3D Printers and Filament Printing

Preamble

This document is a compilation by 3D Industries marketing development and support personnel.

- It discusses aspects of 3D printers, of 3D filament printing and it uses and refers to information commonly available on the internet
- It includes clearly identified specific 3D Industries advice and suggestions
- The last section describes how the 3D Industries printers handle the areas discussed.

Depending on the plastic material used, the printer must be able to have its parameters set either directly and or by interpreting the Gcode file pertaining to the object to be printed in order to:

- Provide a heated bed to the temperature required for the plastic.
- Provide the required nozzle temperature for the plastic extrusion
- Have the facilities to move the nozzle over the object footprint at the speed set.
- Control the movement of the plastic filament from the spool to the hot end to the nozzle. (Function of the extruder).

Some plastics are easier to print with than others. A section below will deal with PLA and ABS as an illustration. However there are other plastic filaments available with specified requirements as to temperature and bed conditions.

Much of the information commonly available can be confusingly presented or not explained very well and in some cases biased towards a certain supplier. Information available on forums is not always reliable and often represents one person's views or other peoples biased views or opinions. This document attempts to describe the various issues with 3D printing and the use of filament in as simple and unbiased a manner as possible with suggestions from 3D Industries plainly identified.

PLA and ABS

This section discusses printing with PLA and ABS plastic; however there are a growing number of other plastics and combinations with their own specific properties and requirements.
Separate documents will address the new materials.

General Printing rules to follow:

PLA and ABS filament in standard colours is available as good quality and at reasonable prices (Less than $40 for a Kg of plastic on a spool). Quality of filament is important. Filament is available from different sources but the quality may not be known regarding filament obtained from new sources. Problems with the filament can be:

- Breakage – the filament in a spool is not continuous
- Parts of the filament is too thin
- Parts of the filament can be too thick
- The filament can be contaminated in parts

(3D Industries suggestion is to use filament from a supplier where they have a known high quality (and are willing to replace it if there is an issue). "Sample filaments" sent from new suppliers may different from the actual filament received if an order is placed.)

Dust is the enemy of 3D printing. Dust can accumulate on the printer as time goes by and particularly on the plastic filament. The 3D printer must provide a method whereby the filament is cleaned before entering the extruder. Dust not removed and entering the hot end can cause the small extrusion hole to be blocked in which case extrusion ceases, but small enough particles of dust can be present in the molten plastic reservoir in the nozzle and cause partial or intermittent blockage that can degrade the resultant printed objects.

(3D Industries suggestion is to ensure where possible that dust does not contaminate the machine and surroundings- using a vacuum cleaner etc, most importantly making sure that the filament as it is drawn from the spool and fed to the extruder is thoroughly cleaned of dust). This means that if the filament entering the system has no outside contaminants the only impurities would be those inside the plastic itself and this comes down to using the quality filament. New filament purchased should be received in a vacuum packed plastic bag with

desiccant. If not going to be used for some time it should be left in that condition. Both sealed and used filament should be stored in a dust free cool and moisture free environment such as a closed metal cabinet.)

Control of the filament is essential. The filament must be drawn from a spool. The extruder has to be able to grip the filament strongly enough to pull it from the spool and feed it into the hot end to the nozzle with enough force to cause ejection of the molten filament. The extruder also has when instructed to cease forward movement and even retract the filament. The method of gripping the filament to move it back and forth in the extruder is commonly using a bearing or plate to press the filament against a knurled wheel. The pressure has to be sufficient to hold the filament as it is extracted from the spool and pushed down into the hot end and also to retract it slightly if required without damaging the filament so that it operates or gets jammed in the path through to the nozzle.

(3D Industries suggestion is to ensure that printer has a well engineered extruder assembly and filament spool and feed mechanism preferably enabling adjustment possible around the mechanism to grip the filament.)

Authorized filament, or filament in proprietary canisters are available from some printer manufacturers.

