WESTERN AEROSPACE EXPO

Additive Manufacturing

Aerospace – Defence

CIMETRIX

Who we are

ADDITIVE MANUFACTURING
Aerospace - Defence

CIMETRIX
Empowering Innovation

20
Celebrating 20 Years

- Founded in 1993
- Full Line Stratasys Partner for Canada
- Strong Design / Manufacturing background
- Service Commercial and Academic Markets
- Business based exclusively on Stratasys Products

Stratasys
AUTHORIZED RESELLER

Who we are

ADDITIVE MANUFACTURING
Aerospace - Defence

Stratasys
FOR A 3D WORLD™

- Stratasys Ltd. (SSYS) Nasdaq
- #1 3D Printer Manufacturer in the world.
- Both in Revenue and Unit Sales
- 350M + Revenue
- Over 1200 employees

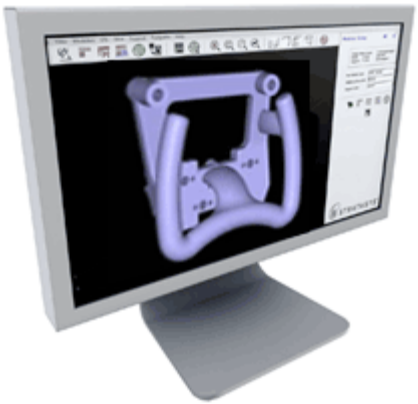
Overview

ADDITIVE MANUFACTURING
Aerospace - Defence

- **FDM Technology Overview**
- **Advanced Applications**
  - Rapid Tooling for Metal Forming
  - Rapid Tooling for Composites
  - Rapid Tooling – Jigs & Fixtures
  - Direct part production – End Use Parts
- **Success Stories – Case Studies**

FDM Process

ADDITIVE MANUFACTURING
Aerospace - Defence



1 Pre-Process

2 Manufacture

3 Finished Part

FDM Process

ADDITIVE MANUFACTURING
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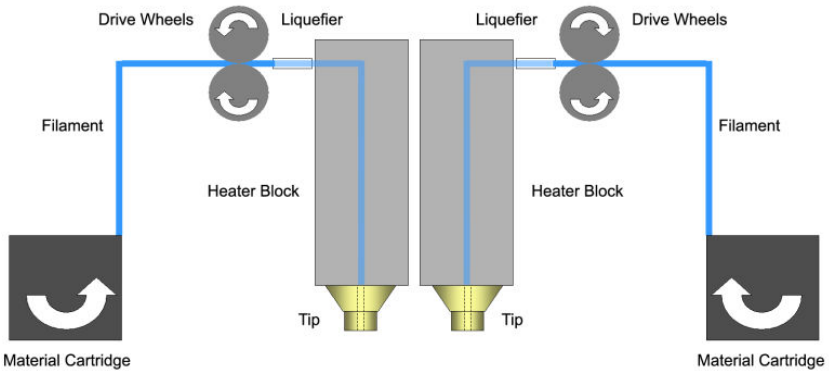
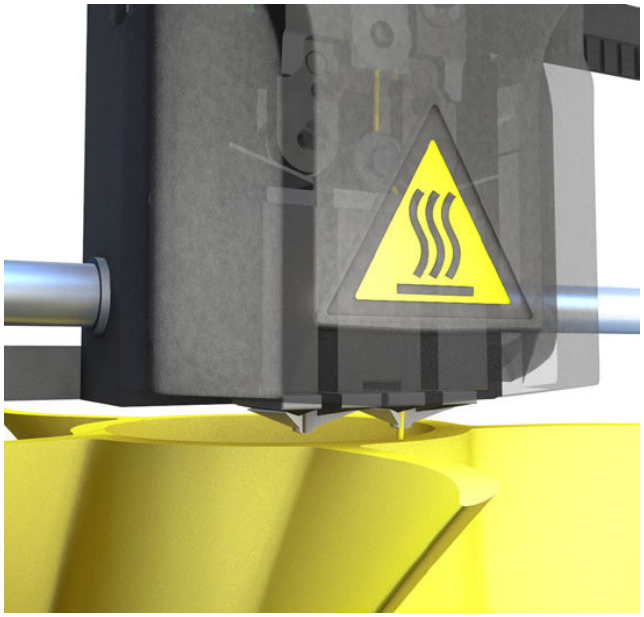
Fused Deposition Modeling : **FDM**

- Dual extrusion head technology
- Deposit liquefied build and support
- Precise Additive Fabrication
- Advanced materials
- Advanced mechanical properties
- Safe, Simple, Clean process





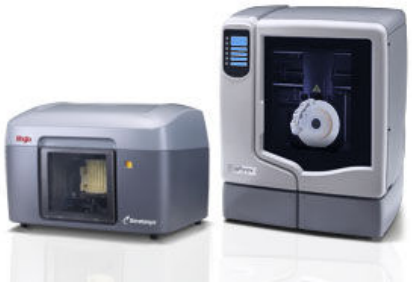
Stratasys Portfolio

ADDITIVE MANUFACTURING
Aerospace - Defence

IDEA Series

DESIGN Series

PRODUCTION Series



Differentiators

- Envelope size
- Materials
- Accuracy
- Throughput
- Resolution

Enablers

- Customization
- Repeatability
- Flexibility
- Complex Part Fabrication

FDM Materials

ADDITIVE MANUFACTURING
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Engineering Grade Thermoplastics

Material Options
ABS-M30
ABS-M30i
ABS-ESD7
PC-ABS
PC (Polycarbonate)
PC-ISO Class 6 : Pharmaceutical
Ultem 9085 *
Polyphenylsulfone PPSF
Support Material

*Ultem 9085 is a trademark of SABIC Innovative Plastics IP BV.

