Tank-automotive and Armaments Command

U.S. Army Armament Research, Development & Engineering Center

Rapid Prototyping Laboratory

Engineers Guidebook

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Introduction

This guide is being provided to the engineering community as a resource guide to Rapid Prototyping through Stereolithography. Included is background on the Stereolithography Process and its' Benefits, Services provided by the Lab, how-to information, Frequently Asked Questions, case studies/examples, Equipment Specifications, and Material Properties.

STEREOLITHOGRAPHY: What Is It? - What Can It Do For You?

What Is Stereolithography ?

Stereolithography is one of a number of methods that comprise a relatively new technology called Rapid Prototyping and Manufacturing. The first rapid prototyping systems became available in the late 1980's. Stereolithography, developed by 3D Systems, pioneered this technology.

Stereolithography is a rapid prototyping technique that actually creates a precise physical object from three-dimensional (3-D) CAD data. It is, in essence, a 3-D printing process that produces a solid plastic model. The process involves an automated laser beam that draws or prints cross sections of an object onto a photo-curable liquid plastic. Successive cross sections, each of which adheres to the one below it, are built one layer on top of another to form the part from the bottom up.

Benefits

The benefits of using Stereolithography are numerous. These benefits include:

- Accelerated conceptual design
- Quick turnaround of design iteration
- Reduced errors from incorrect design interpretation
- Early identification of manufacturing problems
- Increased product quality
- Hands-on marketing tool
- Reduced time-to-market

Listed below are some samples of items prototyped since 1992:

- Objective Individual Combat Weapon Concept
- Small Arms Weapons Components (mounts, buttstocks, mechanisms)
- EOD Training Aids
- Various Mortars and Mortar Components
- Optic Components
- Fuze Concepts and components
- Various Artillery and Tank Projectiles
- Manufacturing Process Concept Components
- Concept Weapon Systems (i.e. Crusader, Dragonfire, Atlas)
- Recoil Mechanisms

Some examples and case studies are presented in ***Appendix A.***

The SLA-250/SLA-3500 Stereolithography Apparatus (SLA) - How Do They Work?

The SLA-250 and SLA-3500 are the Stereolithography Apparatus' (SLA) which are currently in operation, here, at Picatinny Arsenal. In simple terms, how does it work?

The SLA's software first, interprets 3-D CAD data from a 3-D CAD system (i.e. ProEngineer and AutoCAD) and slices it into a series of thin horizontal layers. The SLA software also creates the desired operational parameters that provide the necessary control information to the SLA to make the plastic part. A controller then positions a vertical elevator housed inside a vat filled with liquid resin so it rests just below the surface. An optical scanning system directs a laser, which "draws" the image one layer at a time on the surface of the resin. As the laser beam strikes each layer, the liquid resin is converted to a solid plastic. The elevator then lowers the newly built layer, recoats it with a new layer of resin, and the process is repeated until the part is complete. A future article will describe in greater detail, how one gets from a 3-D CAD model to an actual physical 3-D object.

The Stereolithography Process - A More Detailed Look

The Stereolithography process is basically comprised of four major steps:

1. CAD Process
2. Part Preparation
3. Setup and Build
4. Post Processing.

CAD Process

The CAD process involves the utilization of a CAD system to structure the object/part data for use on the Stereolithography Apparatus (SLA). The process begins with a design created on a solid modeling CAD system. Pro/Engineer and AutoCAD 14.01 with Autodesk's Mechanical Desktop are two examples of available 3-D modeling software packages. It should be noted that a part could only be produced on the SLA from 3-D CAD data. The data generated being a clearly defined enclosed volume.

Once a CAD part is generated, the CAD system must convert the object to a format that can be interpreted for use by the SLA. This format is similar to a finite element analysis model consisting of triangular surface elements. The formatted output to be provided to the SLA workstation is known as an STL file. Some of the CAD systems in use at ARDEC which support the output file format required are Pro/Engineer, SDRC, and AutoCAD 14. Once an STL file is generated, it is then transferred over to the Stereolithography Labs workstation for preparation to be made on the SLA. See ***Appendix B*** on how to create and send an STL File with Pro/Engineer, as well as ,sending a file to the Lab for processing.

Part Preparation

The part preparation process basically involves four steps: part orientation, part support, operational parameter definition and part slicing. This process is performed utilizing the SLA manufacturers proprietary software, “Maestro” (Unix based) or “Lightyear” (NT Based), on the Labs SLA setup workstation.

Typically, three part orientation tasks are performed. These include: placing the part(s) in positive space, orienting the part(s) in such a way as to minimize support structure and positioning the part(s) to optimize the total number of parts to be made during the build process. At this stage of the part preparation process, if required, the parts can easily be scaled up or down in size.

Once oriented, the parts are then supported. Support structure is required to hold a part in place on the elevator tray and support any overhanging surfaces that are greater than 1/8" at any angle less than 50 degrees from the horizontal. Support structures are basically thin vertical webs.

Support structures are generated utilizing 3D Systems "Maestro" or “Lightyear” Software. This software automatically analyzes a part to determine what support structure is needed and then supports it based upon known workable default parameters or user tailored parameters. Supports are usually generated in a matter of minutes.

The third step of the part preparation process involves defining operational parameters for the SLA. These parameters which are defined on a spreadsheet include: part build layer thickness (.006 in), resin shrinkage compensation for increased part dimensional accuracy, resin specific parameters (i.e. laser overcure depth), settling time between layers and wiper arm start point and sweep pattern. These parameters are usually tailored by the operator, based on information provided by the manufacture and hands-on experience.

The final step, part slicing, involves the execution of a software program that utilizes a sophisticated, proprietary algorithm to slice the STL file(s) into cross sections typically between .006 in. in thickness. During this process, several other data files are created from operator input that will be utilized as operational instructions for the SLA-250. In the case of the SLA-3500, only one file is generated.

Setup and Build

The third step of the Stereolithography Process involves the initialization and set up to build parts on the SLA. Prior to initializing the build process, the laser is warmed up for approximately 15 minutes. The time required allows the laser to stabilize and reach maximum output capacity. During this warm-up period three tasks are performed: transfer of slice and operational data files from the build setup workstation to the SLA control computer, lowering of platform into the vat and resin level adjustment. This process exemplifies that of the SLA-250. The SLA-3500 does not require a warm-up, since its’ laser is solid state. Therefore, after the build data is transferred, the operation starts once the platform is lowered and resin level adjustment is made.

The build process of the SLA software is now activated by the operator which begins building the part by moving a focused laser beam across the surface of the vat of resin. The laser draws the first support cross section, which adheres to the platform. Typically, .4 inches of base support structure is built up before initiating the part build itself and whatever additional supports are needed for overhanging surfaces.

