

Study on Encroachment of RPT in Wind Tunnel Testing Models – A Review

Jassim Ahamed S.J¹, Armstrong.M², Aravind.K³, Chakravarthi.J⁴

PG Scholar/Teaching Assistant, Department of Mechanical Engineering, Government College of Engineering and Technology, Salem, Tamilnadu, India¹

PG Scholar/Teaching Assistant, Department of Mechanical Engineering, Government College of Engineering and Technology, Salem, Tamilnadu, India²

Pre Final Year UG Student, Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, India³

Pre Final Year UG Student, Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamilnadu, India⁴

ABSTRACT: Rapid Prototyping Technology (RPT) is a feasible and alternative productive approach for manufacturing sector to reduce time and cost by creating mathematical (CAD) model of the product to be built. The primary aim of this review is to provide platform to researchers to gain information about which rapid prototyping material and process is sufficient for constructing wind tunnel models and if these models meets the structural requirements of subsonic testing while still having the high fidelity required to produce accurate aerodynamic data for educational purpose (Preliminary Design Study) with low budget. Subsequently this paper deals with time reduction and cost effectiveness of rapid prototyping in aerospace industry.

KEYWORDS: Aerospace, Cost Effectiveness, Time Reduction, Rapid Prototyping Technology, RPT models and Wind Tunnel Testing.

I.INTRODUCTION

In 21st century, when “better, faster, cheaper” are the words to live up, new technologies must be employed to try and live up to these axioms. In this spirit, Rapid prototyping has emerged, it is defined as a group of technologies used to quickly produce a scaled model of component using 3-Dimensional computer aided design (CAD). Due to pressure of worldwide competition of product development and manufacturing, industries has given more importance for product development phase to reduce manufacturing time and cost with high quality product and service. This manufacturing process is also called layer manufacturing because this produces 3-Dimensional model layer by layer.

The basic working principle of RP technologies is totally different from conventional machining processes, which is build by means of addition approach (layer by layer) like construction of the building. Conventional machining can produce prototypes using metal removal method with almost any type of engineering materials however there are only a limited type of materials for any type of RPT systems. RP&M systems are usually used for making one or a few samples of prototypes, while the number of prototype produced in conventional machining can be adjusted as required. Rapid prototyping technique is classified into three types based on material i.e. the material that the prototype or part is built with. In this manner, all RP Technologies can be categorized into (1) liquid-based (2) solid- based and (3) powder-based. In liquid-based RP technique the initial form of material is in liquid state. By a curing process, the liquid is converted into solid state and solid-based RP technique has the initial form of material in solid state. In this

context, the solid form can include the shape in the form of wire, roll, laminates, pellets and powders. Rapid prototyping is widely used in the automotive, aerospace, medical, and consumer products industries. The Aeronautical industry is playing a leading role in the application of the new technologies to improve aircraft design, development and manufacturing. From figure 1 describes the percentage of use of RPT in aerospace industry which is nearly 8.2%. In aerospace industries rapid prototype method is used for production of complex parts. Many parts used in space shuttle and space stations are manufactured by using RPT. Boeing's Rocket-dyne has used RP technology to produce hundreds of parts of space shuttle and international space station and to manufacture parts for fighter jets, RP technology is used.