FDM Materials

ULTEM 9085 Aerospace & Defence Grade

**Ultem 9085 is a trademark of SABIC Innovative Plastics IP BV.*

- SABIC Engineered
- Certificate of Conformance available
- High tensile and compressive strength
- High operating temperature
- Passes FAR 25.853

FDM Materials

Ultem 9085

ADDITIVE MANUFACTURING
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Aerospace Grade Thermoplastic

Passes FAR 25.853

- ✓ Vertical burn test
- ✓ FST zero rating
- ✓ UL94 V0

Radiant Heat OSU 55/55 PASS

	Result	Limit
Off Gassing ASTM E595	**PASS**	
Total Mass Loss (TML)	0.41 %	1.00 %
Collected Volatile Condensate Material (CVCM)	< 0.01%	0.10 %
Water Vapour Recovery Report (WVR)	0.37	Report

Primary Applications

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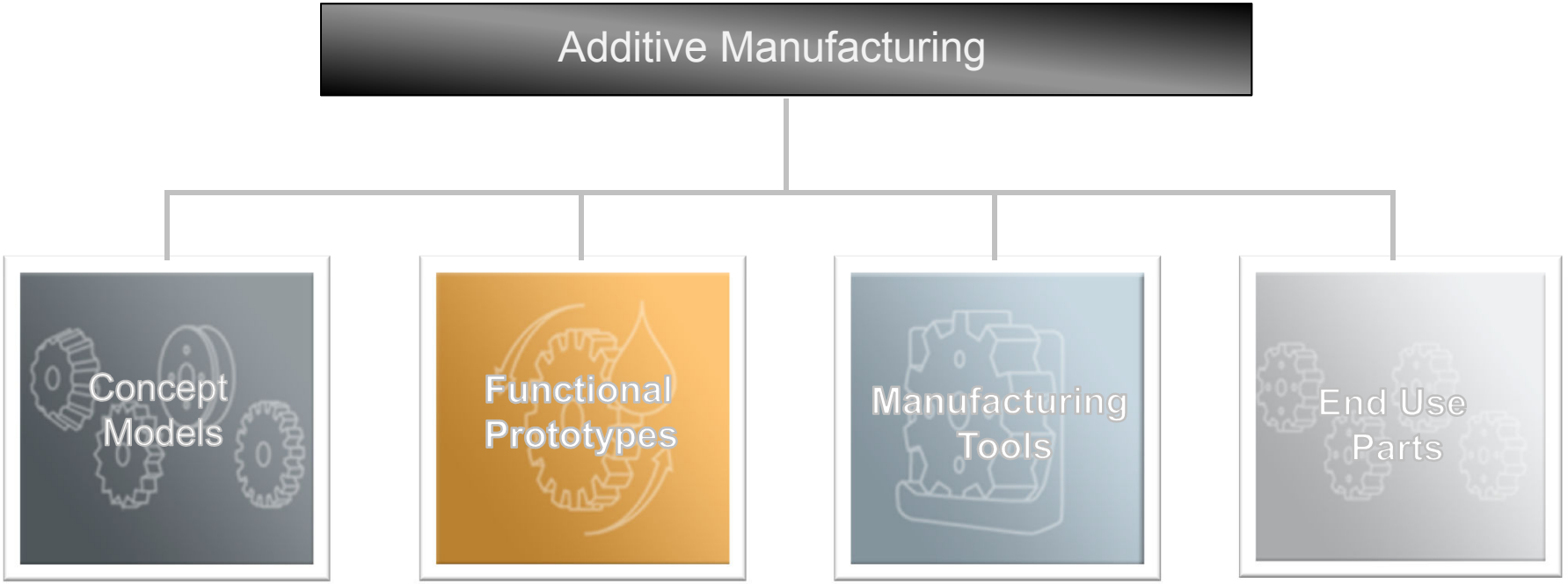

Established / Traditional

(Design)

Direct Digital Manufacturing

(Manufacturing)

Product Lifecycle Opportunities

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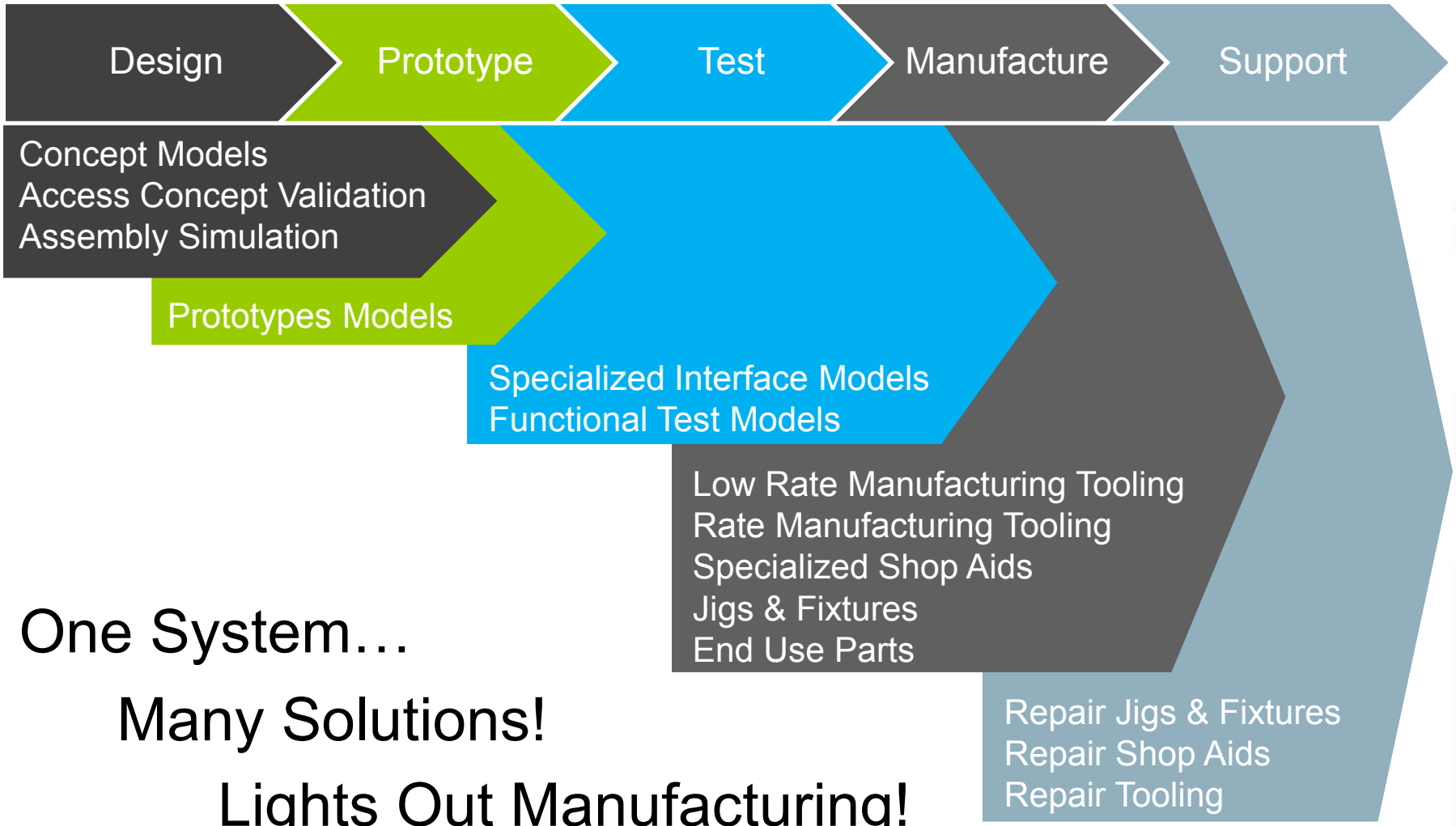

