LE SOLUZIONI STRATASYS PER LA PRODUZIONE DEI COMPOSITI

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30 Years of Additive Applied.

Headquarters:
Eden Prairie, MN
and Rehovot, Israel

Over **1,200** Granted or Pending Additive Manufacturing **Patents Globally**

$668 Million
Revenue (2017)

Publicly Traded On **Nasdaq (SSYS)**

Over 30 Technology and Leadership Awards

Our Solutions

Industry-Specific Applications

» Investments in advanced applications spark innovation in targeted industries

» Custom solutions, such as certified materials, are developed to fit unique needs of each industry

» Dedicated personnel have deep expertise in education, dental, medical, aerospace, automotive and manufacturing

Customers

BMW · SAFRAN · faurecia · BENTLEY · WILLIAMS F1 TEAM · VOLVO · MBDA

RENAULT F1 Team · adidas GROUP · BAE SYSTEMS · DASSAULT AVIATION · AIRBUS · GKN

ASTON MARTIN · straumann · ABB · DAIMLER · LAND ROVER · JAGUAR · BOSCH · gsk GlaxoSmithKline

KUKA · ZODIAC AEROSPACE · Valeo · PHILIPS · Haas F1 Team · PSA PEUGEOT CITROËN · DB

RWTH AACHEN UNIVERSITY · VW · SAHARA Force India formula one team · THALES · MEGGiTT · LOTUS · Red Bull RACING FORMULA ONE TEAM

RENAULT Passion for life · brose Technik für Automobile · SCHAEFFLER · ROLLS ROYCE · SIEMENS · F1 · McLaren · Schneider Electric

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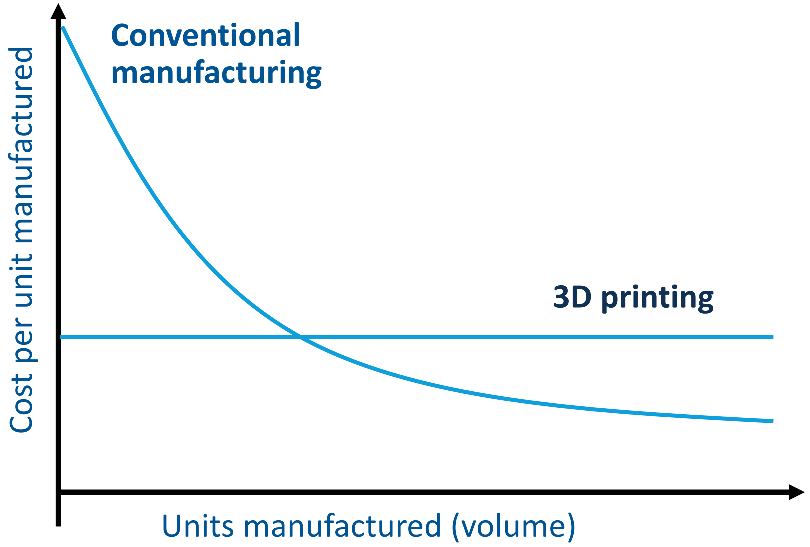
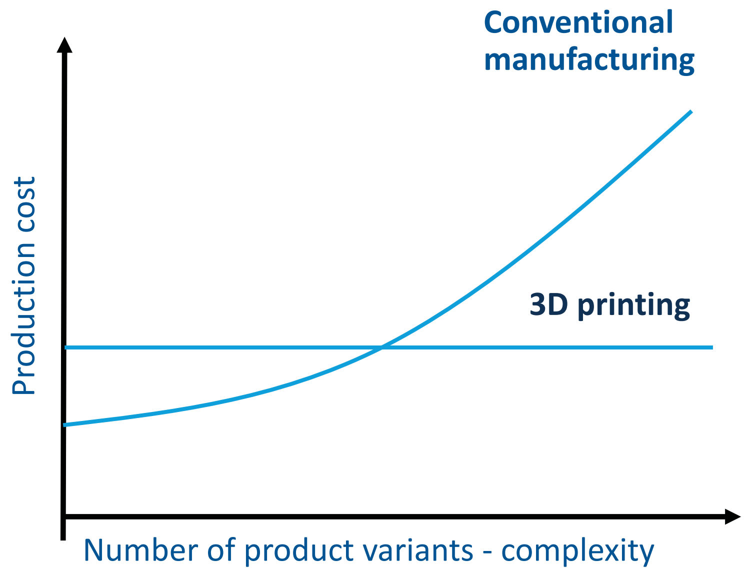
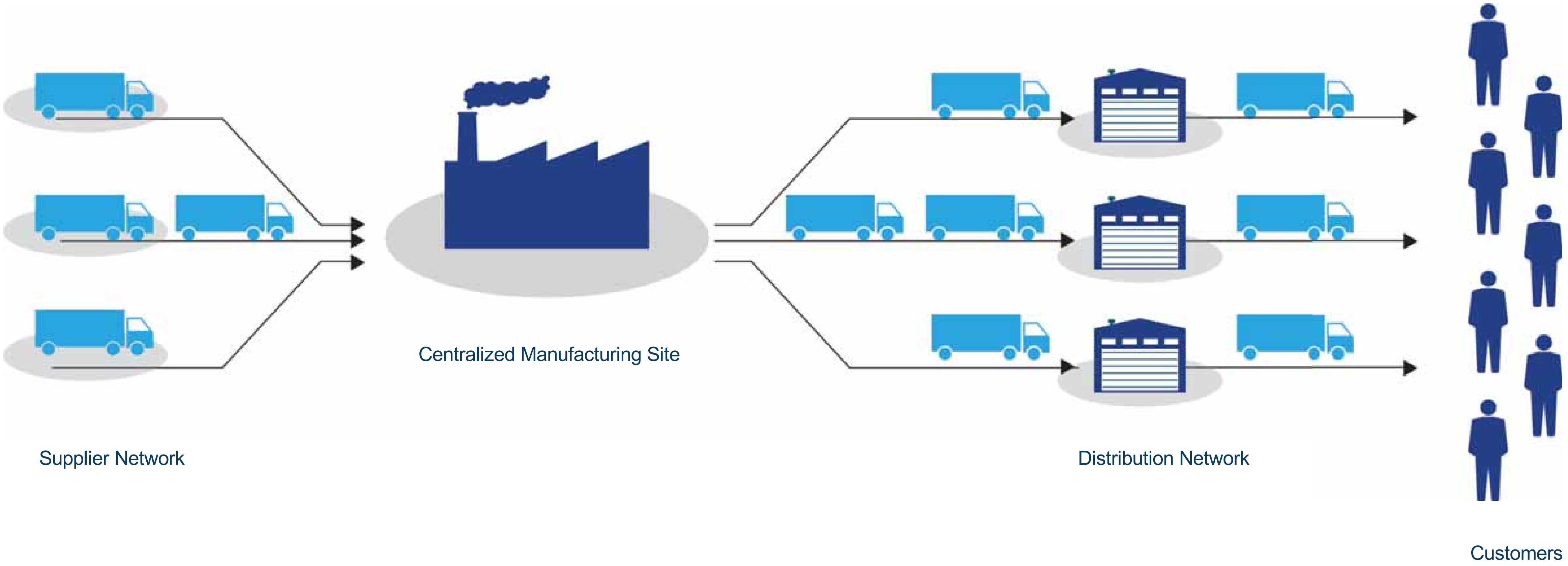
Changes in the Economics of Production