When creating each cross section of the part itself, the inside and exterior boundaries are solidified along with the internal crosshatch. Once the laser cures a cross section, the elevator dips the part below the liquid resin surface, the platform then adjusts itself for the next layer and a wiper arm sweeps across the platform to remove excess resin from the coated part cross section. The resin is allowed to settle for a short period of time and the process of the laser curing a cross section is repeated. The laser not only cures each new layer of resin, but actually cures down into the layer below it so that they may become attached. This process is repeated until all layers have been drawn to form the 3-D object.

The SLA is designed for round-the-clock operation and is usually left unattended while the part is building. When the last layer has been printed, the completed part is raised out of the vat and the laser turned off automatically.

Post Processing

The final step, post processing, involves cleaning, UV-curing and final finishing of the part. First, the part is raised out of the vat and as much liquid resin as possible is allowed to drain off the part. The part and platform are then removed from the process chamber and the remaining excess liquid resin is removed by rinsing in a solvent with the aid of an ultrasonic cleaner. The part is then removed from the platform and the support structure is removed from the part. Support structure is usually removed with the use of a scrapper or Hobby knife. Once the support structure is removed, the part is rinsed in water to remove the solvent and any residual particles or supports that are clinging to the part. The part is then towel dried.

Post curing is next. Here the part is placed into the Post Curing Apparatus (PCA) where it is exposed to low intensity UV light to solidify any remaining trapped liquid and increase the strength of the part. Post curing is required, since a part is only about 90% cured by the SLA's ultraviolet laser when it is built.

The final cured part can be finished in a number of ways. Finishing techniques, such as sanding, sand blasting, polishing, painting, or dyeing, can be applied. The Stereolithography Lab is equipped with the majority of items required for finishing which include a sand blaster, Belt/Disc sander and access to a lathe.

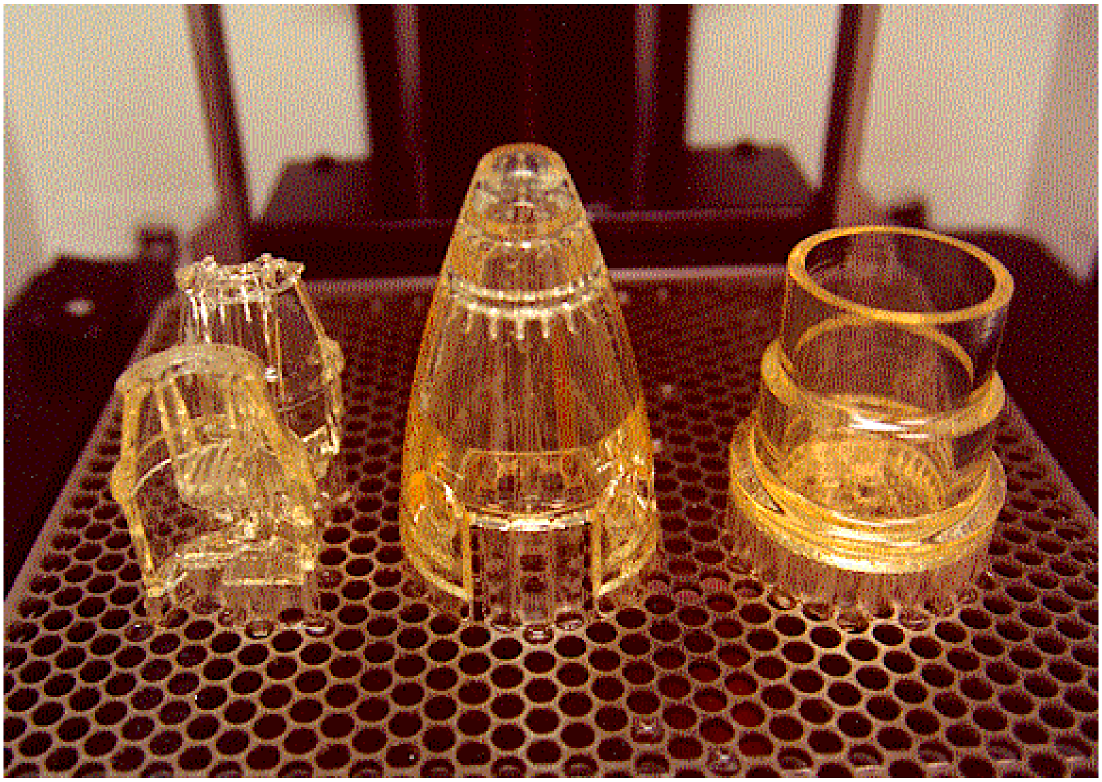
Rapid Prototyping Labs Services Provided

The Lab currently occupies 1520 square feet in the north end of Building 65 of the CCAC. It is operated and maintained by CCAC. The Lab can provide services to other government organizations, ARDEC engineering personnel, ARDEC contractors and academia. Some Frequently Asked Questions about the Lab and the Stereolithography process are presented in ***Appendix C***. The Labs services include:

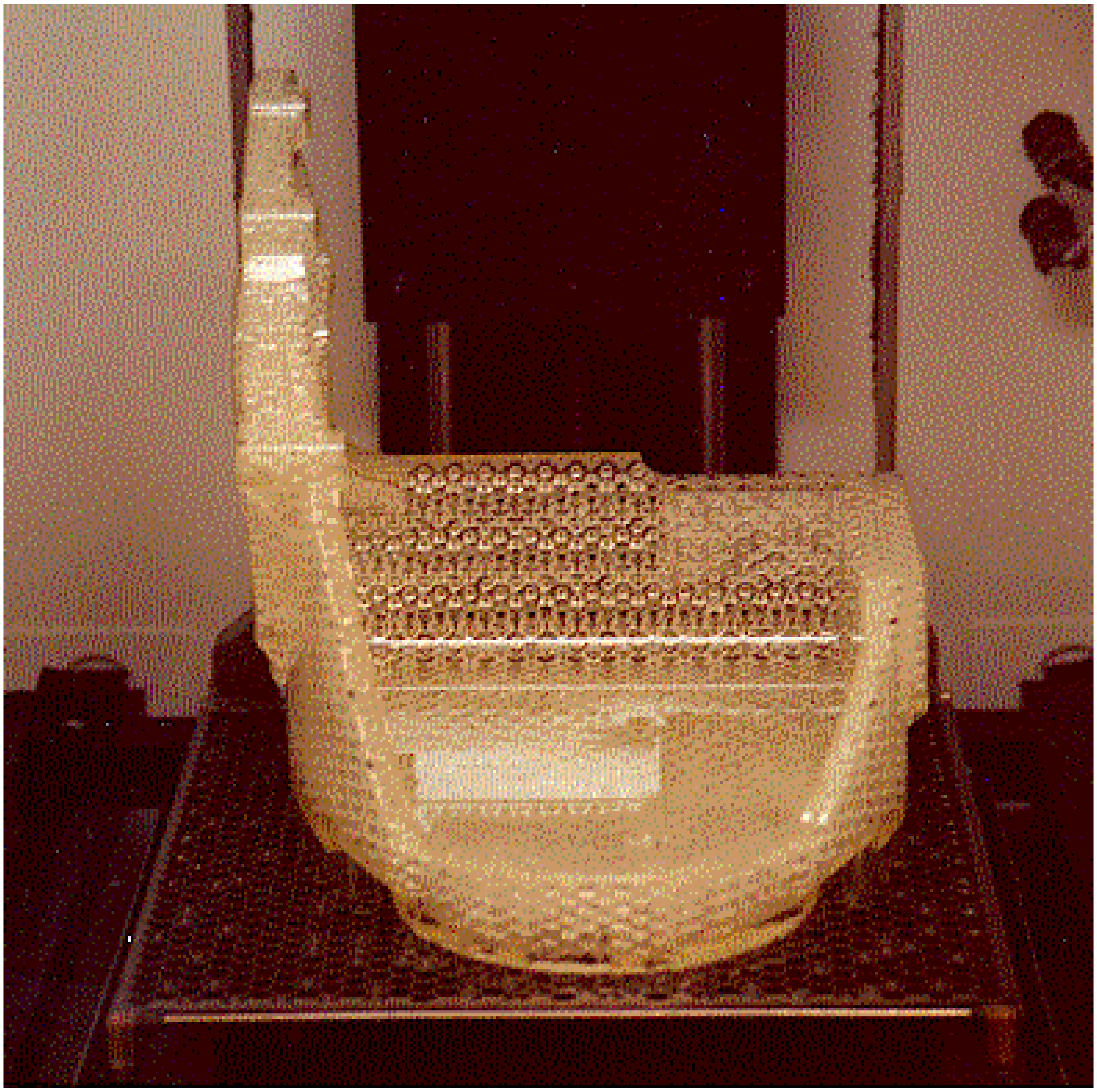
- Rapid Prototyping through Stereolithography
- Investing Casting through Stereolithography
- RTV Molding
- 3-D CAD Services