(3D Industries suggests that printers should be able to handle commonly available high quality filament in different sized spools. "Approved filament" or cassettes of filament from manufacturers are generally much more expensive that common filament and no better.)

Bed Levelling is an important part of object print quality.
The bed must be horizontal to the vertical nozzle position such that the initial gap before printing can be set to 018 – 0.2 mm over the entire bed footprint. While the gap between the nozzle and the bed can be measured with feeler gages there are problems in performing this test over the entire bed and also in doing this while the nozzle is clean so that no residue plastic affects the readings.
The bed levelling adjustment should be as accurate and as easy as possible and there should be a published procedure to follow.
Many printers use three screw adjustments to raise and lower the bed from front relating to the back and left hand side relating to the right hand side.

Note: There are some printers that use the firmware option to automatically measure the bed height at various locations on the bed and then using the measurements obtained cause the nozzle height to be automatically adjusted as the nozzle travels over the bed where parts of it may be lower or higher than other parts. This is far from ideal and can result in an object that is not vertical or accurate. This also indicates that it may not be possible to accurately set the bed levelling to the requirements on the printer.

(3D Industries suggestion is to ensure that the 3D printer has an easy but accurate and secure bed levelling mechanism and that it has facilities to check the bed level as this is an important part of the features, particularly of printing in ABS.

The **bed temperature** must be correct. The bed is generally heated by a heater cartridge or PC heater. The bed temperature is monitored by a thermistor fixed to the bed. The resistance of the thermistor changes as the temperature changes and the electronics of the printer use this change of resistance to indicate the deduced temperature for both control purposes and depending on the printer also for display purposes. Thermistors are made in batches and have an accuracy of around 10%. At the higher temperatures it is common for the electronics of the printer to think that the bed temperature is higher or lower than it actually is.

The results of the incorrect temperature can vary depending on whether the temperature is too high or too low. Too high may not be an issue, too low depending on the filament used can may cause problems with the object sticking to the bed.

(3D Industries suggestion is to measure the temperature of the nozzle directly using a thermocouple or some other accurate, measuring thermometer to compare the actual temperature to that calculated by the firmware.)

The **nozzle temperature** must be correct. The nozzle is generally screwed into or is part of the heater block. The heater block is generally heated by a heater cartridge. The temperature of the heater block and nozzle is detected by a thermistor attached to the hot end. The resistance of the thermistor changes as the temperature changes and the electronics of the printer use this change of resistance to indicate the deduced temperature for both control purposes and depending on the printer also for display purposes.

In 3D printing the range of temperatures important for PLA and ABS printing is from 180 to 260 degrees centigrade. Depending on the thermistor the graph corresponding to the resistance at temperatures above 150 degree centigrade often changes from almost linear (as for the heated bed range above) to exponential. Generally the electronics firmware makes use of a table and algorithm that attempts to convert the measured resistance of the thermistor to the corresponding temperature according to this graph.

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The results of the incorrect temperature can vary depending on whether the nozzle temperature is too high or too low. Too high a temperature can produce effects such as “wispiness” – these strands like cobwebs appear in the structure particularly between different parts of the object. Too low a temperature can also result in inadequate cohesion of the plastic layers resulting in weaker object and in some cases easy separation of the object parts. Too high a temperature can result in bubbling or splitting of the filament at the nozzle hole and a degraded printed object.

It is important to ensure that the thermistor is connected to the nozzle or heater block in such a way that it cannot fall off. If this happens the resistance of the thermistor rises as it cools and the firmware thinks that the temperature is falling and tried to raise it resulting in an overheated nozzle and possible damage.

