC-9 around – but after putting in the time to model the mag, I figured I'd print it. It didn't work well at all, but I saw promise. I figured that with proper reinforcement, Glock mags could be printed in PLA – a cheap, easy to print polymer. After 6 months of working on the Glock mags, I finally got a design that works reliably, costs under 1 dollar to print (plus two bucks for the spring, but springs can be reused), and can be printed on virtually any printer (anything that can do PLA or PLA-level strength). Professor Parabellum saw the promise of the printed mags as a new standard to design guns around – gone are the days of relying on shoddy STEN mags or trying to do Luty-style DIY mags. You can print 30 G17 mags on a single build plate and have all the mags you need." (ARES, 2019).

At this time Ivan's activities came to the attention of U.S. Senator Bob Menendez of New Jersey who upon becoming notified of a newly released technical data package for the AR-15 rifle compiled by Deterrence Dispensed, sought to pressure Twitter to remove Ivan's account (Campbell, 2019; Richer 2019). This led Ivan to name the 3D-printable Glock magazine the 'Menendez Magazine' when it was officially released. A 30-round high-capacity version, the 'Extendez' was later released (ARES, 2019). 3D-printable magazines have so far been released for weapons compatible with 7.62 AKM magazines, 5.56 AR-15 magazines, and 9 mm Glock series magazines. Most new 3D-printed designs and receiver releases have been standardized around the existing 3D-printed 9mm Glock 17 and AR-15 magazine designs, dramatically reducing the need for further development of magazines for each individual model or reliance upon factory magazines. The latest release of a 3D-printable Browning Hi-Power pistol frame accepts Glock 17 magazines rather than Hi- Power pattern magazines. The increasing range of functional so-called 'high-capacity' or 'large-capacity' 3D-printed magazines has the potential to significantly foreshorten repeated legal efforts to restrict magazine capacity.[20] As with other 3D-printed components, detection of these feed devices is likely to prove extremely difficult.

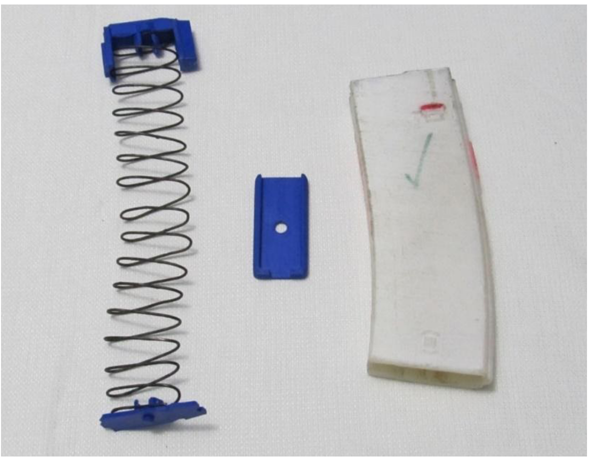


Figure 7.12 *A 3D-printed AR-15 magazine disassembled (source: Ivan T./ARES).*

Figure 7.13 *The 'Menendez Mag' is a 3D-printable Glock 17 magazine developed and released by IvanTheTroll in July 2019 (source: Ivan T./ARES).*

20 Bans on 'high-capacity' magazines in the U.S. and worldwide are too numerous to list. However, for example, the U.S. state of California has effectively banned magazines of greater than 10 rounds capacity since 2000; see Duncan et al. vs The State of California, 2019.

Drop-in Auto Sears (DIAS)

Firearms capable of automatic fire cannot be legally owned by civilians in much of the world, and are heavily restricted in other countries, such as the United States and Switzerland. Lower receiver designs that may be readily converted from semi-automatic only to automatic fire are widely prohibited for commercial sale, even in permissive countries.[21] A semi-automatic AR-15 self-loading rifle may be adapted to be capable of automatic fire by the addition of a device known as a drop-in auto sear (DIAS). This simple device, usually taking the form of a single strip of bent metal, is in the USA itself regulated as a 'machine gun' under the 1934 National Firearm Act (ATF, 1981).[22] Improvised solutions to create DIY versions exist and have been shared online, including steps to fashion one from a piece of coat hanger wire simply by bending the wire (Chen, 2019). In December 2019, files for a 3D-printable DIAS named the 'Yankee Boogle' were released along with a video demonstrating it functioning in an AR-15 rifle (see *Figure 7.14*) (YankeeBoogle, 2019).

Figure 7.14 *The 'Yankee Boogle' is a 3D-printable AR-15 DIAS which was released in December 2019 (source: CarnikCon).*

Another switch device capable of making a Glock pistol fire automatically was released in 2020. This device was designed by the users known as digitalmaniac and FreeMenDontAsk and is called "Make Glocks Full Auto" (The Gatalog, 2022). It can be easily 3D-printed and installed in any factory Glock. Switches of this design have become widespread with criminals and gangs in the United States (Stephens, 2022) and have proven to possess a remarkable longevity.[23]

21 Despite the confusion caused by the differences in legal and technical use, some nations use the term 'machine gun' to refer to any weapon capable of automatic fire. In the United States, for example, the law defines a 'machine gun' as "...any weapon which shoots, is designed to shoot, or can be readily restored to shoot, automatically more than one shot, without manual reloading, by a single function of the trigger. The term shall also include the frame or receiver of any such weapon, any part designed and intended solely and exclusively, or combination of parts designed and intended, for use in converting a weapon into a machinegun, and any combination of parts from which a machinegun can be assembled if such parts are in the possession or under the control of a person" (26 U.S.C. 5845 (b)).

