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Fused Deposition Modeling – A Rapid Prototyping technique for Product Cycle Time Reduction cost effectively in Aerospace Applications

Prof. Deepa yagnik
Mechanical Engg. Dept. Institute of Diploma Studies, Nirma University, Gujarat, India

ABSTRACT: *Rapid Prototyping (RP) is the term given to a set of processes that can quickly fabricate any given three-dimensional object into a model or prototype, directly from a CAD file via the additive deposition of individual cross-sectional layers of the part. Over the years, RP has evolved from producing prototypes for form, fit and functional testing to producing final end products for functional use. FDM, a RP technique has made its mark for providing cost effective product along with making impossible geometries possible. It also confirms performance prior to implementation. Fused deposition Modeling is being used to shorten and simplify the product development cycle cost efficiently and act as ideal method for many applications including aerospace, medical, automobile and consumer products etc. This Paper Focus on Fused Deposition Modeling (FDM) Technique, Use of FDM for Aerospace applications with a case study of Aernautics Engineering depecting FDM as sole way for product cycle time reduction cost effectively. (courtsey DRDO & Stratasys).*

Keywords *- Fused Deposition Modeling (FDM), Rapid Prototyping (RP), Aerospace application, Kaveri engines*

I. INTRODUCTION

In recent years, global markets have led to a fundamental change in product development. Today it is very important to guide a product from concept to market quickly and inexpensively. Rapid prototyping (RP) is a method to make these prototypes much quicker and also more cost-effective.

Rapid prototyping was introduced in late 1980's. Rapid Prototyping can be defined as a group of techniques used to quickly fabricate a physical working model / component layer by layer (additive deposition) of a part or assembly using 3-D CAD data.

RP is the next frontier for researchers, publishers & users of advance technologies. This Paper will show how FDM technology that leads RP has not only proven to be cost effective but also evolved as unique unavoidable need for many applications and research studies.

II. OVERVIEW OF RAPID PROTOTYPING

RP technologies is grouped according to their fundamental metal deposition, working principles as seen in Fig:1

FDM Technology was invented about two decade ago and has continued to lead RP revolution ever since. Even today FDM is most widely used RP technique.

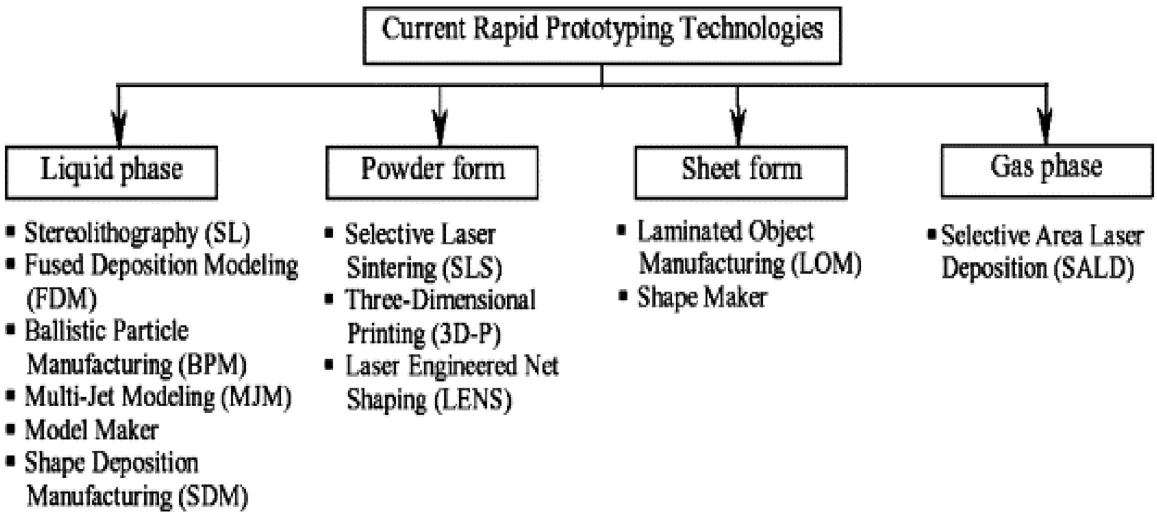


Fig:1 Classification of Rapid Prototyping Techniques

Global Scenario of Fused Deposition Modeling

Stratasys has got more than 60% market share of FDM in India and having more than 200+ FDM Systems Installed in Indian Market in various segments like Education, Defence, Government, Automotive, Aerospace, Consumer Goods and Heavy Industries. Balance 30% market share is of other RP Technologies.
Globally Stratasys (FDM) has more than 45% market share.