Economies of Scale

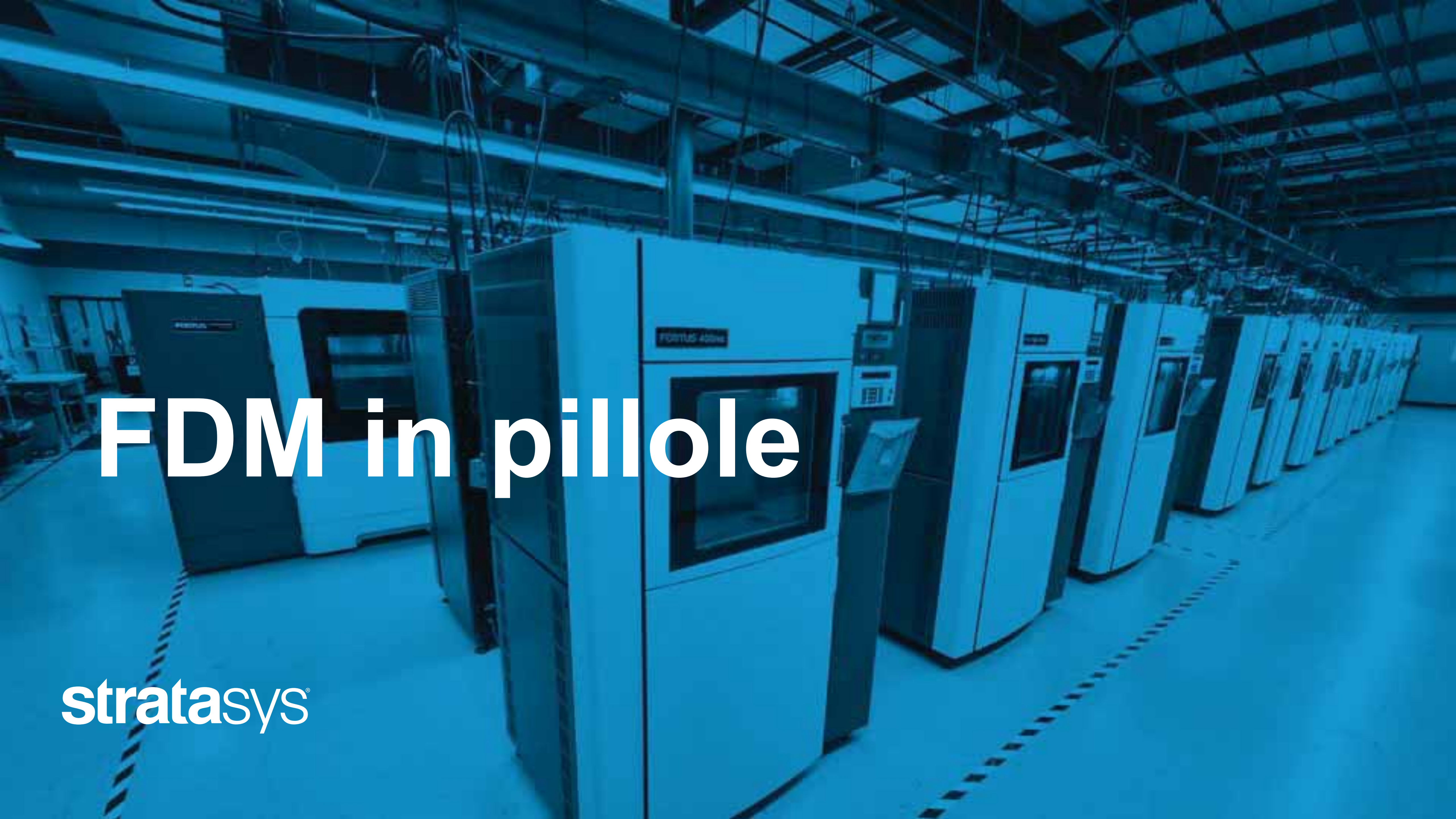
Economies of Scope



New Business Models and Supply Chains

Centralized Manufacturing

FDM in pillole



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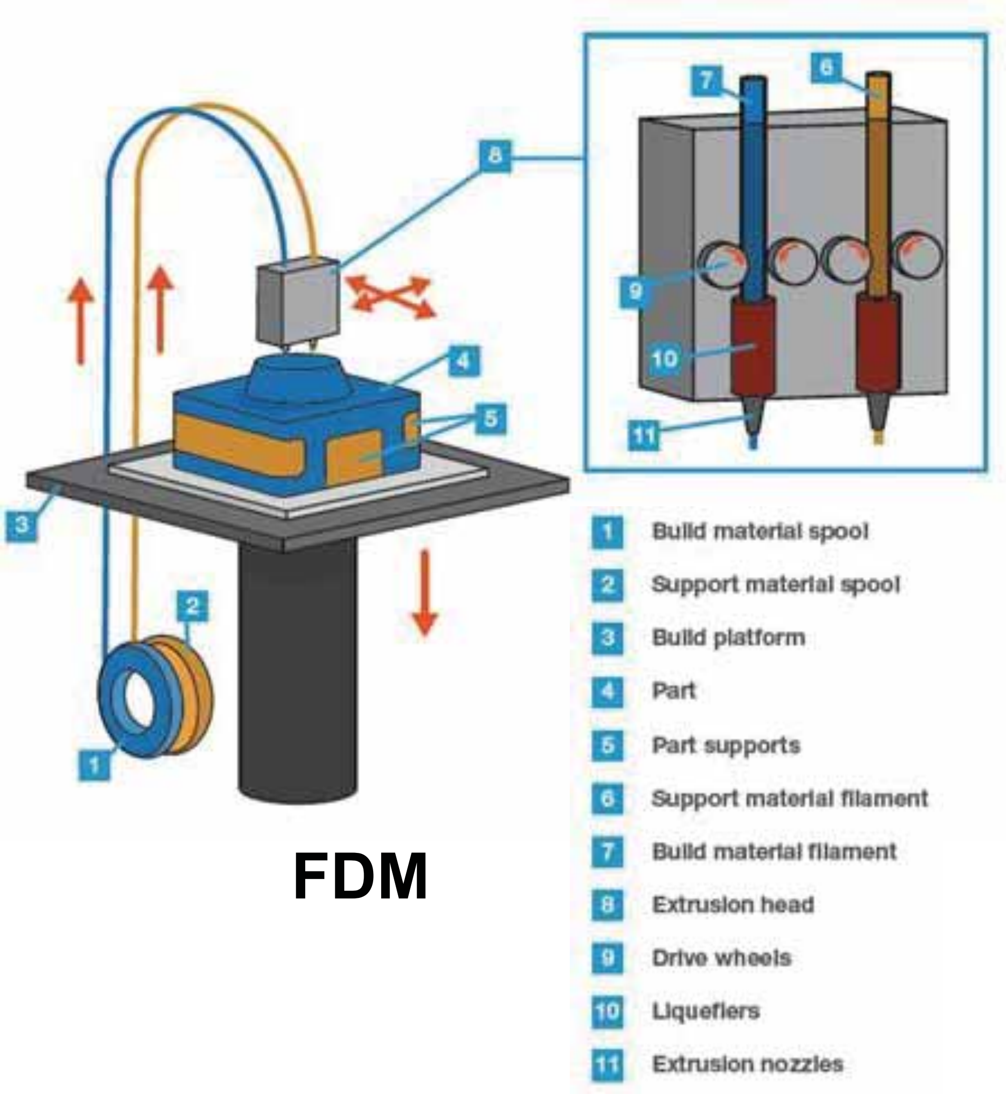
Le principali tecnologie di Manifattura Additiva di Stratasys

Fused Deposition Modeling

Un filament termoplastico viene riscaldato allo stato semiliquido e steso lungo un percorso guidato da computer per costruire il solido, strato dopo strato.

Material Jetting

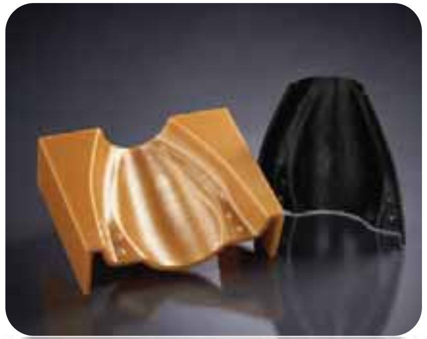
Miriadi di goccioline di fotopolimeri in vari colori vengono depositate per realizzare prototipi dai dettagli incredibilmente fini.

