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4th DOCUMENT ANNEX II: RAPID MANUFACTURING SYSTEM

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3 NOMENCLATURE

UAV	Unmanned Air Vehicle
RMS	Rapid Manufacturing System
CAD	Computer Aided Drawing
RP	Rapid prototyping
UV	Ultraviolet
ABS	Acrylonitrile butadiene styrene

SLA, STL	Stereolithography
DMDs	Digital mirror devices
DMD	Direct Metal Deposition
DLPT	Direct light processing technologies
HVJS	High-viscosity jetting systems
SLS	Selective laser sintering
DMLS	Direct metal laser sintering
3D P	3D Printing
MIT	Massachusetts Institute of Technology
FMDS	Fused metal deposition systems
EBM	Electron beam melting
SLM	Selective laser melting
SMS	Selective masking sintering
SIS	Selective inhibition sintering
ELM	Electro photographic layered manufacture
HSS	High-speed sintering
FDM	Fused deposition modeling
LOM	Laminated object manufacturing

4 INTRODUCTION

The term Rapid Manufacturing is defined as ‘the use of a computer aided design (CAD)-based automated additive manufacturing process to construct parts that are used directly as finished products or components’ (1)

The term ‘additive’ manufacturing is used in preference to ‘layer’ manufacturing as it is likely that some future RM systems will operate in a multi-axis fashion as opposed to the current layer-wise manufacturing encountered in today’s Rapid Prototyping (RP). Although current RP systems are being successfully used in specialist applications for the production of end-use parts, these RP systems have not been designed for manufacturing and many problems remain to be solved. These include surface finish, accuracy and repeatability; all them intrinsic to the aim of this study.

The field of Rapid Manufacturing has grown in recent years and offers such significant potential that it must be considered as a discipline in its own right that is independent from its predecessors of Rapid Prototyping and Rapid Tooling. This new discipline, which eliminates tooling, has profound implications on many aspects of the design, manufacture and sale of new products. CATUAV[1] has opted for this new technology.

[1] *CATUAV is a private Catalan Company dedicated to Earth observation using Unmanned Aerial Vehicles. http://www.catuav.com/*

5 RAPID MANUFACTURING SYSTEMS

Rapid Manufacturing systems are not annotated since the definition is not clear. There are a large number of systems that could be included to this definition. This study has made alternatives selection based on the UAV requirements and possibilities.

5.1 LIQUID-BASED PROCESSES

Liquid-based layer additive manufacturing approaches involve the formation of a solid by selectively curing regions of photosensitive polymers.

These technologies were the pioneering processes in RP and have a number of distinct advantages for prototyping, including superior accuracy and definition when compared with other processes. In recent years a number of filled resins that produce parts that look very much like injection molded components have been commercialized.

The fact that these components have a similar appearance to injection molded parts may help to ease the decision to adopt RM with these materials. However, the material properties of photo-cured parts tend to be relatively poor when compared with other processes, especially over a period of time when ageing, for example, by exposure to sunlight, which causes continued curing, can severely affect mechanical properties and appearance. Sensitivity to humidity can also be a problem with photo-curable resins. Photo-curable resins that can achieve stable properties over time and in different environments would provide a significant new set of potential applications for RM.

5.1.1 Stereolithography (SLA)

This is widely considered as the founding process within the field of RP, with the first patent granted to Chuck Hull in 1986 leading to the first commercial machine from 3D Systems in 1987 (2). This is the most popular method in order to build prototypes rapidly. It allows to create very complex 3D plastic pieces. (3)

This process works using an ultraviolet (UV) laser to initiate a curing reaction in a photo-curable resin. Using a CAD model file to drive the laser, a selected portion of the surface of a vat of resin is cured and solidified on to a platform. The platform is then lowered, typically by 100 mm, and a fresh layer of liquid resin is deposited over the previous layer. The laser then scans a new layer that bonds to the previous layer. After building, parts are removed from the machine and platform, supports are removed (1).

The fact that the resin is liquid initially forces to generate many columns in order to support the piece while it is in generation. Without this, the solid part would not be supported by the liquid resin. In order to obtain the best mechanical characteristics needed, prototypes are post-processed in a UV special oven, where non cured remaining parts are solidified. (4)
The input material can be acrylic or epoxy resins. The most used one is Somos 12120 White, it have properties close to the ABS plastic which are the high durability, good mechanical properties, white color, opacity and water resistance. (3)This process has advantages which are the transparency of the products, the good accuracy that it brings for pieces with reduced size or small details which must be defined clearly.(4)

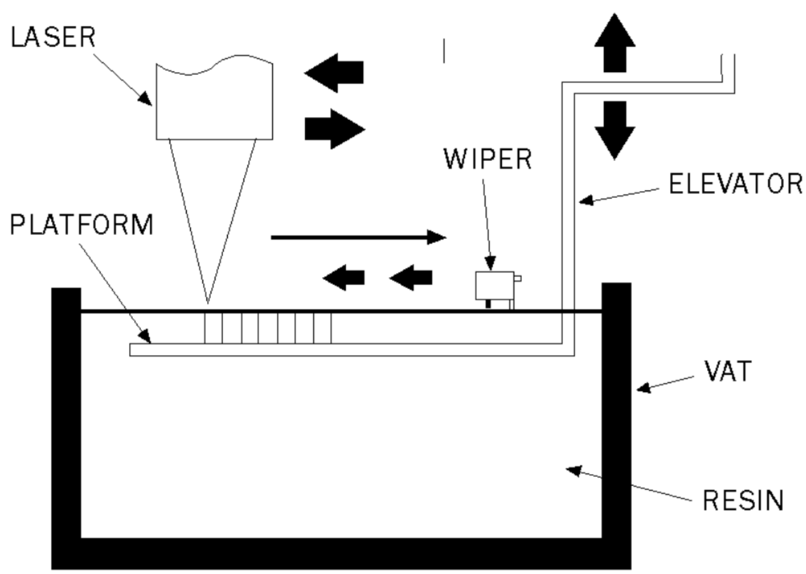

Figure 1: Schematic SLA machine (1)

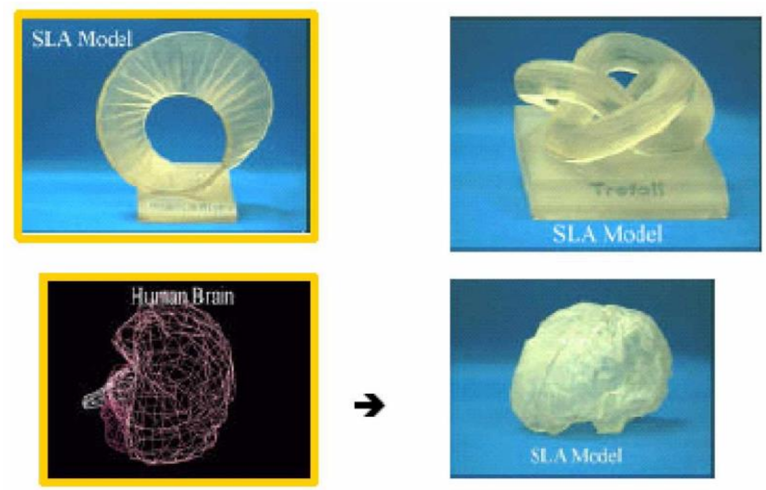

Figure 2: Pieces made SLA process (by http://www.robotec.com)

5.1.2 Jetting systems

There are two different commercialized technologies that use ink-jet technology to create parts from photo-curable resins. These are the PolyJetTM[2] process from Objet[3] of Israel and the In Vision process from 3D Systems[4].