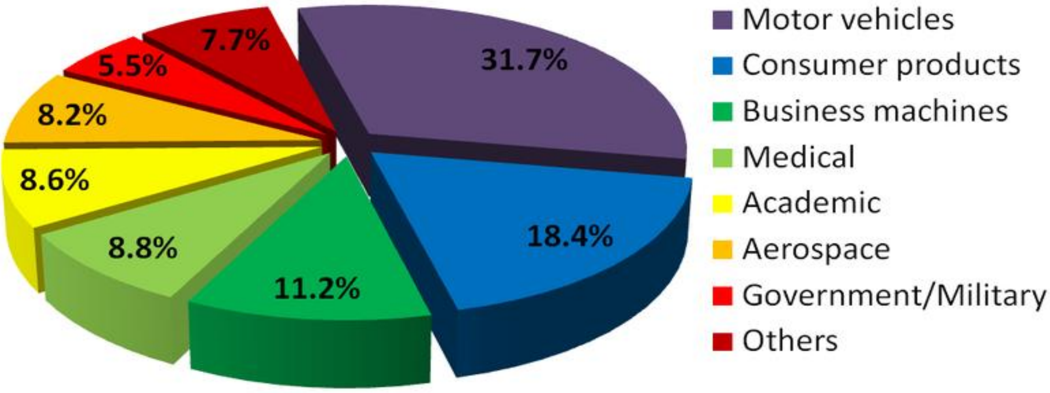


Fig: 2 Percentage use of rapid prototyping worldwide

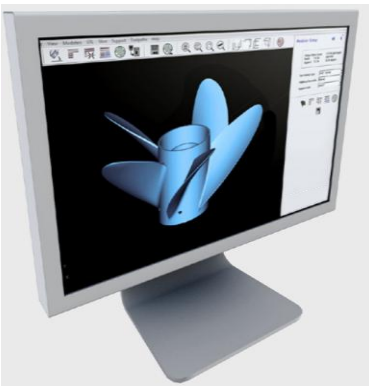
FUSED DEPOSITION MODELING

Fused deposition Modeling (FDM) was developed by Scott Crump, the founder of Stratasys. It was commercialized by Stratasys in 1991.

Fused Deposition Modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications.

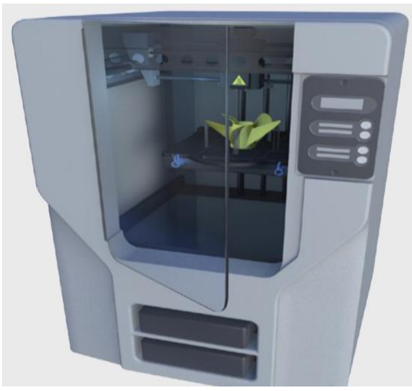
FDM Process is categorized by three distinct steps:

Step1 Pre-Processing



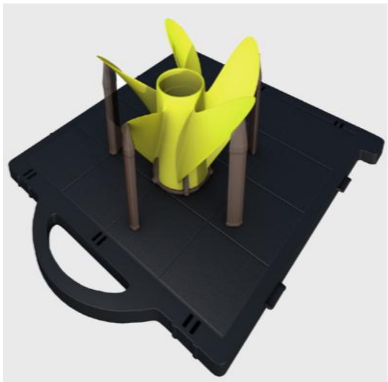
A CAD model is constructed,then converted to STL format ready for FDM process.