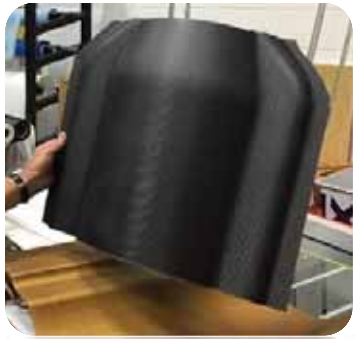


FDM: Applicazioni per I compositi

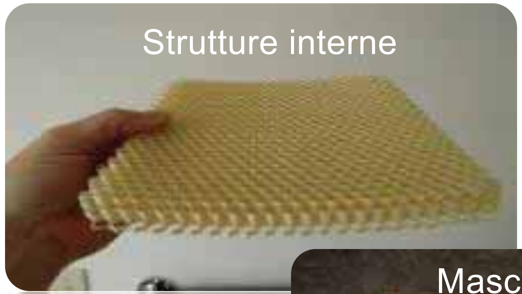
Applicazioni per la produzione di Compositi

Stampi per il lay-up di Compositi





Famiglie di attrezzi coordinati



Stampi incapsulati o Anime solubili

Composite Tooling

FDM Composite Fabrication Applications

- Patterns
  - Masters
  - Pre Lay-up
  - Consolidation Tools
- Lay-Up & Repair Tools
  - Low Temp
  - High Temp
  - Bond Fixtures
  - Intensifiers
  - Caul Plates
- Consumable Tools / Cores
  - Sacrificial Tooling
  - Printed Cores
  - Integrated Interfaces
- Jigs & Fixtures
  - Trim Tool
  - Drill Tool
  - Check Fixture

Composite Tooling – Presentation Focus

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  - Drill Tool
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Panoramica dell’applicazione

Anime sacrificali e mandrini

Produzione di parti cave complesse in composito

- Condotti e tubatismi
- Serbatoi e contenitori
- Membri strutturali tubolari o cavi

Anime sacrificali e mandrini: panoramica

Processi supportati

- Filament-wound
- Pre-impregnate, wet lay-up, resin-transfer

Stampi incapsulati: campi di applicazione

Componenti in Composito a geometria cava

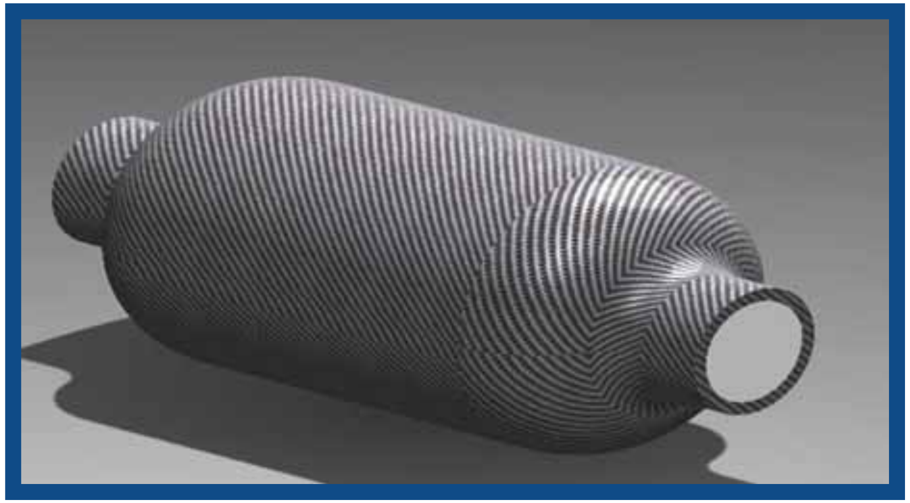
Supporto interno incapsulato nella geometria

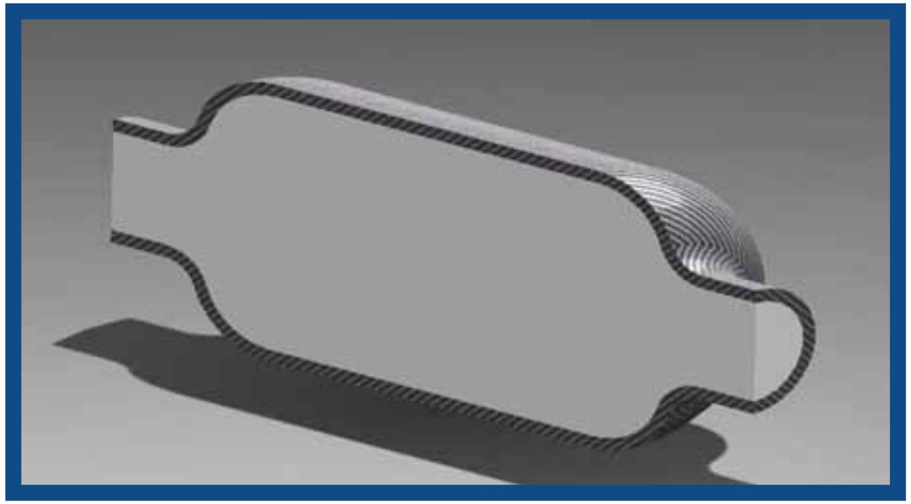
L’anima deve essere rimovibile

- Materiale solubile
- Materiale collassabile

Compatibilità con i processi per compositi

- Temperature
- Pressioni





Soluzioni Tradizionali

Soluzioni tradizionali

Diverse soluzioni

Dipendenza da processo produttivo e geometria

Comuni metodi tradizionali

- Sali eutetici
- Ceramiche solubili
- Uretani flessibili
- Stampi a conchiglia

Anime con Sali eutetici

Vantaggi

- Molto resistenti
- Alte temperature
- Alte pressioni

Svantaggi

- Richiedono stampi in metallo
- Difficili da rimuovere
  - Acqua ad alta temperature
  - Getti ad alta prtessione
  - Scalpelli
- Alta incidenza di scarti

Anime in Ceramica Solubile

Vantaggi

- Resistenti alle alte temperature
- Rimozione delicate in acqua
- Buona finitura superficiale

Svantaggi

- Richiedono stampi in metallo
- Fragili
- Pareti sottili o dettagli delicate sono impossibili
- Scarsa compatibilità con processi produttivi

Uretano flessibile

Vantaggi

- Rimozione delicate in acqua
- Buona finitura superficiale
- Riutilizzabili

Svantaggi

- Richiedono stampi in metallo
- Coefficiente di espansione termica eccessivo
- Ideali per geometrie semplici
- Richiedono inserti solidi e removibili

Anime e mandrini: processo tradizionale

Produzione di anime

- Dallo stampo lavorato alle anime fuse
- Anime removibili multiparte lavorate

Problemi

- Limitazioni geometriche
- Parti inconsistenti
- Scarsa ripetibilità

Core mold.

Forming sacrificial core in mold.

Stampi Clamshel (a conchiglia)

Produzione degli stampi a conchiglia

- Opzione 1: stampo ricavato dal modello
    - Estrarre lo stampo dal modello
- Opzione 2: stampo lavorato

Vantaggi

- Riutilizzabile
- Buona finitura superficiale <u>esterna</u>

Svantaggi

- Limitazioni sulla geometria
- Lead time degli stampi
- Stampi con diversi componenti
- Richiedono giunzioni, quando l’accesso è limitato
- Finiture superficiali interne, grinze

Pattern and first side of

Pull composite strips through tool and press against walls.

Cured composite duct with clamshell tool

Anime sacrificali FDM

Anime sacrificali: il processo

La creazione di anime solubili FDM richiede due modifiche principali al processo FDM standard.

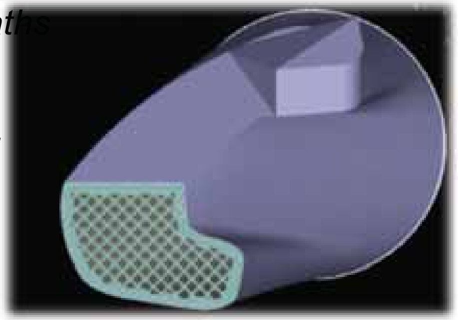
Primo: il termoplastico standard di una parte FDM viene sostituito con un materiale solubile, normalmente utilizzato per la costruzione delle strutture di supporto della parte.

Secondo: la struttura interna è realizzata principalmente cava per renderne più facile pulizia e rimozione.
Due strade:

- Insight - il software Fortus di preparazione – è in grado di implementare l'opzione di riempimento parziale per creare automaticamente una struttura interna che riduce al minimo il volume interno del nucleo
- Creare nello strumento CAD una struttura interna che mantenga il nucleo stabile sotto l'azione delle temperature e pressioni del processo di stampa del composito

Insight : Sliced file of the Soluble core

Insight : the toolpaths will automatically create a hollow interior reinforced with structure that dissolves quickly,



The final shape of the inner structure (Sparse double dense option)

Anime sacrificali: la scelta FDM

Un nuovo approccio offre sostanziali miglioramenti, sostituendo lo stampo con un nucleo solubile FDM.