22 In the wording of the ruling: "The AR15 auto sear is a machinegun as defined by 26 U.S.C. 5845(b)".

23 Confidential communication with ATF agents.

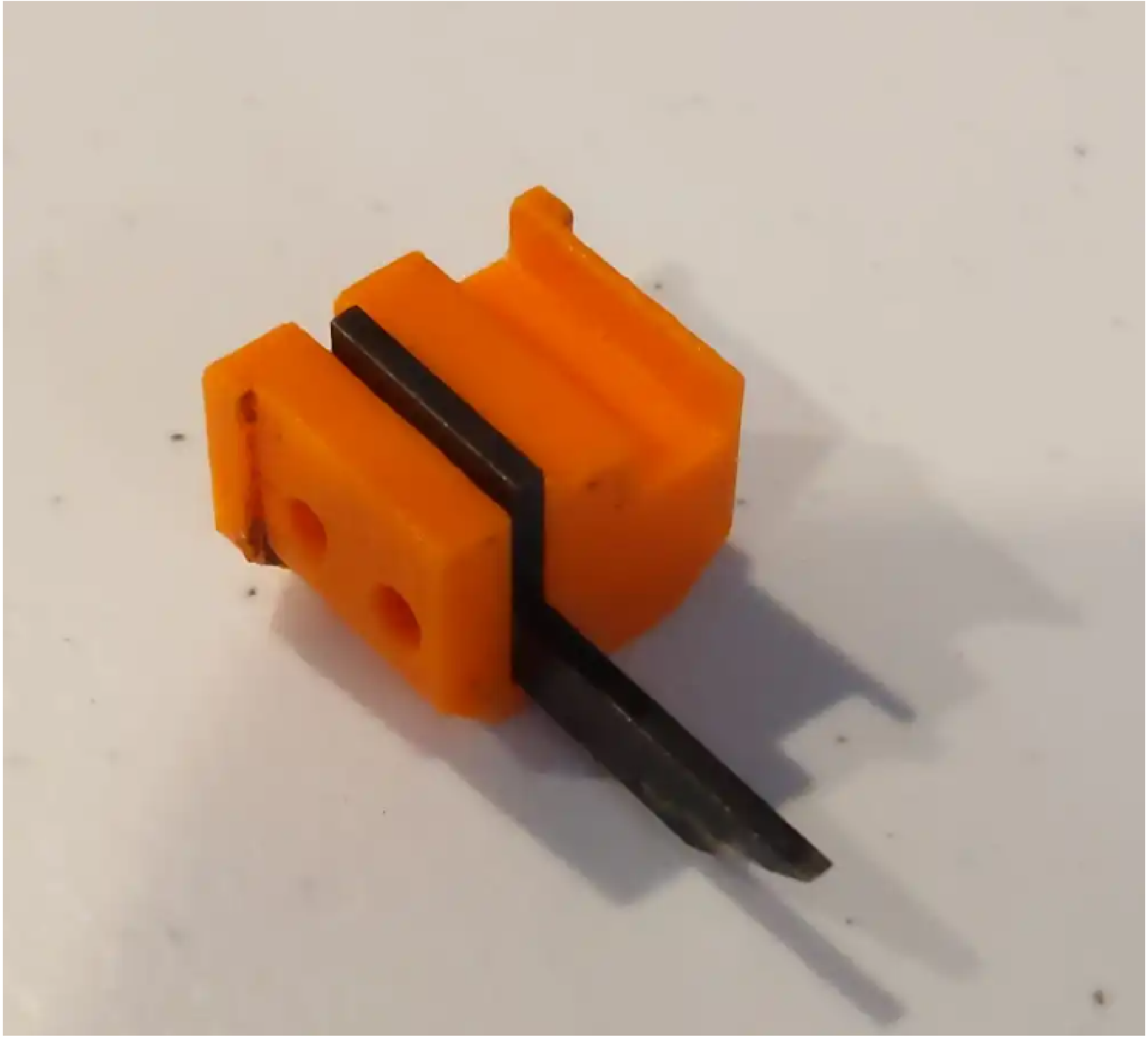


Figure 7.15 *A 3D-printed "Make Glocks Full Auto" auto sear for Glock pistols (source: Ctrl + Pew).*

Desktop CNC

Desktop computer numerical control (CNC) machines are generally subtractive manufacturing tools such as mills, which utilise an automated computer-controlled process to precisely machine a variety of materials including metal, plastic, and wood. This process enables a computer model to be loaded for automated manufacture instead of a user manually operating machinery or using hand-tools to remove material according to a set of drawings. Traditionally, CNC milling machines are large, heavy pieces of equipment and comparatively expensive investments for commercial operations to make. In recent years, smaller, relatively affordable 'desktop' CNC mills have emerged that allow the machining of small components for the home machinist. Micro CNC mills, as the name would imply, are even smaller-scale CNC devices akin to desktop 3D printers in scale. These can carry out machining operations on small workpieces—often less than 200 mm square.[24] Firearms craft-producer 'BoostWillis' explains:

24 Some, however, may have user-defined ways, allowing for much larger work envelopes.

"I use it to make light cuts in aluminum for things like DIY pistol rails, but it can be used for any number of other materials like wood, plastics, carbon fiber, and even some mild steel. Aluminum reinforcements in printed parts (like buffer towers in AR-15 lowers or FGC-9 trunnions) become pretty simple with a machine like this. Also designs based on layers of sheet metal, like JStark's Protector pistol, become much easier to design, iterate, and reproduce. It can't operate at nearly the Material Removal Rate of professional CNC mills. These inexpensive CNC routers sacrifice a lot of rigidity in order to hit a price point. But with modern adaptive/trochoidal CAM strategies, it's possible to maintain decent tool life (Rauch, Duc & Hascoet, 2009). Instead of using only the very tip of the tool, making shallow cuts with 100% of the cross section of the endmill, you make deep cuts with ~10% of the tool's cross section, spreading the tool wear along a much larger area. Cycle time suffers, but that's ok. This isn't a production machine. Capability is more important than volume. My experiments on this topic have focused around the Mostly Printed CNC from V1Engineering.[25] It can be built for about $350, assuming you already have a printer. This is an inexpensive general-purpose CNC machine made from printed parts, EMT conduit, and skateboard bearings that can be used with various tools like routers, lasers, plasma cutters, extruders, drag knives, reciprocating needle cutters, and maybe even things like ECM toolheads in the future. This is the project that got me interested in 3D printing in the first place, because I wanted to be able to work with "real" materials and push the envelope of the democratization of manufacturing. Small and "rigid" machines can do important things like milling aluminum, while larger variants can cut 4'x8' sheets of plywood for important human-scale objects like furniture (opendesk.cc) or even housing (wikihouse.cc). Eventually, other higher quality routers will be available from Chinese manufacturers, further expanding access and the capabilities of this class of machines." (ARES, 2019).

Some desktop/micro CNC units have even been marketed specifically for manufacturing firearm components. The 'Ghost Gunner' is a small CNC milling machine built specifically to complete 80% lower receivers for AR-15 rifles, Polymer80 Glock pistol frames, and Colt 1911 pattern handguns. While micro-CNC milling machines currently offer a cheap, versatile way to machine aluminium, these types of mills lack the rigidity and weight required to cut steel. As a result, they can't yet be used to make parts like barrels or slides that are generally made from steels. The upcoming Ghost Gunner 3 will expand the capability of the Ghost Gunner series to include 80% AKM receivers, and to provide a general steel-cutting capability.[26] The ability to cut steels (including stainless steel) will allow the Ghost Gunner 3 to complete gunsmithing tasks such as making cuts for optics in pistol slides, as well as milling rail blocks for 3D-printed Glock frames out of stainless or mild steels (ARES, 2019).

Electrochemical Machining (ECM)

The most significant development in home craft-production technology in recent years has been the successful employment of simple electrochemical machining (ECM) set-ups to produce rifling grooves in barrels made from steel tubing. Historically, rifling has been often overlooked in craft-produced firearms as it is difficult to achieve and non-essential to function. It is however vital for proper spin-stabilisation of a bullet if the intent is to hit a target at any kind of range. ECM is a process that works, in practical terms, in the opposite manner to electroplating—removing material from the anode via electrochemical dissolution, rather than adding material through electrodeposition. ECM set-ups consist of an electrically conductive workpiece, an electrically conductive cathode (which will act as the cutting tool), and an electrically conductive liquid electrolyte, which fills the dual purpose of completing the circuit between the workpiece and electrode, and flushing away dissolved metal (see Figure 7.16) (Ghosh & Mallik, 2010).

25 See: https://shop.v1engineering.com/collections/parts.

26 In the words of the manufacturer: "Ghost Gunner 3 is a general purpose CNC mill that gives you the ability to finish 80% receivers and frames with ease, in the comfort of your own home" (Defense Distributed, 2018).

