Manufacturing Solutions

John F Dobstetter
Business Development Manager
Direct Digital Manufacturing

Overview

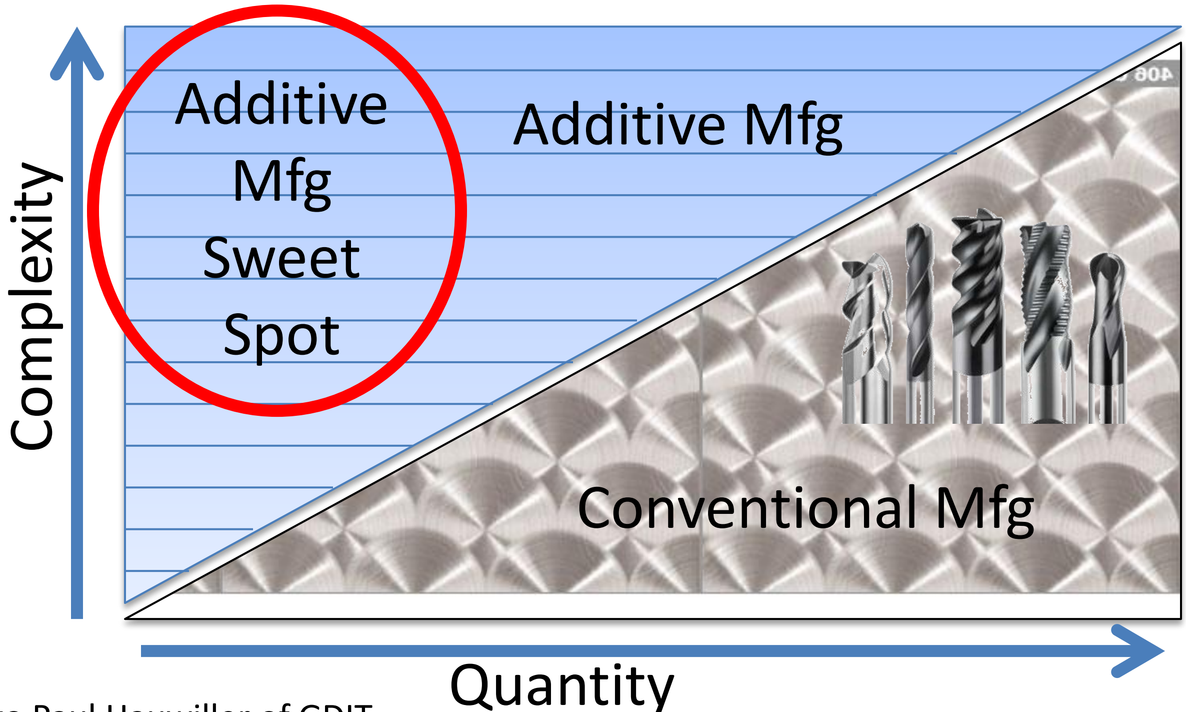
Stratasys
FOR A 3D WORLD™

- Additive overview
- Tooling applications
- End use part applications
- Tooling for composites

Additive Mfg Sweet Spot

High Complexity, Low Quantity

- Specialty End Use Parts
- Tooling!



Slide Style Credit to Paul Hauwiller of GDIT

Product Lifecycle Applications

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Design | Prototype | Test | Manufacture | Support

Design
- Concept Models
- Access Concept Validation
- Assembly Simulation

Prototype
- Prototypes Models

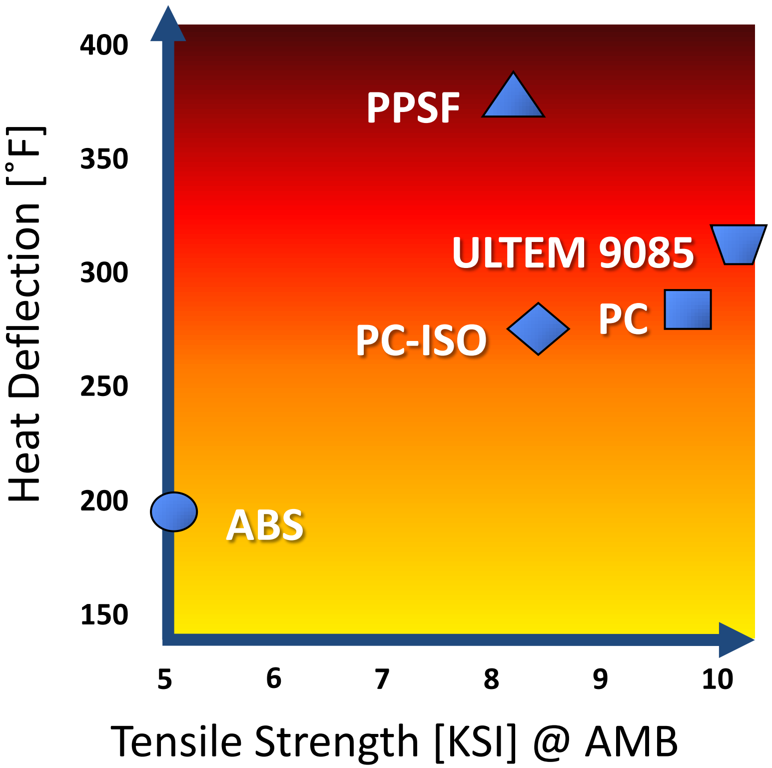
Test
- Specialized Interface Models
- Functional Test Models

Manufacture
- Low Rate Manufacturing Tooling
- Rate Manufacturing Tooling
- Specialized Shop Aids
- Jigs & Fixtures
- End Use Parts

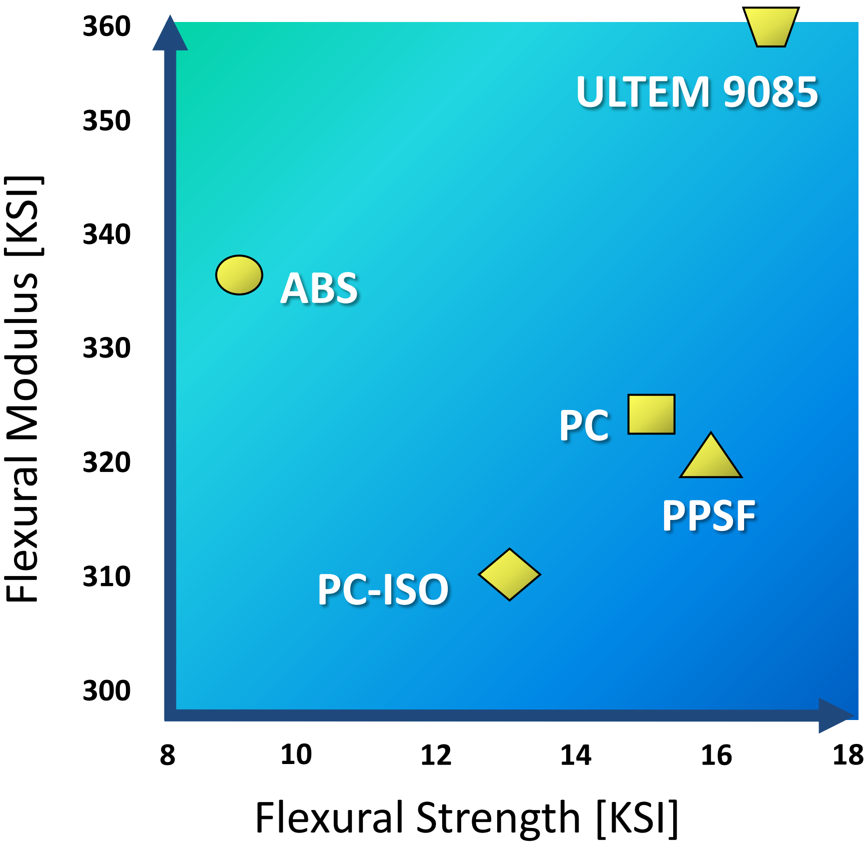
Support
- Repair Jigs & Fixtures
- Repair Shop Aids
- Repair Tooling

FDM Materials

Strength vs Heat Deflection



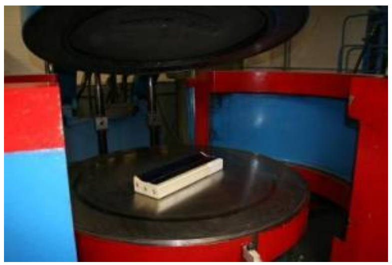
Flex Modulus vs Flex Strength

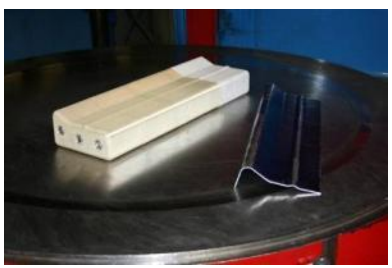


Metal Forming Tools

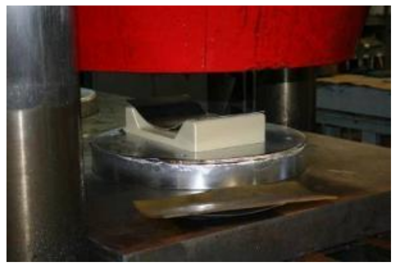
US Naval Air Systems Command Depots NAVAIR

