GAINING COMPETITIVE ADVANTAGE BY USING RAPID PROTOTYPING IN AIRCRAFT MODIFICATION

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1.0 INTRODUCTION

Raytheon-Waco (formerly Chrysler Technologies Airborne Systems) is an aircraft modification facility in Waco, TX, specializing in military, executive, and head-of-state aircraft modifications. Raytheon-Waco has over 25 years of aircraft modification experience, and is a leading contractor for major US and foreign government programs that require system design, airframe modification, installation, flight testing, and post-delivery technical and logistical support. Current programs at Raytheon-Waco include foreign government Head-of-State wide-body aircraft modifications consisting of luxury interiors, secure communications, and airframe modifications, and US and foreign military aircraft modifications involving electronics, communications, avionics, and airframe modifications.

The aircraft modification industry is highly competitive, with a variety of very competent companies constantly trying to increase market share and move into new markets. Raytheon-Waco has focused primarily on military communications and transport aircraft, and Head-of-State wide-body aircraft. Due to increasing competition and customer cost-conscientiousness, Raytheon-Waco is working to reduce cost and cycle time while maintaining its reputation for delivering on time and within budget. There is also movement into other markets, such as lower-cost wide-body executive aircraft.

Raytheon-Waco is currently transitioning to a paperless design process, with the ultimate goal of performing all design, analysis, manufacturing, and aircraft installation from CAD models without requiring paper drawings. Increased use of electronic models will also allow more parallel processes to be performed, eliminating many of the sequential design steps currently required. Among the steps that will be performed in parallel will be detailed design, manufacturing and installation planning, technical publications, and design analysis. Without improved initial designs, parallel work will only lead to increased rework and wasted effort. Rapid prototyping is a key factor in reducing risks associated with concurrent processes, and its benefits are critical to efforts to reduce the cost and schedule of future aircraft modifications.

2.0 RAPID PROTOTYPING AT RAYTHEON-WACO

2.1 RAPID PROTOTYPING NEED

Traditional high-volume production is seldom required at Raytheon-Waco. Most of the commercial wide-body and military modifications are unique designs that are similar to traditional prototypes in that the designs are constantly evolving, typically only small pieces and sub-assemblies of previous designs can be re-used, and lessons learned in previous aircraft modifications only have limited application. Reducing cost and cycle time for many aircraft components by quickly and cheaply producing prototypes of new designs for customer approval and design verification on the aircraft prior to part fabrication was a real need, and was the driving factor behind the acquisition of rapid prototyping (RP) equipment. Potential manufacturing and tooling uses of RP technologies also contributed to the decision to invest in RP, but were not the driving factors.

2.2 RAPID PROTOTYPING EQUIPMENT

In 1995, Raytheon-Waco began investigating rapid prototyping equipment to be used primarily by design engineers to ensure form, fit, and function of parts and assemblies. This led to the purchase of a 3D Systems SLA-500 Stereolithography Apparatus (SLA) in early 1996. In the SLA process a solid physical part model is made directly from 3-D CAD model data within a relatively short period of time, usually less than one day. The model is built by successively laser curing layers of photopolymer resin until the part is completed. After the model has been built, it is removed from the SLA processing chamber and placed in a Post Curing Apparatus (PCA), where the model is flooded with intense ultraviolet light to complete the polymerization process. It is then finished using a variety of sanding and painting techniques. The total processing time is typically one to three days.

2.3 SLA IMPLEMENTATION

Raytheon-Waco has a laboratory dedicated to rapid prototyping, with the SLA-500, an accompanying centrifuge and PCA, as well as a model finishing facility. The SLA technician is responsible for finishing each model, including post-curing, removing excess resin, sanding, painting, and when necessary bonding models into assemblies. The SLA technician works directly with engineers considering SLA models to determine if they have a good application, modify CAD models to improve the SLA model quality, and ensure that the part model can be built in the SLA-500. He will also input the appropriate shrink factors into the build process for models used as tooling.

SLA modeling is part of a move to paperless design, fabrication, and installation in order to reduce costs and compress schedules. The process of ordering an SLA model is completely electronic, and requires 3-Dimensional (3D) surface or solid models. New design work at Raytheon-Waco is done in Pro/Engineer[1] 3D solid modeling, which has a standard .STL file output that can be input into the 3D Systems software. There is also an approved ISO 9001 procedure and work instruction for electronically ordering SLA models.

3.0 SLA IN DESIGN

In the six months since obtaining RP capability, Raytheon-Waco has realized significant benefits from using SLA, with potential for even larger benefits in the future. Specific advantages have been seen in the design process and in an increase in customer input and satisfaction. Allowing the designers, engineers, management, purchasing, and customers to review physical models of designs before releasing a drawing is expected to reduce the number of engineering change orders issued during the design and production phase. In addition, check fitting full scale SLA models of various parts and assemblies in the aircraft is expected to reduce last minute changes resulting from airframe variations. These applications will in turn reduce the amount of lost production time, retooling, rework, and scrap waste incurred during manufacture and installation. Following are some specific examples of uses of SLA in the design process.