Rapid Prototyping through Stereolithography

The Lab utilizes 3D Systems, Inc. SLA-250 and SLA-3500 Stereolithography Apparatus' to create 3-Dimensional prototypes directly from CAD files (.STL format). Both SLA's create two part styles, ACES and QUICKCAST. The ACES is a solid plastic part style and QUICKCAST is basically a honeycomb pattern (80% air) which can be utilized as an investment casting pattern. These are shown below in the following two examples:



ACES Part Style



QUICKCAST Part Style

System Capabilities

(1) SLA-250

The SLA-250 pictured below has the capability of providing both ACES and QUICKCAST part styles. The SLA-250 can produce individual parts within a maximum envelope of 10"X10"X10". Larger parts can be made through assembly of smaller parts designed to interface/interlock with each other in the CAD modeling process. The SLA-250 has a part creation dimensional accuracy relative to its' CAD Model of better than .005"

An interchangeable vat system provides the capability of utilizing other resins. It should be noted that a changeover is expensive and requires additional turnaround time. Cibatool SL-5170 is currently in use. In the future, the Lab will be converting over to SL-5220. Properties and applications information of these materials is provided in ***Appendix D.***

ARDEC SLA-250

(2) SLA-3500

The SLA-3500 pictured above has the capability of providing both ACES and QUICKCAST part styles. The SLA-3500 can produce individual parts within a maximum envelope of 13.8”X13.8”X15.7”. Larger parts can be made through assembly of smaller parts designed to interface/interlock with each other in the CAD modeling process. The SLA-3500 has a part creation dimensional accuracy relative to its’ CAD Model of better than .005”

The SLA-3500 utilizes Cibatool SL5510 Resin. Properties and applications information can be found in ***Appendix D.***

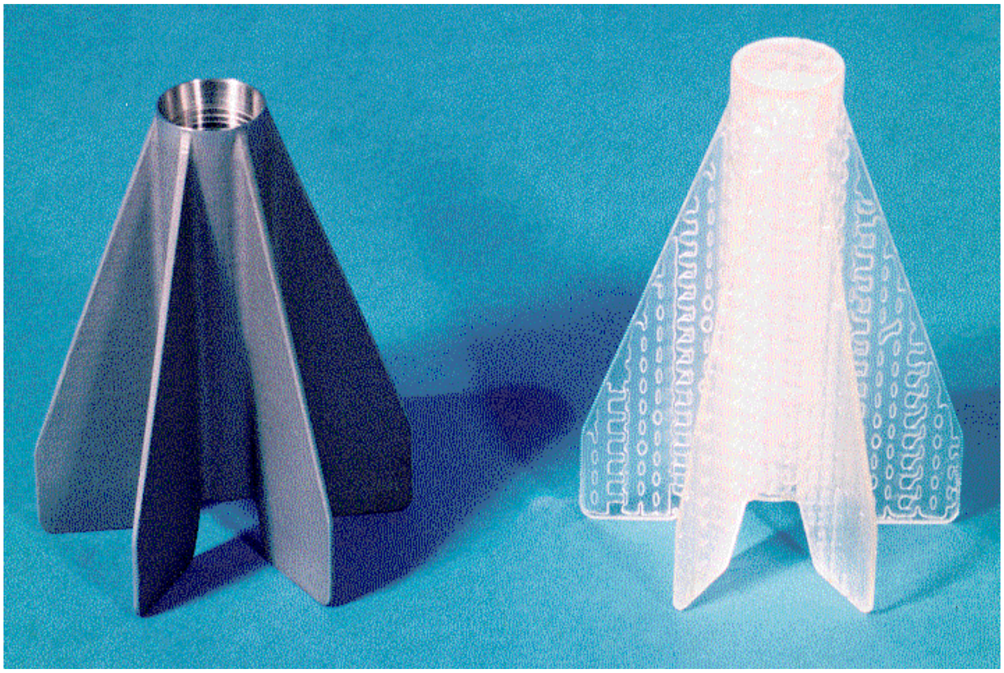
ARDEC SLA-3500

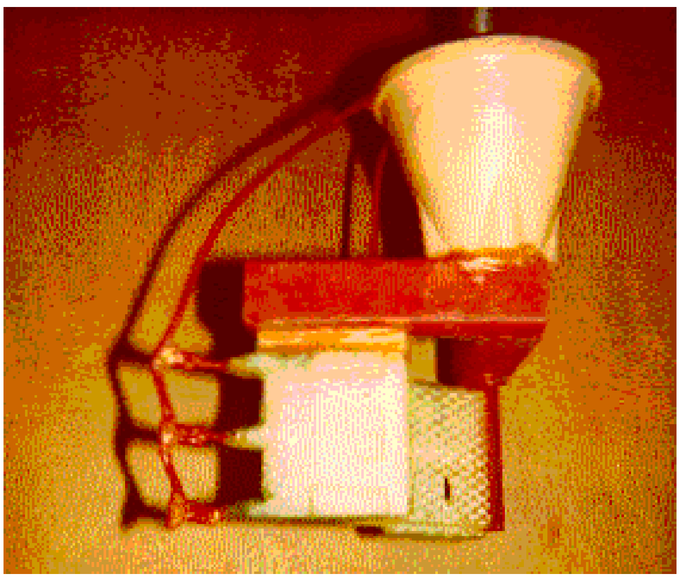
Rapid Prototyping Network

The Lab has networked itself with other government facilities to provide additional capabilities to a customer, as needed. The Lab currently has access to a SLA-250 and SLA-3500 with injection molding capabilities at Benet Labs, an SLA-500 (20"X20"X20") at Watervliet Arsenal and a LOM's at TARDEC, Warren MI. and Rock Island Arsenal, Ill.