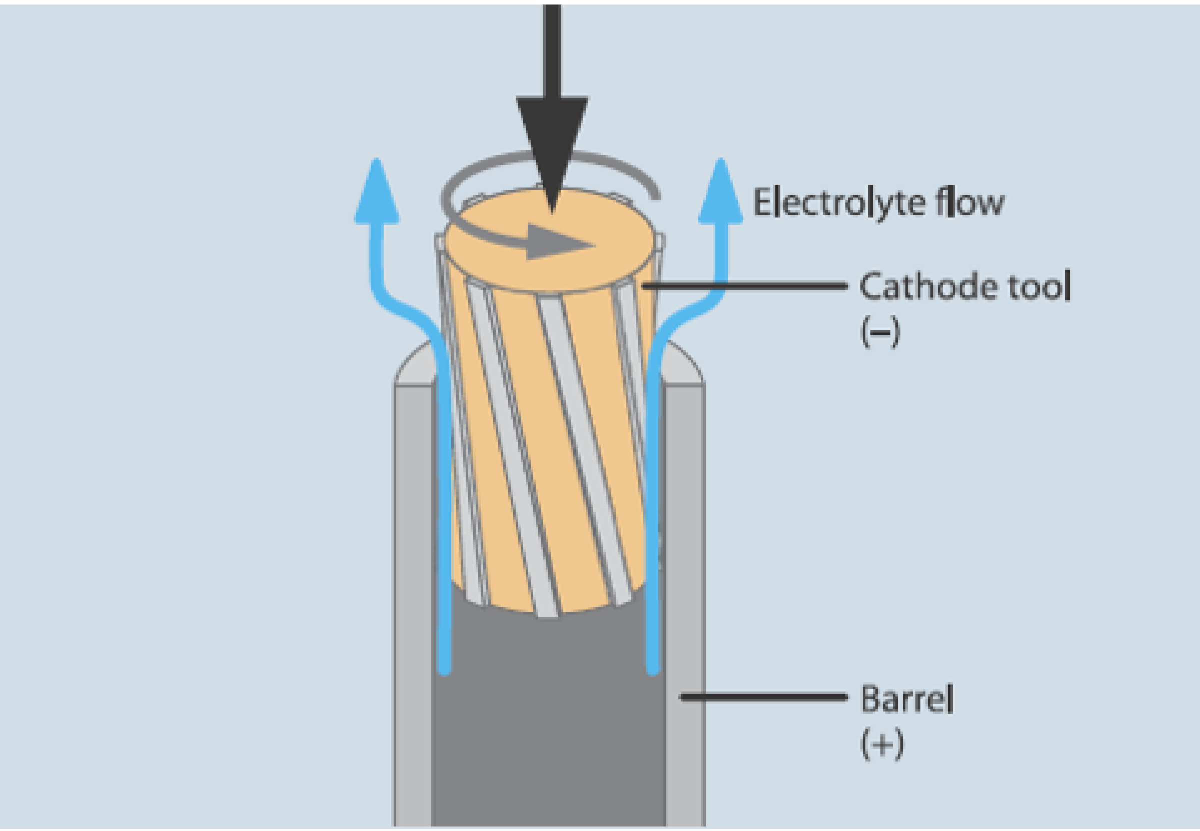


Figure 7.16 *An Illustration showing the basic ECM rifling process (source: Extrudehone).*

ECM is an interesting process for craft-producers for several reasons. Perhaps most importantly, it is useful in low-cost DIY set-ups because it can be employed as a static process, as opposed to most other forms of machining. In order to increase the bore diameter of a tube using a lathe, mill, or electrical discharge machining (EDM) process, at least one moving part is involved—be it the spindle on the lathe or mill, or the ways[27] of an EDM machine. In a home ECM set-up, both the workpiece and tool are static. As a result, there are no wear forces involved, and no need for a high-rigidity machine. Another of the most attractive benefit of ECM is that it cuts independent of workpiece hardness. In traditional machining, material removal rates—and, in some cases, whether a material can be machined at all—is governed by the material's hardness. In ECM, removal rate is governed by a particular metal's valency and its ability to conduct electricity (Mukherjee et al., 2008; Khan et al., 2019). As such, very hard steels—such as 40Cr hardened chrome alloy steel—can be cut with an incredibly cheap and simple set-up (see Figure 7.17) (ARES, 2019). This ability to machine hardened steel at a low cost is the primary reason ECM is being increasingly employed by craft-producers in barrel making.

The process of rifling a firearm's bore is traditionally achieved by cut rifling, broach rifling, button rifling, or cold hammer forging. Cut rifling is the oldest form of rifling, and uses a cutter to remove material inside the barrel in the desired pattern. Broach rifling uses a 'broach, a tool with a series of integral cutting bits that cut the bore to progressively greater depth as the tool is passed through it. The button rifling method uses extreme hydraulic pressure to form the rifling in the bore by pulling a 'button' with rifling negatives on its exterior surface through the bore. The second swaging method is so-called 'cold hammer forging' in which

27 The rails/flats a 3-axis machine travels along are known as 'ways.'

the rifling is formed along with the bore itself by forging the barrel around a blank form or 'mandrel'. This is both akin to how smoothbore barrels were once forged by hand with hammers and the heat of a forge, and indeed to ECM, which uses a similar mandrel albeit a very different means of 'cutting' (Heard, 2011; Vortakt, n.d.).

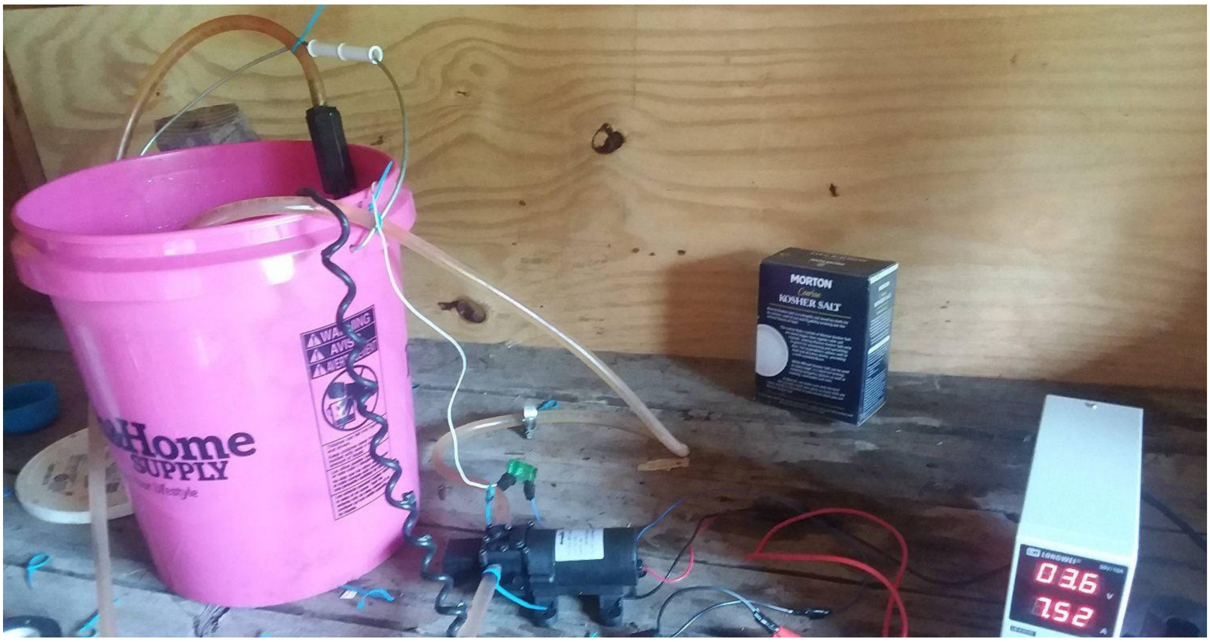


Figure 7.17 *A simple DIY ECM barrel-making set-up (source: Ivan T./ARES).*

Button rifling is the modern industry-standard way of mass-producing rifled barrels, as it can be done quickly, and finished barrels are fairly consistent from one barrel to the next (Kolbe, 2000). Button rifling may be suitable for craft-producers working with softer steels—indeed, leaded steels and tempered or annealed low alloy steels can generally be rifled with something as simple as a bottle jack press (ARES, 2019). However, some materials are too hard for the technique to produce good results with simple equipment. Hardened steels, when button rifled, require immense force to press the button through the barrel—often not achievable by the home gunsmith, and leading to damaged tools and barrels.[28] Should one succeed in button-rifling a hardened steel barrel, they will be left with a barrel that is subject to unpredictable internal stresses as a result of the process. As a result, the barrel may wear prematurely, be subject to creep over time, warp unevenly as it heats when firing, or fail and crack along an area of stress concentration (ARES, 2019). ECM does not disturb the heat treat of a metal, avoiding subjecting the barrel to significant internal stresses (Gurklis, 1965). The method does have some drawbacks, however. Waste material from cut barrels needs to be disposed of responsibly, especially if the steel contains chrome. ECM cannot cut some metals, such as commercially pure titanium (CP Ti), due to a phenomenon known as hydrogen embrittlement. CP Ti cut using ECM will result in a porous, 'spongy' structure, rather than a clean machined finish.32 Nickel-based superalloys should not be cut with ECM as the techniques cuts at inconsistent rates, often causing cracks in the microstructure of the metal, which can lead to unpredictable material qualities and premature failures (Kozak, 2011).

28 Industry tackles the issue of button rifling hardened steels by using a rifle furnace. They will 'bake' a barrel until it is softer before they button rifle, and then anneal the barrel after rifling to relieve internal stresses afterwards. In some cases, a barrel may be hardened again to maximise strength and wear resistance (Gurklis, 1965; Sassen, n.d.). With commercial furnaces priced around 20,000 USD—and homemade examples still costing approximately 2,000 USD to produce and leaving some question of efficacy—such equipment is not readily available to most craft-producers (ARES, 2019).