The PolyJetTM process uses an array of printing heads to simultaneously selectively deposit an acrylate-based photo-polymer. Each layer, which can be as thin as 16 mm, is then cured by a trailing UV lamp that passes over the deposited material. Supporting material is simultaneously jetted through a second series of jets and cured to a gel state with the UV lamp, so that it may be removed by water jet or similar after building.(5)

The In Vision process shares many features with the previous one, including the use of an array of jets to print an acrylate-based material. In this process the supports are created by jetting wax which can be removed by a variety of means after parts

[2] PolyJetTM is the first method that enables the simultaneous jetting of different types of model materials.

[3] OBJET Ltd was a 3D printing Company from Israel acquired by STRATASYS Inc.

[4] 3D SYSTEMS is a leading provider 3D printers, print materials and cloud sourced on-demand custom parts for professionals and consumers. http://www.3dsystems.com/

are built. Colored resins allowing parts to be made in a single color have proved to be popular and should help with respect to achieving improved aesthetics from parts. As with the process of Objet, the main obstacle for widespread use in Rapid Manufacture is the material properties of the parts made. (1)

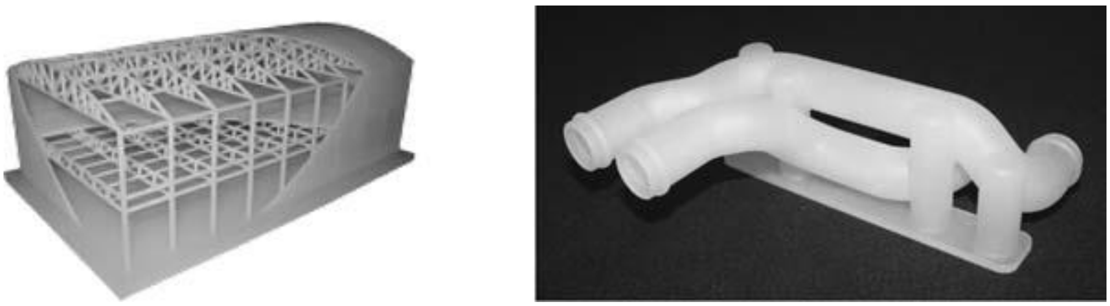

Figure 3: Pieces made by InVision process. (1)

5.1.3 Direct light processing technologies (DLPT)

Digital mirror devices (DMDs) developed by Texas Instruments[5] have found a wide variety of applications ranging from data projectors to the manufacture of electronic products. In terms of layer manufacturing technologies as covered by this text, the PerfactoryTM, a rapid prototype model process developed by EnvisionTec[6] of Germany is the only machine available commercially.

The PerfactoryTM machine is a particularly interesting technology from the perspective of Rapid Manufacture. Interestingly, the name of the machine (an abbreviation of 'personal factory') implies that it is intended to make products (factory) and that these products are likely to be customized to the individual (personal).(1)

[5] Texas Instruments is a USA Company dedicated to complex signal-processing technology. http://www.ti.com/

[6] Envison is a Germany Company dedicated to 3D printing solutions for the rapid manufacture TEC. http://envisiontec.com/

Beyond the name, the process also has a number of distinguishing aspects, starting with the fact that the process builds parts that 'grow' downwards rather than upwards (see Figure 4). As with PolyJetTM and InVision the process builds parts from an acrylate-based photo-curable resin, but it does so by using a two-dimensional matrix of mirrors rather than a '1D' array of print heads to selectively cure the material. In order to selectively cure a layer, the process makes use of DMD technology developed by National Instruments to selectively switch on and off mirrors that reflect UV light from a source on to the build area. Figure 5 shows a number of parts made by the Perfactory TM process. With a build speed of 10-15 seconds per layer the process is well suited to building parts quickly, but the use of a single DMD with a finite matrix of pixels limits the process to small parts if a fine resolution is maintained. Given the suitability to produce small parts, it is of little surprise that the hearing aid industry has shown significant interest in this technology with a number of machines supplied to US-based manufacturers. (1)

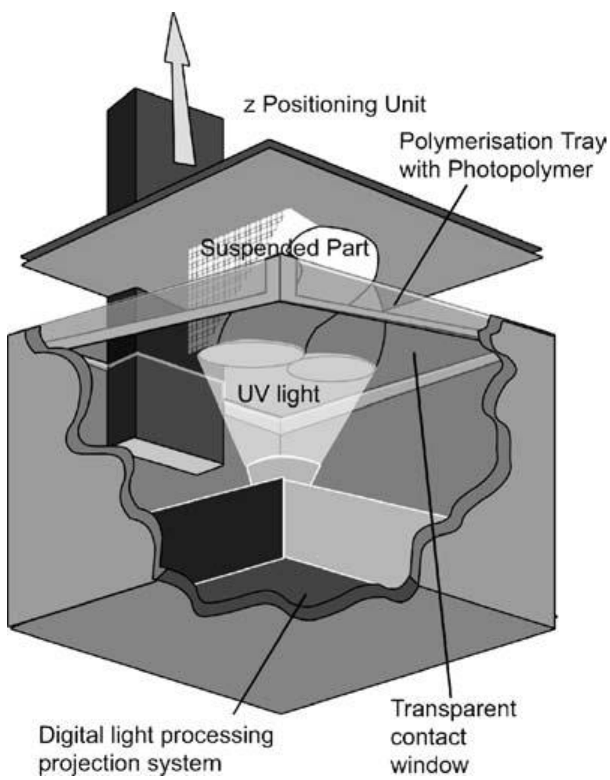

Figure 4: Schematic of the Perfactory TM process. (1)

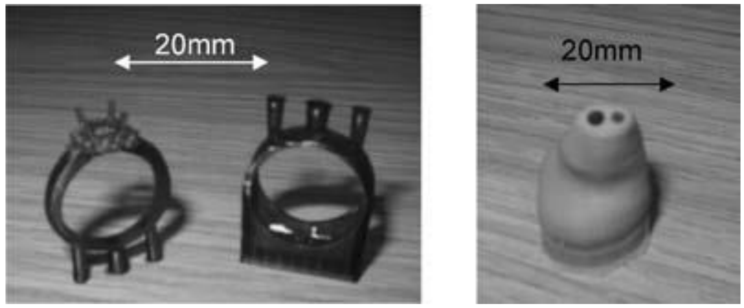

Figure 5: Pieces made by the Perfactory TM process. (1)

5.1.4 High-viscosity jetting systems (HVJS)

The principle involves continuous change in a layer's pattern according to a very thin slice of the object to be printed. This process uses a mechanism based on displacing a small drop of a printable material to a desired location on a substrate. The fundamental unit consists of a single jet controlled by pressure, the distance from the substrate and the length of the jetting pulse (see Figure 6). An experimental program on single jets is being carried out and the results are showing the different shapes and sizes of deposition that can be achieved.