Step2 Production



FDM machine processes .STL file by creating sliced layers of the model
The first layer of the physical model is created. The model is then lowered by the thickness of the next layer, and the process is repeated until completion of the model

Step3 Post-Processing



The model and any supports are removed by washing or stripping it away. The surface of the model is then finished and cleaned.

2.1 How FDM Works?

3D printers that run on FDM Technology build parts layer-by-layer by heating thermoplastic material to a semi-liquid state and extruding it according to computer-controlled paths.

FDM uses two materials to execute a print job: modeling material, which constitutes the finished piece, and support material, which acts as scaffolding. Material filaments are fed from the 3D printer's material bays to the print head, which moves in X and Y coordinates, depositing material to complete each layer before the base moves down the Z axis and the next layer begins.

Once the 3D printer is done building, the user breaks the support material away or dissolves it in detergent and water, and the part is ready to use.

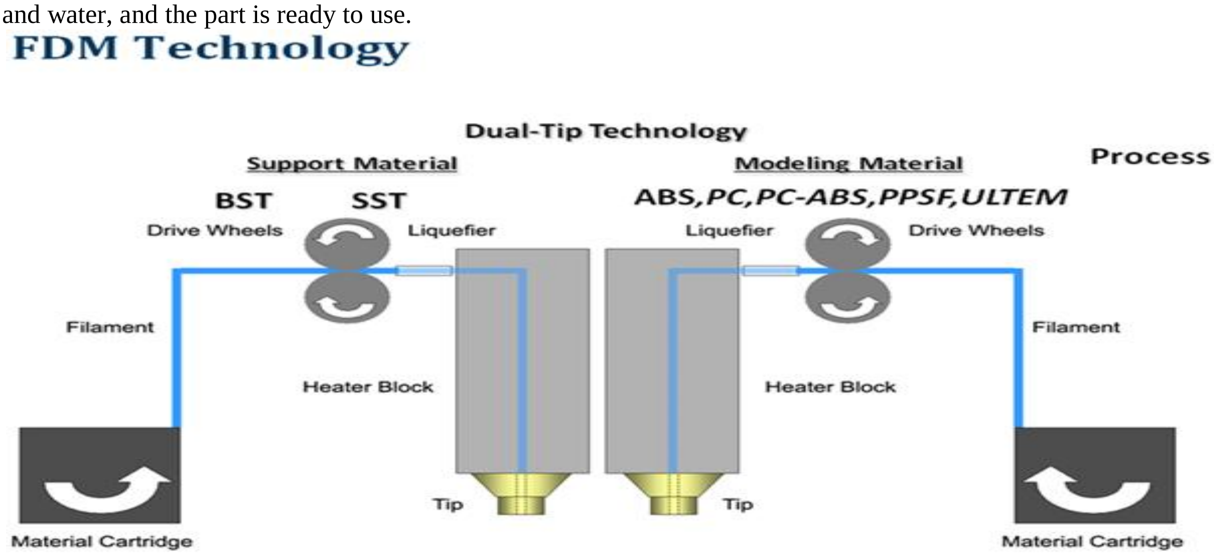


Fig: 3 FDM Working Principle

2.2 Benefits of FDM

FDM is a clean, simple-to-use, office-friendly 3D printing process. Thermoplastic parts can endure exposure to heat, chemicals, humid or dry environments, mechanical stress. Soluble support materials make it possible to produce complex geometries & cavities that would be difficult to build with traditional manufacturing methods.

APPLICATION OF FDM IN AEROSPACE

Aerospace industries are employing FDM technology for endless applications as it gives most flexibility with a variety of thermoplastics designed for aerospace applications.

Although the possibilities are endless for product development and manufacturing, most applications fall in four main categories: Concept Models, Functional Prototypes, Manufacturing Tools, Finished end use parts.

Aerospace icons like NASA & Piper Aircraft employ the most exciting FDM (3D printing) applications in the world.

3.1 Major Application

3.1.1 NASA Mars Rover:

NASA's Human-Supporting Rover has FDM Parts "You always want it to be as light as possible, but you also want it to be strong enough." — Chris Chapman, NASA test engineer.