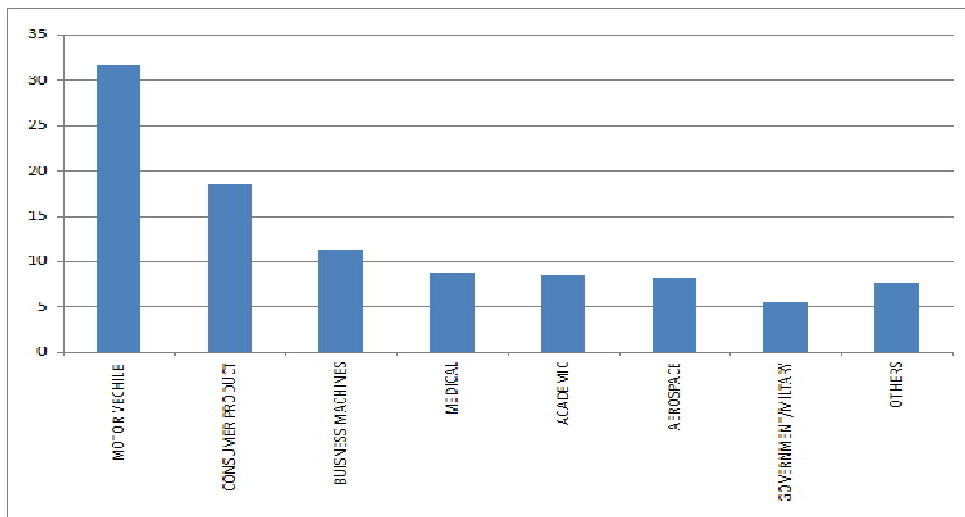


Figure 1: Rapid Prototyping Worldwide

II. PROCESS INVOLVED IN RAPID PROTOTYPING

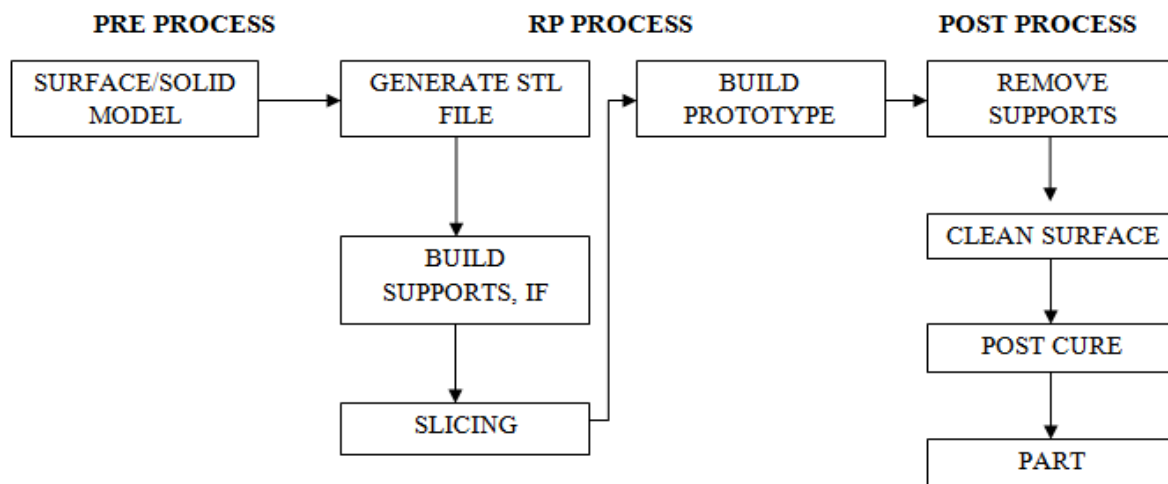


Figure 2: RP Process Workflow

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are: (1) Creation of CAD model of the design; (2) Conversion of the CAD model to STL format; (3) Slicing the STL file into thin cross-sectional layers; (4) Layer by layer construction; (5) Cleaning and finishing the model.

III. LITERATURE REVIEW

Many papers have been published in the rapid prototyping and tooling technique in wind tunnel models. In [1] RPT makes wind tunnel testing more affordable for small programs with low budgets and for educational purpose. In [2] RPT techniques have been shown to be feasible in the limited direct application to wind tunnel testing for producing preliminary aerodynamic databases. Cost saving and model design/fabrication time reduction over a factor of five has been realized for RPT techniques as compared to the current standard model design/fabrication practices. In [3] FDM model with chromium coating was shown best result for majority of the test conditioning compared to initial FDM model because of surface roughness of initial model. Cost saving and model design/fabrication time reduction over a factor of two has been realized for RPT techniques as compared to the current standard model design/fabrication practices. In [4] RPT method and material can be used for any preliminary design studies and limited configuration due to the RPT material properties which allow bending of the model components under high loading conditions.