This concept will be scaled to a block of multi-jets controlled in parallel to deposit a layer of a desired pattern. The final process will provide solutions to a number of problems and limitations known in conventional printing and existing RP machines. It also has flexibility in the degree of accuracy depending on the perforation size being used for the jet. A production speed similar to existing high-volume production methods will be possible and the paste can be loaded with any powder.

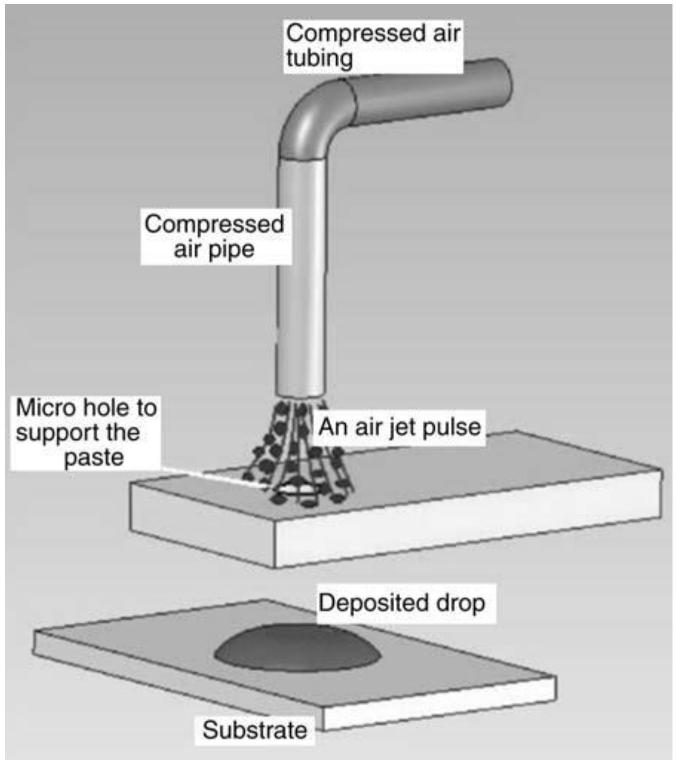

Figure 6: The high-viscosity jetting principle.(1)

5.2 POWDER-BASED PROCESSES

Powder-based processes offer a wider variety of material possibilities with polymers, metals and ceramics all available on current commercial systems. The material properties and stability of parts that may be achieved with powder-based processes means that they will, in the long run, be more suited to RM than the liquid-based systems. Furthermore, combing powders and layer additive manufacturing, provides a unique potential for increased functionality of rapid manufactured components.

5.2.1 Selective laser sintering (SLS)

Selective laser sintering was first invented and patented by Ross House-holder in 1979, but it was only commercialized following the work of Carl Deckard at the University of Texas at Austin in the late 1980s (2). For polymers, is in many ways similar to Stereolithography, but the powdered raw material is sintered or melted by a laser that selectively scans the surface of a powder bed to create a two-dimensional solid shape. A fresh layer of powder, typically 100 mm thick, is then added to the top of the bed so that a subsequent two-dimensional profile can be traced by the laser bonding it to the layer below. The process continues to create a full three-dimensional object and the non-fused powder acts as a supporting material which obviates the need for support removal during post-processing.

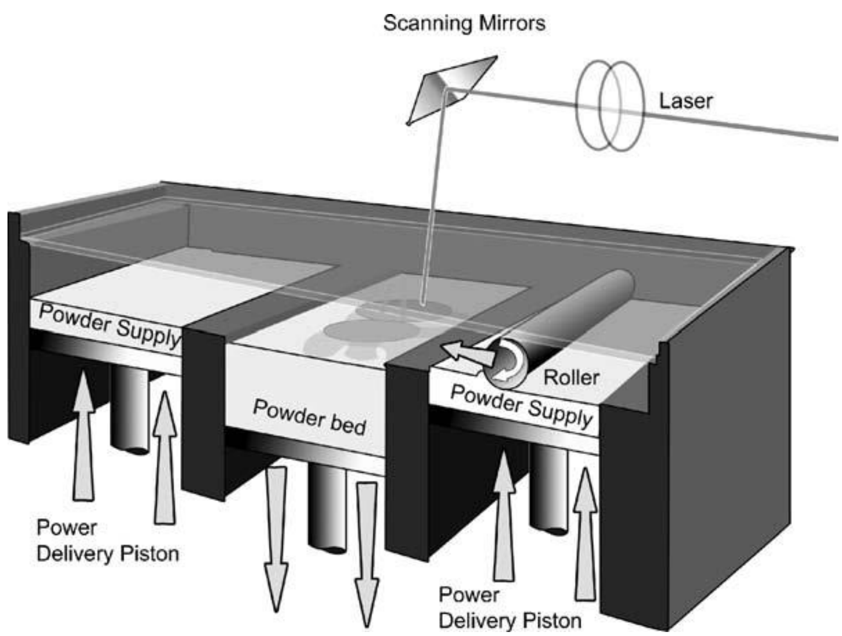

Figure 7: Schematic SLS machine (1)

During the process, the powder bed is heated prior to laser scanning in order to bring the temperature of the powder up to a suitable temperature (typically below the sintering temperature). This pre-heating is usually performed by infrared heaters and helps the process by reducing thermal gradients between sintered and non-sintered powder and reduces the energy required by the laser to sinter the powder. Highly crystalline polymers are sintered using the laser to elevate the powder temperature to the melt temperature (Tm). This leads to good contact between particles and hence parts with relatively good mechanical properties. These good mechanical properties have allowed semi-crystalline polymers to be used in numerous RM applications to date. Amorphous materials, such as polycarbonate, do not have sharp melting points and are sintered by using the laser to elevate the powder temperature to the glass transition temperature (Tg). This leads to weaker parts than those that are sintered at the melt temperature but such parts have been widely used as investment casting patterns that do not require high strength. The low strength of amorphous laser sintered parts is likely to restrict their potential uses in RM applications.