Highlights:

70 Parts having complex shapes durable enough for Martian terrain were built by FDM

Parts on NASA's rover include flame-retardant vents and housings, camera mounts, large pod doors, a large part that functions as a front bumper, and many custom fixtures.

FDM offers the design flexibility and quick turnaround to build tailored housings for complex electronic assemblies. For example, one ear-shaped exterior housing is deep and contorted, and would be impossible — or at least prohibitively expensive — to machine

NASA uses ABS, PCABS and polycarbonate materials

3.1.2 Piper Aircraft

Piper Reduces the Cost and Leadtime of Hydroforming Tooling to Build a Personal Jet

“I can program an FDM part in 10 minutes while a typical CNC program takes four hours to write.” — Jacob Allenbaugh, Manufacturing Engineer, Piper Aircraft

Highlights:
Piper is using hydroforming to produce hundreds of aluminum (Al) structural components of the aircraft such as the inner frame, gussets, brackets, skins, etc.
In the past, the company machined aluminum form tools for use in hydroforming machines.
FDM polycarbonate (PC) could withstand hydroforming pressures ranging of 3,000 to 6,000 psi, suitable for forming all of the structural parts by Piper. For hydroforming applications involving higher pressures, ULTEM 9085 hydroforming tools can withstand up to 10,000 psi
FDM machine Fortus 900mc is used as it provides a large 36 inch (91 cm) x 24 inches (61 cm) x 36 inches build envelope and also provides a high level of accuracy,”
PC form tools are made slightly larger than Al tools as PC has slightly greater deflection than aluminum.
3.2 A Case Study - Gas Tubine Research Establishment (GTRE) FDM Cuts Time to Prototype Jet Engine from 1 Year to 6 Weeks cost effectively
“With FDM we created an engineering prototype that perfectly reflected our design intent and facilitated the complex engine development.” — Dr. U. Chandrasekhar, GTRE

Kaveri Engine Project:
The Gas Turbine Research Establishment (GTRE) of Bangalore, India is a government laboratory whose primary function is research and development of marine and aeronautic versions of gas turbines. Development of GTRE’s flagship product, the Kaveri jet engine, was commissioned for the HAL Tejas aircraft (a light combat aircraft), which has an all-terrain capability that spans from hot deserts to the world’s highest mountain range.

Real Challenge:
One of the greatest challenges in designing the Kaveri was positioning its piping runs and line replaceable units (LRUs) on the outside of the aircraft. Many of the LRUs are connected to the interior of the engine with pipes that carry hydraulic fluid, fuel, and lubricants. It was a major challenge to design each piping run to minimize length to reduce weight and cost while avoiding interference.

Approach 1: The initial piping layout was created with CAD software, but CAD alone can’t portray the complex intertwined piping non-ambiguously to all the developers. “The virtual environment cannot represent the design to the level that we need to meet our requirements,” says Dr. U. Chandrasekhar, GTRE Group Director. “The computer comes close, but close isn’t good enough when you are about to make a decision to invest tens of millions of dollars to bring a new product to market.”

Approach 2: There are approximately 2,500 engine components that had to be included in the assembly. If GTRE would have considered building the prototype using CNC machining it would have taken a minimum of one year and cost of estimated $60,000 to build the physical prototype assembly.

Approach 3: GTRE also considered stereolithography, but the project was not well-suited for this prototyping method due to excessive supports needed for components like turbine blades, combustor swirlers, inlet guide vanes and combustors. GTRE also realized that most conventional rapid prototyping methods would have made it necessary to produce solid pipes which would have eliminated the possibility of flow testing.