One System…

Many Solutions!

Lights Out Manufacturing!

The Sweet Spot

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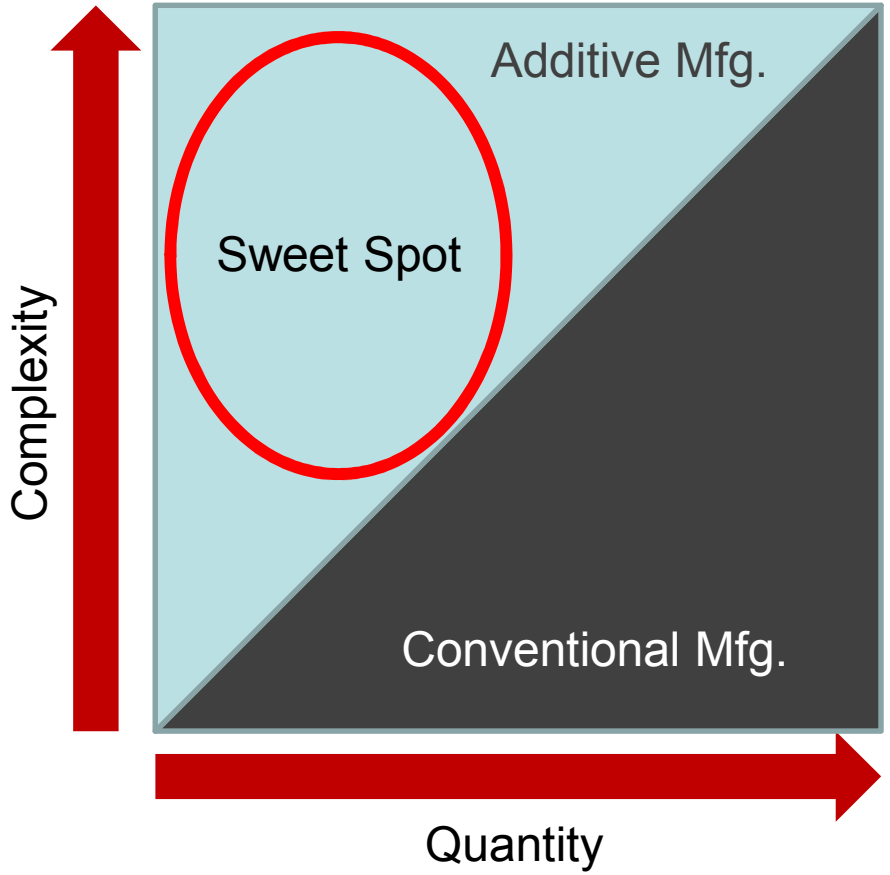
High Complexity, Low Quantity

- Specialty End Use Parts
- Rapid Tooling
- Low Volume Production



Advanced Applications

Metal Forming
Demonstrated Application

ADDITIVE MANUFACTURING
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Demonstrated Applications

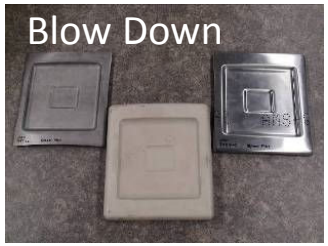
- Hydro Forming
- Rubber Pad Forming

Demonstrated Tooling

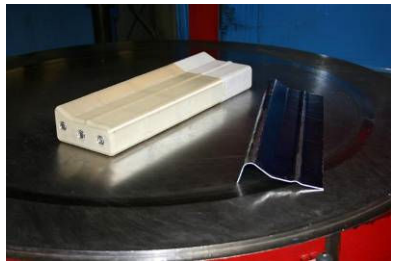
- Female, Blow Down Tools
- Male Tools
- Punch Tools
- Pressure Intensifiers
- Matched Male & Female Tools
- Back Filled Tools

Demonstrated Conditions:

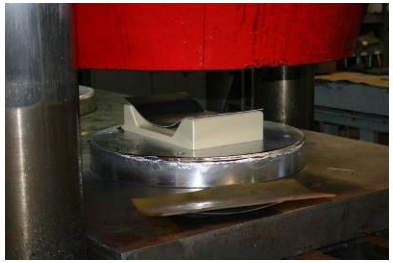
- Range of alloys and thickness tested
- Demonstrated forming pressures up to 10KSI
- Variety of tools >100 cycles, some > 500 cycles
- Large jointed tools have been tested



