Smart Tooling Case Study: ECS Duct

Executive Summary

Figure 1: Representative ECS Duct

Fabrication of complex geometry and trapped composites currently requires the use of costly and labor-intensive tooling solutions. Multiple tooling solutions are currently available to the market, including silicone bladder tools, washout mandrels, and multi-piece mandrels. These tooling solutions are considered state of the art but have significant room for improvement in both functionality and cost.

Smart Tooling offers the composites industry an easy-to-use, low-cost tooling alternative for fabrication of complex and trapped geometry composites. The Smart Tooling product line allows composite fabricators to use a simple geometric blank of thermally activated shape memory polymer to form a net-shaped tool for composite lay-up and cure. Once this tool is re-heated above its transition temperature, it returns to its original blank shape for easy tool extraction and reuse.

One Smart Tooling customer, a worldwide leader in rotorcraft design and fabrication, was interested in characterization of the Smart Tooling product line for fabrication of an environmental control system (ECS) duct. The ECS duct is a non-structural, pre-preg, carbon fiber composite duct used for air circulation in the flight deck. The scaled ECS duct, pictured in Figure 1, is approximately 2.5 ft long and has approximately 2.5 ft^2 in surface area.

Smart Tooling was implemented into a limited rate production demonstration and compared with conventional fabrication techniques. Smart Tooling's benefits were apparent in both hard and soft savings to the customer. Realized hard savings included reductions in labor and tooling cost, while soft savings included reductions in line footprint and utilities cost.

Cost Analysis

During the limited rate production, a comprehensive cost analysis was conducted to determine the competitive advantage of the Smart Tooling product line. The cost analysis accounted for both hard and soft savings and was categorized into the following titles: materials, labor, yield, footprint, capital cost, utilities, disposal, and ergonomics. Categories common to all tooling systems were neglected for this study, for example, composite cure cycle, and labor associated with composite lay-up.

Results

Results of the cost study are outlined in Table 1 and show significant savings associated with the implementation of Smart Tooling into the ECS duct fabrication line. This study was conducted using a Smart Tooling price of $400/$ft^2$, the market accepted price for this product. The majority of the cost savings associated with Smart Tooling, when compared with washout mandrels and multi-piece mandrels, is realized in labor savings. When compared with silicone bladders, the majority of Smart Tooling savings are realized in hard tooling costs. When examined as an entire fabrication system, the hard savings associated with integration of Smart Tooling are 71%, 78%, and 67% for washout mandrels, silicone bladders, and multi-piece mandrels, respectively. Hard savings are also achieved in the minimization and/or elimination of rework and an improvement in both first pass yield and production yield versus washout mandrels and silicone bladders.

Table 1: Cost Study Analysis Results

Tooling Method	Labor (hrs)	Labor ($75/hr)	Ancillary Tooling/Part	Tool Uses	Tooling Cost/Part	Total* Cost/Part	SMP Tooling Savings
Smart Tooling	0.75	$56.25	$12.50	12	$91.50	$152.75	
Silicone Bladder Over Foam	1.00	$75	$5	6/1	$621	$696	78%
Washout Mandrel	6.00	$450	$5	1	$76	$531	71%
Multi-piece Mandrel	5.50	$413	$0	500	$55	$467.50	67%

*Does not include the composite material for part production

Savings with Smart Tooling also come in the form of reduced utilities cost, resulting from the elimination of mandrel cure steps required for washout mandrels and silicone bladders. The elimination of these cure steps also increases manufacturing capacity through increased availability of a common limiting factor, oven space. Savings can also be realized in the ergonomic advantage of Smart Tooling when compared with multi-piece mandrels. Smart Tooling's ECS duct mandrel weighs approximately 5 lbs., a considerable weight savings compared with a multi-piece mandrel weighing approximately 80 lbs.

Conclusions

Integration of Smart Tooling into this production line resulted in savings of at least 67% with no composite part quality degradation. These hard savings are in addition to soft savings, which include increased capacity, increased throughput, and ergonomic advantages. These results are typical and are to be expected for complex geometry and trapped composites currently requiring the use of washout mandrels, silicone bladders, or multi-piece mandrels.

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Cost Comparison for ECS Duct Manufacturing (Tooling & Labor):

Bladder Outer Mold Line Tooling

SMP Bladder	
Labor Costs	
Task	**Labor**
Prep	10 min
Form Mandrel	10 min
Demold Mandrel	10 min
Demold Composite	15 min
Total Labor	**45 min (0.75 hrs)**
Total Labor Cost/Part:	**$56.25**
Tooling Costs	
Form/Cure Tool	$12,500
Form/Cure Tool/Part	$12.50
Machined Foam	N/A
Machined Foam/Part	N/A
Tool Uses (SMP Bladder)	12
Tooling Cost (SMP Bladder)	$400 Sqft
Tooling Cost/Part (SMP Bladder)	$84
Total Tooling Cost/Part:	**$96.50**
Total Cost per Part	**$152.75**

Total Savings 78%

Silicone Bladder Over Foam	
Labor Costs	
Task	**Labor**
Prep	10 min
Assembly	30 min
Demold	10 min
Extract	10 min
Total Labor	**60 min (1 hrs)**
Total Labor Cost/Part:	**$75**
Tooling Costs	
Cure Tool	$5,000
Cure Tool/Part	$5
Machined Foam	$600
Machined Foam/Part	$600
Tool Uses (Silicone, Foam)	6, 1
Tooling Cost (Silicone)	$50 Sqft
Tooling Cost/Part (Silicone)	$21
Total Tooling Cost/Part:	**$621**
Total Cost per Part	**$696**

Rigid Inner Mold Line Tooling

SMP Mandrel	
Labor Costs	
Task	**Labor**
Prep	10 min
Form Mandrel	10 min
Demold Mandrel	10 min
Demold Composite	15 min
Total Labor	**45 min (0.75 hrs)**
Total Labor Cost/Part:	**$56.25**
Tooling Costs	
Form/Cure Tool	$12,500
Form/Cure Tool/Part	$12.50
Tool Uses (SMP Mandrel)	12
Tooling Cost (SMP Mandrel)	$400 Sqft
Tooling Cost/Part (SMP Mandrel)	$84
Total Tooling Cost/Part:	**$96.50**
Total Cost per Part	**$152.75**

Total Savings 67%

Multi-Piece Mandrel (metallic)	
Labor Costs	
Task	**Labor**
Prep	45 min
Assembly	120 min
Leak Check	45 min
Demold	120 min
Total Labor	**330 min (5.5 hrs)**
Total Labor Cost/Part:	**$413**
Tooling Costs	
Cure Tool	$27,500
Cure Tool/Part*	$55
Total Tooling Cost/Part:	**$55**
Total Cost per Part	**$467.50**

*Cure Tool Life: 500 cycles

Total Savings 71%

Washout Mandrel	
Labor Costs	
Task	**Labor**
Prep	10 min
Mix	30 min
Cast Mandrel	15 min
Demold	10 min
Surface Prep	60 min
Seal	120 min
Washout	120 min
Total Labor	**360 min (6 hrs)**
Total Labor Cost/Part:	**$450**
Tooling Costs	
Ceramic Cure Tool	$5,500
Ceramic Cure Tool/Part	$5
Tool Uses (Ceramic)	1
Tooling Cost (55 gal)	$1,138
Tooling Cost/Part**	$76
Total Tooling Cost/Part:	**$81**
Total Cost per Part	**$531**

**Volume of part is 3.67 gallons

Note: Assumes Total Production does not exceed 1,000 Parts