Hydro Form

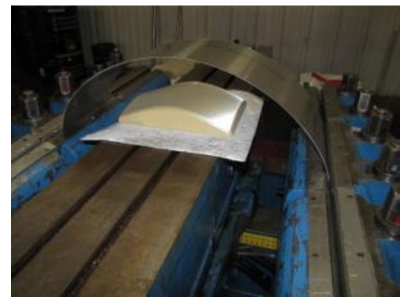


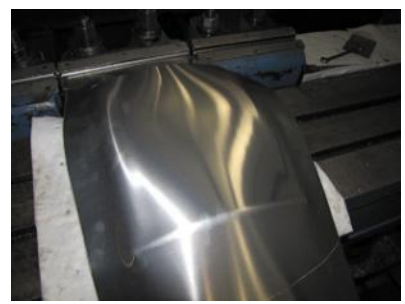


Rubber Pad

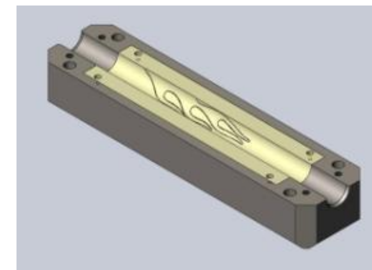


Stretch Form





Tube Form



Metal Forming

Mold Tools

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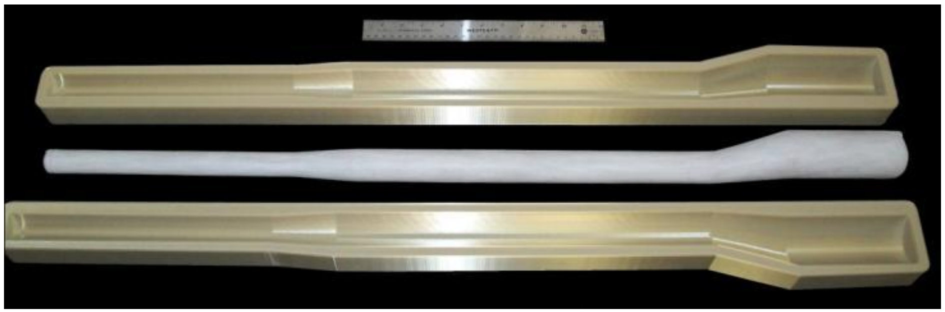
High Temp Washout Core Molds



Silicone Gasket Mold

Reconfigurable Over Mold

Injection Molds

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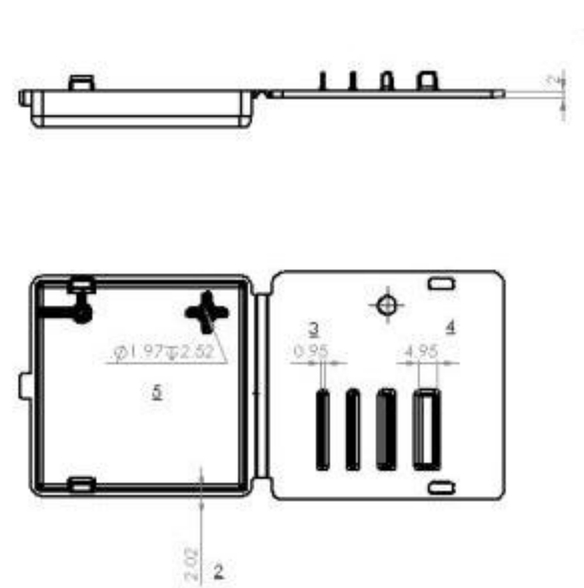
Part description	Test part
Material injected	PP
Special features	Living hinge, bosses, press fit
comments	• 100 parts out of 2 tools • Low pressure developed • Tools did not fail

Material	**PP**
Nozzle Temp [F]	428
Inj. Pressure [psi]	8700
Hold Pressure [psi]	4351
Holding time [s]	8
cycle time [s]	180
Comments	Cooling with air pressure

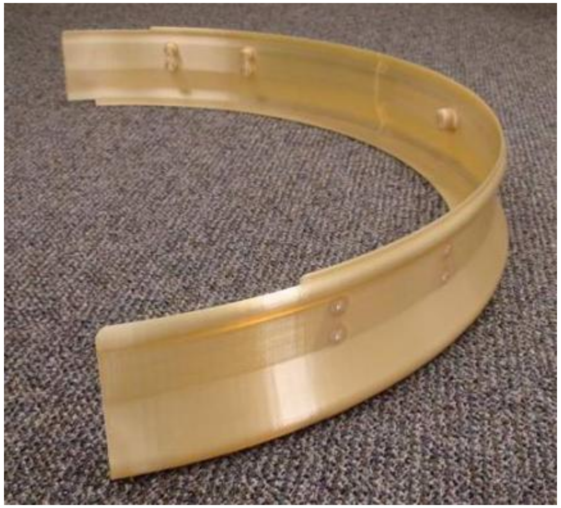


Injection Molds

	Cost (US$)	Turnaround (days)	comments
P20 Steel	3400	18	estimate
Aluminum	1670	7	estimate
ABS-like	960	22 Hr. (1 day)	Connex 500 Consumption: 810gr RGD535 1408gr RGD515 150gr support

Time saving: 700-1800%
Cost savings:
- 43% over aluminum
- 72% over steel

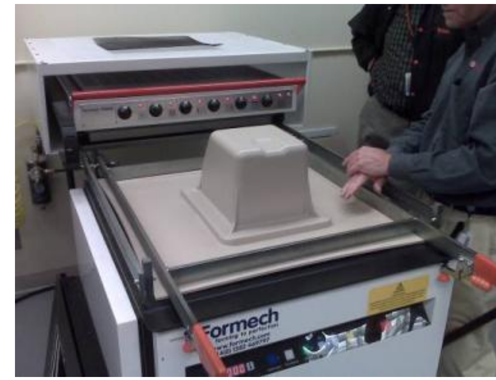
Trim & Drill Tools



Thermoform Tools

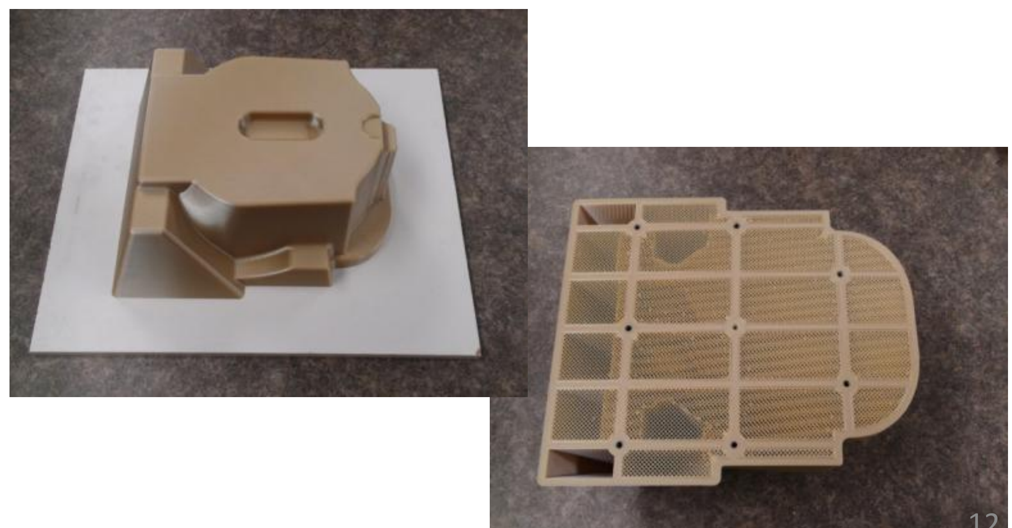
Tool

Trials

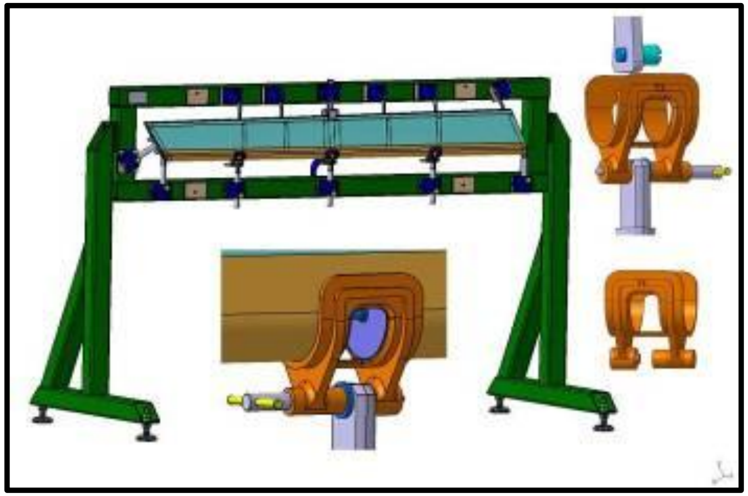


Production

Complex Tooling



Assembly Aids



End Use Parts – Light Aircraft

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evektor

Picture courtesy of

Unmanned Systems

Stratasys
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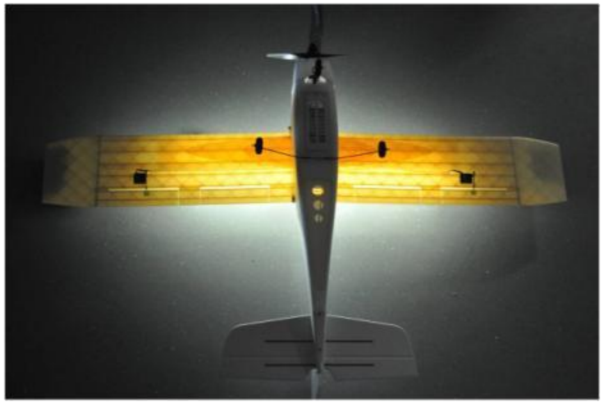
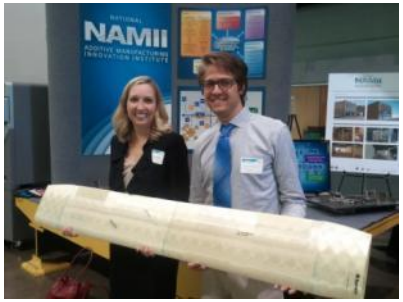