3.1 INCREASING CUSTOMER INVOLVEMENT IN DESIGN

3.1.1 Aesthetic Review

One of the first uses of SLA was in producing models of artistic complex-curved surfaces used in luxury interiors prior to producing part drawings or beginning design work on many interfacing components. These models were reviewed with the customer, who determined that the initial design needed to be changed. Without rapid prototyping, these design changes would not have been made until much later, and possibly not until the parts had been fabricated and significant design had been done on interfacing parts, resulting in additional design changes. SLA models have become common elements of customer reviews, beginning with the earliest stages of the design process.

3.1.2 Functional Reviews

SLA models were made of electronic control panels to demonstrate proposed Air Force C-141 transport cockpit upgrades. The panels were approximately 5" x 3" and showed the expected configurations of meters and switches. The SLA panels were assembled into an on-site cockpit simulator, allowing Air Force customers, including pilots, to provide specific input on changes to increase ergonomics and functionality of the new cockpit elements. Previously, only 2-D drawings were available at this stage in the design process, and cockpit mock-ups were only available much later.

SLA models of several critical parts of a system being integrated into a military aircraft were made for design review meetings with the primary contractor and Air Force representatives. Scale models were reviewed in a series of meetings and several design changes were made. Program officials estimated that without the SLA models, the changes would not have been made until much later at a cost of about $10,000 in time and materials. The same program also produced full-scale SLA models of lofted contoured panels that were taken to the aircraft to confirm existing data and determine fastener locations. The SLA models used in this program have saved many times their expense in time and materials by avoiding design changes later in the project.

3.2 AIDING THE DESIGN PROCESS

3.2.1 Aiding Design Engineering

Engineers at Raytheon-Waco have been encouraged to use SLA models to better visualize complicated designs and confirm that the design will meet their requirements. Some engineers have had models made of small parts they are designing so that they could take them to the aircraft to confirm form and fit of the part before proceeding with additional design work. These same parts are then available to other engineers considering similar designs, or designing parts that must interface with the modeled parts.

An SLA model was made of an exit duct and a machined fitting for a galley being redesigned for a foreign Head of State aircraft. The fitting was a Y-shape with complex contoured flanges.

The model was used by the design engineers and the customer to identify interface requirements and recommend design changes to increase manufacturability and serviceability. The exit duct SLA model was used for a producibility review, and will become a washable sand mold to make a fiberglass part. The SLA model will increase the manufacturability of the part and allow the manufacturer to decrease the lead-time and costs associated with a prototype part.

3.2.2 Verifying Designs with SLA Models

In order to verify fit with existing plumbing interfaces and avoid interference with other structures, SLA models of a custom plumbing system were created for a commercial VIP lavatory refurbishment. The SLA models were installed in the aircraft and revealed interference problems that would not have been detected until much more costly metal parts were fabricated later in the program. New models of design changes were also produced to verify all changes prior to creating drawings. These models will also be available for other engineers to use to ensure that other systems properly interface or avoid interference with the lavatory plumbing fixtures. It is expected that the total savings from using plumbing models will involve reduced engineering changes late in the project, fewer rejected parts, easier installation into the aircraft, and less engineering time required throughout the project.

A military program produced SLA models of a duct manifold and air delivery plenum interfaces. The manifold model was used to ensure conformity to primary aircraft structure before fabrication of the high cost, long lead-time item. The SLA plenum interfaces were made to be assembled into a full-functioning mock up in the systems integration laboratory. The production plenum interfaces were critical items for a mock-up that was needed to meet contract schedules, but delivery was delayed by the supplier by several months. The SLA plenum interfaces were made in under a week and have been successfully installed into the mock-up that will be powered up and shown to customers at a subsequent design review.

4.0 SLA IN FABRICATION

Raytheon-Waco has used rapid prototyping in fabrication in a variety of ways, and has plans to expand current capabilities. The most common direct use of SLA in fabrication is in tooling, although there are some indirect uses of SLA that will aid manufacturers in visualizing and understanding parts to be produced.

4.1 CASTING

SLA models have been used as tooling for investment casting. ACES[2] (solid) models have been used as a master pattern for creating epoxy tooling, which was then used to make expendable wax patterns for forming the investment shell. Quickcast[3] (hollow) models have also been used directly as expendable patterns in creating investment shells for casting. Both methods have proven to be accurate, reliable, and lower-cost alternatives to machined tooling for low-quantity investment casting. Most of the casting applications at Raytheon-Waco involve quantities too low to justify machined tooling expense, so the ability to reduce tooling cost through SLA is a significant advantage. It is also estimated that cycle times are reduced by at least 25% compared to the more traditional investment casting process.

ACES models have also been used as tooling for precision sand casting. Accurate, scaled models of parts have been used in place of machined tooling for forming precision sand molds, reducing cost and time for tooling by an order of magnitude. The final castings were high quality, with no noticeable differences due to RP tooling. Two castings for use in wind tunnel testing were produced in under one week from beginning the SLA model to casting delivery, and the pattern is available for making more parts in the future if necessary.