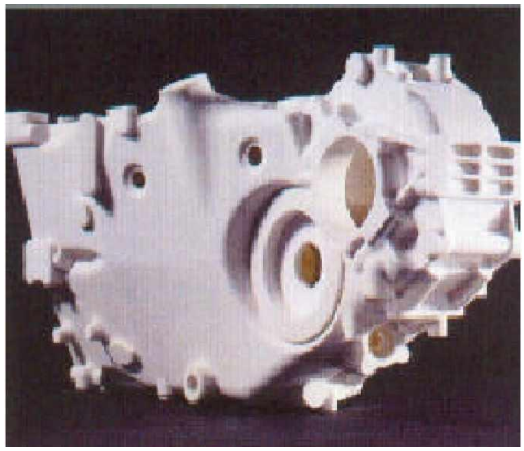

Figure 8: Piece made by SLS (by http://www.robotec.com)

The concept also can be applied to metals or ceramics by using coated powders to metals so that the selective laser sintering machine could produce powder metallurgy steel parts in the green state. These parts could then be subjected to post-processing in a furnace to burn away the polymer binder, sinter the steel particles and finally infiltrate the porous parts with bronze. This process was largely aimed at producing tooling but offers some potential for Rapid Manufacture of end-use products.

5.2.2 Direct metal laser sintering (DMLS)

The initial goal of direct metal laser sintering was to produce tooling, but the process has been used for end-use Rapid Manufacture (3). A variation on selective laser sintering has been developed. It can produce material parts without the need for a binder coating and the subsequent processing that would be required. Essentially the process involves either melting or liquid phase sintering of the metal powder, which typically is a mixture of various components having different melting points. (1)

This process consists in the melting of the metal in powder phase, typically deposited as layers with 20 μm of thickness. The melting is allowed by a laser beam. This process is suitable for materials such as Titanium alloys (Ti64Al4V) or special alloys (DM20 or S20). (3)

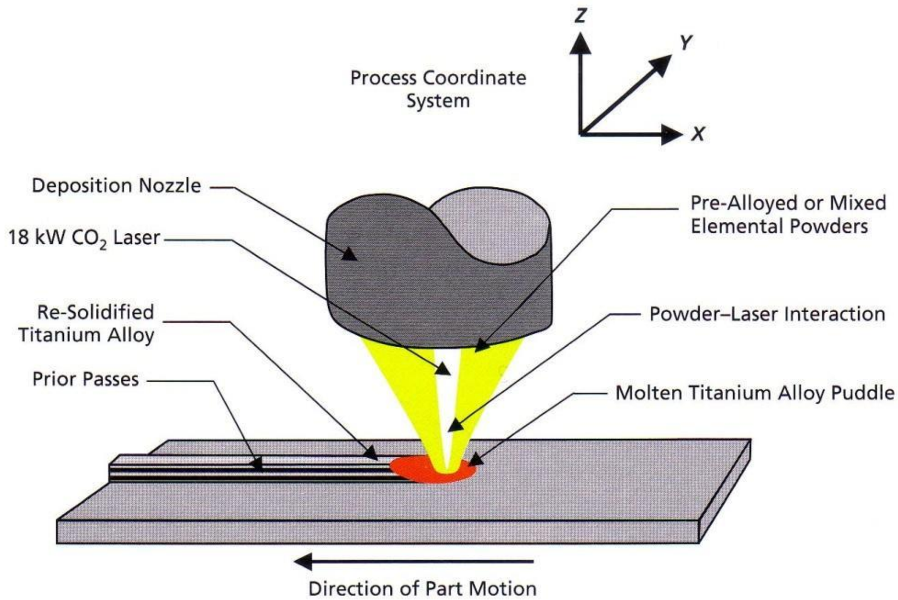

Figure 9: Schematic DMLS machine (3)

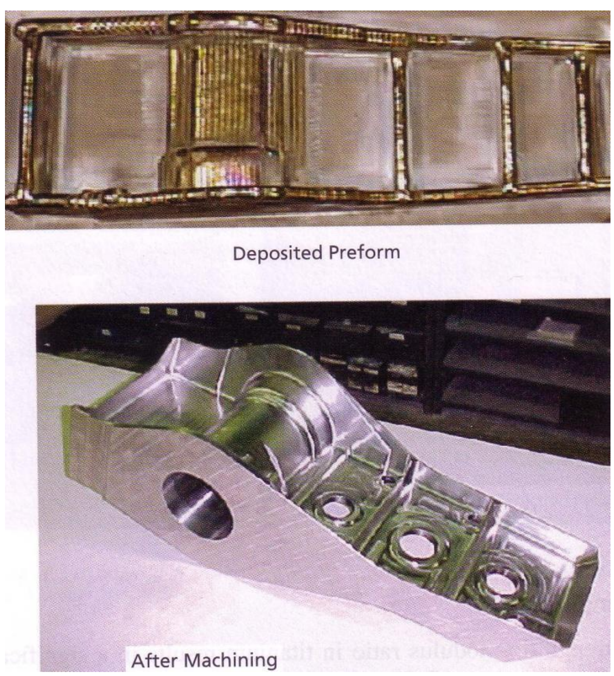

Figure 10: Rib section made by DMLS before and after machining (3)

5.2.3 3D Printing (3D P)

The three-dimensional printing process was invented at MIT. Using '1D' jetting technology the process has a relatively high throughput in terms of creating green parts similar to those by metal selective laser sintering. Post-processing is similar to that for selective laser sintered parts, but surface finish usually requires some form of machining to create a surface suitable for tooling. In terms of RM, the process may be suited to more rigorous applications where polymers will not suffice, especially where fine surface finish is not required. (1)

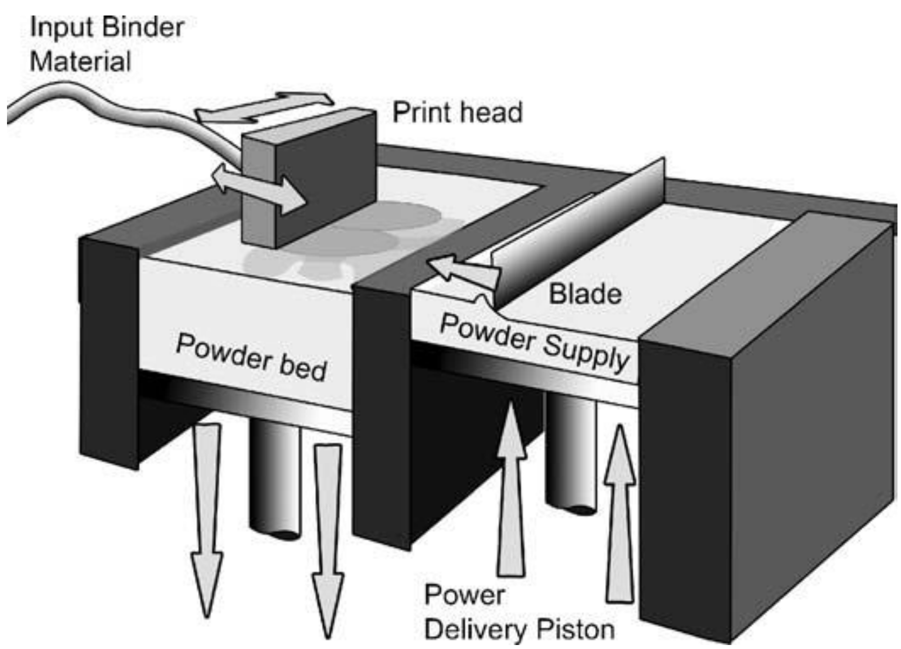

Figure 11: Schematic of the 3D printing process. (1)