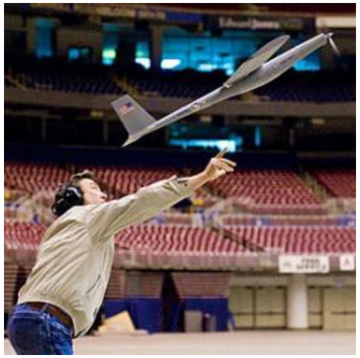


Pictures courtesy of Draganfly

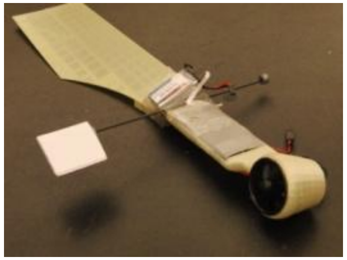
Aurora
FLIGHT SCIENCES

BOEING

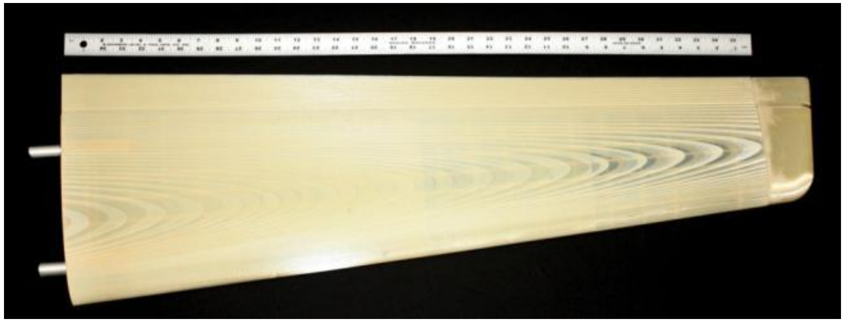
LOCKHEED MARTIN



Pictures courtesy of Leptron



Pictures courtesy of Embry-Riddle



Picture courtesy of NEO S-300 VTOL UAV Swiss UAV GmbH

FDM Composite Tooling

FDM Composite Applications

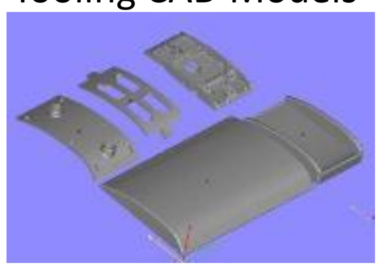
- Patterns
  - Masters
  - Pre Layup
  - Consolidation Tools
- Lay Up / Cure Tools
  - Low Temp
  - High Temp
  - Bonding Fixtures
  - Intensifiers
  - Caul Plates
- ***Consumable Cores***
  - ***Soluble Cores***
  - Net Shaped Cores
  - Integrated Interfaces
- Jigs & Fixtures
  - Trim Tool
  - Drill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

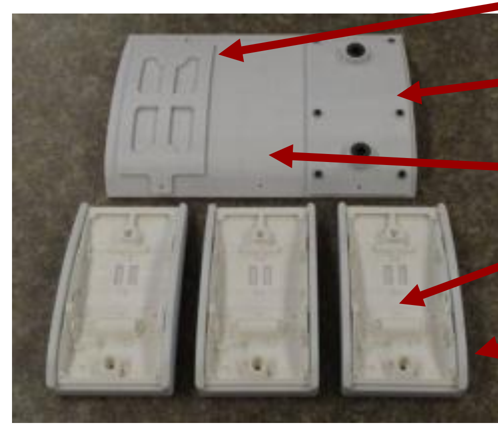
Coordinated Tool Family

- Application
  - UAV wing box
- Benefits
  - Scaled tool size and qty to meet rate demands
  - Digitally mastered tool family
  - Concurrent tool fabrication