Le anime solubili riducono sostanzialmente lead time e costi di manodopera, eliminando la necessità di fare lo stampo e riducendo anche il tempo richiesto per la preparazione del composito.

- metodo tradizionale: realizzare le due metà dello stampo, stendere la fibra su ogni semiguscio, e poi incollare le due metà,
- metodo abilitato FDM: il tessuto composito può essere avvolto attorno al nucleo solubile. A polimerizzazione avvenuta, l'anima è semplicemente sciolta.

Engineers had only three days to design and manufacture a new air-duct outlet.

Monday: First iteration of air-duct outlet concept model is made.

Sacrificial Cores & Mandrels

Anime sacrificali: Materiali e Prestazioni in temperatura

- ST-130 ™ per anime sacrificali - materiale solubile per attrezzature incapsulate complesse
- ULTEM™ Support – maggiori temperature sostenibili al più basso CTE

ULTEM is a registered trademark of SABIC or its affiliates or subsidiaries.

Anime sacrificali (non solubili): Ultem Support

Materiale

- Supporto per ULTEM® (S1) (alternativo)
  - Break-away: rimovibile manualmente
  - Maggiori temperature di processo
    - < 176 °C
  - Compatibile con inserti in alluminio

Processo

- Supporto per ULTEM®
  - Costruire il mandrino
  - Sigillare l’anima
  - Lay-up e curing
  - Applicare acetone per rendere fragile la struttura
  - Rimuovere manualmente il mandrino
    - Non si dissolve
    - Richiede un buon accesso all’interno

Cured composite on ULTEM S1 core.

ULTEM S1 core break out.

Vantaggi dei Sacrificial Tooling FDM per Compositi

Anime sacrificali FDM

Sostituisce gli stampi a conchiglia

- Elimina le giunzioni, per parti più robuste
- Aumenta la finitura superficiale interna (controllata)

Rimpiazza I metodi tradizionali per le anime

- Eliminazione dello stampo delle anime e la fusione delle anime
  - Realizzazione automatizzata delle anime
  - Riduzione dei tempi e del lavoro richiesto
  - L'anima o il mandrino si dissolvono dopo il processo di polimerizzazione del composito
- Aumento di consistenza accuratezza e resistenza
- Rimozione agevole del mandrino (lavaggio o rimozione manual assistita)
- Interno solido o con struttura lattice per ottimizzare tempi di rimozione e tenuta
- Piena compatibilità con resine epossidiche
- Nessuna variazione ai processi produttivi

Carbon fiber manifold.

Sacrificial Cores & Mandrels: Competitive Overview*

	Ease of Removal	Consistency	Low Production Labor	Design Freedom	Core Strength	Requires Dedicated Tooling
Water Soluble	✓✓✓✓	✓	-	✓	✓	**Yes**
Removable Cores	-	✓✓✓✓	**(Reusable)**	-	✓✓✓✓	**No**
Shape Memory Bladders	✓✓✓	-	✓	-	✓✓✓	**Yes**
Sand Cores	✓	✓✓	-	✓	✓	**Yes**
Eutectic Salts	-	✓✓	-	✓	✓✓✓	**Yes**
FDM	✓✓✓	✓✓✓	✓✓✓	✓✓✓✓	✓✓✓	**No**

Compatibility (— = *N/A*, ✓ = *Low*, ✓✓ = *Good*, ✓✓✓ = *Great*):

** Subjective qualities based on expert analysis*

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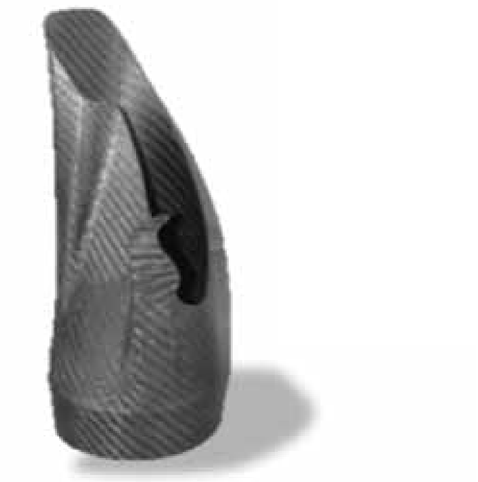
Anime e mandrini sacrificali: Benefici FDM



Riduzione di tempi e costi

- Fino al 95% di riduzione
- Sino a 1 giorno dal concetto alla realizzazione della parte

Lavoro manuale

- Meno aggiustaggio dello stampo e drastica riduzione delle fasi manuali
- Assenza di incollaggi tra semicomponenti

Miglioramento della parte in composito

- Realizzazione in pezzo singolo
- Controllo sulla finitura delle superfici interne

Riduzione dei rischi

- Investimento minimo e modifiche facili ed economiche
- Aumento di consistenza e resa delle anime

Typical time and cost savings derived from numerous end-user analysis, testimonials and feedback. Actual savings may vary based upon numerous factors, including traditional time/cost, part geometry and utilized technology.

Customer Stories

Alcuni nomi di riferimento

Motorsports

Aerospace

Automotive - Performance

Aerospace

Bicycles

Motorsports

Aerospace

Automotive

(Numerosi clienti e service bureau,,che attualmente utilizzano la tecnologia FDM / Fortus per applicazioni nel campo dei mandrini solubili o degli stampi per il carbonio, non sono citati per accordi di riservatezza)

Customer Success Story – Sacrificial Tooling
Champion Motorsport

Porsche 997 Turbo inlet duct, Y-pipe, manifold

- Better airflow
- Lighter

Tried many approaches – none were sellable

- Bonded halves
- Molded sand core

FDM sacrificial core method

- Seam-free construction w/ consistent quality
- Control over interior and exterior

FDM composite core benefits

- ~85% faster
- ~85% less expensive

Carbon fiber inlet ducts.

Method	Cost	Time
Traditional	unusable	unusable
FDM core*	$150	1 day
Savings	**~85%**	**~85%**

* Produced in-house.

SWIFT ENGINEERING | Sacrificial Tooling Success

Swift Engineering Inc.

"Partnering with Stratasys is a huge benefit because they have engineers that have worked in the aerospace industry, they know composite fabrication and the know how to support the industry."

- Kerry Dang, Manufacturing Manager

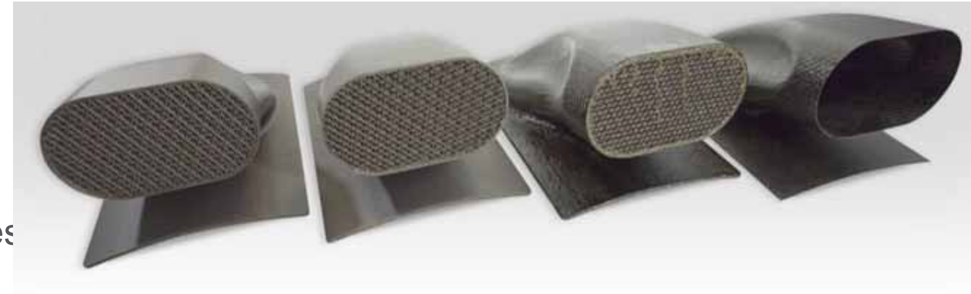
Swift Engineering, a leader in design and manufacturing for the motorsport, aviation and aerospace markets

CHALLENGE

Meet the increasing demands of shorter client lead times and improve product iteration cycles

SOLUTION

Fortus 900mc Printer and Stratasys ST-130 material for sacrificial tooling



BENEFITS

Reduced lead times for tool production by up to 90%

- Build tools in hours or days, compared to weeks or months with traditional processes
- Eliminate multi-piece bonded assemblies
- Reduce post-production work