Form a 3D CAD file, this method adds material in powder or resin phase, which will solidifies or polymerizes by the application of light. In this process the most common used materials are PVD, acrylic resin, thermoplastics and photo-polymers. (3)

One of the problems of this method is the volume limitation of the printed piece, which has to be maximum 250x250x200 mm. The accuracy is up to the millimeters, with tolerances of 0.1-0.5 mm and the velocity depends on the thickness; 25 mm/h for a 100 μm layer and 2.5 mm/h for a 10 μm layer. (3)

Figure 12: Piece made by 3D printer. (3)

5.2.4 Fused metal deposition systems (FMDS)

A number of processes have been developed that use the principle of blowing metal powders into a melt pool created by a laser (see Figure 13). Generally these processes have relatively slow deposition rates and produce parts with poor surface finish. Is used in high melt temperature metals including titanium. These processes have also proved to be particularly adept at fixing broken parts such as moulded tools by adding material where required. This may form an RM niche for these processes in the comparably high-added-value area of product repair/maintenance.

There are many different processes, one was developed by Sandia National Labs who used the expression laser engineered net shaping (LENS) (6) in collaboration with John Hopkins University, Penn State University and the MTS Systems Corporation. (7)

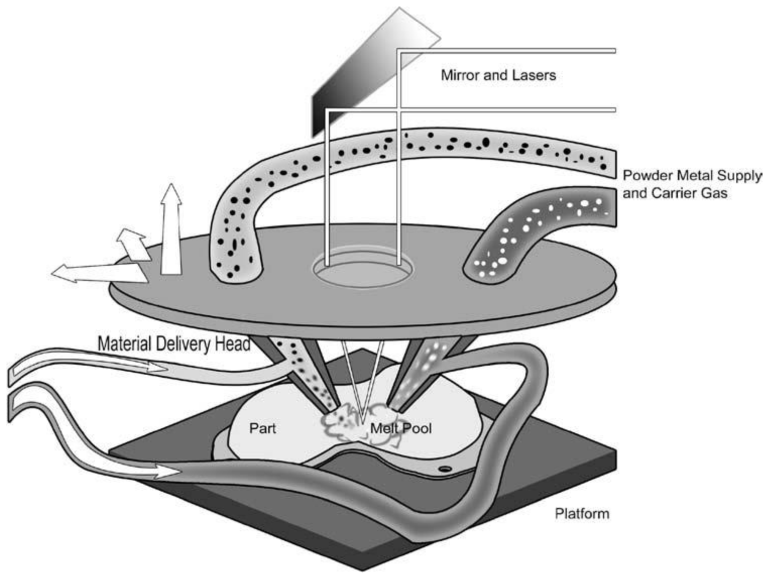

Figure 13: Schematic of fused metal deposition. (1)

5.2.5 Electron beam melting (EBM)

The electron beam melting process was first commercialized by Arcam in Gothenburg, Sweden, in 1997 [5.8]. The process uses a similar approach to selective laser sintering but replaces a laser with an electron beam. Consists in making pieces by melting metal powder deposited on each layer. The melt is obtained using an electron cannon with high voltage and electron acceleration power. (3)

Firstly, the electron beam may be directed by changing the electromagnetic field through which it passes. This eliminates the need for scanning mirrors and can significantly increase scanning speed. Secondly, the power developed by the electron beam is very high, allowing the process to fully melt a wide range of metals including titanium alloy using a very fast scanning rate. However, the process is limited to conductive materials and surfaces, as with many other layer-based processes, often require extensive finishing. The speed of scanning coupled with no requirement for further furnace processing may make the process a leading contender for Rapid Manufacture. In particular, the process offers significant potential for high temperature or medical applications. (8)

The materials commonly used are light titanium alloys as Ti6Al4V and heat-resistant alloys as Inconel series. As the 3D printing, the total volume is also limited, the maximum useful size is 200x200x180 mm (3)

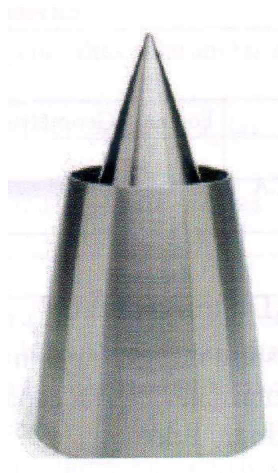

Figure 14: Titanium aerospace prototype made by EBM (3)

5.2.6 Selective laser melting (SLM)

MCP Group have commercialized the Realizer machine that uses a laser to fully melt stainless steel parts in a similar manner to laser sintering. The process is particularly adept at producing very small components, including ones with complex lattice structures. (9)

5.2.7 Selective masking sintering (SMS)

The process was initially aimed at producing vacuum forming tools, making use of the process's inherent porosity, but new materials may make this one of the next generation of RM machines. The SMS process involves printing a mask of infrared radiation reflecting material on to a glass sheet and placing the sheet over a powder bed. Infrared radiation is then applied to the glass sheet and allowed to selectively pass through the mask in order to sinter the powder directly below. A schematic of the SMS process is shown in Figure 15.

This eliminates the requirement for a laser and in instances where a significant portion of the surface needs to be sintered this should dramatically reduce processing times when compared with selective laser sintering. Each layer can be fully processed in 10-20 seconds and that the use of a mask in place of a laser ensures that build times are easy to predict and independent of part volume. Consequently, this approach should have maximum benefits when being used for Rapid Manufacture in high volumes.