(3D Industries suggestion is to measure the temperature of the nozzle directly using a thermocouple or some other accurate, measuring thermometer to compare the actual temperature to that calculates by the firmware.
The actions to take if such testing indicates the nozzle temperature is actually lower or higher than that believed to be by the firmware – electronics depends on the user. It can vary from changing the table or algorithm used in the firmware to determine the temperature from the thermistor resistance to making allowances for the known differences when making settings.
It is important that the thermistor is captive to the heater block or nozzle and cannot fall off)

The Hot end

The hot end is a critical component in any 3D printer. The unmelted plastic filament is pushed through the hot end heat sink and throat in a solid state to the heater block and the nozzle where the solid filament is melting the pressure of the unmelted filament causing melted filament to be ejected from the nozzle.
Hot ends and advice from manufactures vary. Many suppliers recommend that blocked nozzles be removed and cleaned and replaced, others recommend that the blocked nozzle is replace with a new nozzle.
There is a lot of discussion regarding the hole in the nozzle (0.3 mm to 0.5 mm), which is best to use and which gives the best printed and detailed result.
As above the hot end must include a captive arrangement for the thermistor so that it cannot be dis connected from the headed nozzle/block.

(3D Industries suggestion is to use hot end that is well built and not necessarily to buy on price.

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3D Industries recommends a 0.4 mm nozzle. The reason for this is that this is less likely to get blocked or produce intermittent results than a 0.3 mm nozzle. The quality of the object printed does not rely on the nozzle hole alone and other factors particularly the layer height has as much if not more influence on the quality and detail much more.)

Printing with PLA

PLA plastic is *Polylactic Acid*
PLA is a biodegradable material.
PLA plastic typically uses a nozzle temperature of 210-240º C although the exact temperature for the plastic used may need to be adjusted by trial and error.
PLA printing can be accomplished by using a heated or cold bed.
The method of ensuring that the printed object adheres strongly to the bed while it is being printed is a decision of the user as there are several approaches and to some extent these can also depend on whether the printer uses a stationery bed with the extruder being moved in the X and Y axis or whether the printer uses a extruder that only moves in one axis and the bed holding the printed object moves in another.

3D Industries suggestion is to use a printer where the object is stationery in the X and Y axis i.e. the print bed is not moved back and forth.
3D Industries suggests the uses of a 4mm glass bed clipped to the aluminium bed heated to 40- 50 degrees centigrade.
3D Industries recommends either:
A spray adhesive e.g. hairspray. Completed objects can usually be removed from the glass by allowing it to cool (or hastening the process in a cool environment) so that the difference in the coefficient of expansion of the plastic and glass results in separation or weakening of the object to the glass so that it can easily be removed by a spatula.
Use of the FlashForge (blue) bed. PLA sticks to this very well and can be removed post print using a flexible spatula.

Printing with ABS

ABS plastic is *Acrylonitrile Butadiene Styrene*
ABS plastic typically uses a nozzle temperature of 260 centigrade although the exact temperature for the plastic used may need to be adjusted by trial and error.
ABS printing generally requires a heated bed above 80 centigrade up to 110Centograde.
The method of ensuring that ABS plastic adheres to the bed varies according to user preference and the objects being printed.
ABS prints often curl at the corners where contact with the bed is lost thus deforming the object.
Larger ABS objects can undergo significant shrinkage, when cool.
Options for the bed for ABS printing include:

- The use of a bed with holes through which a raft" of plastic is first laid down and the printed object printed on top of this. (The raft has to be removed and discarded.)
- The use of Kapton tape
- The use of proprietary pads
- 3D Industries recommends the use of the FlashForge (blue) bed.

This is an area where users can (and are) experimenting for themselves. There are many people experimenting with printing ABS on a cold bed.

Printing with Flexi-Filament

This is generally similar to PLA in temperature characteristics however the rubbery and flexible properties mean that to handle the filament drawing it from the spool, pushing it down into the extruder requires an extruder that is able to handle these. In practice this means gripping the filament strongly enough to extrude and retract but not hard enough to distort or damage it. Generally this means an adjustable extruder is required.

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Printing with other specialized filament

Filaments differ in their properties regarding hardness, melt temperature bed temperature required and so forth. Provided the 3D printer can control the bed and nozzle temperature and handle the different physical properties of the filament then it should be able to print with these.