Model Based Definition

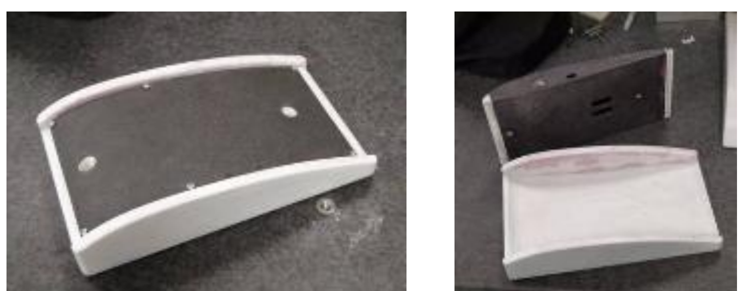
Tooling CAD Models





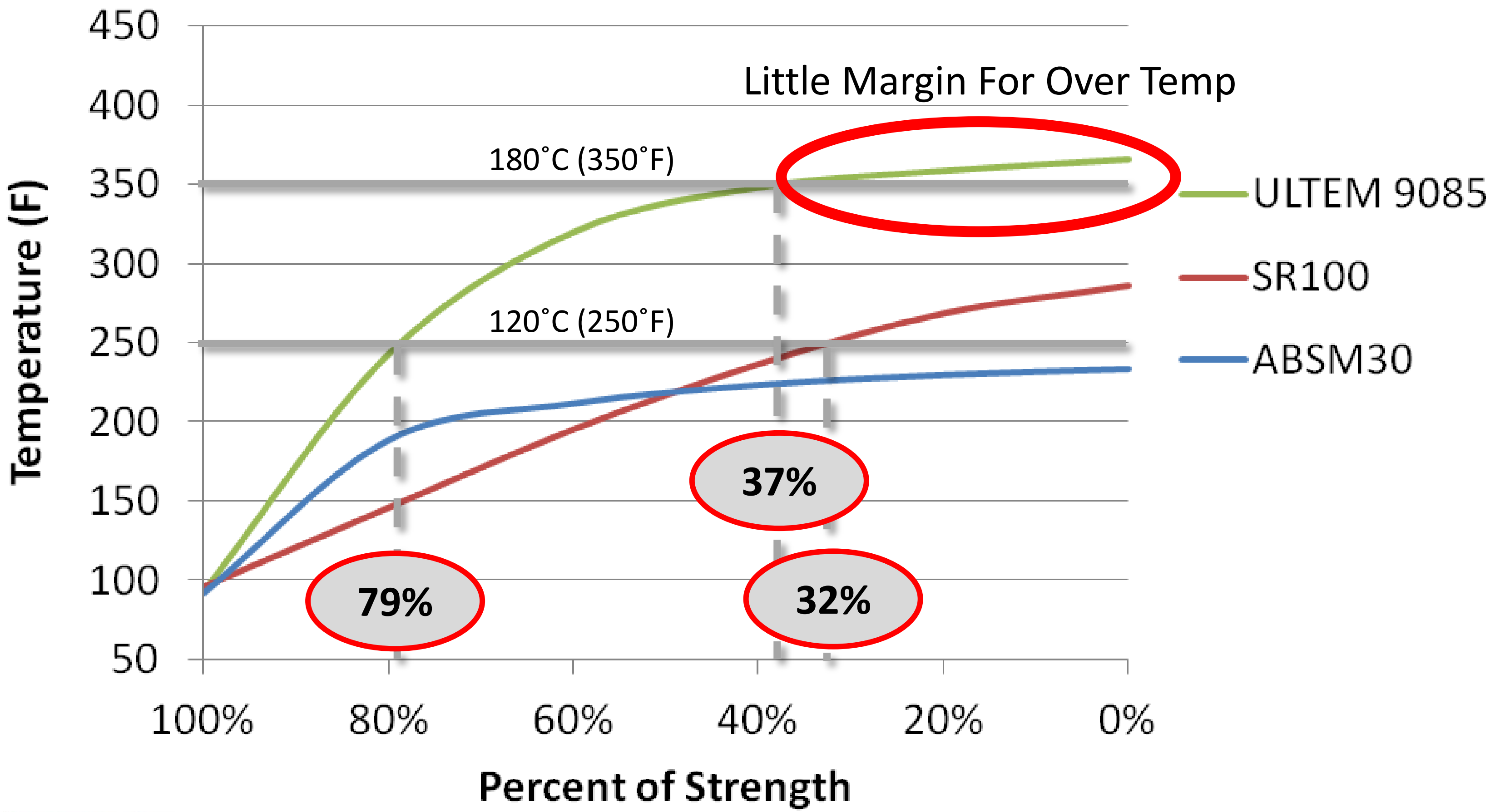
Completed Cover

Female Co-Bond Tool



Finished Part

Dynamic Flex Test

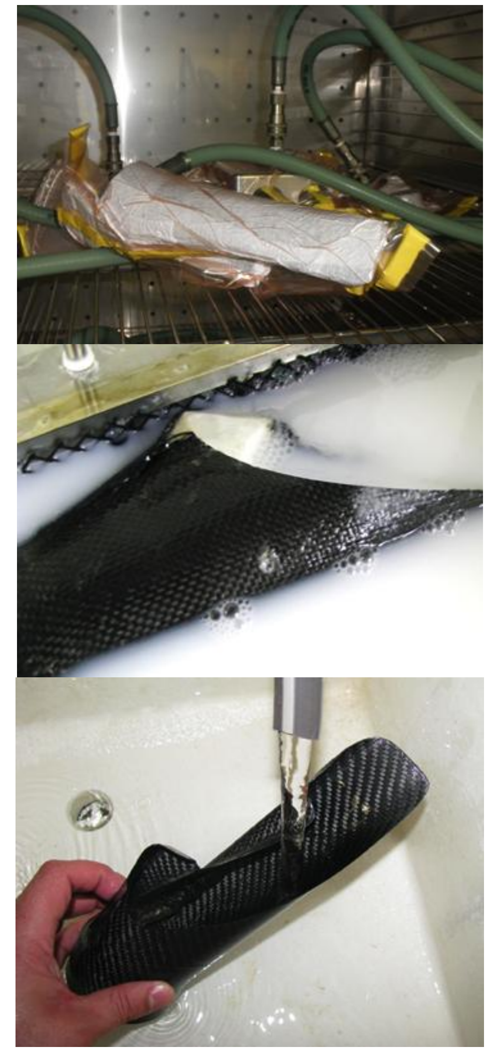


FDM Material Application Map

FDM Materials \ Service Temp	AMB (AMB)	80˚C (180˚F)	120˚C (250˚F)	175˚C (350˚F)
ABS	•Low Temp Tools •Low Temp Consumable Cores •Master Patterns			
SR30/SR100/S1	•SR30 Soluble Cores	•SR100 Soluble Cores	•ULTEM S1 Break Out Cores	
PC	•Low Temp Cure Tools & Consumable Cores •Master Patterns •Trim & Drill Tools			
ULTEM 9085	•Med Temp Cure Tools & Consumable Cores •High Strength Trim & Drill Tools		•Caution above 150˚C/300˚F	
PPSF	•High Temp Tools & Consumable Cores			
ABS Master & Tooling Composites	•High Temp CTE Matched Tools			200˚C (400˚F) Max
ABS Master & Nevada Composites	•High Temp CTE Matched Tools •High Temp CTE Matched Soluble Cores			371˚C (700˚F)

Soluble Cores

- Dissolve FDM soluble core
  - WaterWorks bath solution
  - Heated tank ~ 140˚F (60˚C)
  - Agitation & circulation recommended
  - Rinse composite part
  - Duration is dependent on geometry
- Compatible with most epoxy resins
  - WaterWorks has been demonstrated to attack some polyester resins
  - Tests to confirm resin compatibility are recommended



Break Out Cores

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ULTEM S1 CORE

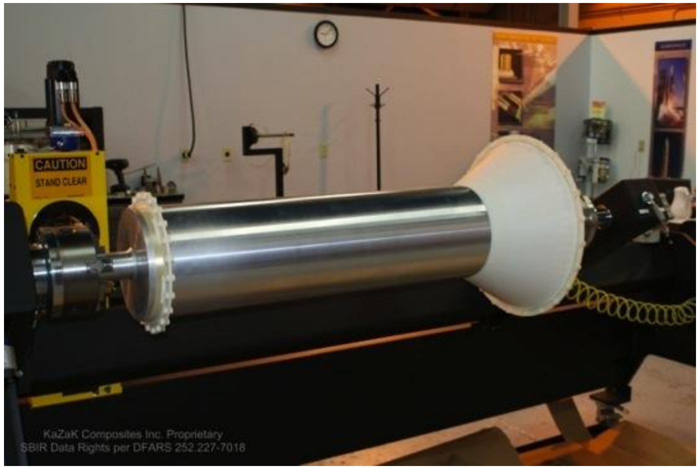
Cured Part

Finished Part

- ULTEM S1 core compromised with acetone after cure
- ULTEM S1 becomes brittle
- Core is broken into pieces for removal

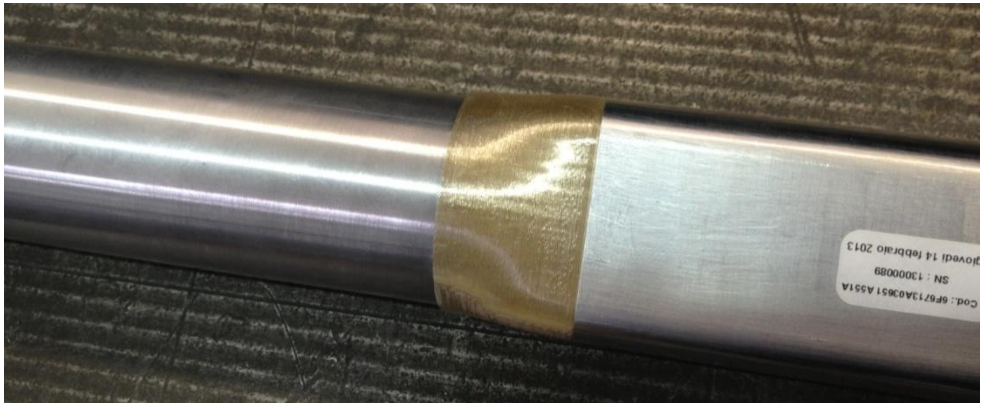
Large Hybrid Cores

- Mandrel Specifications
  - Hybrid mandrel
    - Aluminum main shaft
      - ~ 6' (15.2cm) long x 9" (22.9cm) dia
    - FDM soluble core ends
      - 24" (61cm) diameter x 12" (30.5cm) tall
  - 12 lb normal load for tow winding
  - 200˚F (121˚C) Cure
- Lessons Learned
  - Washout process is a design driver
  - Part rotation during cure evens out loads during cure cycle



Hybrid Break Out Core

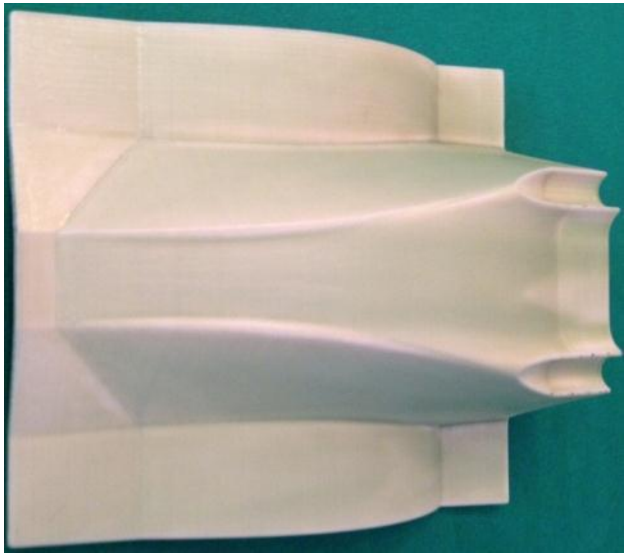
- Aluminum/ULTEM-S1 Hybrid
  - Reusable aluminum sections
  - ULTEM-S1 trapped section
  - Build time minutes
  - Minimal costs
  - Size mitigated CTE mismatch

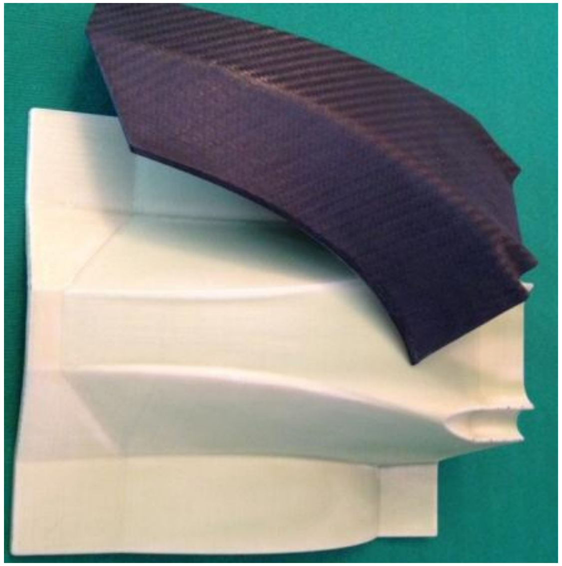


Automotive Applications

SR-100 Soluble Tool Material
- Produce 250°F cured composite parts
- 80 psi pressure
- Supports complex geometries

Thin Skin Tooling





- Design
  - Ultem material
  - 6mm thick
  - 5hrs build time
  - Tool surfaced with epoxy
  - Vibratory polished hands off for 1 hr
- Use
  - Released surface
  - Lay up part
  - Envelop bagging balances forces
  - Cured at 250F, 80 psi
  - Caution: geometry sensitive

Larger Scale Tooling

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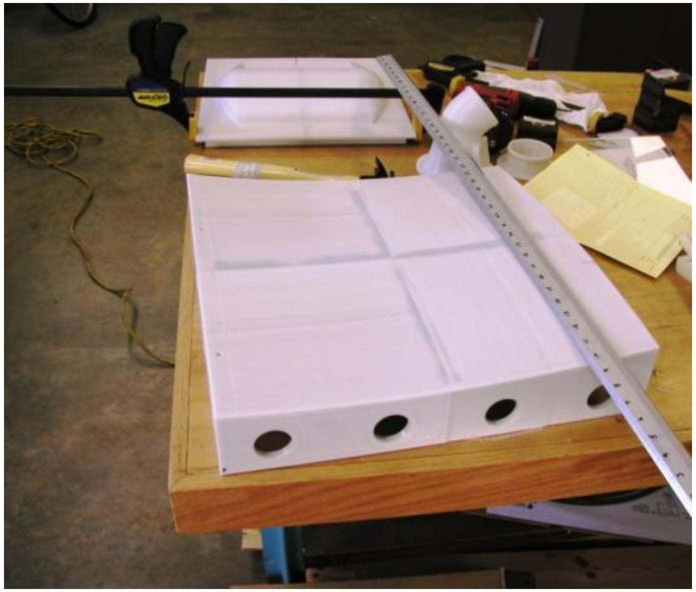
Lockheed Martin Layup Tool