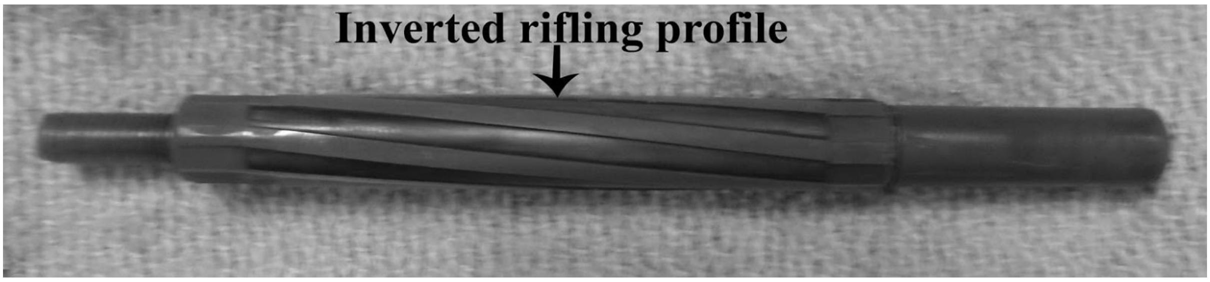


Figure 7.18 *An industrial rifling cathode used in the production of SIG Sauer pistol barrels in Germany (source: Bolton-King et al., 2012).*

The concept of using ECM to produce rifling grooves, or electrochemical rifling (ECR) as it is specifically known, is not new, having been used in the firearm industry to produce barrels commercially for many years (Vishnitsky, 1987). Patents for the technology date back over 60 years (Hartley, 1958). Notably the German firm SIG Sauer employed ECR in the production of barrels from 2002 onwards in an effort to reduce costs (see Figure 7.18) (Bolton-King et al., 2012). Whilst ECM has been used for a considerable length of time, there is only limited information regarding the manufacture of firearms parts using this technology in the literature. What discussion exists is almost entirely confined to large-scale, high-amperage commercial applications, and holds little value to the home gunsmith. A viable home-manufactured method however has only recently been realised, however—enabled, and made all the more useful, by recent advances in 3D printing. The first proof-of concept experiment to demonstrate the basic home-ECM method was posted online in March 2017 by designer Jeff Rodriguez (ImproGuns, 2017). This quickly led to further improvements on the design resulting in a near-commercial-quality 9 mm barrel being tested in 2019 by amateur firearms designer 'IvanTheTroll'. ECM allows craft-producers to work with hardened steels and produce viable rifle barrels cheaply. Pressure-bearing parts of an acceptable quality can be made with a substantially lower tooling cost compared to conventional machining methods. Prehardened, pre-drilled hydraulic tubing has proven a reliable starting point for an ECM process, which can be used to bore the tube to the desired diameter, rifle the bore, and create a chamber in the barrel. A 3D-printed mandrel with exposed copper wires acts as the cathode, making the tooling remarkably cheap. The process as it currently stands provides a viable barrel made from a hardened steel for under 100 USD (ARES, 2019). The basic process is described by 'IvanTheTroll', below (see Figures 7.19 & 7.20):

> *"The electrochemical machining (ECM) barrel cutting process starts with initial setup – the tooling is taken from raw stock and cut to size, and the fixtures and mandrels are printed and prepared. The supplies are then taken to the ECM setup, and the first operation is prepared – the boring operation. This operation is used to increase the bore diameter of the barrel – because off-the-shelf steel tubing doesn't have the 8.82 mm inside-diameter bore that 9 × 19 mm barrels require, 8 mm inside-diameter stock is taken and bore out to 8.82mm using ECM. This operation is the slowest of the ECM operations (as the most material is removed during it) but is easy to set up and measure. The second operation is rifling – the rifling mandrel is mounted and indexed to the barrel (so that the mandrel and barrel can be properly re-installed to the ECM setup between inspections of the rifling after cutting). This operation goes quickly and can be a little tricky to measure due to the polygonal-shaped rifling profile that the simple ECM rifling mandrel cuts into the barrel. For the final cutting operation, the barrel has a throat and chamber cut. This operation takes a bit longer than rifling but is the operation that takes the most precision – the depth of the throat and chamber needs to be quite accurate in order to ensure reliable feeding and extraction." (ARES, 2019).*

Figure 7.19 *Two finished FGC-9 barrels (left) and the 3D-printed cathodes, jigs, and materials used (right) (source: Ivan T./ARES).*

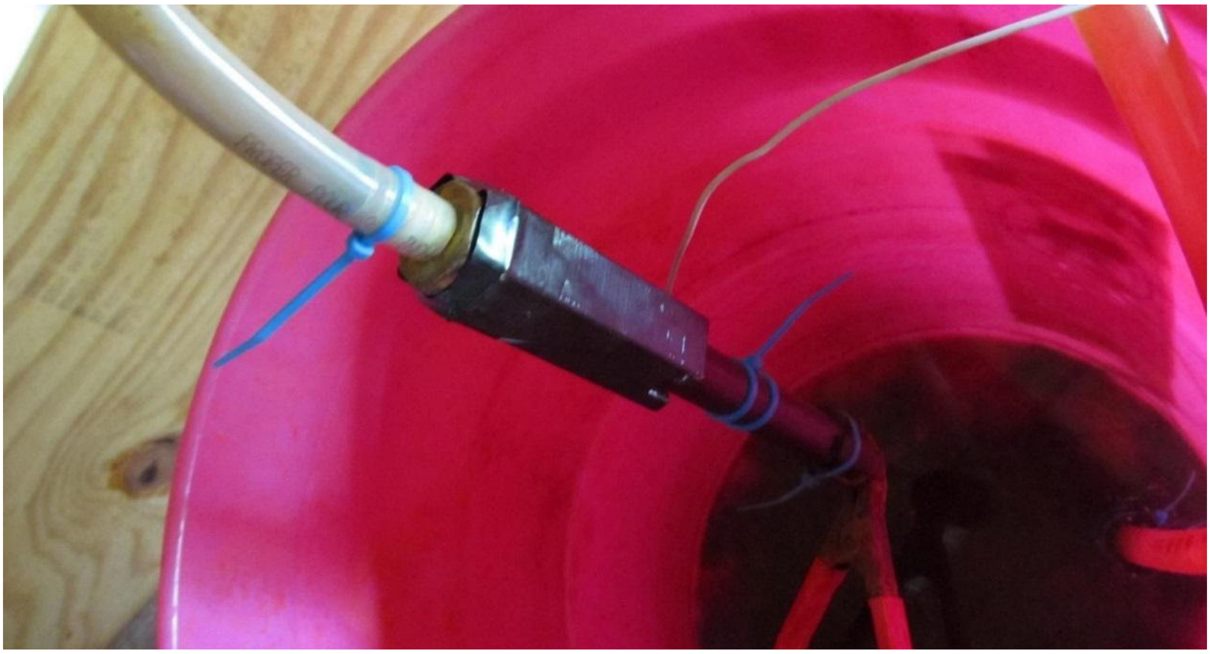
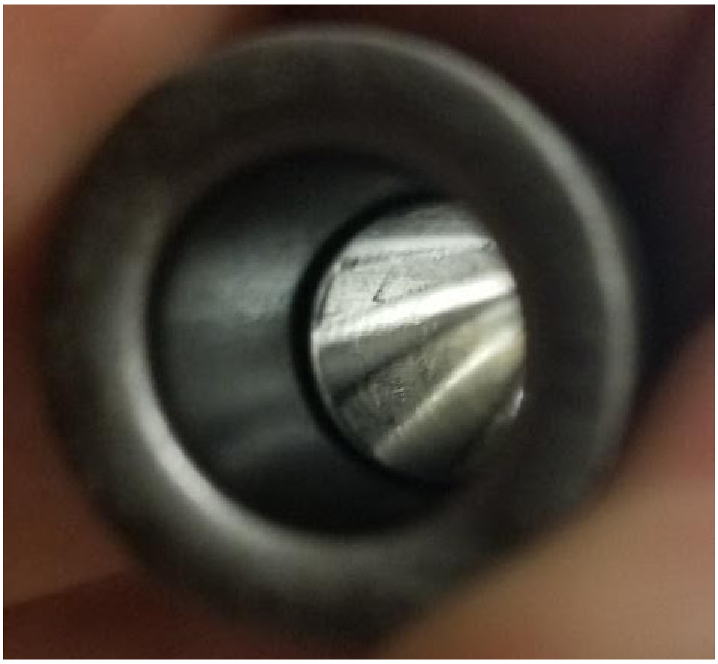


Figure 7.20 *The ECM boring process in action (source: Ivan T./ARES).*

IvanTheTroll's work has resulted in a near-factory-quality barrel capable of firing 9 × 19 mm projectiles relatively accurately. In August 2019, test shots having "achieved 2.5 in groups at 25 yards, with no signs of tumbling or unstable flight" (see Figure 7.21) (ARES, 2019). As the tools and techniques improve, so too will the accuracy of the barrels produced using this method.