Support material

Not all objects are simple structures, many of then have holes or arches or overhangs.
A good 3D printer with object stationery in the X and Y axis should be able to print arches and overhangs where this does not result in a greater angle than 45 degrees. This enables the layer above the previous layer in the overhang part of the object to partially rest on the previous layer and the same with subsequent layers so that the resultant object has an overhang part that does not require any post processing.

Horizontal holes though objects can be created in this way.

Some printers that are very accurate and can be used to print bridges of varying sizes by varying the plastic temperature and using a slower printing speed).

Some printers require support material to be used for all overhangs. This material has to be removed and discarded in a post processing operation when the object print has finished. This can require the use of more filament, it can take time and in many cases leave a mark on the object that is may not always be removable and take more time if it can.

For overhang situations the settings of the printer in regard to speed and temperature are more critical that an object with straight or inward sloping gradients. The settings on the printers and the filament used may require some experimentation and recording

> *(3D Industries suggestion is to ensure the printer chosen has the capabilities required. A more solid and accurate printer that can print generally without support material is liable to be more expensive than*
> *3d Industries suggestion is to experiment and record settings used as a record of operation and also to determine the capabilities of the printer as to whether support material is required or not.*

User display and control of printer settings

Many of the printer settings can be selected when producing the Gcode file for printing. However it is useful to be able to view what these settings are and even more useful to be able to change them during printing.

> *(3D Industries recommends that a printer that both displays the current printer settings and progress as well as permitting certain settings to be changed during printing is essential. This displayed information displayed can include nozzle and bed temperatures, printing speed, printing progress*
> *Settings that can be changed can include nozzle and bed temperature, printing speed).*

Printer testing

Printers should have the facility for the user to test that all functions are working correctly without printing an object. Such tests should include:

- Printer bed heat settings
- Nozzle heater setting
- X Y and Z Axis homing operation
- Individual homing and moving of the Carriage on the X and Y axis and the bed on the Z Axis
- Extruding of the plastic filament

- Retracting of the plastic filament
- Setting and testing of the Z Gap
- The supply of calibration objects
- The supply of sample objects to test overall performance

Printers should also include calibration and sample test objects.

> *(3D Industries recommends that a printer with the functionally above will save a lot of time and frustration. For example if an object is not printing properly then aspects of (or all of) the printer can be individually tested permitting quick identification of the cause of the problem.)*

3D Industries summary and recommendations

3D Industries recommend that ideally printers should have the following features:

- Solid construction
- Bed size sufficient for requirements
- Stationary bed (Implies a CoreXY carriage movement)
- Easy settings for bed levelling
- Easy settings for Z Gap setting
- Guaranteed accurate bed and nozzle heat detection
- Visual display of printer during printing
- Ability to control printer settings during printing
- Ability to test the printer without printing an object
- Dust management control

3D Industries recommends that where possible print in PLA types of filament
Where an object is required in ABS filament types bear in mind that the larger the object the more difficult it is to control the lifting from the bed and the shrinkage.
Where an object is being developed in a profiling loop. I.e. The object is designed and then printed and then tested. As a result of testing changes need to be made to the original CAD file and then the object printed again, this cycle being repeated until the object size and properties are correct. Then it is easier to print the versions being prototyped in PLA until the object is correct, and then it can be printed in ABS.

References to Internet published information.

#1 http://makezine.com/2014/11/11/abs-or-pla-choosing-the-right-filament/

#2 http://www.printinz.com/zebra-plates/

#3 http://www.digitaltrends.com/cool-tech/abs-vs-pla-3d-printing-materials-comparison/

#4 http://www.makergeeks.com/pla-vs-abs4.html

3D Industries printers

This section describes the ways in which the 3D Industries printers address the issues discussed earlier.