Watch the video https://www.youtube.com/watch?v=YcLFaTMfB04

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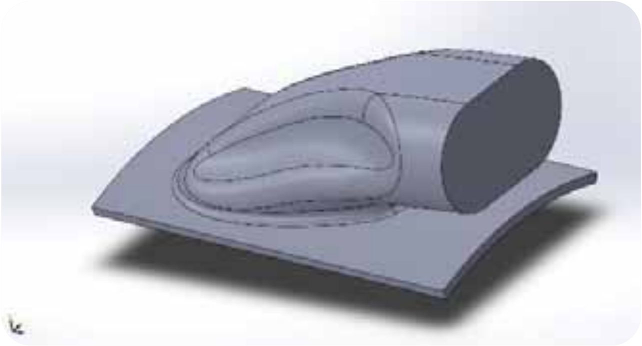
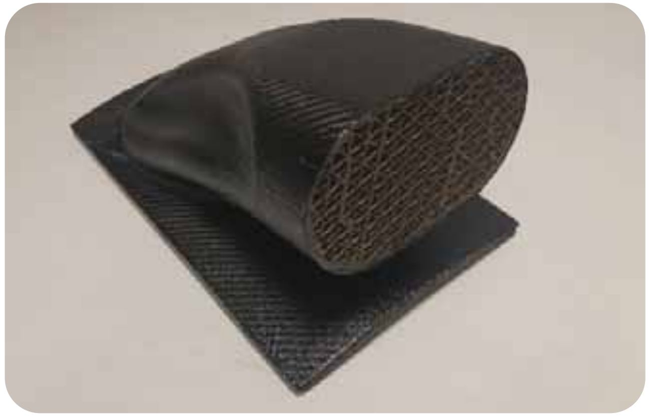
Customer Success Story – Sacrificial Tooling

Enabling an advanced product development team through complex part fabrication

Swift Engineering Inc.

- Aero inlet duct with a complex, trapped-tool geometry
- Wash-out tooling material (ST-130) used in place of multi-piece bonded assembly and traditional wash-out tooling materials
- From concept design to composite part in < 1 week
  - FDM build time is < 24 hours
  - Default porous triangle fill pattern – optimized for autoclave curing and tool dissolution
  - Low temperature (<90 °C), 6 bar cure cycle





Composite Tooling – Presentation Focus

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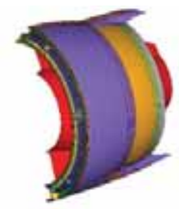
Benefici del Composite Tooling FDM

Composite Tooling Today

Metal Tooling - ~75% of market

Model



Mold
$300-600K
6-12 months

Machining Fixture
$100-200K
3-4 months

Part Fabrication

FRP Tooling - ~25% of market

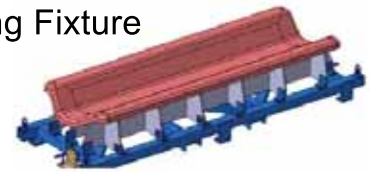
Model

Master
$40-60K
7-8 weeks

Hand Lay-Up + Machining

Mold
$40-60K
9-11 weeks

Machining Fixture
$40-60K
9-11 weeks



Current Pain Points

- High costs and long lead times
- High levels of touch labor
- Lead time paces entire development programs, prevents introduction of new technology, evolution, optimization, etc.
- Costly design changes
- Large, heavy tools – difficult to move and store

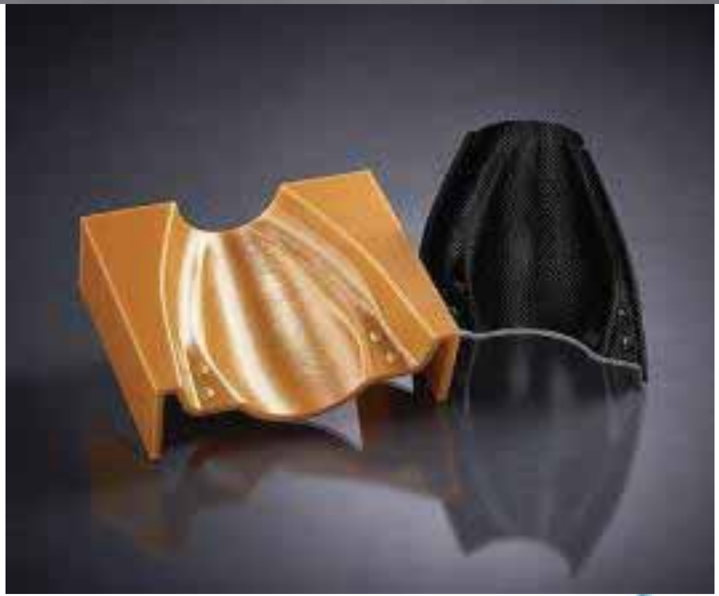
Benefits of FDM

- Disruptive time & cost savings
- Reduced lead times enable iteration, change, optimization
- Respond quickly to demand fluctuation
- Tailor the tool to the application vs. one-size-fits-all
- High temperature capable materials
- Handle tools with people, not cranes and forklifts

FDM Composite Tooling

3D PRINTED LAYUP MOLDS
Incredible strength-to-weight ratio

- **Reduced lead time** – No need to wait for the machine shop
- **Reduced cost** – Less labor intensive, generally less expensive than machining and no cost penalties for design updates
- **Inert mold material that doesn’t inhibit curing** – materials can withstand high pressure vacuum processes
- **Stability, eliminating distortion from heat** – There are many high-temperature engineering thermoplastics and photopolymers compatible with fiber layup resin and epoxy
- **Decreased core weight** – FDM offers the ability to print lattice structures within parts to reduce weight



Design and Build Considerations

Tolerances

- Fortus 900mc™: ± 0.035 inch or 0.0015 inch/inch

Build orientation impacts

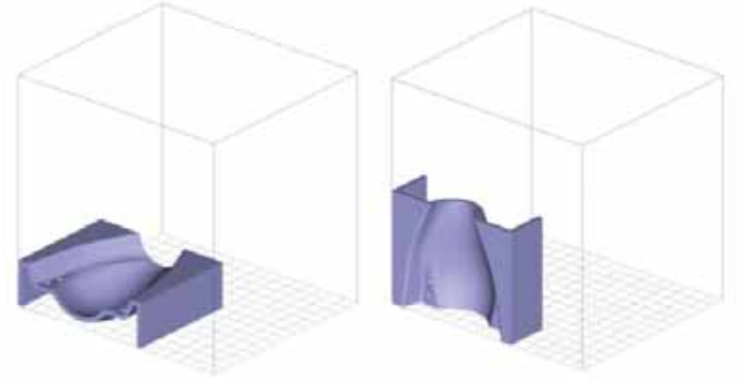
- Surface finish, mechanical properties, build time

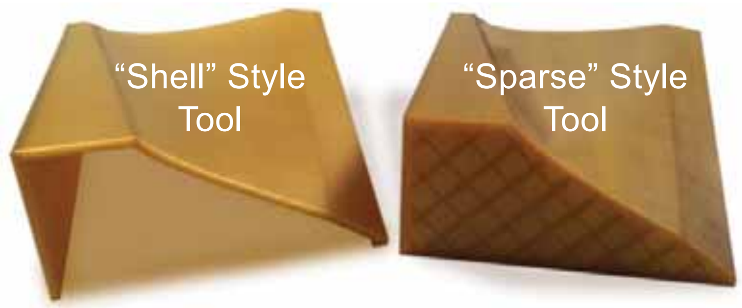
Build style impacts

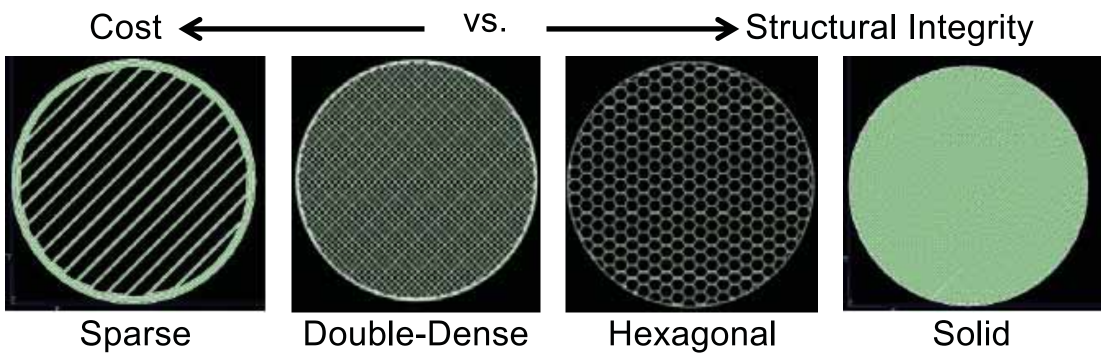
- Material usage, build time, mechanical properties

Design for AM (DFAM)

- Design for cost and function
- Tailor the tool design to the application







Customer Stories

DASSAULT FALCON | Disrupting the Supply Chain

Dassault Falcon Jet is one of the leaders in the business jet segment.