LOCKHEED MARTIN

Boeing FDM C-channel Mandrel

BOEING

Hybrid Assemblies

- First Robotics Team #3824
  - Hardin Valley Academy
  - RoHawktics
  - Sponsored by ORNL Manufacturing Demonstration Facility (MDF)
- Hybrid Assembly
  - FDM Fittings
  - Pultruded Rods
  - Filament winding
- Benefits
  - Additive is great at relatively smaller more complex
  - Carbon fiber is great at long, simple, light weight, high strength structures
  - Combining provides strengths of both technologies

First Robotic Team #3824

Stratasys
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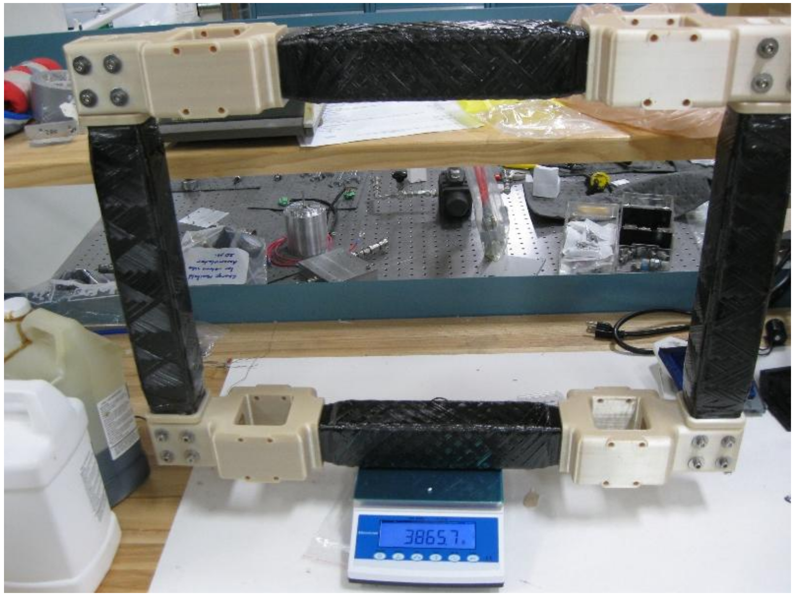
- Application
  - Robot Chassis
  - Stiff/light weight
- Solution
  - FDM light weight end pieces with critical interfaces
  - Pultruded carbon rods for spanners
  - Filament wound for bonding and strength/stiffness
- Results



Part	Length	AM Only		Hybrid	
		Fab Time	Weight	Fab Time	Weight
Long Beam	54”	90 hrs	14.64 lbs	15.5 hrs	3.86 lbs
Short Beam	21”	24 hrs	7.44 lbs	8.25 hrs	1.77 lbs

Summary

Stratasys FOR A 3D WORLD™

- Additive has a growing role in manufacturing
- Stratasys provides solutions over product life cycle
- Enabling a wide spectrum of tooling options
- Performance materials enable end use parts
- Real solutions for composite tooling
- R&D efforts expand validated applications

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Back Up Slides

Thin Skin Tooling

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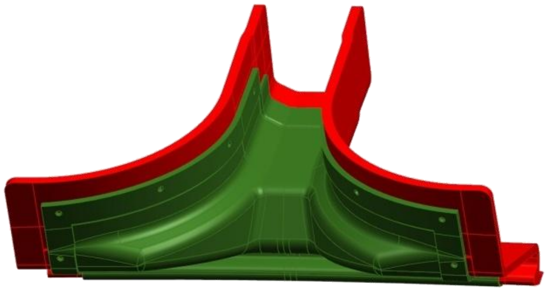
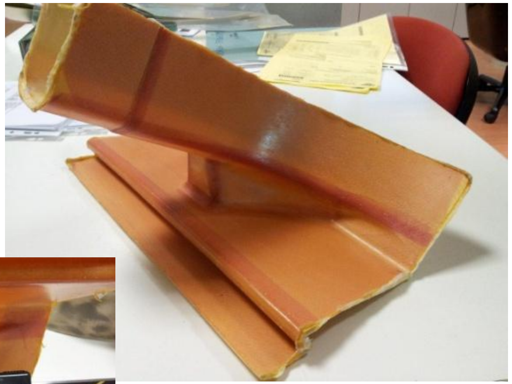
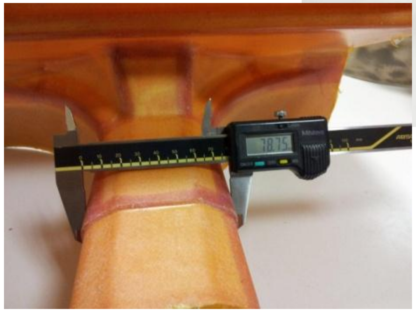
- Tool
  - Thickness 8mm (0.31”)
  - Material PPSF
- Lay Up
  - Aramid fiber, 108g/m^2
  - 180C epoxy resin
- Results
  - Final tolerance: ±0.25 (0.010”) on 350mm (12”)
  - No spring back effect on “C” shape”







plyform

Aerospace Application

- Application
  - Inlet duct, size = 0.6m x 0.6m x 0.9m (2’x2’x3’)
  - Trapped geometry
- Solution
  - 180˚C OoA composite system
  - 2 hr 130˚C (266˚F) initial cure
  - 2 hr freestanding 180˚C (356˚C) 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



Project worked with NGC under AFRL Call 6 Program

Break Out Core Application

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Tool Preparation

Out of Autoclave
Composite Layup

Debulking

Envelope Bagging

Cured Composite
Structure

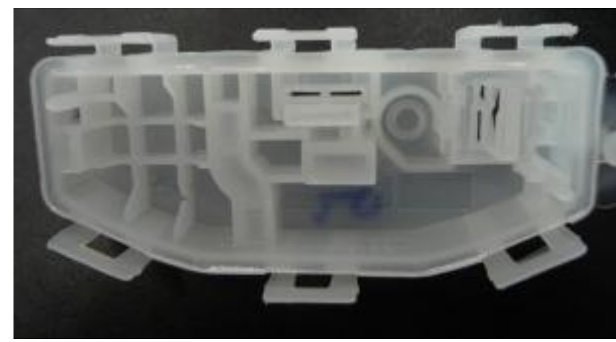
Tool Break Out

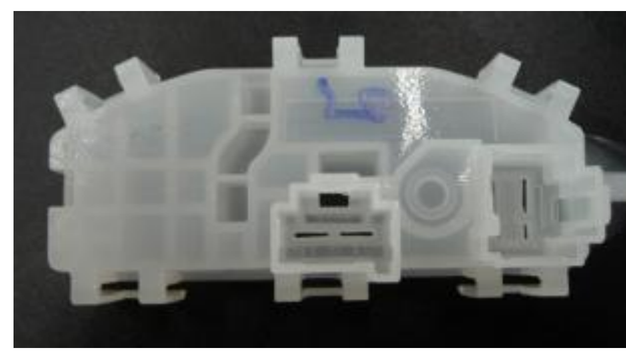
NORTHROP GRUMMAN

Injection Molds

Industry	Automotive
Part description	Steering wheel connector
Material injected	Wax, HDPE
Special features	Highly complex. Thin walls
comments	10 parts molded, long cycle time

Material	**HDPE**
Nozzle Temp [F]	365
Inj. Pressure [psi]	8700
Hold Pressure [psi]	4351
cycle time [s]	360
Clamping force [kN]	300

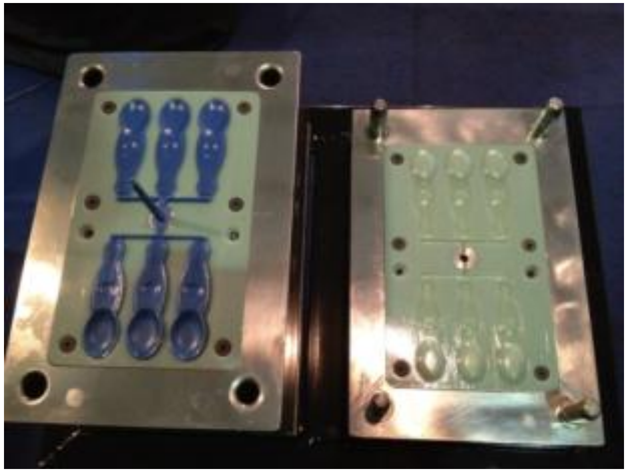




Injection Molds

Industry	Consumer goods
Part description	Ice cream spoons
Material injected	PP
Special features	6 cavity mold
comments	Injected in different colors

	Cost (US$)	Turnaround (days)	comments
P20 Steel	3200	30	
Aluminum	1400	30	
ABS-like	785	7 hr. (1 day)	Connex 260 Consumption: 400gr RGD535 480gr RGD515 100gr support



Time saving: 3000%

Cost savings:

- 44% over aluminum
- 75% over steel

Solution Breakdown

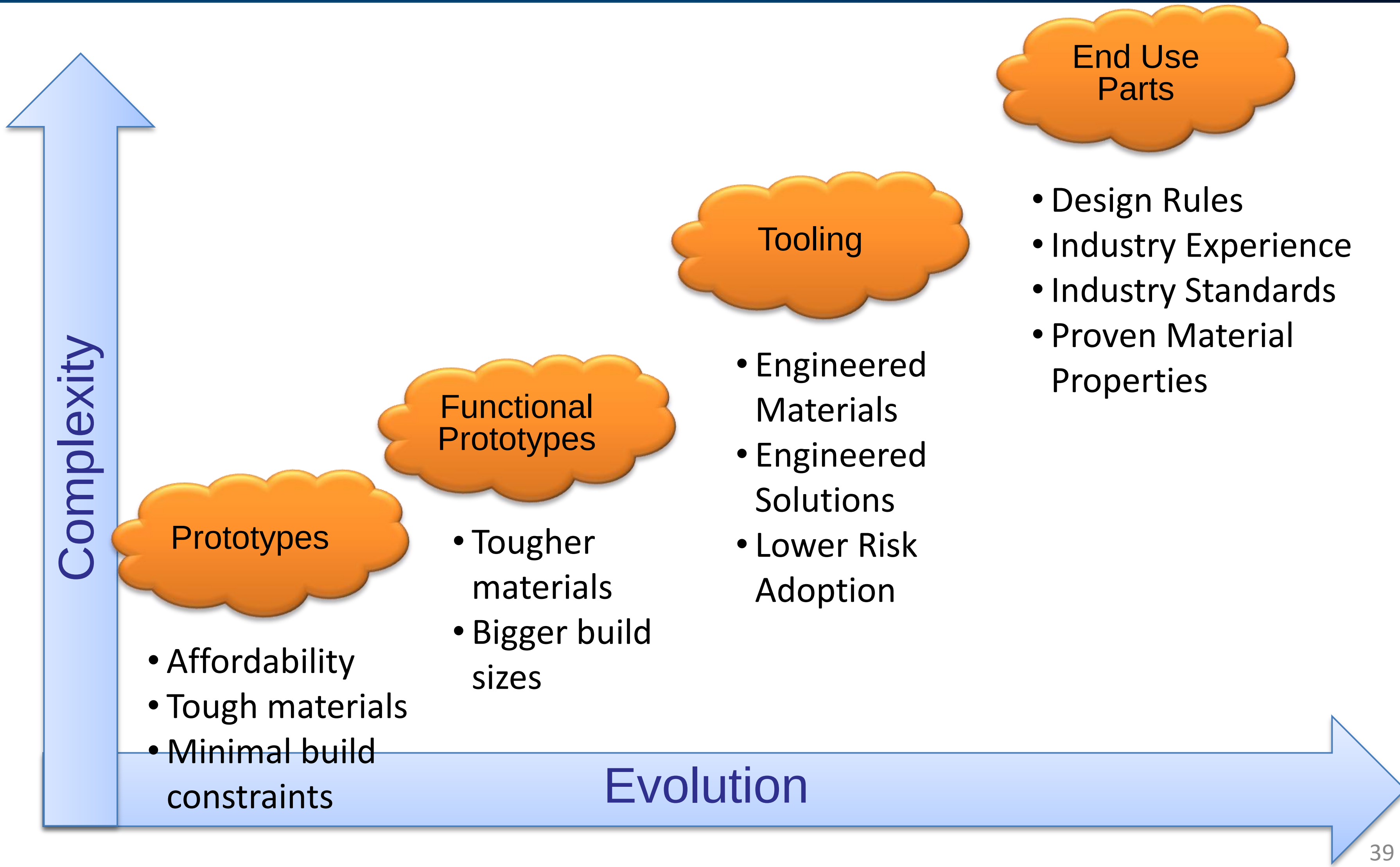
Item/ Material Group	A	B	C	D
Materials	PP, PE, PS, ABS, TPE..	• PP +GF, PA, POM, PC+ABS, PVC…	• PA+GF, PC, POM+GF…	• PC+GF, PPO, PPS..
Geometry	• Accuracy up to 0.1mm • Thin walls down to 0.5mm • Pins down to 0.8mm			
Size	• Insert/ Mold up to 500*400*200mm			
Number of parts	~100	• ~30	• ~15	• ~5
Process	• According to Rapid Molds IM guidelines			
Tool Design	• According to Rapid Molds IM guidelines			

- Answers to FAQ are mostly found in this table

Part 1 – Injection parameters

Material	PP+GF	PA+GF	POM
Nozzle Temp [C]	195	285	195
Inj. Pressure [bar]	200	200	200
Hold Pressure [bar]	200-400	200-400	200-400
cycle time [s]	110	110	110
Clamping force [kN]	400	400	400

Additive Manufacturing Evolution



Aero – Interior Applications

Fused Deposition Modeling

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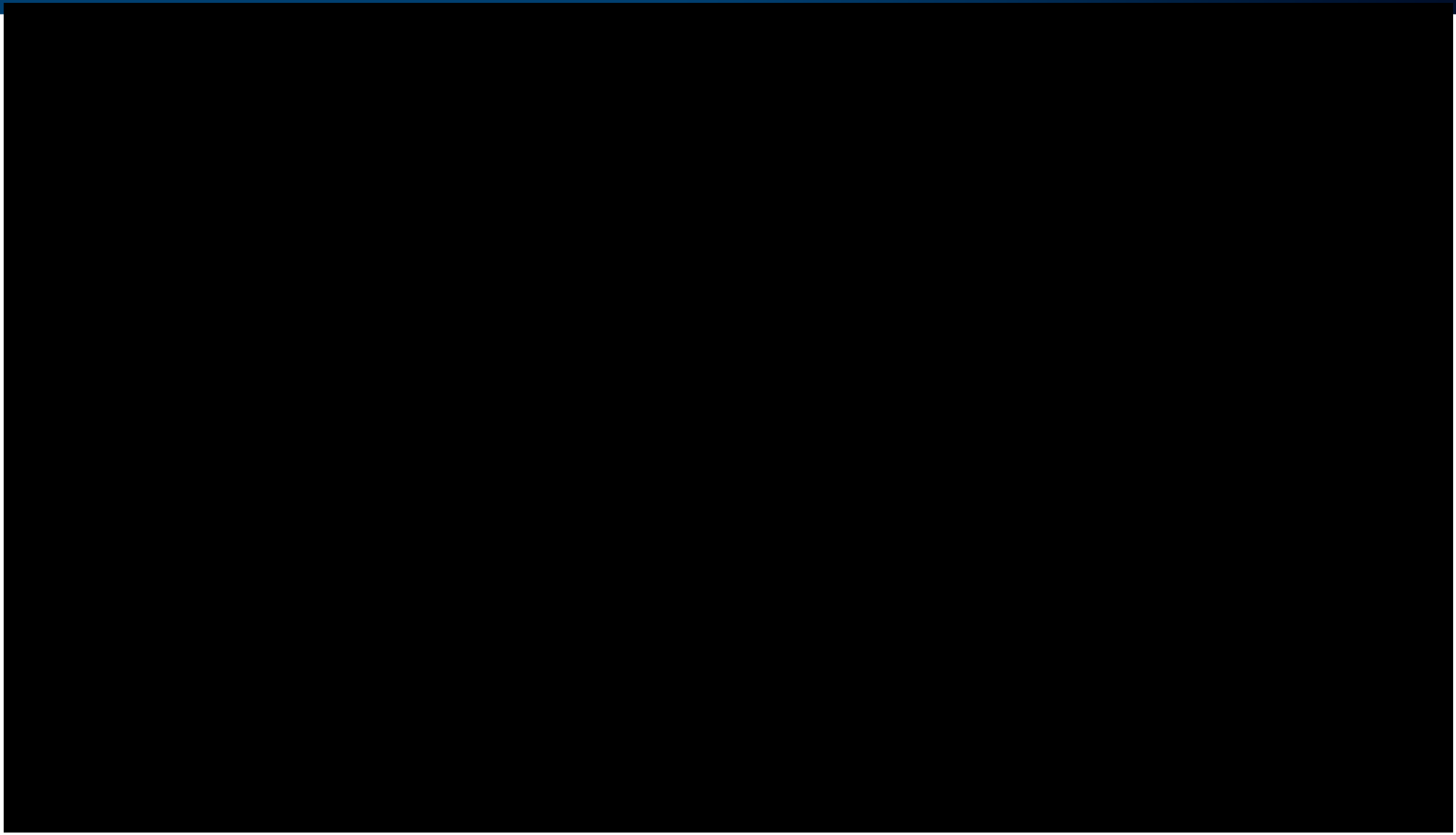
- Additive Manufacturing Process
- Thermal Plastic Materials
- Lights Out Fabrication

Process CAD File **Manufacture** **Completed Part**

FDM Process



FDM Process

Stratasys
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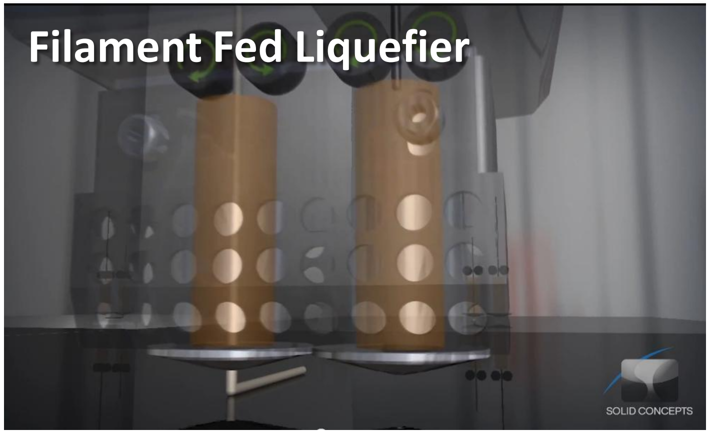