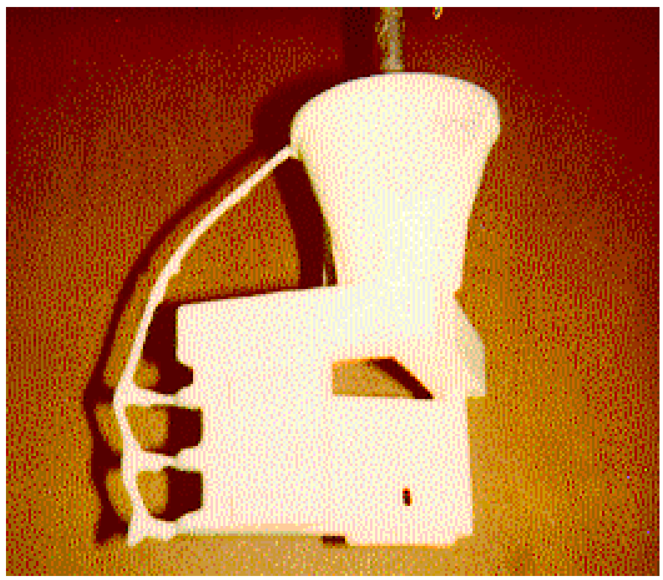
Investment Casting Through Stereolithography

Investment Cast prototypes are possible utilizing a Stereolithography QUICKCAST part as the casting pattern, limited quantity prototypes from steel, aluminum and assorted other metals can be fabricated at relatively low cost.





Quickcast part set up with gating



Quickcast part coated with ceramic shell

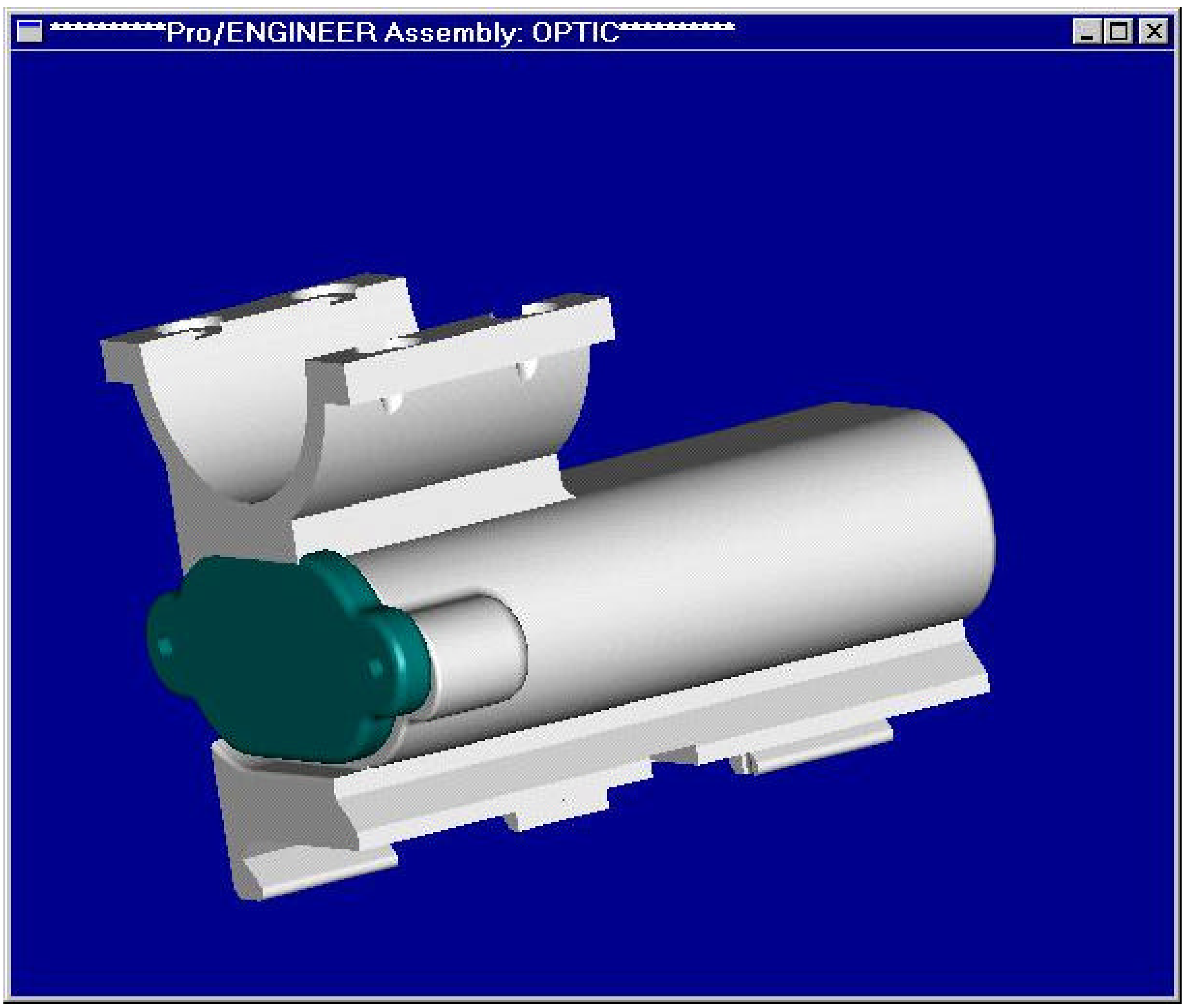
RTV Molding

The Lab has the capability of providing prototypes of various material properties other than that of a typical Stereolithography prototype through the use of RTV Silicone molding techniques. Utilizing a Stereolithography generated prototype as the mold pattern, prototypes can be made from an assortment of polyurethanes to acquire the desired properties.