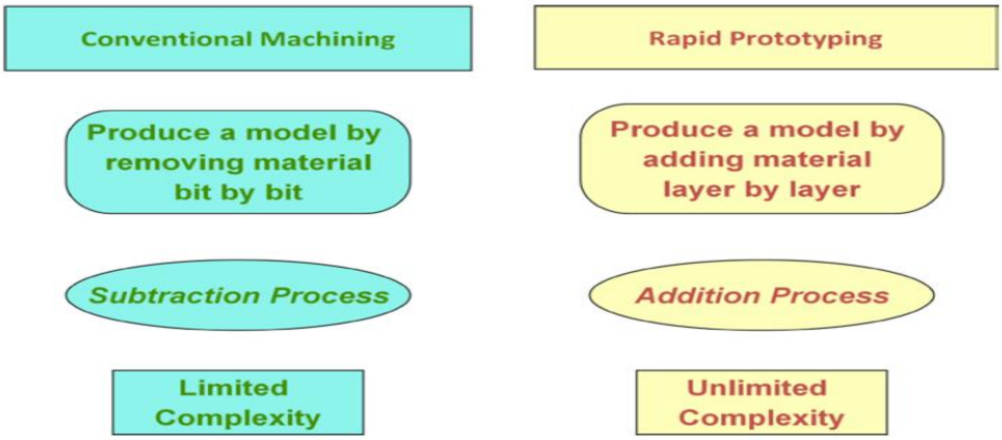


Fig: 4 Difference between Conventional Machining & Rapid Prototyping

There is great uncertainty as to whether a new design will actually do what is desired. New designs often have unexpected problems. A prototype is used as part of the product design process to allow engineers and designers the ability to explore design alternatives, test theories and confirm performance prior to launch of new product.
RP is capable of making parts with very small internal cavity and complex geometrics. It is possible to see the real product in an early stage of the development process.

Real Solution: Approach 4 - Implemented
"FDM technology provided the ideal solution because the supports & interior of hollow components can be easily dissolved in a water-based solution," says Dr. Chandrasekhar. "It allowed us to create the geometry we needed. FDM was also much faster [than traditional means] because it is possible to combine several parts into assemblies, which can be produced in a single run." GTRE also like the fact that FDM creates parts from real engineering thermoplastics, such as ABS, which allowed them to make high-strength durable components for the project.
FDM Machine Specification: FDM TITAN allows creating real parts with complex geometries that are strong enough for functional testing and end use.

	FDM TITAN	Other Features	
Build Envelope	16 x 14 x 16 inches (406 x 355 x 406 mm)	Achievable Accuracy Models are produced within an accuracy of +/- .005 inch (+/- .127 mm) up to 5 inches (127 mm). Accuracy on models greater than 5 inches (127 mm) is +/- .0015 inch per inch (+/-.0015 mm per mm). Note: Accuracy is geometry dependent.	Operator Attendance Limited attendance for required.
Materials	ABS, ABSi, PC, PC-ABS, PC-ISO, and PPSF		Operating Environment Maximum room temperature of 85°F (29.4°C). Maximum room dew point of 78°F (25.6°C).
Layer Thickness	ABS and ABSi 0.013 inch (0.33 mm) 0.010 inch (0.254 mm) 0.007 inch (0.178 mm) 0.005 inch (0.127 mm) PC-ABS: 0.010 inch (0.254 mm) 0.007 inch (0.178 mm) 0.005 inch (0.127 mm) PC and PC-ISO: 0.010 inch (0.254 mm) 0.007 inch (0.178 mm) PPSF: 0.010 inch (0.254 mm)	Support Structures WaterWorks™ soluble support for ABS, ABSi and PC-ABS BASS™ breakaway support for PC, PC-ISO and PPSF Network Communication 10/100 base T connection. Ethernet protocol	Power Requirements 230 VAC, 50/60 Hz, 3 phase, 16A/phase (20 amp dedicated circuit required) System Size 50.25 inches wide x 34.75 inches deep x 78 inches high (1276 mm wide x 883 mm deep x 1981 mm high). Regulatory Compliance CE
Material Canisters	Two auto load canisters* 92 cubic inches (1508 cubic cm)	Software FDM Titan uses Insight™ software to import STL files which automatically slices the file, generates the necessary support structures and material extrusion paths.	
Support Material Canisters	Two auto load canisters* 92 cubic inches (1508 cubic cm) *Automatic changeover between canisters		

ABSi Material Specification: ABSi has superior strength than standard ABS specially used for aero applications