Hydroform



Rubber Pad



Punch

Pressure Intensifiers

Metal Forming
Demonstrated Application

ADDITIVE MANUFACTURING
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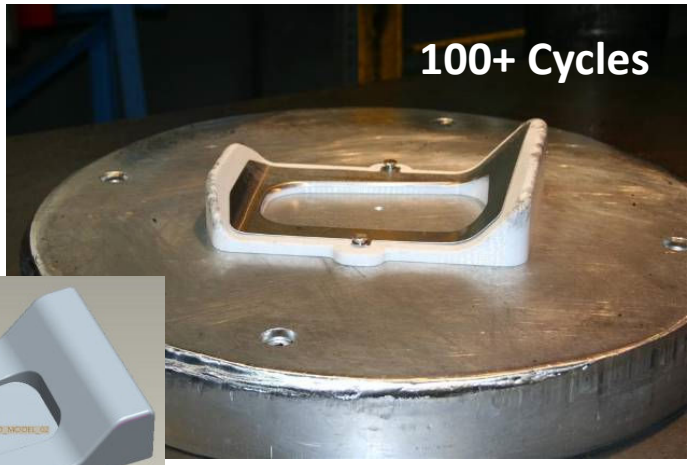
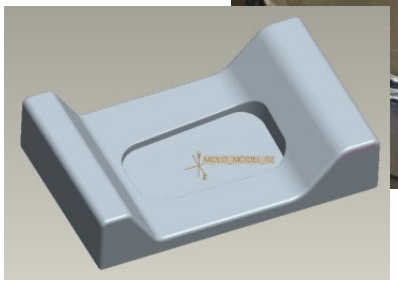
Large Tools

- 2.3m Long Hydro Form Tool
- PC Material
- Methods to join parts proven

Optimized Tool

- Match FDM material to forming pressure
  - ABS max 20.7 MPa
  - PC max 55.2 MPa
  - ULTEM max 68.9 MPa
- Rubber Pad Tool optimized for cost and build time
  ~ $200. in material
  ~ 8 hour build time





Original Tool

PRYER TECHNOLOGY GROUP

Metal Forming

Demonstrated Application : Coordinated Tool Family

ADDITIVE MANUFACTURING
Aerospace - Defence

Example

- MRO application
- Corrosion in frame needs repair

Solution

- Damage area is reverse engineered
- CAD model of repair is created
- Tool family built “lights out” with FDM
- Repair part fabricated with Hydroform tool
- Part trimmed & piloted at bench level

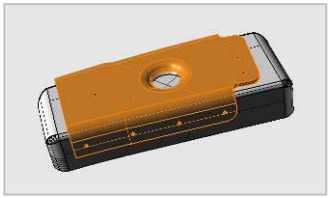
Benefits

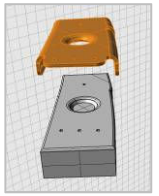
- Entire repair is digitally coordinated
- Lights out tool fabrication
- Minimize time on aircraft

Pryer Technology Group

Frame needing repair

Tool Design





Hydroform Tool

Trim & Drill Tool

Installed Part

Metal Forming
Case Study

Piper Reduces the Cost and Leadtime of Hydroforming Tool to Build a personal Jet

"I can program an FDM part in 10 minutes while typical CNC program takes four hours to write"

-Jacob Allenbaugh, Manufacturing Engineer, Piper Aircraft

PIPER

Metal Forming
Case Study

ADDITIVE MANUFACTURING
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- Producing hundreds of aluminum structural components
- Inner frame components, gussets, brackets, skins etc.

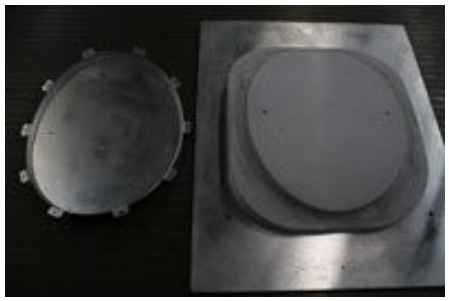
- FDM as the manufacturing process
- PC Material 3000 to 6000 psi
- Ultem 9085 for up to 10,000 psi

- Hydroform Tooling
- Produce route , drill and trim fixtures with FDM

- Program FDM part 10 min vs. 4 hrs CNC
- No operator attendance
- Less material waste

How Did FDM Compare to Traditional Methods for Piper Aircraft?

Method	Time
CNC Machined Tooling	14 days
FDM Tooling	4.5 days
SAVINGS	**9.5 days (68%)**



Aluminum Window Pan (left) FDM Tool

Aluminum Window Pan on top of FDM Tool

PIPER

Composite Applications

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FDM Composite Applications

- Patterns
  - Masters
  - Pre Layup
- Lay Up / Cure Tools
  - Consolidation Tools
  - Low Temp
  - High Temp
  - Bonding Fixtures
  - Intensifiers
  - Caul Plates
- Consumable Cores
  - Soluble Cores
  - Net Shaped Cores
  - Integrated Interfaces
- Digitally Coordinated Tool Families
  - Trim Tool
  - Drill Tool
  - Check Fixture

Composite Applications

FDM Tool Design Considerations

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FDM Tool Material Selection

- Maximum tool use temperature (usually the same as resin cure temperature) determines the material choice.

CTE Compensation

- Part size & accuracy requirements determine whether CTE compensation is required.

Tool Bagging Method

- Determines developed loads on tool & tool surface finish requirements.

Tool Build Orientation

- Build orientation affects surface roughness and tool strength.

Tool Finishing

- Tool finishing method is dependent on desired part surface finish.