3-D CAD Services

3-D CAD Services are available to customers who do not have the capability or time to provide the necessary file format for Stereolithography prototyping. The Lab utilizes Pro/ENGINEER, Version 18 CAD software. Other CAD related services available through the Lab include:

- Part Design and Assemblies
- Engineering Drawing Output
- Dimensional Analysis
- Mold Design
- CNC Tool Path Design
- Finite Element Analysis



APPENDIX A

Case Studies/Examples

Case # 1 - Advanced Medium Machinegun (AMMG) Program (1993)
Case # 2 - 120 mm Tank Cartridge Container Standardization (1994)

Example # 1 - XM194 Recoil System (1995)
Example # 2 - Electric Drive Tank Turret Concept (1995)
Example # 3 - XM984 Ext. Range 120mm Mortar (1999)
Example # 4 - Dragonfire (1998)
Example # 5 – Advanced Medium Machinegun Concept (1994)

Case #1 - Advanced Medium Machinegun (AMMG) Program (1993)

The AMMG Program included the development of a state-of-the-art light weight ground mount. The development effort for this mount was patterned after the prototype development for the XM192 Ground Mount for the M249 SAW.

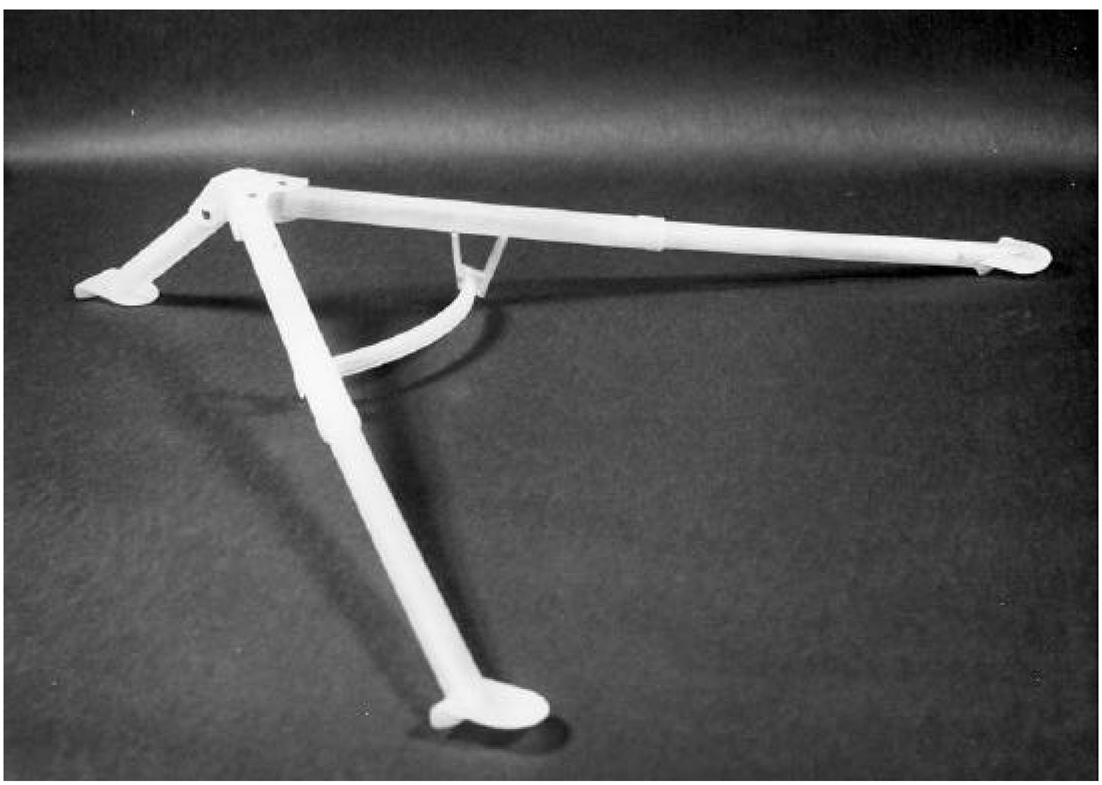
Stereolithography was utilized to fabricate a prototype ground mount to investigate the performance of the design configuration. As a first design iteration, this prototype identified the following design concerns:

1. The leg lock spring design utilized on the prototype when actuated demonstrated that it may roll out of position.

2. The angle of traverse bar/bracket interface could be modified to provide a more compact folded mount size.

This prototype also provided verification of the drawing package , operation of the traverse bar lock, leg locks, and mount folding operation. The design questions answered by this first design iteration prototype would normally have been addressed by fabricating a full scale metal prototype. In comparison, the XM192 Ground Mount development effort required more than four months to manufacture the first prototype at a cost of $40,000 while the AMMG Ground Mount produced with Stereolithography was fabricated in about a week and cost less than $4,000. As you can see, Stereolithography provided an effective means of addressing design concerns for a fraction of the time and cost normally associated with the manufacture of prototype hardware.

For further information contact Frank Dindl, X6761



Case #2 - 120 mm Tank Cartridge Container Standardization (1994)

The purpose of this project was to create an adjustable projectile support to accommodate the variety of 120mm rounds in the PA116 square rimmed metal container. This programs intent was to solve a logistical burden identified during Operation Desert Storm. Having one adjustable nose support in lieu of six unique nose supports for the variety of 120mm projectiles.

Stereolithography was utilized to fabricate two different adjustable projectile support design concepts. One being a threaded adjustable support and the other a pinned position adjustable support. The two concept models were utilized to demonstrate the best design for field use, as well as identifying design deficiencies prior to purchasing field useable prototypes for further evaluation.

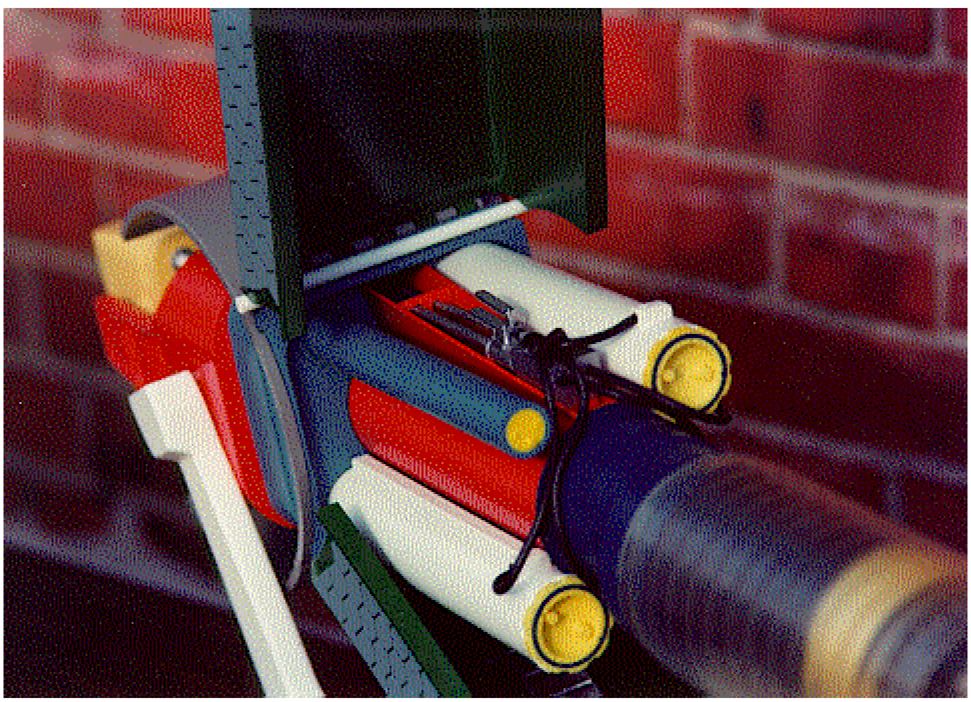
Conventional prototyping of the nose support systems would involve the purchase of two polyethylene logs and machining them to the desired design configuration. This was the case for the first iteration of 120mm nose supports, where materials and machining amounted to $9,500.