Importance of RPT in Aerospace Industry:

Aeronautical industry produces some of the most complex geometry (i.e., Turbine blade design, internal structure of wing, etc.) design can be easily done by RPT method. Design of aeronautical element involves lot of intermediate phases which might be eliminated by RPT techniques. This process is completely automated so the requirement of skilled personnel is minimum. RP has the potential of processing more exotic materials, faster and cheaper. It also allows for prototyping and small volume trials of new materials without the need to invest in tooling.

Application of RPT in wind tunnel testing:

Wind tunnel testing is an integral part of the design process in many industries. It provides effects of air as it moves over or around the test model. Wind tunnel determinations are essential in aerospace industry. Even in an age of advanced computer simulation, aerospace engineers still rely on the testing of wind tunnel models to verify the computer data and establish baseline of aerodynamic information. The aerospace companies may test an entire vehicle or they will also evaluate the aerodynamical data's of individual components, such as tail, body and wing. Wind tunnel models are mostly fabricated by metal component using computerized numerical control (CNC) milling machines. Fabrication of metal wind tunnel model is very expensive and time consuming. RP materials and methods have been considered as potential source of improvements from conventional wind tunnel models.

Analysis of various Wind tunnel RP Models:

This section reports the various RP Materials used in wind tunnel models with its applicability. It can initially be stated that machined metal models cannot be replaced by RP models for all aspect of wind tunnel testing. This study focused on small aspects of wind tunnel testing and related to preliminary vehicle configuration design for educational purpose.

Before start the review these criteria were as follows: (1) Could RP (Especially FDM) method be used to produce a detailed scale model within required dimensional tolerance; (2) Which materials (RP or Standard Aluminum or Standard Steel) Produces the best results; (3) Whether cost and time of RP method is reduced compared to conventional method?

From the reference [1], researchers is using wing-body-tail configuration as shown in below Figure 3. In this project, they had chosen three RP models such that Fused Deposition Method (FDM), Stereolithography (SLA) and Selective laser sintering (SLS) and one standard aluminum model for analysis. In order to determine the aerodynamic characteristics of the four models, wind tunnel test was done from 0.3 to 5.0 Mach number.

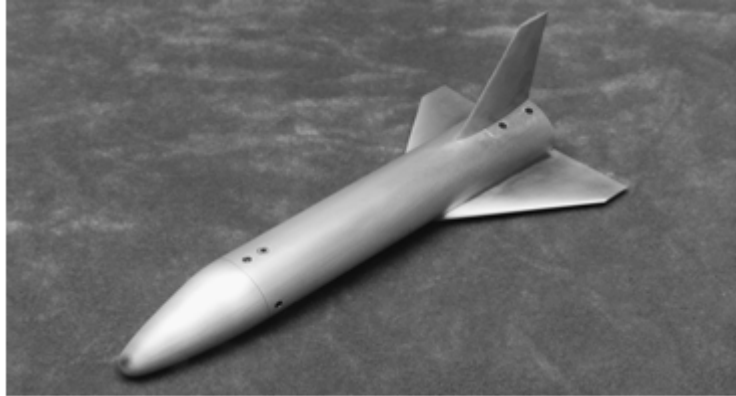


Figure 3: Wing-Body-Tail Configuration

Here they determined the applicability of RP process to the design of wind Tunnel model. Subsequently various RP methods were compared to produce best suited Wind tunnel model. Longitudinal aerodynamic data showed very good agreement between the aluminum and SLA model up to 12 degrees angle of attack. After 12 degrees of angle of attack, SLA model started to diverge due to ending under higher loading. Next SLS model tested showed much better agreement with the data trends from the other model, but was not as good as the FDM and SLA. In general, it can be said that all the RP model longitudinal aerodynamic data at subsonic Mach numbers showed a slight divergence at higher angles-of- attack when compared to the metal model data. At transonic Mach numbers the majority of the configurations started diverging at about 10 to 12 degrees angle-of-attack due to the higher loads encountered by the models.