Composite Applications

Material Compatibility

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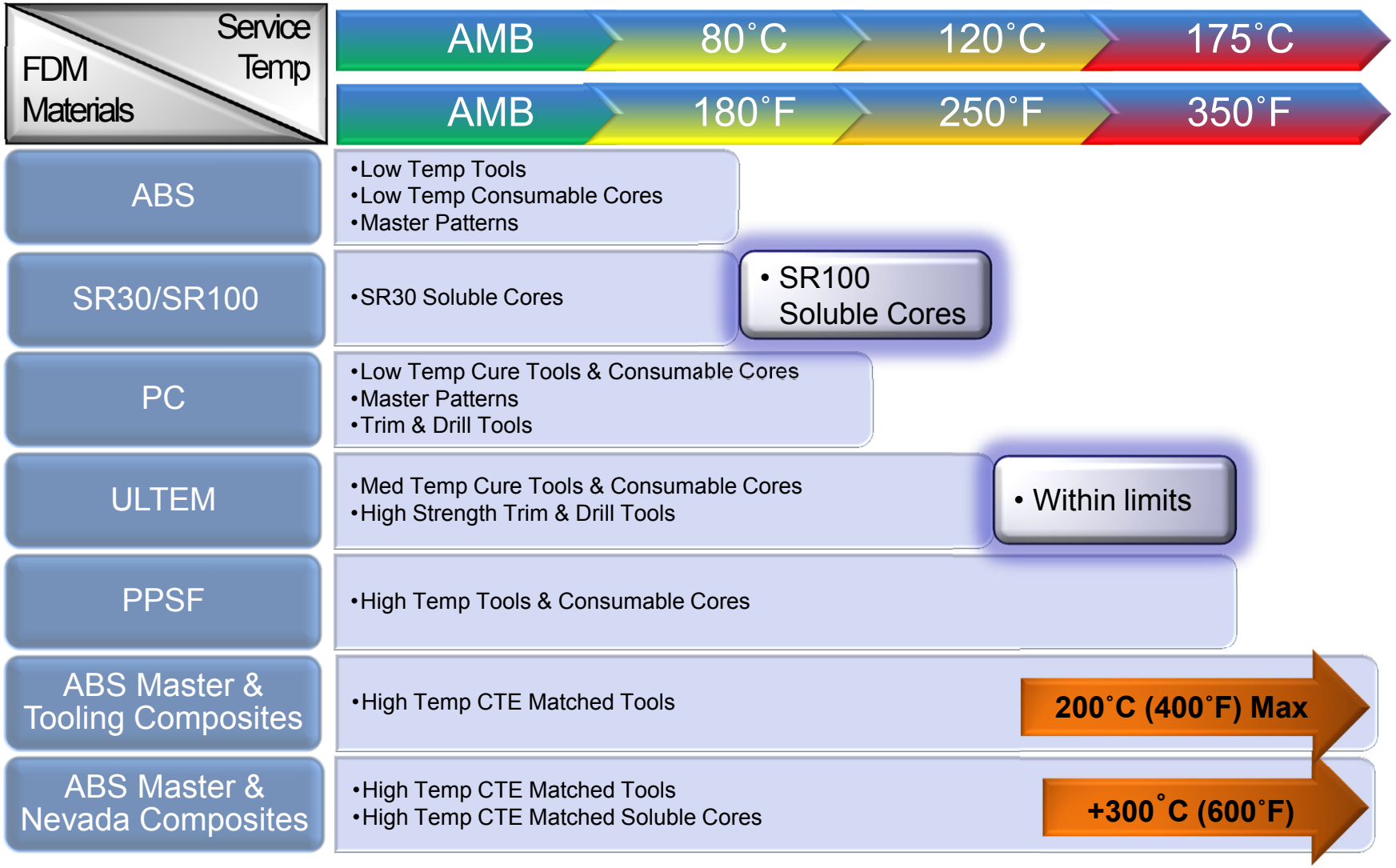

Composite Lay-Up Tooling

Demonstrated Application

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Demonstrated Lay-Ups

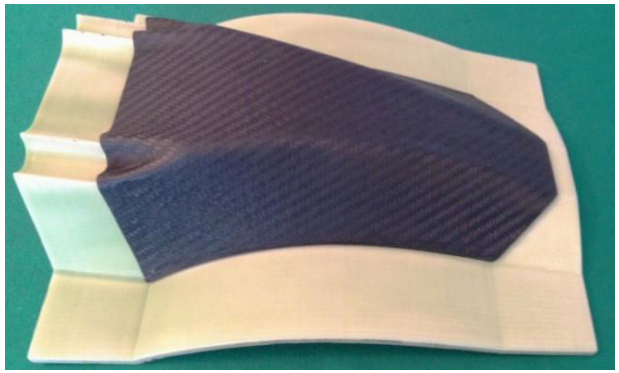
- Fibers: Carbon, Glass, Kevlar
- Resin Systems: Epoxy & Polyester

Demonstrated Tools

- Patterns – Low Temp Cure Tooling Composite
- Lay Up Tools < **350˚F** (177˚C) cure
- Pre-lay up/ply consolidation tool
- Pressure intensifiers / caul plates

Notes

- Surfacing methods available
- Release agents tested
- CTE compensation must be considered
- FDM material CTE information available.



Composite Lay-Up Tooling

Thin Skin Application

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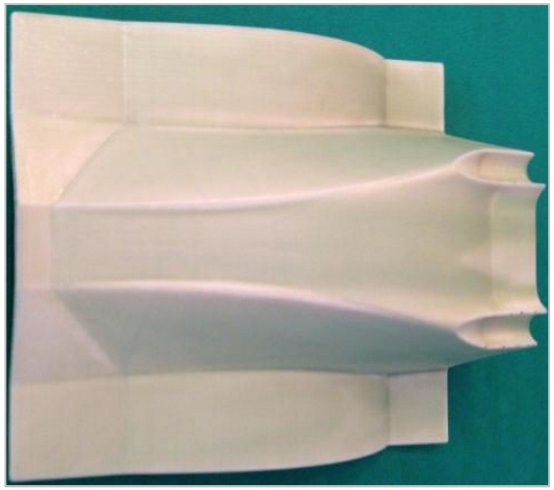