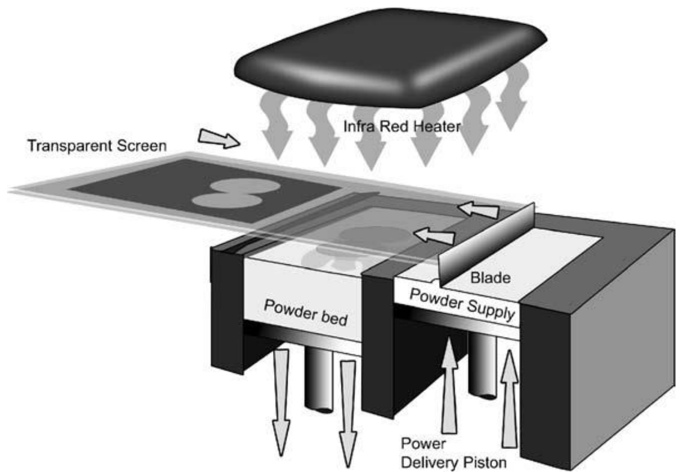

Figure 15: Schematic of the SMS process. (1)

5.2.8 Selective inhibition sintering (SIS)

Rather like selective masking sintering, the process seeks to combine the benefits of SLS (material properties) and jetting processes (build speed) to address two of the major concerns behind Rapid Manufacture. However, SIS is likely to achieve better resolution and definition than the selective masking sintering process as the inhibiting material is printed directly on to the powder and uses no mask that might allow for light diffusion .(10)

The process uses a print head to jet fluid to inhibit sintering on to selected areas of the build volume. This is followed by using a radiating heat source to traverse the build area and sinter any powder that has not had the inhibitor printed on to it. Initial work used a single nozzle to print around the edge of parts but the process could easily be developed to simultaneously print the inhibiting material in a '1D' array or possibly a two-dimensional matrix. Figure 16 shows parts made by the SIS process.

Recent research has considered the use of a variety of inhibiting materials ranging from commercial cleaning agents to potassium iodide. Another aspect of materials that has been researched is the powder material of the parts themselves, with success reported when sintering a variety of polymer powders including polystyrene, polycarbonate and polyester. Unlike most of the other powder sintering processes, SIS does not require that the material comprising the part be elevated to a higher temperature than the material not to be sintered, and as a result there is a reduction of thermal gradients across the surface. SIS needs to apply the inhibiting material to the majority of each layer with parts only comprising a minority of each layer. From the perspective of high-volume manufacture this appears to be a counter intuitive approach. Having said this, the goal of high-volume manufacture by RM will often be to pack part beds as densely as possible, so this apparently counter-intuitive approach is likely to be less of an issue than it would be for RP, where densely packed part beds are seldom used. (11)

Newer implementations of SIS incorporate power waste reduction mechanisms that act in the form of shutters that block selected areas of a passing heater bar from emitting heat to the powder surface underneath. In this way, areas of powder treated by inhibitor as well as sintering of non-part powder sections will be minimized.

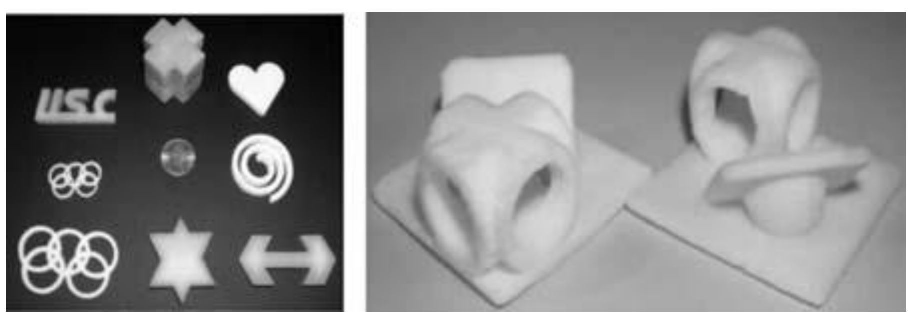

Figure 16: Parts made by the SIS process. (12)

5.2.9 Electro photographic layered manufacture (ELM)

Ashok Kumar has been developing the electro photographic layered manufacturing (ELM) process at the University of Florida. (13)

This process uses an interesting mix of ideas that have been used for laser sintering. Figure 17 shows how the process uses electro photographic methods to deposit a part powder and then a support powder for each layer. Initial work focused around the idea of producing a green part by depositing separate part and support powders and then using a furnace operation to sinter the part material in a separate step; this required that the support material had a higher melt point than the part material. However, further work has experimented with the idea of sintering each layer before the next layer is deposited, as with other powder-based layer manufacturing processes (14). One of the problems that need to be overcome is in depositing material electro photographically to create parts with a large height. It appears that the process could be suited to very high production rates but limited to smaller parts such as electrical components.

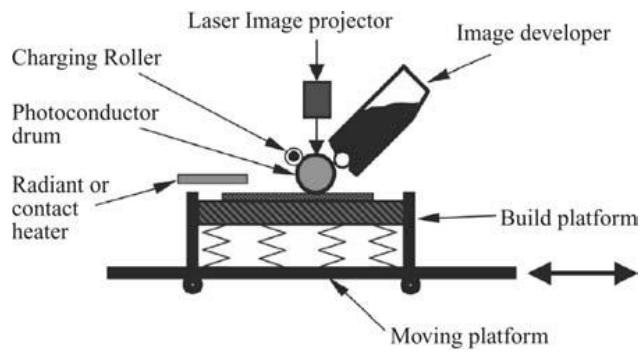

Figure 17: The electro photographic layer manufacturing process. (1)

5.2.10 High-speed sintering (HSS)

As with the processes previously mentioned, HSS is aimed at taking advantage of the mechanical properties given by SLS while achieving an increase machine throughput and reduced machine cost by eliminating the need for a laser. (15)

HSS defines the geometry of each layer by printing a material that promotes absorption of radiation on to the powder bed surface, rather like a negative of SIS (see Figure 18). The key to HSS is the ability to control the rate of sintering across the build surface. (15)

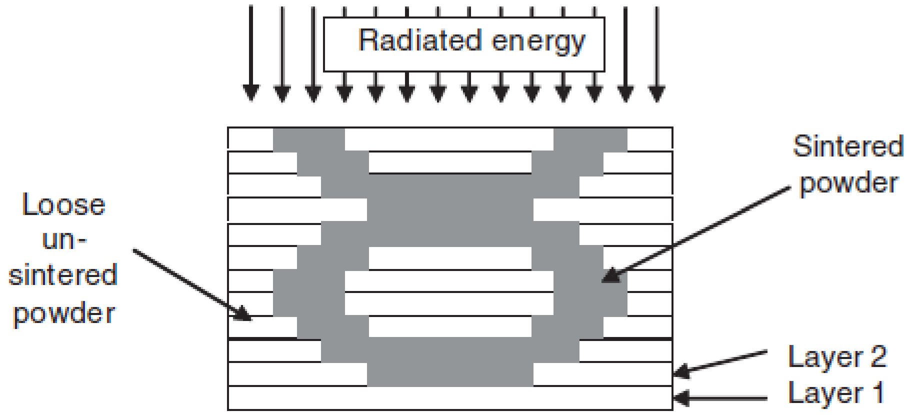

Figure 18: Schematic of HSS process. (1)

Research has shown that a high sintering rate results in minimal shrinkage and good edge definition but poor mechanical properties, while slow sintering achieves better mechanical properties but at a cost of definition and accuracy. By controlling sintering rates via techniques such as the use of greyscale and materials that absorb energy at different rates the goal of achieving good mechanical properties with good accuracy and surface finish is being pursued.