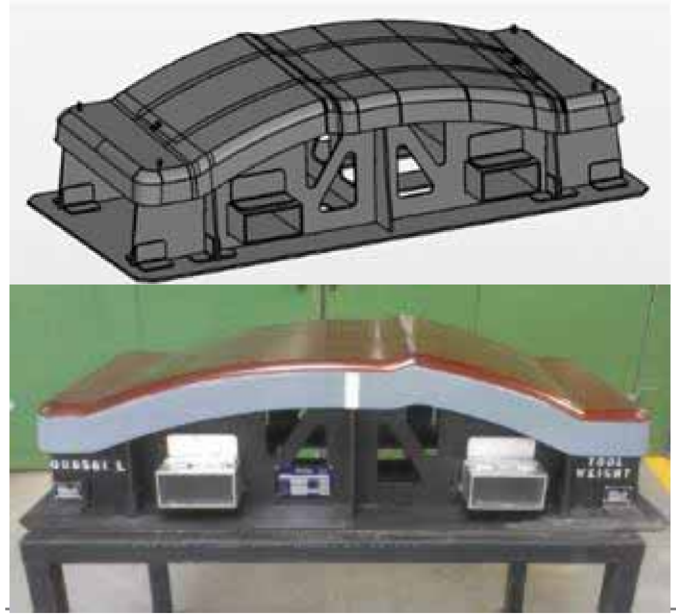
CHALLENGE

Reduce tooling lead times to keep pace with composite part design cycles, and to keep up with accelerating manufacturing and processing speeds.

SOLUTION

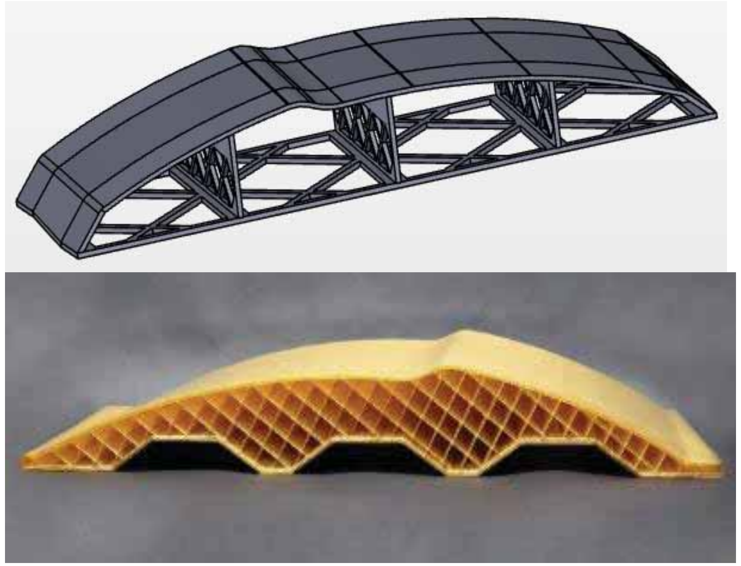
Fortus 900mc Printer and ULTEM 9085 Material

BENEFITS



Fiber-Reinforced Tooling (FRP)

Cost: $40-60K (master & mold)
Lead time: 10-14 weeks
Weight: >150 lbs



FDM Tooling

Cost: $2500
Build time: 40 hours
Weight: 15 lbs

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Composite Tooling Success Story

Aurora Flight Sciences

Addressed a rapid-response, critical customer need for a 9-foot-long composite “belly pod” fairing tool

- Multi-segment tool (seven unique sections)
- Produced in < 2 weeks
- Used sparse filled sections and hollow sections with foam fill
- Tool segments joined with printed mechanical joints
- Geometry produces a trapped tool – design of tool segments allowed for “drop out” (easily removable) reusable tooling
- Low temperature cure (200°F), no manual post-processing, quickly sealed with Teflon tape to meet tight time requirements
- Featured in June 2015 Composites World magazine article


First flight

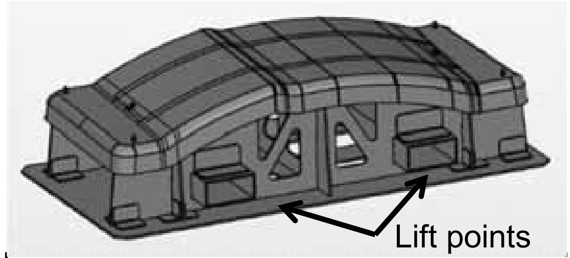

Finished/painted fairing


Fiberglass/epoxy fairing on the FDM tool

Vantaggi economici

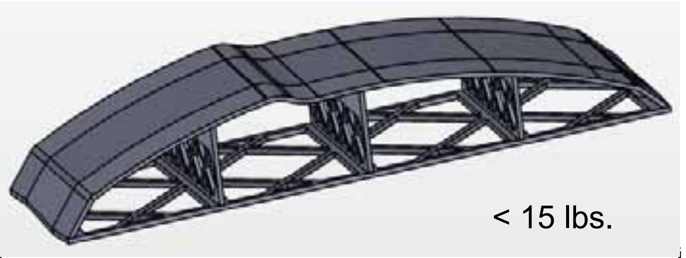
Examples – Disruptive Cost Reduction

“Small” Tool Example (~6-ft long):



Existing FRP Tooling
Cost – $40-60K (master & mold)
Lead time – 10-14 weeks

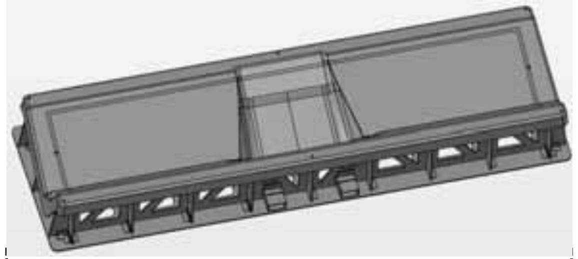
DFAM



FDM Tooling
Cost – $2500
Build time – 40 hours

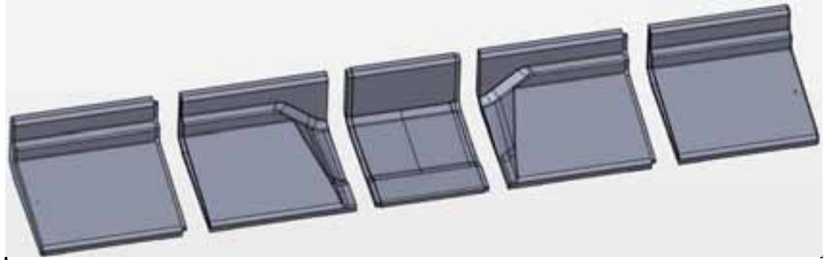
> 90% cost/time reduction

“Large” Tool Example (~15-ft long):



Existing FRP Tooling
Cost – $80-120K (master & mold)
Lead time – 15-20 weeks

DFAM



FDM Tooling
Cost – < $25K
Build time – < 2 weeks

> 75% cost/time reduction

Materiali FDM rinforzati in fibra: NYLON 12CF

Il materiale FDM più rigido di sempre

MARKET PROBLEM

- Some manufacturing tooling is heavy; need a strong, yet light material
- Need lightweight tools/parts that won’t deform
- Strong demand for composite materials