3D Industries printers address the issue of **performance and reliability** by being designed to be rugged accurate and reliable. The structure of the printers with the steel 25mm box frame, the large 12mm gantry rods and bearings and the other components of the printer was developed over several years. They have been subject to stringent soak tasting for months of operation, rough handling testing and destruction testing to ensure that the printers are able to perform flawlessly for long periods.

3D Industries printers address the issue of **dust prevention by including** an efficient filament cleaner. This us attached to the frame above the filament spool and acts as an anchor point for the PTFE tube used as a guide of the filament to the extruder also ensuring that once cleaned the filament is not exposed before entering the extruder.

3D Industries supplies **Quality filament and** can recommend suppliers of filament.

3D Industries has as an accessory, a **Printer dust cover for** each model. This is if special fabric that prevents dust getting onto the printer when not in use and also has a backing to prevent the ingress of any ingrained dust accumulated between cleanings.

Over time even taking precautions against dust on the external filament and using quality filament, it is possible to get a blocked or partially blocked hot end.
3D Industries addresses the different problems of **blocked or partially blocked hot ends** by:

- Making the changing of the hot ends very easy
- Providing a service for printer customers whereby the hot end that become blocked can be quickly changed with the spare provided and the blocked hot ends can be returned to 3D Industries for free replacement.

3D Industries does not recommend the user changing the nozzles. This is because the build process of the hot ends is subject to specific build procedures and tests and also because it is not always the nozzle that needs replacement as other parts of the hot end may need to be changed.

3D Industries printers handles the issue of **accurate filament handling** by providing a spool holder that

- Offers little resistance to the extraction of the filament
- Prevents run on and entanglement.
- Handles different spool sizes and quality

3D Industries addresses the issues of the **build platform** as follows.
The heated bed consists of aluminium, plate support by three widely spaced 5 mm adjustable bolts. These can be easily adjusted to provide a very level bed.

3D Industries addresses the issue of **Bed Levelling** by including widely space adjustment bolts and an easy procedure to provide an initially levelled bed. 3D Industries provides a specific bed level object that can be printed and will highlight if the bed is level and if not where the adjustment has to be made.

3D Industries address the issue of the **Z gap setting**, by making this an operator setting when needed. It is possible to set the Z Gap after the bed has been levelled with code in the object gcode. However there are some reasons why it is more convenient to set the Z Gap manually.

- The gcode file does to have to be produced again
- If a different bed thickness (e.g. thicker glass is used then the Z Gap can be quickly adjusted b by turning the thumbscrew
- If the type of plastic used or the nature of the object requires a firmer bed adhesion than the normal plastic this can be done by slightly adjusting the Z Gap so that the first layer is pushed harder onto the bed.

3D Industries provides **visual indications and control of printer settings** during printing.

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The Rumba board driving the printer is housed in a box cooled by fans and protected from dust. The cover of the box contains an LCD controller and SD card socket. The gcode file for printing are copied to the SD card which is inserted into the LCD controller. Using the controller the relevant gcode file on the card can be selected for printing. Other settings can be controlled from the LCD controller. While printing the status of the object being printed can be displayed and if required adjustments made.

Evaluation of 3D printers

There are a large number of lower and medium cost printers available and not a lot of accurate information available. It can be difficult to judge which printers offer best value for money from published information alone and determination by price is not a valid indication as the features and prices vary considerably.

Where possible the prospective printer should be seen and be observed printing.
The printer should be checked against a list of the features required are included.

The support provided is also an important consideration. Is the main components user changeable? What is the solution for this printer for blocked nozzles? Is on site support possible or is it a "return to base".

If it is an imported printer does the importer / reseller know the printer, have available the spares, provide support and so forth.
Is it possible to use standard plastic filament on a spool or is it necessary to get manufacturers' filament and or use a cassette.

Is the printer certified for Australian use? Many manufacturers say that they are certified but point to the certification for other countries not relevant in Australia. The only certification accepted in Australia is that certified locally and registered in the ERAC register.