Figure 7.21 *Informal testing of the precision achievable using an ECM-rifled 9 x 19 mm barrel (source: Ivan T./ARES).*

After the final cutting operation, the barrel is ready for us. At this stage, however, it can be tested to ensure a good rifling profile has been cut by ‘slugging’ a projectile through the barrel. Slugging the bore is done by taking the correct calibre projectile and tapping it down the length of the barrel using a punch or dowel rod. This process helps determine whether there are any portions of the barrel where the bore is either too tight or too loose, ensuring consistency and accuracy. It also allows the craft producer to assess the rifling engagement on the projectile. The ECM technique described above, as used by many producers, imparts a polygonal (hexagonal) rifling profile, which leaves a distinctive pattern on fired projectiles (see Figure 7.22). This provides around 50% rifling engagement on the bullet, and leaves striations where the imperfect surface finish of the ECM-cut bore of the barrel contacts the projectile (ARES, 2019). This pattern is distinctive, and forensic techniques will be able to match barrels and fired projectiles, with many existing techniques being broadly applicable.



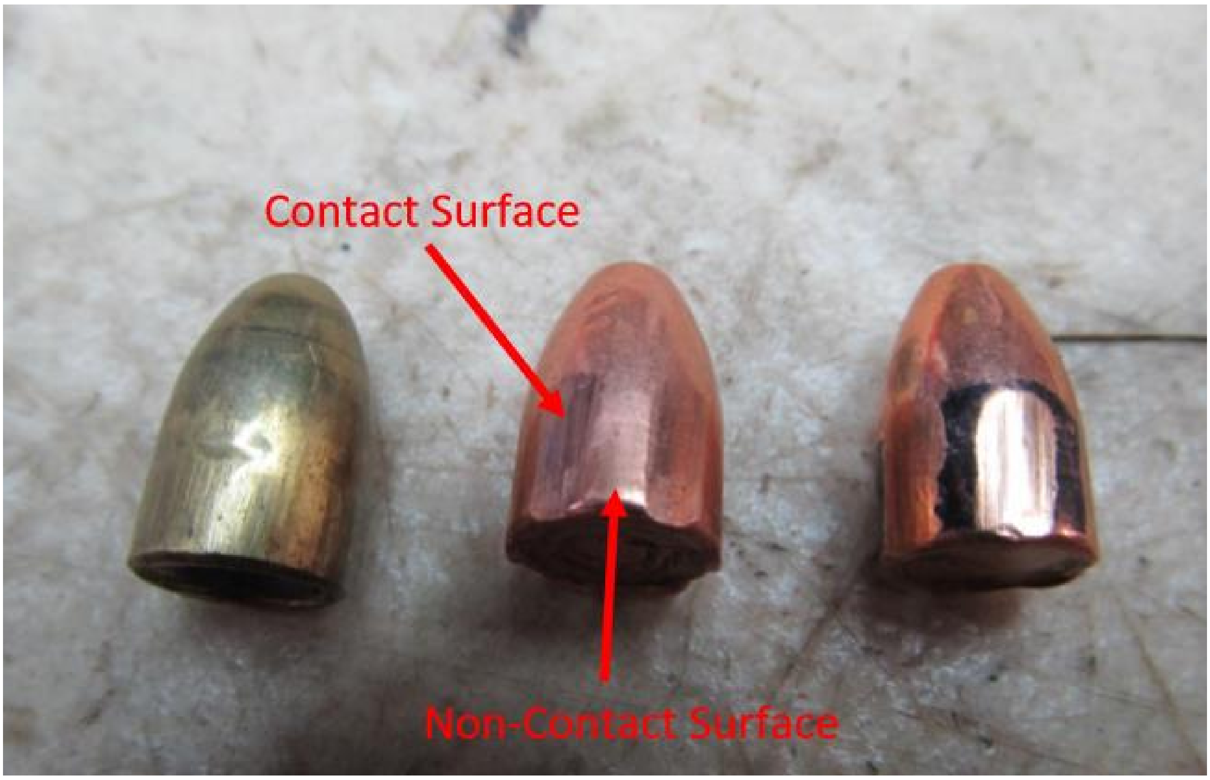


Figure 7.22 *Above: the resulting rifling grooves produced inside the bore of the barrel are the inverse of those of the 3D-printed ECM guide. The horizontal striations are particularly characteristic of the 3D-printed mandrels used in this particular ECM process, which are printed upright. Below: Distinctive rifling marks on a 'slugged' bullet indicate a successfully produced barrel (source: Ivan T./ARES).*

Craft-produced Ammunition Production

Whereas several of the major challenges facing the home gunsmith have been significantly aided by emerging technology (3D-printed magazines, barrels by ECM), home manufacture of ammunition remains problematic. There are several 'legacy' techniques available, such as the conversion of blank ammunition, reloading fired cartridge casings, or even craft-producing ammunition entirely from scratch (Jenzen-Jones & Hays, 2018; Jenzen-Jones & Ferguson, 2018b). However, there are emergent technologies applied in this area, too. Developer 'Jefford', has demonstrated 3D-printed 12-gauge shotgun cartridge cases for a variety of loadings, including slugs, buckshot, and multiple types and birdshot. Shotgun cartridges are relatively low-pressure and suitable for polymer cases (indeed, most commercial shotgun cartridges use polymer cases), yet they can provide a powerful firearm for home builders. As a result, being able to easily create a primary component the shotgun cartridge enhances the viability of homemade shotguns. Another idea in its infancy is to 3D-print polymer cartridge cases that can be sleeved over nail gun cartridges to accept a variety of projectiles (ARES, 2019). Nail gun cartridges are unregulated in much of the world, and are already used as the basis of craft-produced ammunition in some countries (Jenzen-Jones & Ferguson, 2018b). The end result would bear similarities to the Dardick 'Tround' cartridges. Thanks to the relative precision of a 3D printer, much of the human error involved in mating a projectile to a blank or nail gun cartridge could be avoided. As ammunition technology continues to develop—with the increased introduction of conventionally produced polymer cartridge cases, as well as less-developed technologies such as cased telescoped ammunition[29]—it is likely that craft-producers will experiment with a range of novel approaches to this perennial DIY firearms challenge.

Figure 7.23 *3D-printed shotgun cartridges in a variety of loadings, including slugs at left (source: Jeff Rodriguez).*

29 See Jenzen-Jones & Fitch, 2019; Jenzen-Jones, 2016).

3D-printed Suppressors

Like suppressors more generally, there is a wide variety of designs and materials used to produce 3D-printed suppressors. 3D-printed suppressors have been around for almost a decade, but their early development was driven primarily by commercially produced suppressors. Seeing the potential benefits in efficiency and precision that 3D printing provided, some companies began to produce 3D-printed suppressors with metal alloys. One such example is Tronrud's Te-Titan suppressor, which used the Ti64 titanium alloy (Hays, Ivan T. & Jenzen-Jones, 2020, p. 41). These are well-designed and sturdy, owing to the materials used to make them, and show the overall potential of 3D-printed firearm components. Craft-produced ('home made') 3D-printed suppressors, emerged properly only later and, rather than using prohibitively expensive metal alloys, are generally manufactured using FDM, which utilises more brittle plastic filament.

Figure 7.24 *The Te-Titan 3D-printed suppressor, manufactured using Ti64 titanium alloy by Tronrud (source: The Firearm Blog).*

Craft-produced 3D-printed suppressors are usually printed as one whole assembly (with or without baffles) or are assembled from some combination of 3D-printed parts and improvised commercial materials. The latter case often takes the form of 3D-printed baffles inserted into steel tubing, which acts as the suppressor's main body. This tends to increase the reliability of the suppressor, but is more time-consuming than 3D-printing the entire assembly. Thus, much of the development history of craft-produced 3D-printed suppressors has centred on increasing the reliability of entirely 3D-printed designs, as shown in the following section.