5.3 SOLID-BASED PROCESSES

Processes that use a solid raw material in non-powder form have been an integral part of the RP industry since its formative years in the early 1990s. The two predominant forms of solid-based processes which are fused deposition modeling and laminate object manufacturing, have been commercialized for some time, but incremental improvements continue by both the suppliers and academic institutions worldwide .

5.3.1 Fused deposition modeling (FDM)

This process was first commercialized by Stratasys in 1991 with patents awarded to Scott Crump, the company founder in 1992 (7). The fused deposition modeling process creates parts by extruding material, normally a thermoplastic polymer, through a nozzle that traverses in X and Y to create each two-dimensional layer. In each layer separate nozzles extrude and deposit material that forms the parts and material that form supports where required. The use of a nozzle with a diameter of typically 0.3 mm limits resolution and accuracy. Also the need for the nozzles to physically traverse the build area limits build speed, but the process is very easy to set up and can operate in an office or factory environment. Support removal can be manual or, when water soluble supports are employed, they may simply be dissolved, the latter approach being most valuable with more complicated geometries. (1)

Figure 19 shows a schematic of the FDM process that can produce parts in materials including polycarbonate, polyphenyl-sulfone and, most commonly acrylonitrate butadiene styrene (ABS). The simplicity of the process should make it suitable for the development of a wide variety of thermoplastic polymers, which may open up opportunities for Rapid Manufacture. (2)

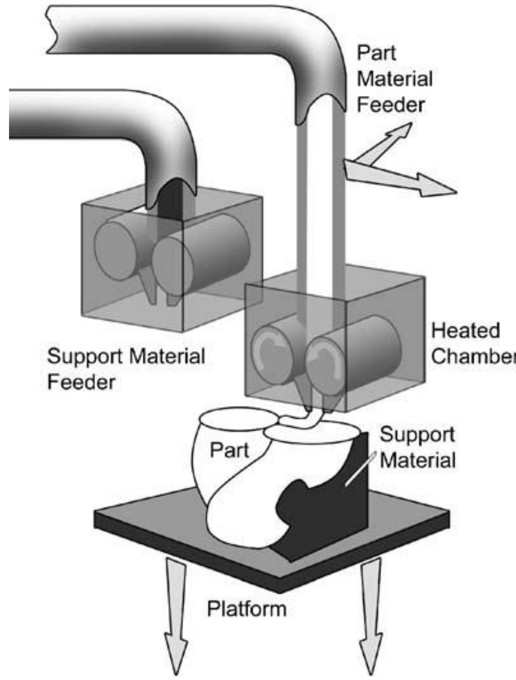

Figure 19: Schematic FDM machine. (1)

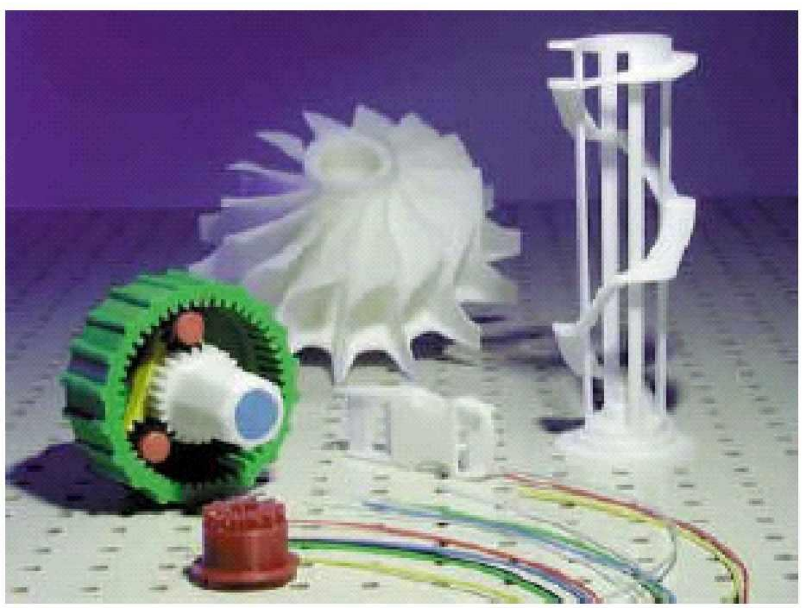

Figure 20: Pieces made by FDM (by http://www.3dsystems.com)

An interesting development based on FDM is contour crafting (CC) process. CC exploits the surface-forming capability of trowelling in order to create smooth and accurate planar and free-form surfaces out of extruded materials - mainly construction ceramics. As the material is extruded, the traversal of the trowels creates smooth outer and top surfaces on the layer. The side trowel can be deflected to create non-orthogonal surfaces. The extrusion process builds only the outside edges (rims) of each layer of the object. After complete extrusion of each closed section of a given layer, if needed, filler material such as concrete can be poured to fill the area defined by the extruded rims.

Some materials used are ABS, polyester, polycarbonate and the cost of suitable material for the process can be until 500 EUROS/kg. The volume of the resultant piece can me maximum 500x600x600 mm. (3)

5.3.2 Laminated object manufacturing (LOM)

A number of technologies have been developed to create three-dimensional parts by cutting and stacking two-dimensional sheets of various materials. Different approaches have been used to cut sheets, bond them together and remove waste material from each sheet.

The processes commercialized involve stacking layers of paper with a bonding material and creating the part profile by cutting each layer of paper with a laser (see Figure 21). Post-processing involves using hand tools to remove the unwanted material and to reveal the part inside. The main problem for the process is that for complicated geometries, and especially those with thin walls, post-processing is difficult, time consuming and can damage the part. For simple geometries this is less of a problem, but simple geometries are usually more suitably produced by machining.