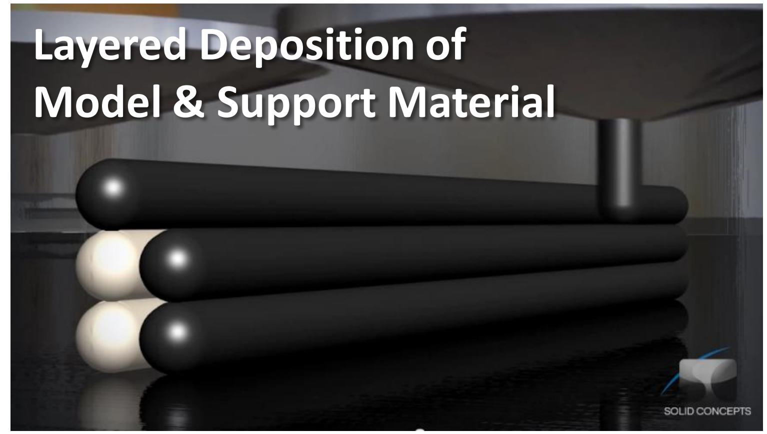

Source of images – Solid Concept YouTube Video http://youtu.be/oujzQvz79ig

FDM Material Properties

Property		SR30	SR100	ULTEM S1
Tg	(˚F) (˚C)	212 100	271 133	365 185
CTE (ASTM E228) 95˚F-212˚F 35˚C-100˚C	 [E-5 in/(in˚F)] [E-6 m/(m˚C)]	 6.5 115.53	 5.5 100	 Not Applicable
CTE (ASTM E228) 212˚F-266˚F 100˚C-130˚C	 [E-5 in/(in˚F)] [E-6 m/(m˚C)]	 Not Applicable	 10.4 195	 Not Applicable
CTE (ASTM E228) 95˚F-330˚F 35˚C-165˚C	 [E-5 in/(in˚F)] [E-6 m/(m˚C)]	 Not Applicable	 Not Applicable	 3.6 64.6

ADVANCED JOINING & PROCESSING LABORATORY

ULTEM S1 Mechanical Properties

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Property		Room Temp	High Temp	% Diff
Test Temp	(˚F) (˚C)	70 32	350 160	
Tensile Strength (ASTM E228)	(KSI) (MPa)	7.97 54.95	3.81 26.27	48%
Tensile Modulus (ASTM E228)	(KSI) (MPa)	336 2317	305 2103	91%
Compressive Strength (ASTM E228)	(KSI) (MPa)	6.97 48.06	3.39 23.37	49%
Compressive Modulus (ASTM E228)	(KSI) (MPa)	98 676	72 496	73%

NIAR
ADVANCED JOINING & PROCESSING LABORATORY

PRELIMINARY TEST DATA
Flat Build Orientation Only
Initial Material Tuning

FDM Core Material Summary

Stratasys FOR A 3D WORLD™

Increasing Core Service Temp

ABSM30

- Pattern/mold for traditional tooling materials
- Pattern/mold for Nevada Composites tool materials

ULTEM S1

- Breakout, embrittled with acetone
- 300˚F (150˚C), 100psi (6.9 Bar) autoclave
- 350˚F (175˚C) as a free standing post cure

SR100

- Soluble, WaterWorks bath
- Up to 250˚F (120˚C), 80psi (5.5 Bar) autoclave

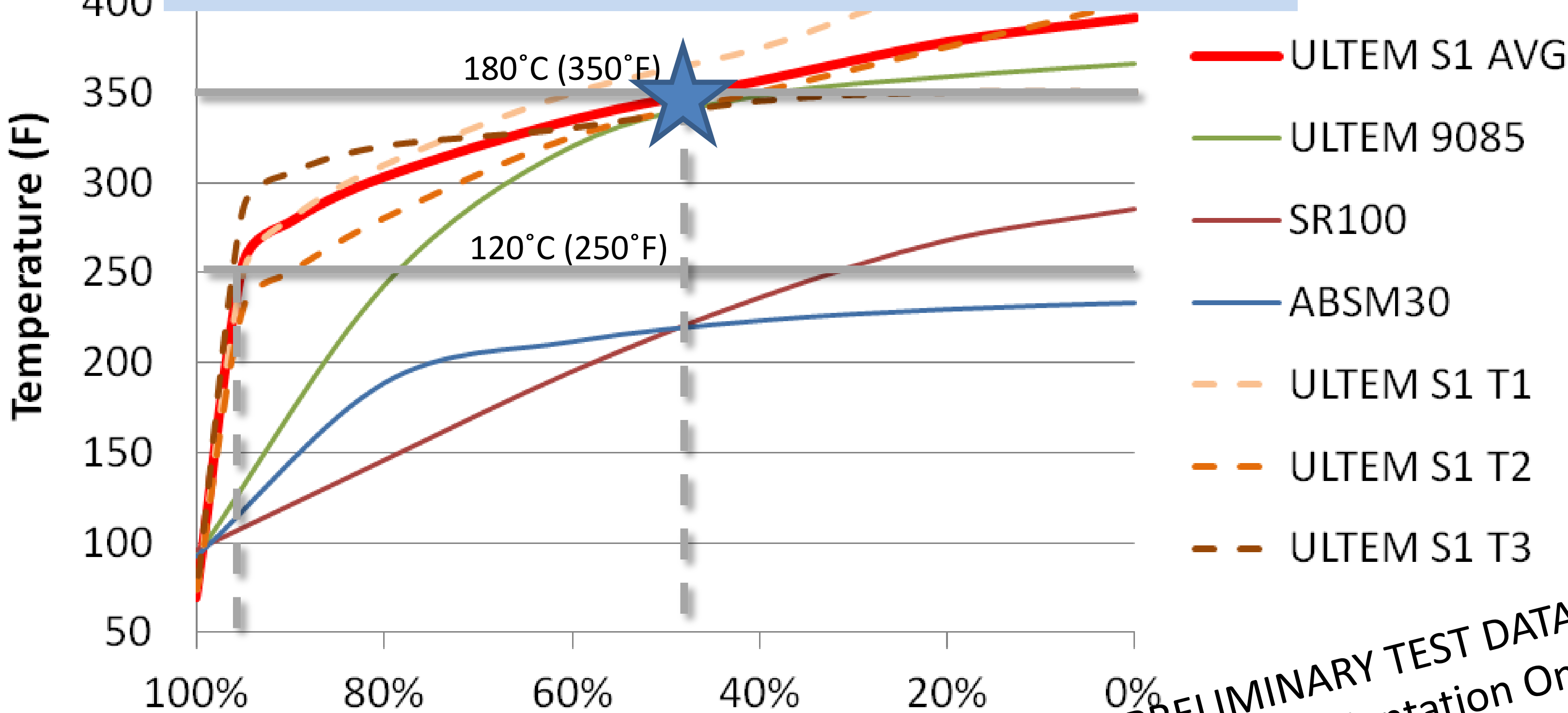
SR30

- Soluble, WaterWorks bath
- Up to 180˚F (80˚C), 80psi (5.5 Bar) autoclave

ULTEM S1 Dynamic Flex

High Temp testing of Tensile & Compression Strength indicate 49% of ambient strength at 180C (350F)

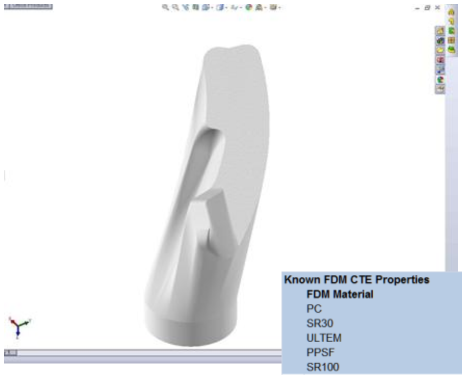
Good Correlation w/ Dynamic Flex Results!



PRELIMINARY TEST DATA
Flat Build Orientation Only
Initial Material Tuning

FDM Core Tool Design

- Design your core
  - Create geometry in CAD
  - Scale for CTE Growth
  - Export STL
- Process in Insight
  - Determine part density
  - Adjust raster air gap
  - Set wall thickness
  - Set "Invert build materials" checkbox
  - Generate tool paths
  - Save and send to FORTUS system



Known FDM CTE Properties

FDM Material	CTE µm/(µm°C)	Max Temp (°C)
PC	81.0	93
SR30	117.0	93
ULTEM	66.6	177
PPSF	70.2	204
SR100	99.0	121

	Value	Unit	Input One or the Other			
Input Ambient Temperature						
Ambient Temp	21.1	°C				
Input CTE of Part Material						
Part Material CTE	1.69E+01	µm/(µm°C)		µm/(µm°C)	9.39E-06	in/(in°F)
Select FDM Tool Material With Pick List						
FDM Tool Material	PPSF	Select From Pick List				
Input Length of Feature						
Feature Length	0.6096	m				
Input Resin Lock/Cure Temperature						
Resin Lock Temp	177	°C				

Calculated Values	Delta Length	Units	Scalar
FDM Tool Growth @ Resin Lock	6.672	mm	1.1%
Cured Part Shrinkage	1.606	[illegible]	0.3%
Delta After Cooling	[illegible]	[illegible]	0.8%