4.2 RAPID TOOLING FOR INJECTION MOLDING

Raytheon-Waco has begun working with a plastics vendor to produce rapid tooling for low-volume injection molding. The injection molding vendor's tooling engineers will work with Pro/E part models to design the mold and then Raytheon-Waco will build the mold with the SLA-500. Raytheon-Waco has also interacted with tooling vendors to produce rapid tooling with SLS[4] technology for higher durability molds. Rapid tooling will allow Raytheon-Waco to afford to purchase very low-quantity injection molded parts that will save weight and be cost-competitive with machined aluminum parts. It is also expected that rapid tooling will reduce the time to receive injection molded parts by at least three weeks per order.

4.3 METAL DEPOSITION MASTER TOOLING

The first significant use of SLA in fabrication was in producing a complex-shaped lavatory sink with unique cross-sections. This sink was too deep and irregular for traditional processes such as stamping or deep-drawing to be reliable. The process that was used involved making a plaster tool from a SLA master pattern, and then depositing a nickel alloy on the plaster tool. It is estimated that this process saved Raytheon-Waco over $140,000 for a single aircraft, in addition to the likelihood that the parts would not have been delivered within the required schedule if traditional processes had been used. This process was so successful that it has been used on other aircraft for similar circumstances, and is planned for other such instances in the future.

4.4 COMPOSITE PANEL TOOLING AT RAYTHEON-WACO MANUFACTURING FACILITY

The SLA lab is working with the Raytheon-Waco composite panel fabrication personnel to develop a system for producing tooling. The SLA model will serve as tooling, with the composite panel built directly on the SLA model, or for parts that require autoclaving or heating the SLA model can be a master pattern for producing plaster tooling. Traditionally, this type of tooling is machined metal, so the potential for saving time and cost is great.

4.5 TEMPLATES FOR CABINETS AND TRIM

SLA templates can also be used to aid fabrication of VIP aircraft components. The templates will be used by cabinet makers or composite panel producers in forming complicated shapes, and also by machine shops or other vendors that will be fabricating parts to mate with the complicated surfaces. It is expected that templates will reduce the amount of rework required to achieve quality interfaces for complex surfaces that require manual operations to produce.

5.0 MODELS USED IN TESTING

The most significant use of SLA models in testing has been for specialized pressure taps to measure duct manifold static pressure while experimenting with various air handling system configurations. These pressure taps are small tube-like protrusions with a round base that had previously been made out of aluminum at a cost of approximately $85 each. The SLA pressure taps were produced at a cost of $45 for 100, allowing higher levels of stocking to reduce the likelihood of a program having to wait two weeks or more for machined parts to be made. The SLA pressure taps were designed to be used in testing of air-conditioning and other low-temperature applications due to the sensitivity of the SLA resin to heat and humidity. The total program savings from using SLA are $8455 per run.

SLA models are also being used in wind-tunnel testing. Scaled models of designs for new under-wing pods for Navy aircraft were produced, and were matched to existing scale aircraft models to test the impacts on flight dynamics from the addition of the pods to the aircraft. The SLA models were produced in far less time and significantly cheaper than metal castings of the same design, and were able to withstand the stresses of wind tunnel operation. The use of SLA models in the wind tunnel is expected to dramatically increase the flexibility and reduce the cost of wind tunnel testing new designs for aircraft modifications.

6.0 SUMMARY OF RAPID PROTOTYPING BENEFITS

Raytheon-Waco has made significant use of the SLA-500 in the five months it has been on-site. There have been over 300 parts made, with over 150 different designs for at least twelve different aircraft programs. Much of the cost and time savings associated with using SLA models is very hard to reliably quantify, but conservative estimates are that over $350,000 has been saved through finding changes and problems early, reducing fabrication costs, and the reduced cost of in-house SLA modeling versus service bureau costs. There have also been substantial intangible benefits, such as increased customer involvement early in the design process and improved engineering designs due to the opportunity to visualize designs and create models that can be fitted into assemblies. The largest unquantified benefit from on-site SLA modeling has been increasing the ability of Raytheon-Waco to meet contract schedules through time savings in design, analysis, and manufacturing.

7.0 CONCLUSION

Raytheon-Waco has had in-house SLA capability since February, 1996, and has already realized significant benefits from rapid prototyping. These have taken the form of increased customer input early in the design process, improved engineering designs through the ability to better visualize CAD models, and decreased fabrication costs for a variety of parts and manufacturing methods. These benefits have far exceeded the original expectations in both quantity and variety, and have more than justified the acquisition of in-house rapid prototyping technology. It is expected that rapid prototyping will play an ever-increasing role in Raytheon-Waco's efforts to reduce operating costs, compress delivery schedules, and enter the next century as one of the world's premier aircraft modification centers.

FOOTNOTES:

1. Pro/Engineer is a registered trademark of Parametric Technologies, Corp. (PTC)
2. ACES is a trademark of 3D Systems
3. Quickcast is a trademark of 3D Systems
4. SLS is Selective Laser Sintering, a registered trademark of DTM Corp.