To illustrate Stereolithography's cost effectiveness, the two prototype designs, a modified insert for the pinned position adjustable support system and an additional copy of the pinned position adjustable support system were provided at a cost of $6,500. Some machining was required for the threaded version, as well, at an estimated cost of $500. As one can see, a cost savings of at least $3,000 dollars is realized utilizing Stereolithography over conventional prototyping means.

For further information contact Ed Zuckerman, X2814

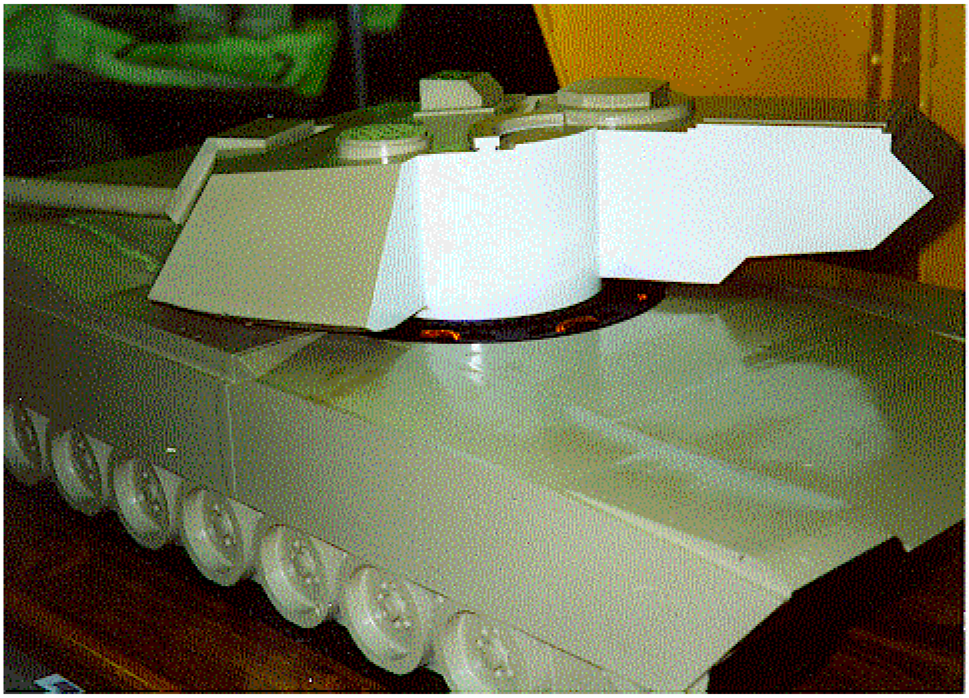
Example # 1 – XM194 Recoil System (1995)

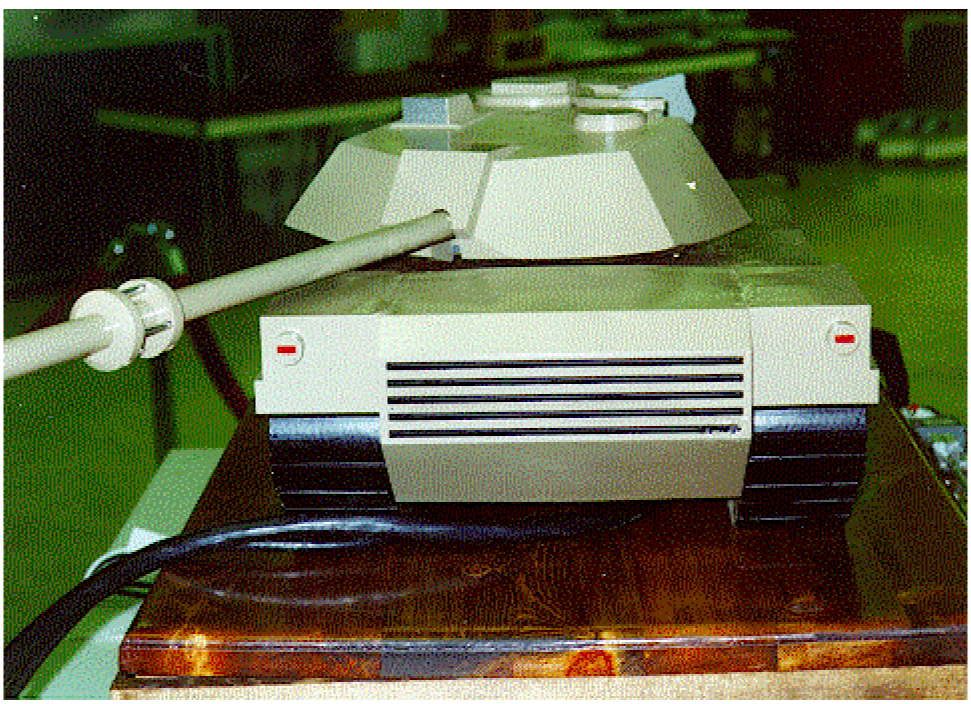
For further information contact Tony Franchino, X3254



Example # 2 - Electric Drive Tank Turret Concept (1995)

For further information contact Mike Mattice, X7287





Example # 3 - XM984 Ext. Range 120mm Mortar (1999)

For further information, contact Gordon Cheung, X2940

Example #4 – Dragonfire (1998)

For further information contact Tony Franchino, X3254

Example #5 – Advance Medium Machine Gun Concept

For further information, contact Frank Dindl, X6761

APPENDIX B

Creating an .STL File with ProEngineer

And

How to Send an .STL File to the ARDEC Rapid Prototyping Laboratory

Creating an .STL File with ProEngineer

Once a design has been modeled on Pro/ENGINEER, outputing a file for use on the Stereolithography Apparatus (SLA) is quite easy. The file format required is known as an STL (for StereoLithography) file. Because no acceptable CAD file format was available, 3D Systems, the designers of the SLA, had to develop a 3D file format that would provide an unambiguous description of a solid part that could be interpreted by the SLA's software.

What is an STL file?