When printing a suppressor, the end user must also take into account the threads required to attach it to their selected firearm. This becomes particularly tricky with 3D-printed firearms, such as the Liberator, which are not printed with a threaded barrel by default. In such instances, designing an improvised thread assembly that attaches to the firearm's barrel is essential. In the case of the Liberator, an updated design with a threaded barrel was released by user KadeCAD in May 2020 (Hays, Ivan T. & Jenzen-Jones, 2020, p. 42; KadeCAD, 2020). Other 3D-printed firearms have been slower to be adapted to fit suppressors.

Figure 7.25 *A 'Liberator' 3D-printed handgun equipped with a suppressor, designed by user KadeCAD (source: KadeCAD on Twitter).*

The primary challenge for producing a 3D-printed suppressor is making it heat and pressureresistant.[30] As stated prior, the main function of a suppressor is to cool down and slow the high-pressure gases produced when a cartridge is fired. Doing so requires the suppressor to be able to resist a significant amount of gas pressure and absorb heat, the latter resulting from the suppressor's ability to transfer thermal energy away from the gas and into the surrounding area – by becoming hot itself. When fired in quick succession, a suppressor can get extremely hot, sometimes over 500° C (932°F) (Maddox, 2021). This is an extreme example but demonstrates the challenge faced by craft-producing an effective, 3D-printed suppressor. Too much pressure and a suppressor made of plastic will break; too much heat and it will warp or melt. To demonstrate the challenge posed by heat in particular, it is worth examining 'glass transition temperature' (GTT). A plastic's GTT is the point at which it begins to soften and deform (Pacakova & Virt, 2005); at this temperature, a 3D-printed suppressor is rendered more or less unusable as it loses its shape. Notably, this means that plastic does not need to reach its melting point for a suppressor to lose its effectiveness. The GTT of the three most common plastic filaments are as follows:

- Polylactic acid (PLA): between 55 and 60 °C (131 – 140 °F) (Innace, Soorentino & Di Malo, 2014)
- Acrylonitrile butadiene styrene (ABS): around 105 °C (221°F) (Rahman, Scott & Sahdu, 2016)
- Polyethylene terephthalate glycol (PETG): around 86 °C (187 °F) (Amza et al., 2021)

30 According to an author's correspondence with Ivan The Troll.

While these numbers may not be exactly where a 3D-printed suppressor made of a given material stops working, it provides a useful demonstration of how heat resistant such plastics are. When the polymer of a 3D-printed suppressor softens, the pressure of a shot widens the holes in the baffles allowing more gas to escape and deforms the expansion chambers—both factors make the suppressor far less effective in reducing the firing nose. Even if the suppressor is not subjected to rapid fire with high-pressure cartridges, it may still fail to operate after a few shots. One solution used so far has been coating parts of the suppressor in epoxy or a mixture of epoxy and ceramic (KadeCAD, 2021). However, the extent to which this has been used—and more importantly, its effectiveness – is unknown. In any case, a more durable long-term solution is likely required for 3D-printed suppressors to handle more powerful cartridges.

The development of 3DP suppressors has been shaped primarily by the dual considerations of pressure and heat resistance. Over time, there has emerged a general trend of these craftproduced suppressors becoming increasingly durable and, importantly, more complete, with more parts of the suppressor being 3D printed. Of course, this is just indicative of a trend; a quick search on many 3D printing design websites will return dozens of results, each claiming to be more or less sophisticated. The following analysis of (effective) 3DP suppressor evolution follows high-profile and well-tested designs, mostly from the individuals associated with Deterrence Dispensed (e.g., users KadeCAD, iprintgunz, and CTRL+Pew). This evolution follows three rough stages of development: 3D-printed baffles only; fully 3D-printed suppressors designed for low energy .22 calibre ammunition; and fully 3D-printed suppressors designed for higher pressure calibres and supersonic ammunition. The first stage of development of functional craft-produced 3D-printed suppressor components began in late 2019 with the release of user KadeCAD's suppressor baffles.[31] Prior to this, most effective 3D-printed suppressor designs were commercially produced. Notably, however, the design itself was only for the baffles, which are then inserted into an aluminium fuel filter can to produce a working suppressor. This is owed in part to the fragility of 3D-printed parts in general, which KadeCAD notes are "weak and can't handle the pressures of higher calibres" (Hays, Ivan T. & Jenzen-Jones, 2020, p. 41). When combined with a fuel filter can, however, the suppressor supposedly handles all pistol ammunition and even subsonic rifle ammunition, especially when printed with filament more robust than PLA (such as ABS or PETG).

Figure 7.26 *KadeCAD baffles and the fuel filter tube they reside into after reportedly being subjected to 150 rounds of continuous fire using .223 Remington ammunition (source: KadeCAD on Twitter; Hays, Ivan T., & Jenzen-Jones, 2020).*

31 As KadeCAD points out, DIY 3D-printed suppressors had existed prior to this. However, due to their general ineffectiveness, KadeCAD's suppressor baffles will be considered the start of this phase of 3DP suppressor development (Hays, Ivan T. & Jenzen-Jones, 2020, p. 41).

However, the use of non-3D-printed parts makes the suppressor more complicated; ideally for interested printers, a suppressor could be entirely 3D printed. Hence, the next stage of 3DP suppressor development beginning around late-2020 – fully 3D-printed .22 calibre suppressors, either monocore or separate baffle designs. One example of this development is the Saturn Suppressor System by user 'iprintgunz', which utilises a monocore design that can, if desired, be one single print. It also has an option to print two parts—the main suppressor and the endcap—which improves flexibility and serviceability in exchange for greater complexity (iprintgunz, 2021_. In either case, the design is significantly simpler than KadeCAD's baffles, though it cannot shoot supersonic rounds that are not .22 short or .22LR. The same applies to KadeCAD's 3D Printed Suppressor Pack, which is fairly simple and customisable but, according to the designer, lacks the durability of the user's previous baffle-and-can design. Even iprintgunz's IPG223—designed specifically as a .223/5.56 suppressor—cannot handle more than slow .223 fire and works best with .22 LR. Regardless, these designs represent a step up from baffle-only prints as they can handle hundreds of rounds of .22 supersonic if treated well while not requiring any external parts. For all three designs, filament more durable than PLA is recommended, especially if intending to fire supersonic rounds (iprintgunz, 2020; iprintzguns, 2021; KadeCAD, 2021).

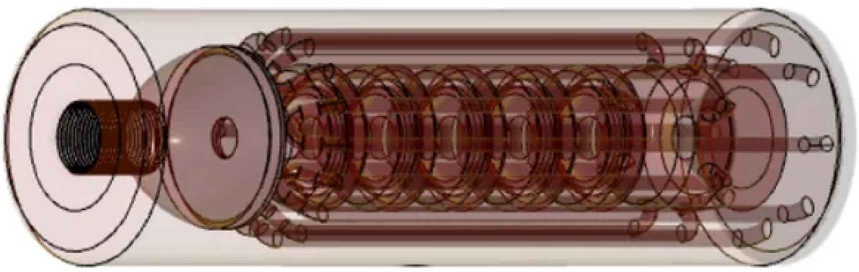


Figure 7.27 *A diagram of the 3D-printed monocore Saturn Suppressor System, designed for use with .22 Short or .22 LR cartridges (source: iprintgunz).*

More recently, fully 3D-printed suppressor designs have emerged that can handle ammunition of higher pressure and heat than .22 LR—including even .223/5.56 supersonic ammunition.[32] These suppressors are generally larger and less ergonomic than other designs, but with this comes a longer lifespan and increased reliability. One example of this is the 'Shush Puppy', a 9 mm suppressor designed by user 'CTRL+Pew' in mid-2021 (CTRL+Pew, 2021). It is large and bulky, and prints out in multiple baffles that have to be assembled (as well as requiring a commercial threading adaptor); however, this relative complexity leads to a suppressor which, according to its designer, can handle over 1,000 rounds of standard 9 mm ammunition (CTRL+Pew, 2021).