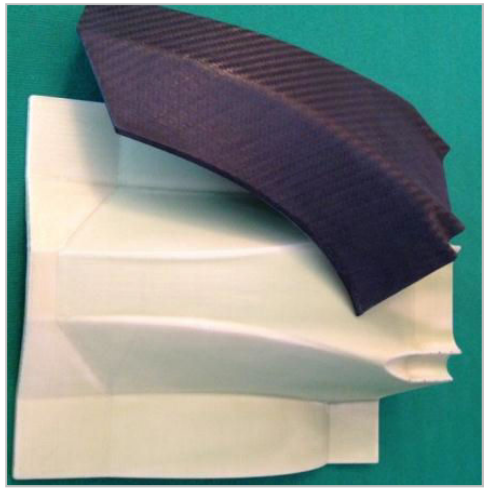

Design

- Ultem Material
- 6 mm thick
- Build Time: 5 hrs
- Tool surfaced with epoxy
- Vibratory polish (hands off) 1 hour

Use

- Release surface
- Lay up part
- Envelope bagging balances forces
- Cured @ 250 F, @ 80 psi
- Geometry Sensitive

Composite Lay-Up Tooling

Thin Skin Application

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Tool

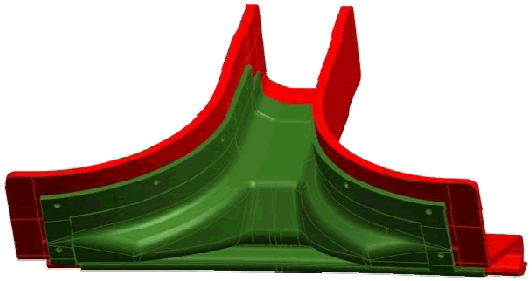
- Thickness 8mm (0.31”)
- Material PPSF

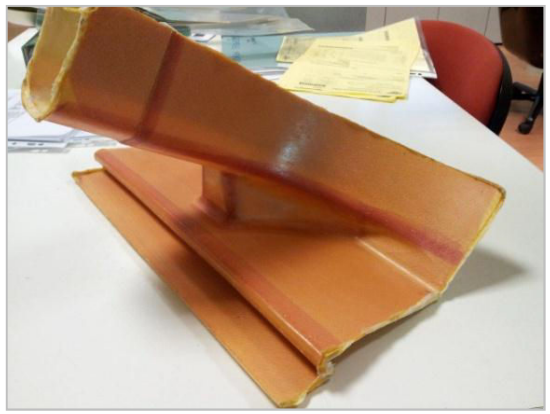
Lay Up

- Aramid fiber, 108g.m2
- 180 c epoxy resin

Results

- Final tolerance ±0.25 (0.010”) on 350mm (12”)
- No spring back effect on “C” shape





plyform

Composite Tooling
Case Study

ADDITIVE MANUFACTURING
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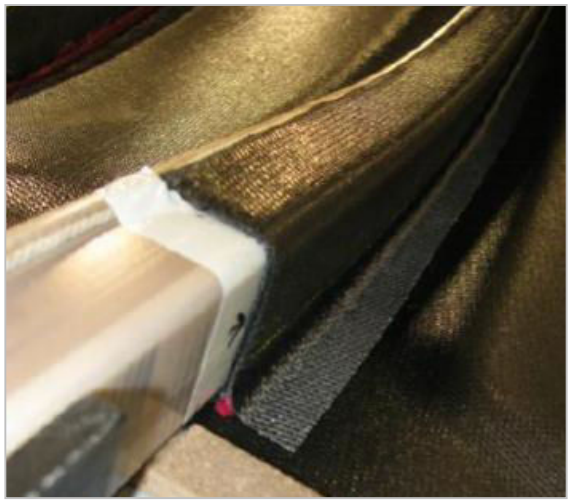
FDM Lay up tooling allowed for:

- Out-of autoclave fabrication of large complex shapes
- Low – cost rapid fabrication tooling for co-cured stiffeners
- Reduction in production time
- Reduction in production costs

FDM Stiffener
Layup Tool



BOEING

Engineering, Operations & Technology
Boeing Research & Technology

Composite Soluble Cores

Demonstrated Application

ADDITIVE MANUFACTURING
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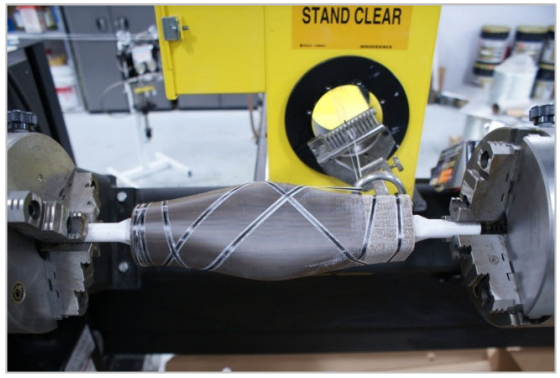
Complex shapes
- Wide variety of shapes and sizes in test

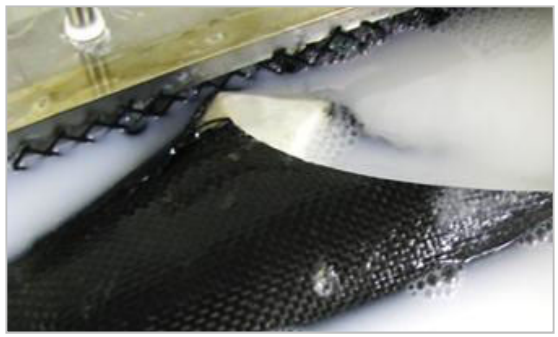
High strength
- Not brittle
- Handles off axis winding loads

Wash Out
- Hot water & detergent
- Compatible with epoxy resins
- Not recommended for polyester resins

Benefits
- Reduces costs, cycle times, risk
- Eliminates traditional mandrel cast tooling & labor & cycle time
- Eliminates scrap rates related to traditional mandrel removal
- Provides flexibility for early design iterations