Mechanical Properties[1]	Test Method	Metric
Tensile Strength (Type 1, 0.125", 0.2"/min)	ASTM D638	37 MPa
Tensile Modulus (Type 1, 0.125", 0.2"/min)	ASTM D638	1,920 MPa
Tensile Elongation (Type 1, 0.125", 0.2"/min)	ASTM D638	4.4%
Flexural Strength (Method 1, 0.05"/min)	ASTM D790	62 MPa
Flexural Modulus (Method 1, 0.05"/min)	ASTM D790	1,920 MPa
IZOD Impact, notched (Method A, 23°C)	ASTM D256	96.4 J/m
IZOD Impact, un-notched (Method A, 23°C)	ASTM D256	191.1 J/m

Thermal Properties[2]	Test Method	Metric
Heat Deflection (HDT) @ 66 psi, 0.125" unannealed	ASTM D648	86°C
Heat Deflection (HDT) @ 264 psi, 0.125" unannealed	ASTM D648	73°C
Glass Transition Temperature (Tg)	DMA (SSYS)	116°C
Coefficient of Thermal Expansion	ASTM D696	12.1 E -05 mm/mm/°C
Melt Point	---------------	Not Applicable[3]

Electrical Properties[4]	Test Method	Value Range
Volume Resistivity	ASTM D257	6.1x10e10 - 1.5x10e9 ohms
Dielectric Constant	ASTM D150-98	3.6 - 3.4
Dissipation Factor	ASTM D150-98	0.15 - 0.12
Dielectric Strength	ASTM D149-09, Method A	320 - 100 V/mil

Real Benefits:

With over 2,500 FDM components, the Kaveri jet engine prototype may be the most complex rapid-prototype assembly ever created. It took GTRE only 30 days to produce all these components from ABS plastic using two FDM-based Fortus (earlier FDM TITAN) machines. It took another 10 days to assemble the engine. The total cost to produce the FDM assembly was about $20,000.

How Did FDM Compare to Traditional Prototyping Methods for GTRE?

Method	Cost Estimate	Time Estimate
Conventional fabricating	$60,000	12 Months
Direct digital manufacturing with FDM	$20,000	1.5 Months
SAVINGS	**$40,000 (66%)**	**10.5 Months (87.5%)**

Fig: 5a Time & cost saving by FDM

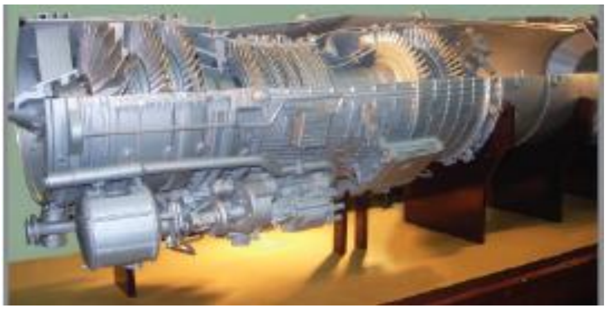


Fig: 5b Kaveri Engine Prototype with 2500 FDM parts

"With FDM we created an engineering prototype that perfectly reflected our design intent and facilitated the complex engine development," says Dr. Chandrasekhar. "It enabled engineers to identify & resolve problems that would have been easy to miss with only the computer model." The FDM assembly allowed the design & manufacturing teams to understand how the engine components need to fit together during manufacturing. In addition, prototype enabled a number of GTRE's partners, including the Indian Air Force, to better understand the engine. <u>The net result was a lighter engine that took less time to validate and build cost effectively</u>.

III. CONCLUSION

FDM is the prototyping and modeling method of choice for engineers and designers in the medical, technology, automotive, military, aerospace, consumer goods, toy, and architecture fields because of it's capability to build in durable ABS plastic. The inexpensive and rapid development of FDM prototypes greatly reduces design-to-production time and allows for much higher return on investment (ROI). Rapid Prototyping & Manufacturing is a fundamental shift in making parts & it is going to serve as next Industrial Revolution.

IV. ACKNOWLEDGEMENT

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