An STL file is a "tessellated surface file" in which geometry is described by triangles laid onto the geometry's surface. Associated with each triangle is a surface normal, which is pointed away from the body of the part. This format could be described as being similar to a finite analysis model, as well.

How to create an STL file

Because all surfaces are defined by triangles, the STL file format is by definition a faceted file format. When creating an STL file, care must be taken to generate the file with sufficient density so that the facets do not affect the quality of the part built by the SLA.
In order to create an STL file on Pro/ENGINEER, the Pro/INTERFACE module is required. This module provides the user with the ability to easily generate high quality STL files. With the part that you need an STL file generated of in the current user window, listed below are the appropriate steps when using Pro/ENGINEER 20:

1. Select "Export" from the "File" menu.

2. Select "Model". Th Menu Manager with the Export Menu will usually appear to the right of the model.

3. Select "STL" from the "Export" menu.

4. Select "Chord Height" and enter the value of 0". Using this value as your entry will prompt the software to tell that the value is unacceptable and tell you what the allowable range is. Select the lowest value in the range for the highest part quality. The chord height setting specifies the maximum distance between the curved surface in a Pro/ENGINEER model and the faceted surface that represents it in STL file format. A smaller chord height value will yield an STL file with a larger number of smaller facets.

5. Listed beneath the "Chord Height" is the "Angle Control". The Angle Control setting regulates how much additional improvement will be provided along curves and small radii. A setting of 0 will provide no additional improvement, while a setting of 1 will provide maximum additional improvement, Pro/ENGINEER uses a default setting of ".5". This setting in conjunction with the minimum chord height selection for all practical purposes is more than sufficient for providing a good STL file, therefore, there is no need to change the Angle Control.

6. "STL Binary" is highlighted as the default format in which the STL file is written. The binary format is the only format the Stereolithography Lab will accept for use on the SLA.

7. Select "Output" from the STL menu.

8. Select "Default" from the "Get Coord System" menu. Since it is not difficult to reposition and reorient a part with SLA setup software, the default coordinate system is sufficient for generating the STL file.

9. The Pro/ENGINEER software will then prompt the user to "Enter triangulation file name". The default is "filename.stl" where filename is the name of the part or assembly is acceptable. Once the name is accepted or entered, the process of triangulating the file will begin.

10. If any portion of the geometry is in negative space with respect to the default coordinate system, a message will appear that reads "Some points have non-positive coordinates. Continue? [N]:". Enter "y" to continue the process.

11. When the process is complete, a message reading "XXXX triangles have been written in output file filename.stl." At this point, the triangulated file will be displayed on the screen for visual inspection. A shaded three dimensional object showing the tessellated surface is shown.

This completes the process for creating the STL file format required for the SLA to create an actual physical plastic part from a three-dimensional model created using Pro/ENGINEER.

How to Send an .STL File to the ARDEC Rapid Prototyping Laboratory

There are three acceptable methods of downloading STL files(s) to the Labs workstation for use on the SLA. Methods 2 and 3 are preferred.

Method #1 - Copy the file to a tape and physically bring or mail the tape to the Lab.

Method #2 - Transfer the file to the Labs' workstation. This method requires downloading through the Picatinny Arsenal Network.

To transfer an STL file over the network, you will need to access a shell window on the CAD workstation to utilize "ftp" in the Unix environment. The procedure is as follows:

1. At the Unix prompt, enter "ftp (lab workstation IP address)". Contact the lab for IP address. This accesses the SLA workstation that you need to transfer the STL file to. Once connected, you will be prompted to enter a name and password to allow access. A special directory has been set up on the slice workstation to transfer STL files to. You will need to contact the Lab for the proper login name and password to access this directory.

2. At the "ftp" prompt only a few command entries are required and are as follows:

    a. Enter "bin" for binary file transfer.

    b. Enter "send filename.stl" to send STL file

    c. Enter "send nextfilename.stl" etc. for each additional STL file.

    d. Enter "bye" to get out of "ftp" mode.

Method #3 - Send as an attached file to an e-mail message (i.e.- MS EXCHANGE or CCMAIL). The e-mail message should include a list of the files attached. Files can be sent by e-mail to any one of the Labs contacts***.***

This is all that is required to send an STL file to the SLA. From here your STL file is in the Labs hands.

APPENDIX C

Frequently Asked Questions

Frequently Asked Questions

1. What is Stereolithography?

Refer to page 3.

2. What is a .STL file?

Refer to Appendix B.

3. How do I create and send a .STL file?

See Appendix B.

4. How large can an individual Stereolithography part be?

There really is no limit as to how large an individual part can be made. The SLA-250 and SLA-3500, however, can only physically make an individual piece within the volume of the SLA vat. 10"X10"10" for the SLA-250 and 13.8"X13.8"X15.7" for the SLA-3500. A larger part, however, will require additional steps. In order to make a large part; the customer will need to break the part down into smaller pieces that will fit within the volume of the vat. This can be accomplished in CAD by breaking the part into smaller pieces making sure alignment pins/holes are provided in order to accurately align the pieces prior to gluing together with resin or Cyanoacrylate glue. Once the pieces are made, the customer will need to provide the .STL files of the individual pieces.

It should be noted, that if the customer does not need a full scale prototype, the SLA setup software can automatically scale down a prototype to fit within the volume of the SLA-250 and SLA-3500 vat.

5. Is the finished part machineable?

Yes, finished SLA built parts are machineable. The customer may choose to drill, thread, sand or cut an individual part. It should be noted that all threaded surfaces would need to be created with the use of a tap or die.

6. How long does it take the SLA-250/SLA-3500 to build a part?

There is no sure-fire way of determining how long it takes the SLA to make an individual part. It can take as little as hours to as long as days. Experiences to date have ranged from one hour to 6 days. Factors which determine how long a part takes to build include the parts height, volume, cross-sectional layer thickness, support structure and complexity. Our experience, however, has indicated that the shortest possible time to build a part can be determined by multiplying the number of slice cross-sectional layers by 1 minute/layer. Large cross-sectional areas or complex parts requiring an extensive support structure will take longer, usually several minutes per layer.

7. How accurate is a SLA part in relationship to its CAD model?

Test parts have indicated that the SLA is capable of reproducing a 3-D CAD model dimensionally to within three-thousandths of an inch.

8. Which CAD programs support the .STL file format?

According to 3D Systems, about 98% of the 3-dimensional solid modeling CAD systems support the .STL file format. We are currently only aware of 3 CAD packages available at ARDEC, which support the .STL file format. They are: Pro/Engineer, SDRC IDEAS, and AutoCAD Rel. 14.01 with Autodesk's Mechanical Desktop.