It can be stated from this study that wind tunnel model constructed using RP methods such that FDM-ABS and SLA produced very good results. The data resulting from FDM-ABS model diverged at higher loading condition producing unsatisfactory results when compared to FDM-ABS, SLA was shown to be the best RP process with satisfactory results for a majority of test condition from this study researches stated that RP methods to make Wind Tunnel models limited direct application to Wind Tunnel testing for producing preliminary aerodynamic databases for educational purposes.

Cost and time saved up to factor of 4 have been realized for RP techniques as compared to current standard model design and fabrication. This make wind tunnel testing more affordable small programs with low budgets and for educational purpose. The accuracy of the data is lower than that of a metal model due to the surface finish and dimensional tolerances, but quite accurate for this level of preliminary techniques. The difference in the aerodynamics to acceptable for this level of preliminary design. However, at this time, RP models are not considered for the practical issues because of the high configuration fidelity require and the loads that deflected control surface must withstand. Consequently further research will be required to prove that RP models adequate for detailed parameter aero dynamic studies that require deflected control surfaces.

From reference [4], authors using transonic wind tunnel covered the Mach number range of 0.3 to 0.75 to compare RP model (FDM-ABS) and standard steel model ASTMA284. Here also traditionally using wing body tail configuration for this test. Researchers can be concluded that both two models showed good agreement in pitching, cost and time requirement of FDM model approximately 50% lesser than standard steel model. From the result analysis of research shows the agreement of standard steel model with FDM model as shown in the following table.

MACH NUMBER	SLOPE OF NORMAL FORCE COEFFICIENT($dc_N/d\alpha$)		SLOPE OF PITCHING MOMENT COEFFICIENT ($dc_M/ d\alpha$)	
	STEEL	FDM	STEEL	FDM
	0.3	0.115	0.11	0.0129
0.5	0.169	0.165	0.0129	0.012
0.75	0.149	0.141	0.0132	0.013

Table 1: Relationship between FDM and Steel Model

According to table 1, average difference between standard steel and FDM model aero dynamical data is 0.006. So that author stated that FDM method was acceptable to design wind tunnel testing model with low purpose. However, accuracy of aerodynamic data is lesser than that of a steel model due to surface finish, but is quite accurate for this level of baseline study.

From reference [3], Researchers are using chromium coating in RP technology for airfoil manufacturing. In this paper authors discusses the application of wind tunnel model configuration constructed using FDM and FDM with chromium coating for subsonic wind tunnel testing. Result from this research shows relatively good agreement with RP technology with chromium coating and standard steel model. Here, researchers are using Electroplating deposition method to build wind tunnel model with chromium coating. This coating gives the appearance of plated parts provides a hard, wear resistance, surface with reflective properties. Consequently this electroplating process will improve the mechanical properties of the model. For this coating, they used alloys such as chromium, nickel, copper, silver and gold. Due to the coating, the part strength, durability and heat resistance will increase. The wind tunnel model is chemically etched, which removes the butadiene molecules from the surface and improves bonding of the subsequent layers. Once etched, the part is then coated with a layer of palladium which acts as an intermediate bonding agent followed by a layer of chromium to provide the necessary durability. Hence it is concluded from this study that wind tunnel models constructed using the FDM model with chromium coating can be used in the wind tunnel testing for the aerodynamic data base development which is shown in the table 2. The initial FDM model did not produce appreciable result to problems with surface roughness. So this was corrected in the model with chromium coating when testing at higher wind speeds, it is true that surface must be very smooth. However, lower speeds are using FDM models directly from the system.