McCLEAN ANDERSON





Composite Break Out Cores

Demonstrated Application

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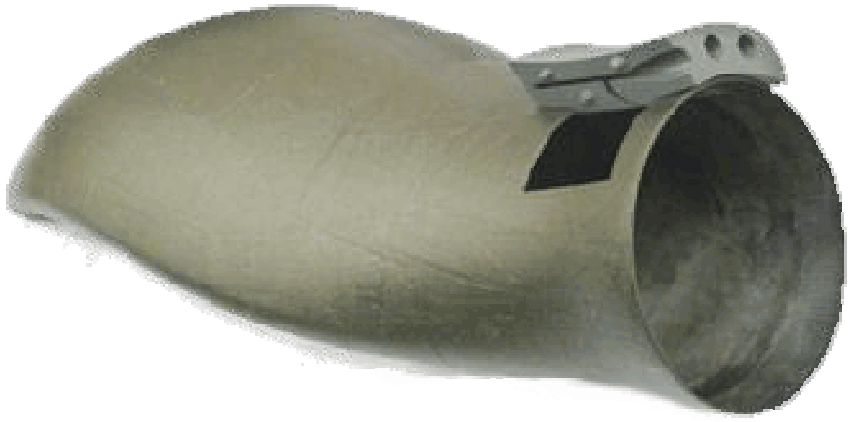
Ultem S1 Core

- Compromised with acetone
- Becomes brittle
- Broken into pieces for removal

Composite Break Out Core

Case Study



NORTHROP GRUMMAN

DEPARTMENT OF DEFENSE
MANUFACTURING TECHNOLOGY PROGRAM

Composite Break Out Core

Case Study

ADDITIVE MANUFACTURING
Aerospace - Defence

Application

- Inlet duct size =0.6 m x 0.6m x 0.9m (2'x2'x3')
- Trapped geometry

Solution

- 180 degree Celsius OoA composite system
- 2 hr 130 C (266 F) initial cure
- 2 hr free standing 180 C (356 F) post cure
- Ultem S1 break out core

Results

- Tool build time < 8 days
- Reduced tool lead time to < 14 days
- Tool maintained less than +/- 1 mm (0.040") accuracy

NORTHROP GRUMMAN

Project worked with NGC under Call 6 Program

Composite Break Out Core

Case Study

ADDITIVE MANUFACTURING
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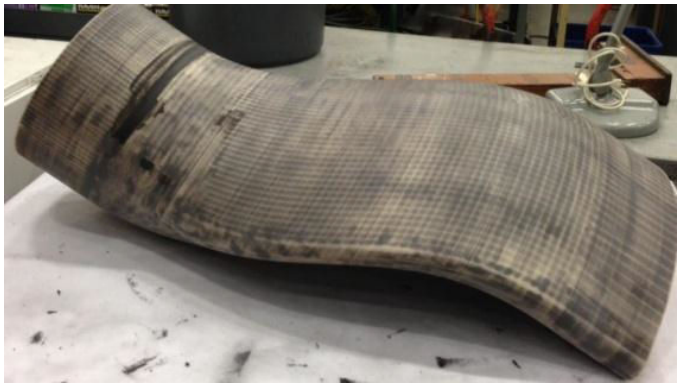


Tool Prep

Out of Autoclave Layup

Debulking

Envelope Bagging

Cured Composite Structure

Tool Break Out

NORTHROP GRUMMAN

Coordinated Tool Family

Demonstrated Application

ADDITIVE MANUFACTURING
Aerospace - Defence

Example

- Aircraft access door

Coordinated Tools & Parts

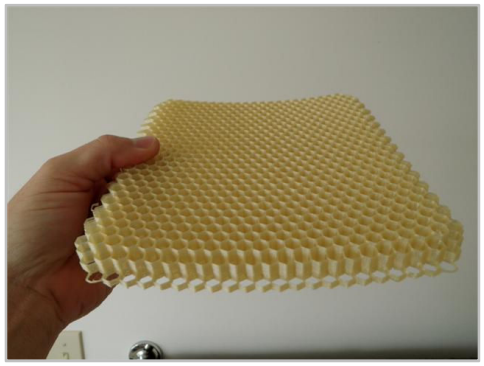
- Lay up mold defined by solid model
- Net shaped core defined by same model
- Trim & drill tool mastered to same solid model

Finished Part

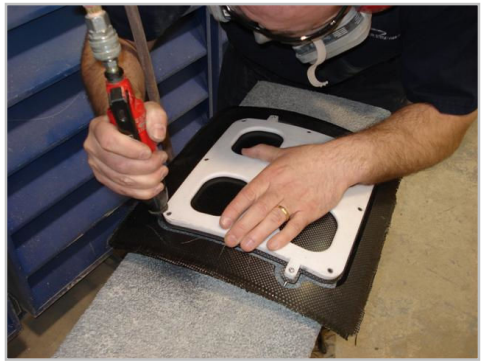
ADVANCED COMPOSITE STRUCTURES

Lay Up Mold

Net Shaped Core



Trim Tool



Trim Tool

Demonstrated Application

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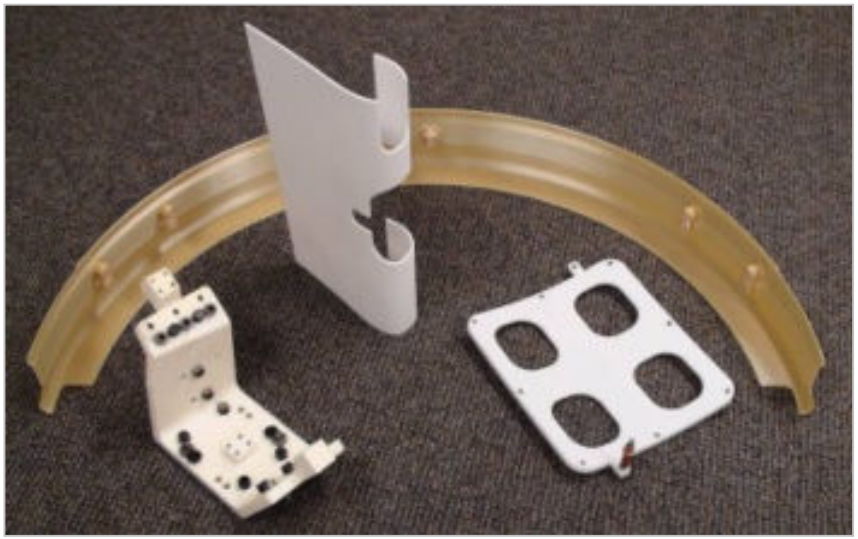
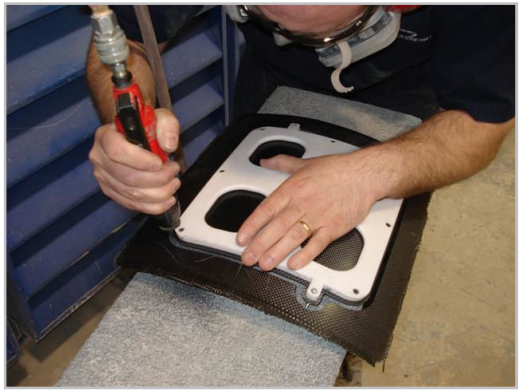
Types