9. What materials can prototypes be investment cast out of using Quickcast as a pattern?

Materials used in Investment Casting at Rock Island Arsenal Foundry are listed below:

Material	**Types**
Steel	1020, 1030, 1040, 4140, 4130, 4340, 8620
Stainless Steel	17-4, 95-14, 330, 347, CF16F, CY40 (Monel)
Aluminum	A356, 355
Bronze	862, 865, 964
Other	Stellite 21 (Co-Cr)

There are, of course, many more materials that can be utilized in investment casting.

APPENDIX D

Resin Properties

SL5170 Resin Properties (SLA-250)
SL5220 Resin Properties (SLA-250)
SL5510 Resin Properties (SLA-3500)

SL5170 Resin

SL 5170 Multi-purpose Material

Cibatool SL 5170 is an epoxy-based resin that offers the greatest degree of accuracy available in any rapid prototyping process. Parts are strong, durable and multifunctional. SL 5170 fits a wide range of applications from form, fit and function to optical stress analysis, and as masters for secondary tooling applications. SL 5170 has several material properties that exceed or are comparable to medium-impact polystyrene.

Ideal for:

- Optical stress analysis
- Investment casting patterns
- Snap-fit assemblies
- Concept models
- Visual models
- Working prototypes

All information extracted from 3D Systems Website. SL5170 is the resin in use on the SLA-250.

Typical Properties: Liquid Resin SL 5170

Measurement	Condition	Value
Appearance		Clear yellow
Density	@ 25°C (77°F)	1.14 g/cc
Viscosity	@ 30°C (86°F) @ 35°C (95°F)	165-195 cps 125 cps
Penetration Depth (D_P)*		4.8 mils
Critical Exposure (E_c)*		13.5 mJ/cm^2
Part building layer thickness		0.10 mm (0.004 in)* 0.125 mm (0.005 in)*

Typical Properties: Post Cured Part**

Measurement	Method	Value
Tensile strength	ASTM D 638	59-60 N/mm2 (8,600-8,800 psi)
Tensile modulus	ASTM D 638	2,400-2,500 N/mm2 (542-603 Ksi)

Elongation at break	ASTM D 638	7-19%
Flexural strength	ASTM D 790	107-108 N/mm2 (15,500-15,700 psi)
Flexural modulus	ASTM D 790	2,920-3,006 N/mm2 (423-436 Ksi)
Impact strength, notched	ASTM D 256 DIN 53455/ISO R 527	27-30 kJ/m2 (0.5-0.7 ft-lb/in)
Hardness	DIN 53505	85 Shore D
Glass deflection temp	DMA, 4°C/min	65-90°C (149-184°F)
Heat deflection temp	ASTM D 648 @ 66 psi @ 264 psi	55°C (131°F) 49°C (120°F)

SL5220 Resin

SL 5220 Multi-purpose Material

Cibatool SL 5220 is an epoxy-based resin that offers parts that are strong, durable and multifunctional. SL 5220 fits a wide range of applications from form, fit and function to optical stress analysis, and as masters for secondary tooling applications. SL 5220 is accurate and is one of the fastest materials in its machine class, providing throughput up to two times faster than SL 5170 for the same layer thickness.

Ideal for:

- Working prototypes
- Visual models
- Optical stress analysis
- Multipurpose models
- Form, fit and functionality
- Investment casting patterns
- Prototype tooling
- Production tooling master patterns

Information provided is extracted from 3D Systems Website. The Lab intends to convert over to this resin in the future on the SLA-250.

Typical Properties: Liquid Resin SL 5220

Measurement	Condition	Value
Appearance		Clear
Density	@ 25°C (77°F)	1.14 g/cc
Viscosity	@ 30°C (86°F)	275 cps
Penetration Depth (D_P)*		5.6 mils
Critical Exposure (E_c)*		9.0 mJ/cm^2
Part building layer thickness		0.10 mm (0.004 in)* 0.15 mm (0.006 in)*

Typical Properties: Post Cured Part**

Measurement	Method	Value**
Tensile strength	ASTM D 638	62 Mpa (9,000 psi)
Tensile modulus	ASTM D 638	2,703 Mpa (392,000 psi)

Elongation at break	ASTM D 638	8.3%
Flexural strength	ASTM D 790	94 Mpa (13,700 psi)
Flexural modulus	ASTM D 790	2,951 Mpa (428,000 psi)
Impact strength, notched	ASTM D 256	37 J/m (0.7 ft-lbs/in)
Hardness	DIN 53505	86 Shore D
Glass deflection temp	DMA, E" peak (UV postcure) ASTM D 648 @66 psi (UV postcure) @66 psi [UV+2 hrs @80°C (176°F)]**	53°C (127°F) 46°C (115°F) 75°C (169°F)
Heat deflection temp	@264 psi (UV postcure) @264 psi [UV+2 hrs @80°C (176°F)]**	42°C (108°F) 62°C (144°F)

SL5510 Resin

SL 5510 Multi-purpose Material

Cibatool SL 5510 is a versatile, accurate, dimensionally stable and highly productive material. For the most demanding applications, SL 5510 sets the industry standard for part accuracy.

Ideal for:

- High humidity applications
- Working prototypes
- Visual models
- Prototype tooling
- Production tooling master patterns
- Investment casting patterns
- Fluid flow studies of complex internal passages

Information provided is extracted from 3D Systems Website. SL5510 is the resin utilized by our SLA-3500.

Typical Properties: Liquid Resin SL 5510

Measurement	Condition	Value
Appearance		Clear
Density	@ 25°C (77°F)	1.13 g/cc
Viscosity	@ 30°C (86°F)	180 cps
Penetration Depth (D_P)*	SLA350/3500 SLA 5000	4.1 mils 4.3 mils
Critical Exposure (E_c)*	SLA350/3500 SLA 5000	11.4 mJ/cm^2 11.2 mJ/cm^2
Part building layer thickness		0.05 mm (0.002 in)* 0.10 mm (0.004 in)* 0.15 mm (0.006 in)*

Typical Properties: Post Cured Part

Measurement	Method	Value
Tensile strength	ASTM D 638	77 Mpa (11,100 psi)
Tensile modulus	ASTM D 638	3,296 Mpa (478,000 psi)
Elongation at break	ASTM D 638	5.4%
Flexural strength	ASTM D 790	99 Mpa (14,400 psi)

Flexural modulus	ASTM D 790	3,054 Mpa (443,000 psi)
Impact strength, notched	ASTM D 256	27 J/m (0.5 ft-lbs/in)
Hardness	ASTM D 2240	86 Shore D
Glass deflection temp	DMA, E" peak (UV postcure) ASTM D 648	68°C (154°F)
Heat deflection temp	ASTM D 648 @66 psi @264 psi	50°C (122°F) 43°C (109°F)
	@66 psi (UV postcure)	62°C (144°F)
	@66 psi [UV+2 hrs @80°C (176°F)]**	87°C (189°F)
Heat deflection temp	@264 psi (UV postcure)	53°C (127°F)
	@264 psi [UV+2 hrs @80°C (176°F)]**	76°C (169°F)

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