MACH NUMBER	SLOPE OF NORMAL FORCE COEFFICIENT($dc_N/d\alpha$)		SLOPE OF PITCHING MOMENT COEFFICIENT ($dc_M/ d\alpha$)	
	STEEL	FDM(CHROMIUM COATING)	STEEL	FDM(CHROMIUM COATING)
0.3	0.115	0.111	0.0129	0.01281
0.5	0.169	0.165	0.0129	0.0127
0.75	0.149	0.1491	0.0132	0.0132

Table 2: Relationship between FDM (Chromium Coating) and Steel Model

Time Reduction and Cost Effectiveness in Aerospace Industry:

In recent years, opening up local markets for worldwide competition has led to a fundamental change in new product development (NPD). In order to stay competitive, manufacturers should be able to attain and sustain themselves as "World Class Manufacturers". The manufacturers should be capable in delivering products in fulfilling the total satisfaction of customers, products in higher quality, short delivery time, at reasonable costs, environmental concern and fulfill all the safety requirements. Hence, Cost and Time saving plays major role in Manufacturing Industries.

One of the major challenge in designing the Kaveri Engine by GTRE (The Gas Turbine Research Establishment) 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. This challenge was done by RP&M by reducing 66% of cost and 87.5% of months from conventional fabrication process.

Piper Aircraft is using hydro forming to produce hundreds of aluminum 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 hydro forming machines. Machining geometrically complex form tools was expensive and time consuming to carry out with CNC machines and to add to that, the considerable material waste involved in machining. Piper has achieved substantial lead-time savings by reducing 68% of days. Material waste with FDM is much less than CNC machining because the FDM support material is typically less than 20% of the total.

COLIBRI (Electro-Optical Gimbal) by using FDM is a technique where the components subject to customizing are composed only of plastic so they can be produced in-house as they are needed. With RP&M, DST Control can now deliver custom COLIBRI units in four weeks, rather than the 10 to 12 weeks. So RP&M reducing the 66% of Cost and 63% of weeks of production unit.

Leptron's RDASS 4 is a unique unmanned aerial vehicle (UAV).Using the traditional approach, injection molding, it would have cost \$250,000 and taken six months to build tooling for UAV fuselage components. Another problem is that any design changes after the tooling was built would have required expensive and time-consuming modifications to the tooling. Major changes would have involved even greater costs and delays to build new tooling. Leptron now uses the Dimension 3D Printer to very quickly build end use parts for the RDASS 4. The core components take 48 hours while smaller components average six hours to print.

Product	RP Usage	Lead Time Saving %	Cost Saving %
Kaveri Engine	Piping Lines and LRUs Design	87.5	66
COLIBRI	Electro Optical Gimbal	63	66
Piper Aircraft	Structural Parts	68	-
Advanced Composite Structures(ACS)	Aerospace Composite Parts	96	79
Leprons	UAV (Leprons RDASS4)	43	59
Sheppard Air Force Base	Pilot Training Equipments	60	-
Wind Tunnel Model	Models	86	99
World War II Aircrafts	Restores Historical Aircrafts	90	-
Average		74	74

Table 3: Lead Time and Cost Saving

IV. CONCLUSION

In this present review work , It can be concluded that RP technology employ various engineering, computer control and software techniques including laser, optical scanning, photosensitive polymers, material extrusion and deposition, powder metallurgy, computer control, etc. to directly produce a physical model layer by layer (Layer Manufacturing) in accordance with the geometrical data derived from a 3D CAD model. RP can deliver working prototype at the early design stage of the new product cycle. So manufacturers can use the working prototypes in

bridging a multi-disciplined team composed of the marketing, design, engineering and manufacturing people to design right at the first instance in catering for the customers.

RP wind tunnel model approximately will save 74% of lead time and manufacturing cost when compared to conventional model. Compared to all RP methods FDM-ABS and SLA was shown to be the best RP process with satisfactory results for a majority of wind tunnel test condition. In general RP models did not have as smooth as did the aluminum or steel model. So this roughness would affect the aerodynamic characteristics. So that RP process with chromium coating would reduce the surface roughness of the model which will give best agreement between conventional and RP model.

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