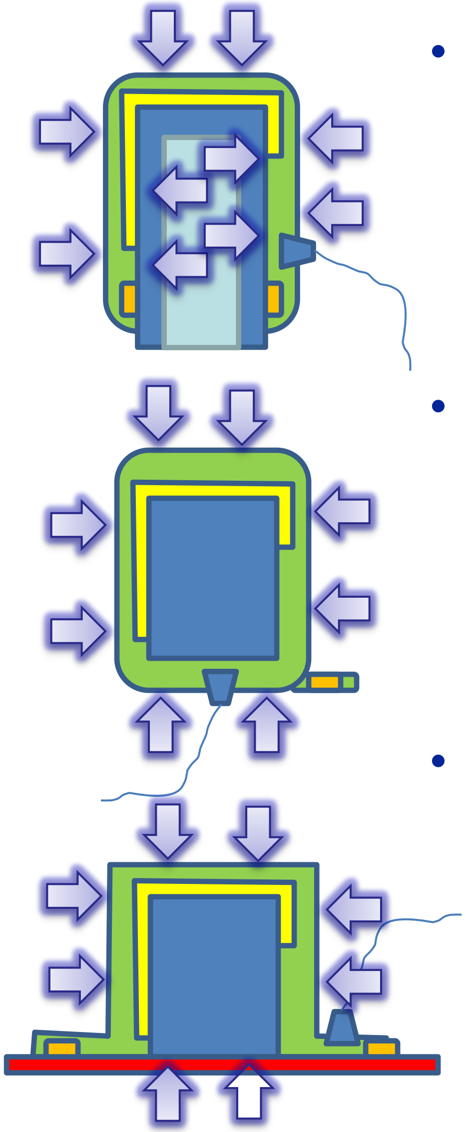
CTE Compensation

- Part Tolerances
  - Part tolerance +/-0.030inch
- CTE Calculations
  - $U_{nadjusted}\ T_{oolFeatureGrowth@CT} = F_{eatureLength@RT} \times \Delta T_{emp} \times CTE_{fdm}$
  - $A_{djusted}T_{oolFeature@RT} = F_{eatureLength@RT}\,(1+\Delta T_{emp}(CTE_{comp} - CTE_{fdm}))$
  - $TSF_{ToolScaleFactor} = T_{oolFeature@RT}\ /\ F_{eatureLength@RT}$

ULTEM Example

Feature	Feature Length @ RoomTemp	Unadjusted Tool Feature Growth @ Cure Temp	Adjusted Tool Feature @ RoomTemp	Tool Scale Factor
Width	1.5	0.015	1.489	99.266%
Height	3	0.030	2.978	99.266%
Length	23	0.232	22.831	99.266%

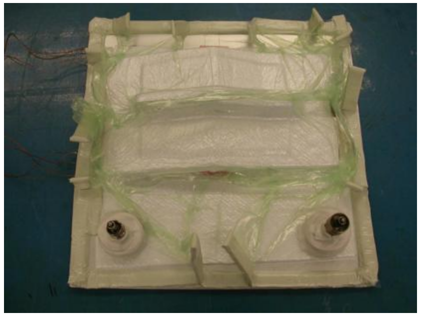
Tool Bagging Method



- Surface Bagged
  - Minimizes autoclave pressure loads on tool
  - Requires good surface seal throughout cure cycle
  - Requires additional tool surface to seal bag too
- Envelop Bagged
  - Full autoclave pressure applied to tool
  - Does not require a perfectly sealed surface
  - Long skinny tools many need special support at temperature
- Bagged to Plate
  - Full autoclave pressure applied to tool
  - Does not require a perfectly sealed surface
  - Plate can reinforce larger tools during cure cycle

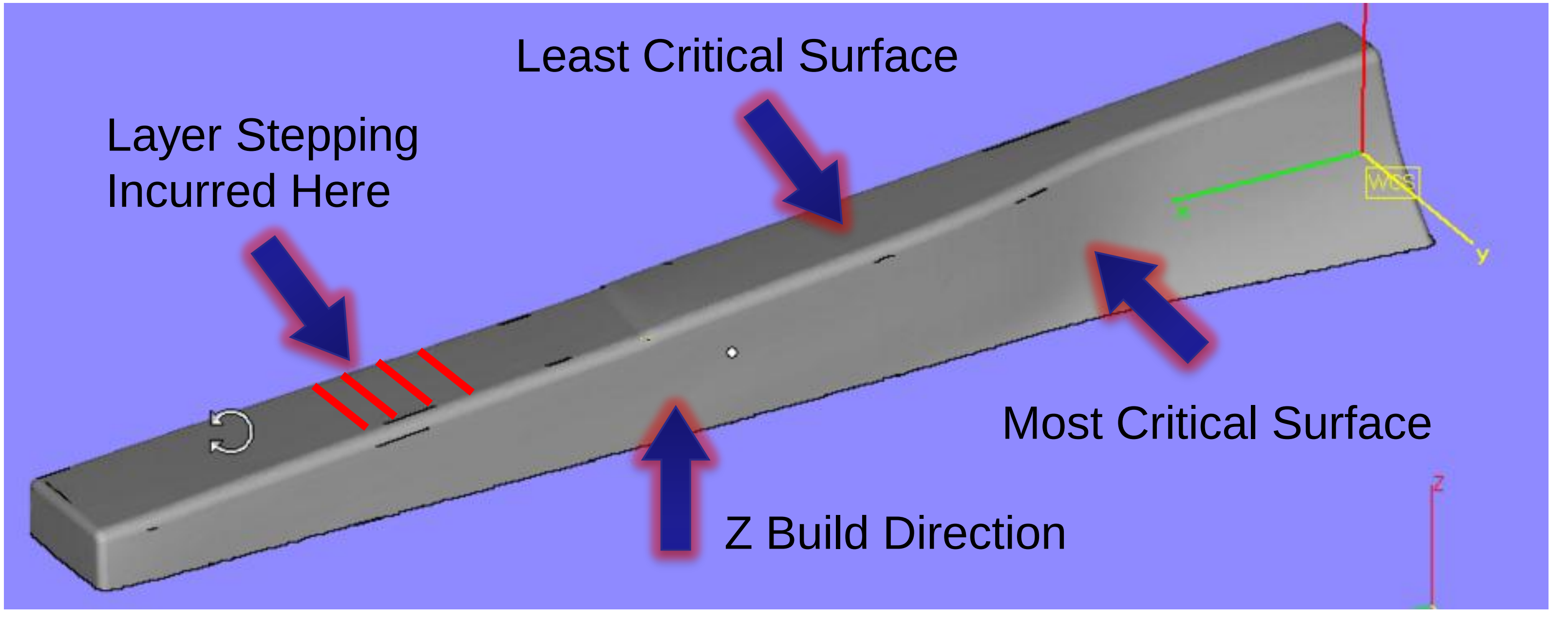
Surface Bagged

Bagged To Plate



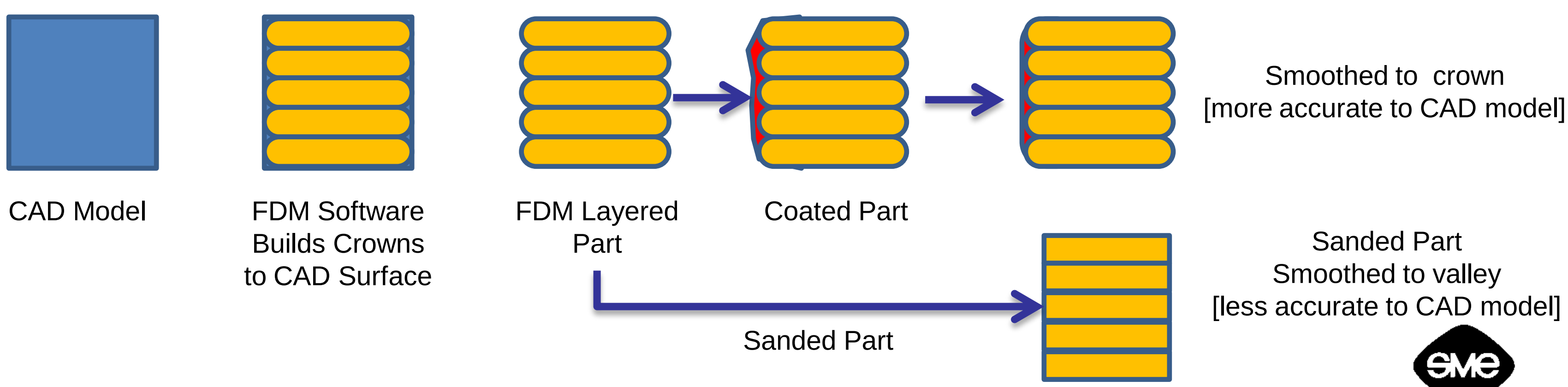
Build Orientation

- Identify Critical Surfaces
- Orientate Build
  - Minimize layer stepping on least critical surfaces
  - Attempt to minimize build costs



Tool Finishing

- “As Is”
  - Fastest, minimal cost
  - Unimproved surface
  - Requires surface seal
- Filled Surface
  - Most accurate surface
  - Tough surface seal
  - Demonstrated multiple releases
  - Supports surface bagging
- Sanded Surface
  - Less accurate
  - Sand to valleys
  - Requires surface seal
- Teflon Taped
  - Provides a good surface seal and reliable release surface
  - Geometry dependent



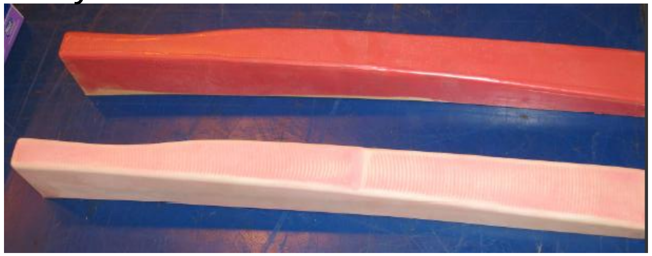
Finishing Products

- As Is"
  - Fastest method
  - Requires surface seal to prevent resin leaching
    - Vacuum bag seal
    - Hysol 9396/Zyvax QuickSkin
- Filled Surface
  - Most accurate surface
    - Fill and sand back to zebra
  - Demonstrated surface coats
    - Hysol 9394 & EA960F
  - Meets 350F service temp
- Sanded Surface
  - Less accurate
    - Sand to valleys
  - 120-220 grit aluminum oxide
  - Requires surface seal to prevent resin leaching
    - Hysol 9396/Zyvax QuickSkin
- Teflon Taped
  - Airtech's "ToolTech" tape
  - Provides a good surface seal
  - Reliable release surface
  - Geometry dependent

"As Is"

Hysol 9394

Hysol EA960F Coated & Sanded



Airtech's ToolTech