Different materials provide the potential for sheet stacking technologies to be used in Rapid Manufacture. In its different processes the material used can be polyvinyl chloride (PVC), metal sheets that are bonded by low-temperature ultrasonic diffusion, with machining employed to cut out the required geometry of each layer. This process has some interesting value added potentials, such as the ability to embed fragile fiber-optic cables within parts. (16)(4)

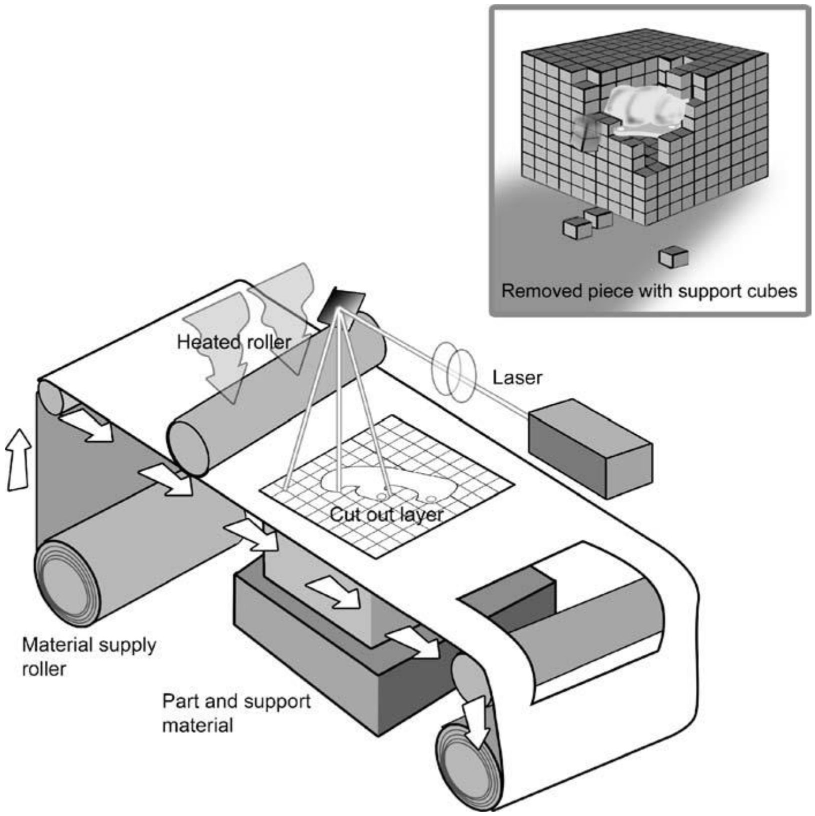

Figure 21: Schematic LOM machine (1)

Once the RMS alternatives have been explained and compared to each other, it is possible to choose the optimal system for this study, RMS for UAV enterprise applications.

6 RMS DECISION TABLE

A VTP has been done in order to find the best rapid manufacturing process satisfying all the requirements imposed by CATUAV.

As shown in Table 1, the most important aspects are the material price and manufacturing. Materials price has to be as low as possible since the process will be used to build cheap and small UAVs and their prototypes. For these reasons, the main material should be a kind of polymer instead of any expensive alloy, such as the ones made of titanium. The manufacturing ratio includes the difficulty of processing, which means whether a post processing is needed or not, if there must be a mold or how much control it is needed. The manufacture ratio affects all the process strongly.

Availability and time-consumption are also important because prototypes have to be built as fast as possible. It is well know that, if a lot of different alternatives that use the same process can be find in the market, the competence will keep the price relatively low. Regarding time-consumption, if a process spends a lot of time implies a lower step in the assembly, which is contrary to the main goal of rapid manufacturing.

A bit of accuracy is needed because this project is related to small UAVs that are full of small-scale pieces that have to be built correctly enough. On the other hand, the accuracy related to the surface finishing is not as important as in a bigger project. The mechanical resistance and durability are the lowest ranked criterions because of the fact that small UAVs are not going to have the same safety restrictions that a commercial airplane has. Oversizing the structure, using high performance materials or complex structures, would increase the safety factor, despite the price would also be increased a lot.

As it can be observed in Table 2, the option that fulfills better the CATUAV's requirements is the 3D printing method. The new features of these printers – currently under development– will improve the manufacturing of CATUAV's technologies and much more companies.

CRITERION	IMPORTANCE	P															
		LIQUID-BASED				POWDER-BASED										SOLID-BASED	
		SLA	JS	DLP	HVJS	SLS	DMLS	**3D P**	FMDS	EBM	SLM	SMS	SIS	ELM	HSS	FDM	LOM
AVAILABILITY	8	7	7	4	7	7	5	7	6	7	7	7	8	5	6	8	8
MATERIAL PRICE	10	8	7	7	7	7	4	8	5	4	6	6	7	6	7	6	8
MANUFACTURING	10	4	4	5	6	7	6	8	7	6	4	7	5	5	7	5	6
ACCURACY	7	8	7	7	6	6	6	7	6	6	8	4	5	8	7	6	4
MECHANICAL RESIST.	6	7	6	7	6	8	6	5	6	6	4	7	8	4	6	6	8
DURABILITY	6	6	5	6	6	7	5	5	7	7	6	6	7	7	6	5	6
TIME NEEDED	8	6	8	7	7	6	7	7	6	8	6	4	8	6	8	5	5

Table 1: Importance of each criterion and its weight on all the processes

CRITERION	PxG															
	LIQUID-BASED				POWDER-BASED										SOLID-BASED	
	SLA	JS	DLP	HVJS	SLS	DMLS	**3D P**	FMDS	EBM	SLM	SMS	SIS	ELM	HSS	FDM	LOM
AVAILABILITY	56	56	32	56	56	40	56	48	56	56	56	64	40	48	64	64
MATERIAL PRICE	80	70	70	70	70	40	80	50	40	60	60	70	60	70	60	80
MANUFACTURING PRICE	40	40	50	60	70	60	80	70	60	40	70	50	50	70	50	60
ACCURACY	56	49	49	42	42	42	49	42	42	56	28	35	56	49	42	28
MECHANICAL RESISTANCE	42	36	42	36	48	36	30	36	36	24	42	48	24	36	36	48
DURABILITY	36	30	36	36	42	30	30	42	42	36	36	42	42	36	30	36
TIME NEEDED	48	64	56	56	48	56	56	48	64	48	32	64	48	64	40	40
SUM (PXG)	358	345	335	356	376	304	381	336	340	320	324	373	320	373	322	356
VTP	0,81	0,78	0,76	0,81	0,85	0,69	**0,86**	0,76	0,77	0,72	0,73	0,8	0,72	0,84	0,73	0,81

Table 2: Values of the product PxG in all the criterions in each process and their final VTP value

7 CONCLUSIONS

The document: Annex II, has justified the 3D PRINTER technology as the optimum RMS for UAV applications. The main reason has been the low cost of this system, see Table: 2.

The main conclusion of this document is that 3D printing is revolutionizing the manufacturing industries and Catalan industry must adopt it.

Annex I, the state of the art, has shown the feasibility of 3D printed, near to SLS, for UAV applications. Worldwide Engineering Universities and Aeronautical Industry have recently started to use this technology in the design process and low series of manufacturing.

SLS –second position in the take decision table– is also a powerful technology with high precision and mechanical properties, but more expensive than 3D Printers. However, the market explosion of 3D printers is generating a fast and huge improvement in 3D printing's features, which are improving much faster than SLS's ones.

For all these reasons, the study will be focused on 3D Printer technology.

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