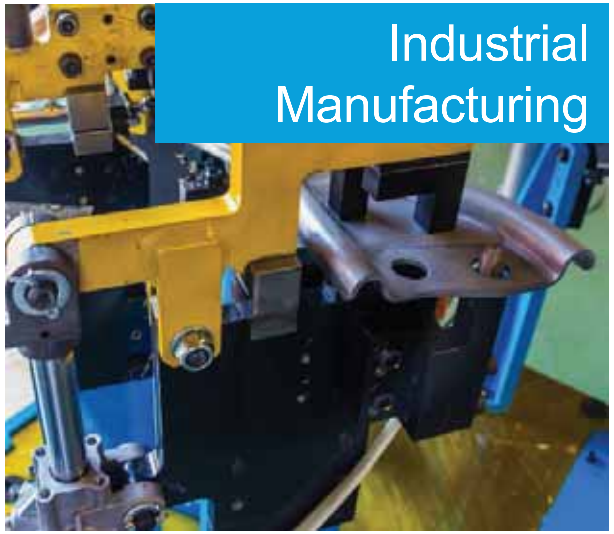
Introducing Nylon 12CF (Carbon-Filled)
FDM Carbon fiber-filled thermoplastic material

Nylon 12CF delivers the **highest strength and stiffness-to-weight ratio** of any Stratasys FDM material

- Unique stiffness and strength allows it to replace metal components in:
    - Functional prototypes
    - Tooling Applications
    - Production parts

Highest strength and stiffness-to-weight ratio

NYLON 12CF, STRONGEST FDM MATERIAL YET: TOP MARKETS



NYLON 12CF LIGHTENS THE LOAD IN WEIGHT AND COSTS

Converting metal to plastic

Nylon 12CF is strong enough to replace metal parts, in order to lightening the weight and reduce part costs.

Metal parts produced in Nylon 12CF

- Brake levers
- Caliper cover
- Chain guard
- Engine cover
- Stand
- Foot pegs

Benefits:

- Reduce part costs
- Lighten motorcycle, increasing performance

STRATASYS NYLON 12CF PORTFOLIO PLACEMENT

Engineering to High Performance Materials (Metric Units)

Product Features	Nylon 12	PC	Nylon 6	ULTEM 9085	Nylon 12CF
Ultimate Tensile Strength XZ	46 MPa	57 MPa	67 MPa	68 MPa	76 MPa
Tensile Modulus XZ	1,282 MPa	1,944 MPa	2,227 MPa	2,151 MPa	7,529 MPa
Temperature Resistance (HDT @ 1.82 MPa)	82 C	138 C	93 C	153 C	143 C
Elongation at break	30%	4.8%	38%	5.8%	1.9%
Flexural Strength	67 MPa	90 MPa	97 MPa	112 MPa	142 MPa
Izod Impact (unnotched)	1655 J/m	875 J/m	2829 J/m	779 J/m	310 J/m
Specific Stiffness	1.2×10^6 m^2/s^2	1.62×10^6 m^2/s^2	-	1.6×10^6 m^2/s^2	6.5×10^6 m^2/s^2

Highest Tensile Modulus & Specific Stiffness

Filling the carbon fiber market gap with professional performance, accuracy and reliability at a breakthrough price

STRATASYS CARBON FIBER PORTFOLIO

STRATASYS PRINTER PORTFOLIO
Nylon 12CF Carbon Fiber Printers

Exceptional price

Fortus 380mc Carbon Fiber Edition

2 materials
(standard & high performance)

356x305x305mm
14 x 12 x 12 in

Expanded build tray and material capabilities

Fortus 450mc

15 materials
(standard, engineer-grade & high performance)

406x356x406mm
16 x 14 x 16 in

Biggest build tray, greatest number of materials

Ultimate in part production

Stratasys F900™

17 materials
(standard, engineer-grade & high performance)

914x607x914mm
36 x 24 x 36 in

CONFIDENTIAL: NO PUBLIC DISTRIBUTION

FORTUS 380MC CARBON FIBER EDITION
Strength, Throughput, and Design Freedom

Reliably build large, strong functional prototypes, production tooling and parts

Strong and Lightweight: High-performance Nylon 12CF FDM material

Design Freedom: Create complex geometries enabled only through the use of soluble support

Speed and throughput: 2-5x faster than competitive composite material printers

Nylon 12CF
Carbon Fiber Material

CONFIDENTIAL: NO PUBLIC DISTRIBUTION

FORTUS 380MC™ CARBON FIBER EDITION
Build Strong, Accurate Tools, Prototypes, and Production Parts

- ✓ Reliability
- ✓ Throughput
- ✓ Accuracy
- ✓ Design Freedom
- ✓ Composite material performance

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FORTUS 380MC CARBON FIBER EDITION
Strength, Throughput, and Design Freedom

Materials:
FDM Nylon 12CF™ Carbon Fiber
ASA

Layer Thickness:
0.330 mm (0.013 in.) – ASA
0.254 mm (0.010 in.) – ASA, Nylon 12CF Carbon Fiber
0.178 mm (0.007 in.) – ASA
0.127 mm (0.005 in.) – ASA

Build Size:
355 x 305 x 305 mm (14 x 12 x 12 in.)

Build strong, accurate tools, prototypes and parts

NYLON 12CF CARBON FIBER
Great Stiffness-to-Weight Ratio

Complex geometries

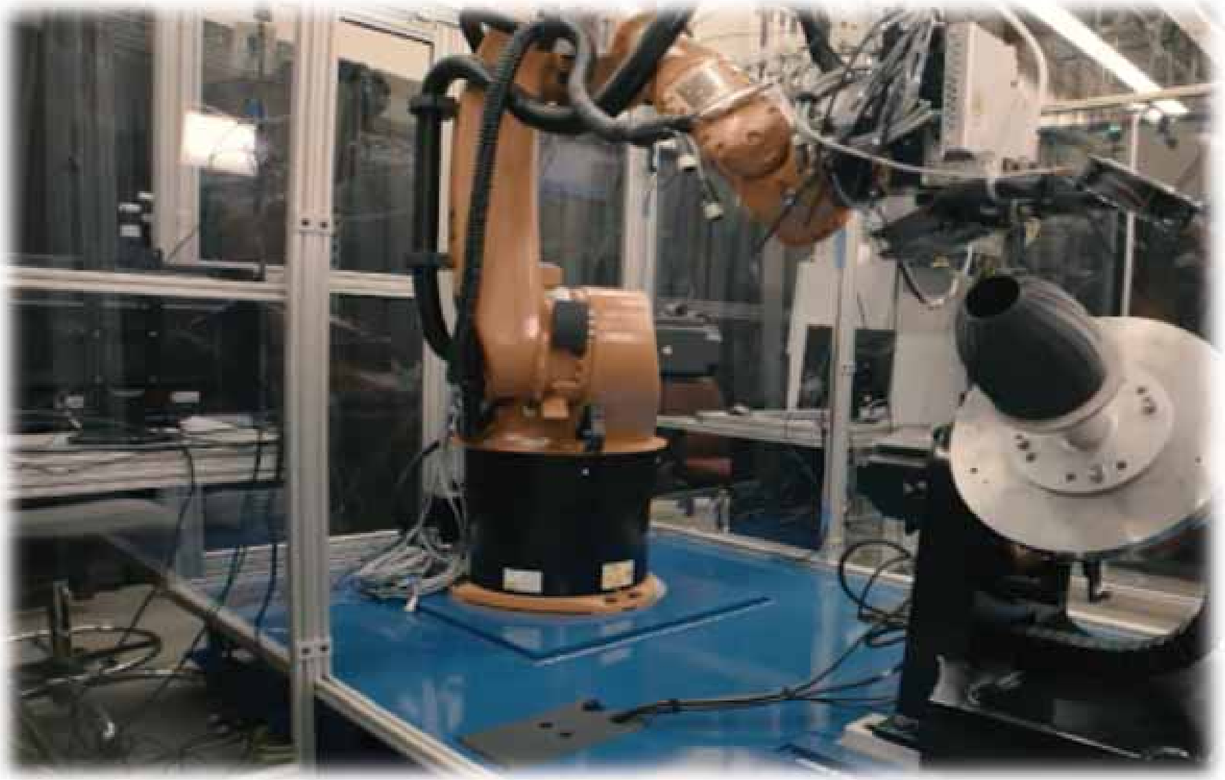
Tooling, functional prototypes, production parts

Consistent & reliable accuracy

Partially dense to fully dense parts

Shaping What's Next

ROBOTIC COMPOSITE 3D DEMONSTRATOR: Revolutionizing the way light-weight Composite Structures are made

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SIEMENS
Ingenuity for life
Reimagining next generation Additive Manufacturing technology for composite parts
Andreas Saar, VP and Head of Additive Manufacturing Program, Siemens PLM Software
Unrestricted © Siemens AG 2016
Realize innovation.