In 2022, a user known as 'Void Armories' released multiple suppressors designed for a wide range of calibres, including .223/5.56 (known as the Void .223 v5, or 'Void') (Void Armory, 2023). While it shares the bulkiness of the Shush Puppy, the Void has notable advantages over it. For example, it is monocore and uses flow-through technology to reduce gas blowback (see Figure 7.29), which is a fairly advanced design and a significant advancement over earlier baffles-only models. In addition, a video posted on YouTube by user 'NeoAeon3D' shows that the suppressor printed with PLA filament can handle around 15 shots of supersonic .223/5.56 ammunition without being warped by the heat (NeoAeon3D, 2022). This design represents the extent to which 3D-printed suppressors have evolved in three short years – from baffles inserted into a fuel filter can, to fully 3D-printed suppressors that, albeit bulky, can handle powerful, supersonic ammunition in short bursts.

32 Author interview with IvanTheTroll.

Figure 7.28 *The 3D-printed 'Shush Puppy' suppressor. Note its bulky design, which allows it to fire more powerful cartridges (source: CTRL+Pew).*

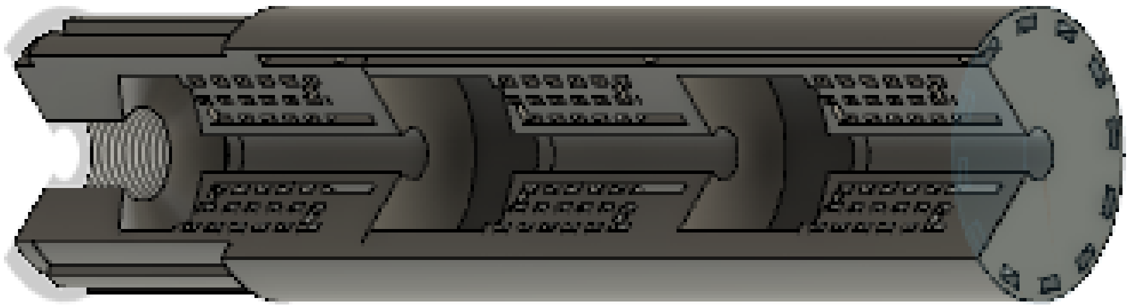


Figure 7.29 *A diagram for the VoidArmories line of 3D-printed suppressors (source: VoidArmories on Facebook).*

The craft-produced suppressor for the (in)famous FGC-9 is worth of mention. By default, the FGC- 9 Mk II, released in 2021, does not have a threaded barrel and hence does not accept a suppressor.[33] However, in the firearm's manual, designer 'JStark1809' provides a detailed explanation on how an end user could use improvised commercially designed materials to craft-produce both barrel threads and a suppressor (JStark1809, 2021). Similar to KadeCAD's baffle system, JStark1809 proposes using a fuel filter as the body of the suppressor but, interestingly, does not suggest the use of any 3D-printed parts for the improvised suppressor. It is unknown why a craftproduced suppressor is suggested rather than a 3D-printed one, especially considering KadeCAD's baffles had been released over a year prior to the Mk II. Perhaps it has to do with the overall quality of current 3D-printed suppressors, which despite their ease of access, could struggle to handle supersonic 9 mm ammunition. Regardless, future development may render such craft-produced improvised designs increasingly irrelevant.

33 For more information on the FGC-9 and its later iterations, see: Senft, 2022.

Despite the shortcomings of many 3D-printed suppressor designs, it is clear that the technology is here to stay and will only gain more sophistication as time goes on. Indeed, recent commercial developments point to the high utility that 3D printing has for manufacturing suppressors, particularly in cost-effectiveness and precision. For example, SIG Sauer, the company recently chosen to produce a rifle and machine gun for the U.S. military's next generation squad weapon (NGSW) program, recently announced that all of their future suppressor designs will be 3D printed (Reeves, 2020). Of course, SIG Sauer is using more sophisticated 3D printing technology than simple FDM, which makes their suppressors significantly more effective and durable. But even so, this development points to the benefits inherent to additive manufacturing.

In the future, it is likely that craft-produced 3D-printed suppressors will continue to follow the trend already documented in this article: improving robustness to allow them to handle higherpressure cartridges and last longer. Achieving this could entail incorporating carbon fibre (CF) or glass fibre (GF) into the suppressor as a sort of 'wrap' or 'cage', printing the suppressors (or some of its parts) out of CF/GF, and using new, more durable filament designs like thermoplastic polyurethane (TPU) (Tractus3D, n.d.), or some combination therein.[34] However, it should be noted that all of these methods of improving a 3D-printed suppressor's durability have not been comprehensively tested. Once such testing occurs, the direction of 3D-printed suppressors should become clearer.

3D-printed Tooling & Jigs

There is no shortage of dedicated gunmaking and gunsmithing tooling available on the market. Typical modern tools available include chamber reamers, dies for accurately threading barrels,[35] and rifling 'buttons'. Commercially made jigs to aid in the completion of unfinished receivers (so-called '80% lowers', as they are commonly known) have been available for more than a decade (ARES, 2019). These usually provide pilot holes at the correct positions for drilling as well as rectangular pockets and depth stops to aid in the milling out of correctly sized pockets for installation of trigger components, reducing the chance of human error. Commercially available versions of these jigs—whether made from plastic or metal—can be relatively expensive, especially as they may often be needed only once. In contrast, 3D-printed tooling and jigs offer low-cost, make-at-home options for craft-producers. Plans for 3D-printed jigs have been developed over the previous years and have been steadily updated. One of the most popular at present is the AR-15 jig released by Ctrl+Pew (see Figure 7.30) (Ctrl+Pew, 2019). 3D-printable jigs will also enable builders of the upcoming FGC-9 to easily locate positions to machine holes in the metal components without the need to accurately measure, as well as facilitate operations such as 'turning down' and threading a barrel for a suppressor.[36]

Perhaps the most important development in 3D-printed tooling has been the emergence of 3D-printable jigs designed for ECM operations. The combination of these two technologies has enabled the successful creation of near-factory-quality rifled barrels from off-the-shelf steel tubing without requiring the use of expensive tooling. Such jigs were first documented in December 2016, when a user by the name of 'Jeffrod' shared his successful results at producing deep helical grooves in a length of steel tubing by running salt water combined with an electric current through a specially designed 3D-printed jig inserted into the bore of the tube. 'IvanTheTroll' further improved upon the tooling used in the process (see Figure 7.31). Because of their ability to print custom jigs on demand, 3D-printers can be just as useful for the creation of gunsmithing tools as they can be for making firearms components. Using a novel process like ECM to take

34 Author interview with IvanTheTroll.

35 To mount flash hiders, suppressors, and other muzzle devices.

36 Turning is a manufacturing method used to reduce the diameter of a workpiece. In this context it is used to reduce the diameter of the barrel at the muzzle.

advantage of the complex geometry printers can produce with ease, is a significant step towards simplifying the craft-production of firearms.