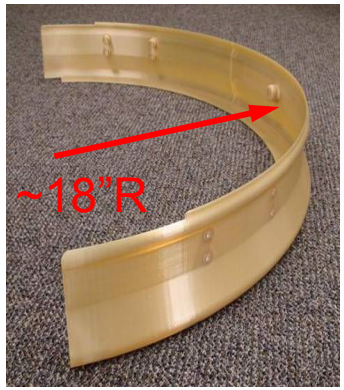
- Scribe Tool
  - Edge of tool is net
  - Scribe is used to transfer EOP to part
- Off Set Tool
  - Tool edge is inset
  - Provides guide surface for cutting tool
  - Prevents removal of too much material

When to use FDM

- Complex shapes
- Ergonomic light weight
- More stable than fiberglass in high humidity environments







ADVANCED COMPOSITE STRUCTURES

Drill Tool

Demonstrated Application

ADDITIVE MANUFACTURING
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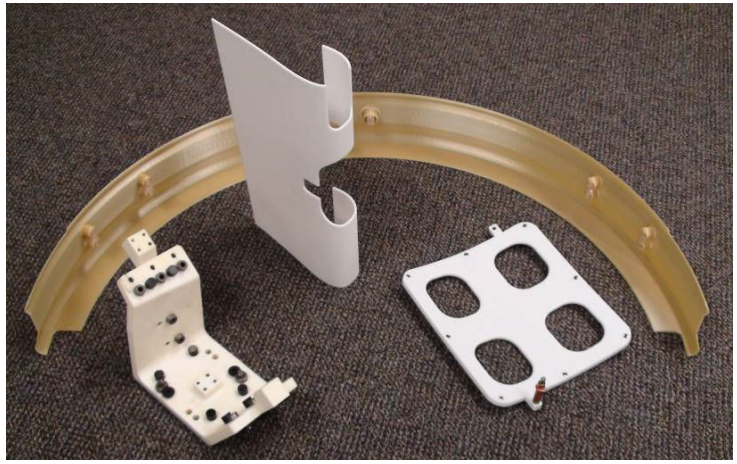
Types

- Direct Built
  - Shape and hole pattern are controlled by FDM build
- Precision
  - Shape built on FDM
  - Hole pattern drilled by CNC
- Transfer
  - Build desired shape with FDM
  - Bushings potted while pinned to master

When to use

- Complex shapes
- Multi axis hole patterns
- Ergonomic light weight
- More stable than fibreglass in humid environments



Coordinated Tool Family
With Drill Tool

Thermoforming
Demonstrated Application

ADDITIVE MANUFACTURING
Aerospace - Defence

Demonstration

- FDM Tool Material – ULTEM
- Formed 0.25” Kydex material
- Tool built with internal structures for
  - Combination of internal porosity and stiffeners
  - Heavier forming pressures
  - Higher temperatures
  - Higher material shrinkage forces

Results

- 100% drawn down achieved
- Tough corners formed well
- Shape & complexity is a strength of FDM

Assembly Aids

Demonstrated Application

ADDITIVE MANUFACTURING
Aerospace - Defence

- Assembly Tools
- Jigs & Fixtures
- Surrogate Parts

Benefits

- Custom interfaces for complex surfaces
- Minimize part handling damage
- Optimized for access without increased costs
- Light weight ergonomic

FDM Tooling

Benefits Summary

ADDITIVE MANUFACTURING
Aerospace - Defence

Enables:

- Reduced dependency on external suppliers
- Overnight fulfillment of new tooling requirements
- Lights out fabrication
- Digitally mastered coordinated tooling

Resulting in:

- Reduced cycle times up to 85%
- Cost savings up to 80%
- Improved quality

FDM End Use Parts

ADDITIVE MANUFACTURING
Aerospace - Defence

Direct benefits:

- Lower cost
- Shorter lead time

Indirect benefits:

- Design freedom
- Change freedom
- Mass customization
- Weight reductions
- Part consolidation
- Supports lean initiatives
- True JIT (just-in-time) manufacturing
- Reduced warehouse space/inventory cost

End Use Parts

Case Study

ADDITIVE MANUFACTURING
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FDM End use parts allowed for:

- Flexibility when designing complex parts
- Manufacture of less expensive part
- Weight saving solutions
- Production of parts that meet FAA regulatory requirements to be installed on aircraft
- Low volume production
- No tooling required

TDA
Taylor-Deal Aviation

End Use Parts

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Best fit when:

- **Relatively low volumes**
  - Short run production
  - Bridge to tooling
- **High part complexity**
  - Eliminate expensive tooling
  - Reduce long lead times
- **Part acceptable**
  - Aesthetics not critical
  - Finishing processes feasible
  - Physical properties acceptable

Path to Flight Worthy Parts

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First Article Flight Test Parts

- Ultem 9085
- FST zero rating & strength

Part Level Qualification

- Part level testing approved by governing aviation authority
- Non structural parts are primary targets today
- Numerous parts in flight

Material Property Certification

- Testing in work at 3rd party test labs
- Test labs recognized by commercial aerospace & DOD authorities

Pictures courtesy of Evektor

Picture courtesy of Rapid PSI

What **inspires** you is your business

How you make it **real** is ours.

THANK YOU

Contact Info.

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