COMPOSITE STRUCTURES WITH STRENGTH IN ANY DIRECTION

Strength

Directional Composites

Speed

Support Elimination

Flexibility

Hybridization

8-Axis Motion & PLM Workflow

SIEMENS

Robotic Composite 3D Demonstrator

Robotic Composite 3D Demonstrator

Breaking the print-by-layer mentality enabling composite structures with strength in any direction

- Strong parts – Using 8-axes of motion to control alignment of directional composites
- Enhanced throughput – 10x fast deposition, elimination of layer transition, elimination of support printing, and elimination of support removal
- Simplified workflow – Hybrid add/subtract/inspect in one cell
- Factory-integration – powered by **Siemens**

Robotic Composite 3D Demonstrator – partnership with Siemens

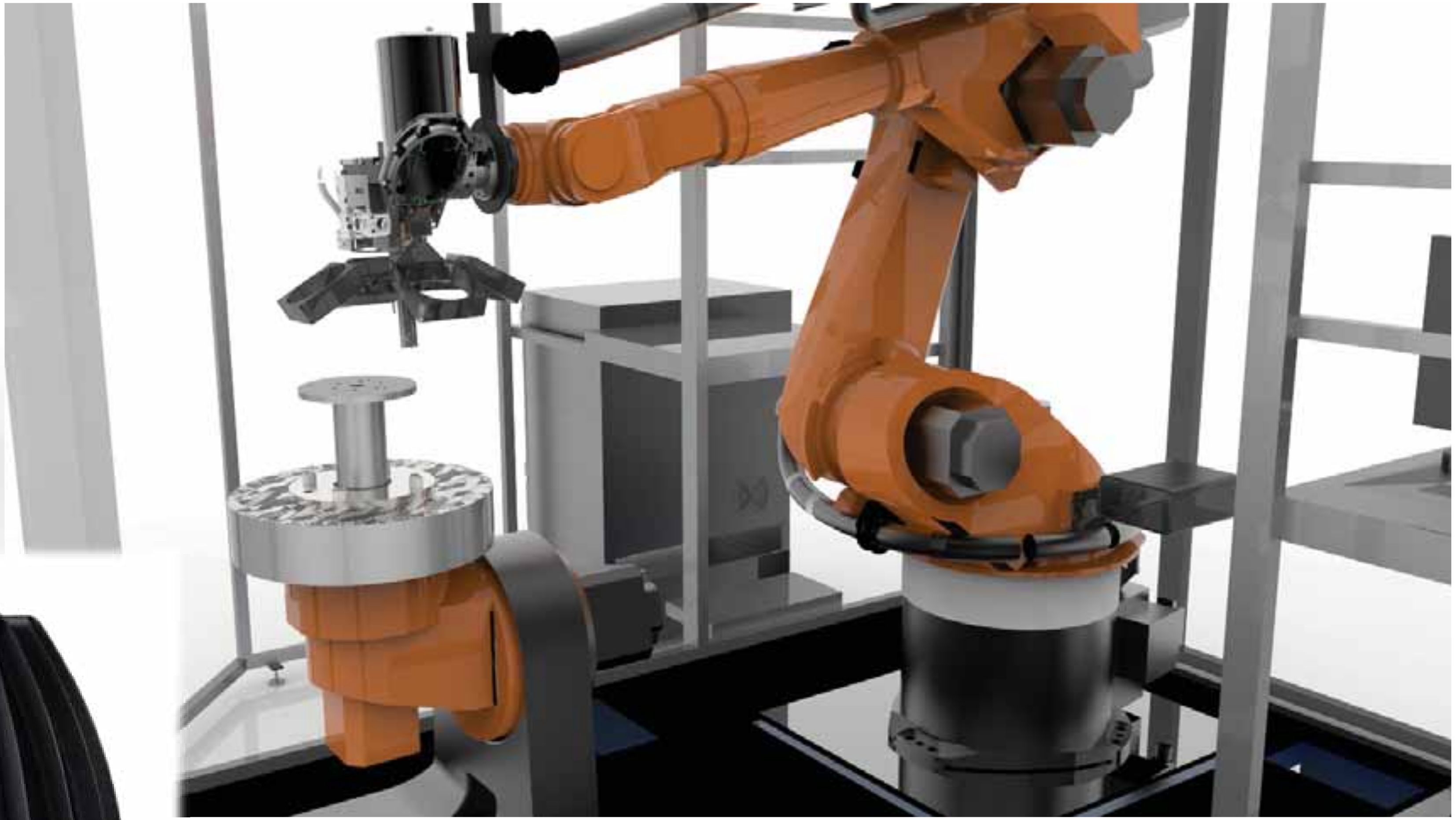
RC-3D

- Unveils a **hybrid approach** for automated composite part production that **breaks the print-by-layer mindset** and enables the full value of additive manufacturing to be applied to high value composite structures making them **lighter** than ever before

- Aimed at increasing the proliferation of composite parts across aerospace, automotive, and other industries – making them **lighter and thus more fuel efficient**.

- Integrates **advanced extrusion technologies** with **Siemens Industry Motion Control and Siemens PLM Software** to revolutionize **3D printing of composite parts**.

- The system eases labor-intensive processes and geometric limitations associated with composite part creation - powering 3D printing via an **8-axis motion system** to deliver **precise**, directional material placement for **strength**, while significantly reducing complex support strategies.



THANK YOU

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stratasys®

Supply Chain Flexibility, Improved Buy-to-Fly Ratio, Weight Reduction

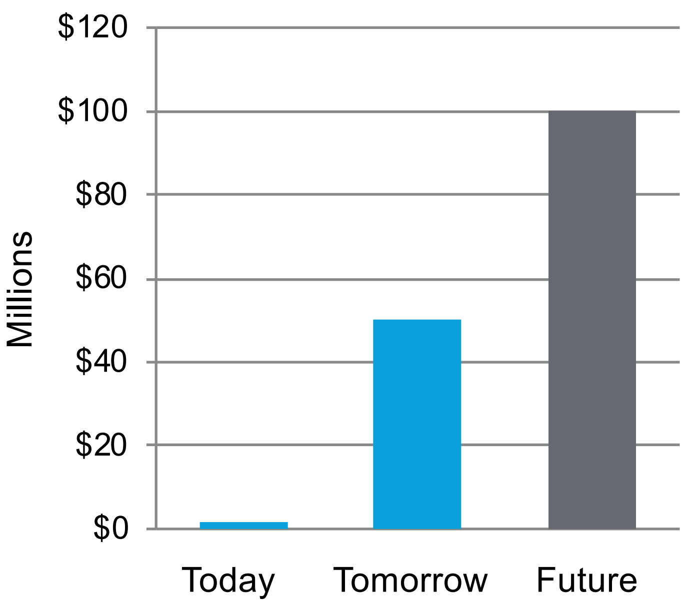
AIRBUS

Composite Tooling

$1B AERO MARKET	FDM TOOLING	VALUE

$1B AERO MARKET

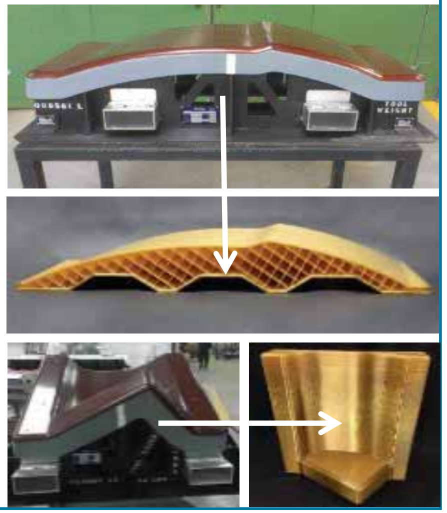
Source: “Tooling for Aerostructures 2014” report from counterpoint market intelligence



FDM TOOLING

$60K → **$3k**

4 months → **3 days**



VALUE

High Temp

Time-Cost-Labor Reduction

Tailored Construction

STRONG AND LIGHT COMPOSITE STRUCTURES

$13 Billion

Aerospace composite structures market 2016

7.1% CAGR

Robotic Composite 3D Applications

Source: Counterpoint Market Intelligence