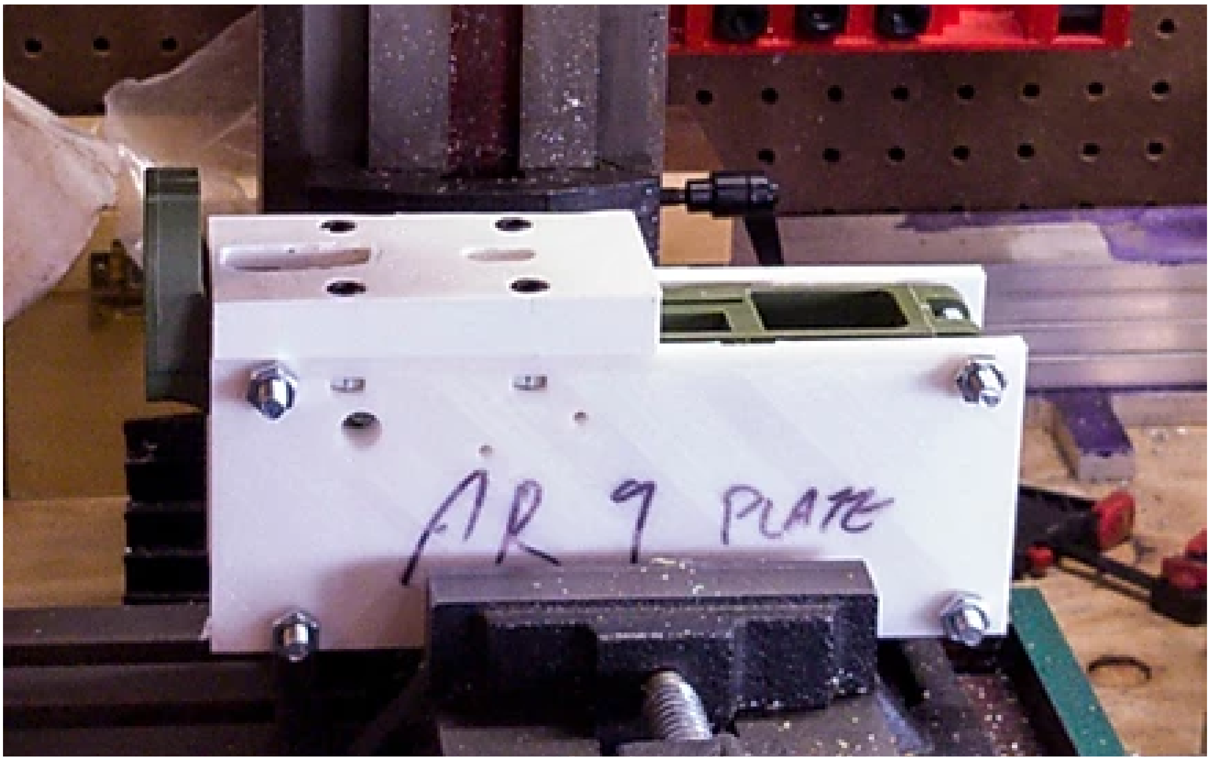


Figure 7.30 *A 3D-printed receiver milling jig for AR-15-type '80% lowers' (source: Ctrl+Pew).*

Figure 7.31 *A 3D-printed ECM rifling cutting tool being inserted into a barrel which is held in place by a 3D-printed collar (source: Ivan T./ARES).*

Conclusion

The primary way in which 3D-printed designs depart from the traditional methods of craft-producing automatic and semi-automatic firearms—such as those described in established DIY publications such as Expedient Homemade Firearms (Luty, 1998) and The DIY STEN Gun (Anon, n.d.)—is by dramatically lowering the barriers to entry for the layperson. The time, level of skill, and requirements for hand fitting are reduced, and the rapid assembly of viable firearms becomes a possibility for the average person, particularly when operating with access to the data repositories, designs, and shared knowledge available via the Internet. The cost of producing capable 3D-printed small arms is rapidly decreasing, in-line with the reduction in price for 3D printers and other technologies. These technologies also allow users to obtain firearms without having to access criminal networks or legally controlled firearms distribution channels, maintaining anonymity and independence.

At present, the material limitations of consumer-grade 3D printers, and the high cost of those small number of industry-grade printers capable of producing objects in metals, means that certain essential pressure-bearing components must either be fabricated from metals using alternative methods or substituted for commercially made parts. In the case of a Glock-series handgun, for example, the frame and magazine body may be printed from PLA while the slide, barrel and trigger would usually be original, factory-made parts. The emergence of other technologies such as ECM and desktop/micro-CNC milling machines have bridged the technological gap, and now mean that viable, capable self-loading hybrid firearms such as the FGC-9 can be produced by the home gunsmith without using any regulated components. Other areas for development, such as the production of 3D-printed ammunition, remain in their infancy.

The advent of these increasingly capable, digitised technologies is rapidly turning the layperson into a de facto gunsmith or gunmaker.[37] It is highly likely that the FGC-9 is simply the first of a new wave of cheap, nearly-entirely-homemade 3D-printable firearm designs which solve material limitations by incorporating readily available metal components and unregulated firearms parts. This new breed of hybrid design offers adopters a cheap and effective firearm that is very difficult to trace, and may have the potential to rival or outstrip previous trends in the acquisition of illegal firearms modified from replica and deactivated firearms—themselves subject to increasing legislation (EU, 1991; EU, 2008; Warlow, 2007). There are very limited control options for restricting access to the materials or design files used in craft producing such weapons, and progressively more affordable machines and tools—as well as ongoing refinement of techniques—are likely to make their continued development and acquisition increasingly commonplace.

It is also crucial to note that ECM is still a nascent technology within the craft-produced firearms community, and the outputs will only improve as techniques and tooling are refined. In much the same way the FGC-9 has now demonstrated the potential for craft production of viable, durable pistol-calibre carbines and sub-machine guns, new technologies and techniques will make increasingly durable and capable firearms available to the home gunsmith. On the horizon for the home gunsmith, static ECM set-ups could be used to machine locking actions, more complex trunnions, and other high-strength components. A dynamic ECM machine—essentially a 3-axis CNC with an ECM cutting head—could provide the home gunsmith with a cheap yet powerful way to machine more complex parts out of metal. Advanced tooling and jigs will allow for the desktop machining of increasingly complex high-strength machined components such as bolts, locking lugs, and slides from combinations of high-strength raw bar steel bar stock and tubing. Once this next technical hurdle has been overcome, rifle-calibre firearms requiring strong locking actions—previously the preserve of factories—may be produced in the same low-tech manner as the FGC-9.

37 In modern vernacular, a 'gunsmith' is akin to a military armourer; a technically skilled individual able to maintain, repair, and modify firearms and their accessories. Although there has traditionally been little overlap of skillset between gunsmiths and gunmakers—able to fabricate an entire firearm from scratch—modern technology is increasingly blurring this gap and permitting those without any gunmaking or gunsmithing experience to not only modify, but actually build, entire weapons from scratch.

Annexe 1: Digital Data Types

SourceCAD

SourceCAD files are generally proprietary filetypes tied to a specific CAD studio; examples include .sldprt for Solidworks, .f3d for Fusion 360, and .ipt for Inventor. These files usually include a history of edits to the file, detailing how the part was made from first edit to last. They are the most valuable files to a designer because of this edit history, as edits can be undone and modified easily. Source CAD can often be opened and converted to a solid model if opened in a CAD studio that isn't native to them—e.g. Inventor can open .sldprt files and convert them to a solid model, but it will not retain the edit history.

Solid Models

Solid models are files generally found in the .step, .stp, and .igs formats. Solid models can be edited, but have no edit history attached to them. This means that a designer can edit the file, but past edits must be manually undone, and the order edits were made in is not recorded. The advantage to solid models is that they are used as exchange standard; all modern CAD studios can open common solid model formats and allow a designer to make new edits to the model. These files are the most important for designers to share because of their standard compatibility and ability to be edited. In addition, solid models can be converted to point clouds, a filetype useful to production.

Point Cloud/Mesh

Point cloud files are types of files usually used in the physical production of a CAD model. Common filetypes include .obj and .stl. Point clouds are different from solid models in that point cloud files exist to simply sketch out the outer boundaries of the part—the interior volume of a part isn't present—and thus point clouds are not solid models. Point clouds are useful in production of physical parts because the points that they consist of each have discrete coordinates. With enough of these points, toolpaths for CNC operations (like on a 3D printer) can be generated. The downside to point cloud files is that they cannot be edited like solid models or source files can be. Additionally, point cloud files cannot be converted back into solid models— making point clouds less-than-ideal for sharing, unless they are shared alongside solid models.

Renders

Renders come in two forms: physical items and CAD screenshots. They are common image filetypes (.jpg, .png, .bmp), and depict a part. They are useful in showing how a physical item looks after production, as well as helping people browsing repositories to understand what a part looks like without having to load it up in CAD.

Readmes/Tutorials

Readmes and Tutorials come in many formats, but the filetypes .txt, .pdf, and .md are the most common amongst the craft-produced firearms community. These files are text-based instructions on how to make use of the CAD they accompany. They include information on what sort of settings to use, what parts are needed to finish a build, where to source parts, how to troubleshoot reliability issues, as well as information about who designed the part in question and how to get into contact with them.

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