TECHNICAL APPLICATION GUIDE

FDM For Robotic End Of Arm Tooling

A robot's end of arm tooling (EOAT), also known as an end effector, is specific to the task it will perform, such as gripping, welding, painting or sensing. Although there are standard, off-the-shelf EOATs, robot owners and integrators often need customized solutions to engage uniquely shaped parts, optimize operations and improve productivity (Figure 1).

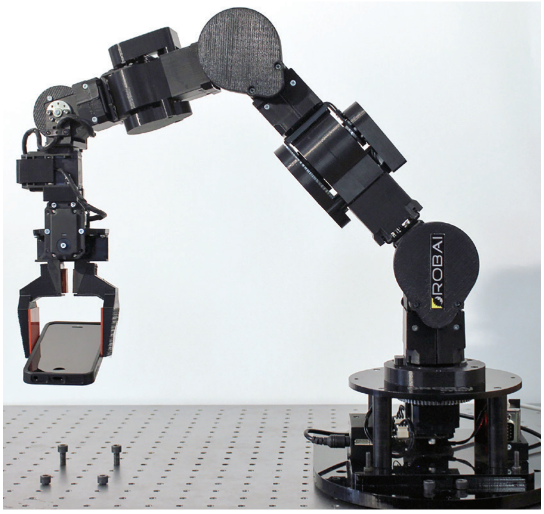

Figure 1: Robotic arm with claw-style EOAT (ABS-M30™ black).

Because of the low-volume nature of custom EOATs, many are machined from metal. They are combined with stock components, such as vacuum cups, actuators, framing components and quick changers. However, the time, cost and effort to machine custom EOATs can be prohibitive, which is why end-users may settle for non-customized, stock solutions (Figure 2).

FDM® technology makes custom EOATs practical by avoiding the time and cost associated with traditional machining. EOATs can be produced in-house quickly and affordably, from stable, durable, and lightweight thermoplastics. Companies often report 70% to 85% savings in time and cost compared to machined EOATs, and weight reductions up to 90%, which increases robot travel speed and service life.

Custom EOATs can be also optimized for specific applications because FDM technology eliminates the design constraints imposed by machining. Integrated vacuum channels, hollow interiors, organic shapes and part consolidation are possible, while still keeping production cost and time to a minimum (Figure 3).

TECHNICAL APPLICATION GUIDE

FDM For Robotic End Of Arm Tooling

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CONTENTS

APPLICATION COMPATIBILITY

TECHNOLOGY	IDEA	DESIGN	PRODUCTION
FDM	3	3	5
PolyJet	x	3	3

(0 – N/A, 1 – Low, 5 – High)

COMPANION AND REFERENCE MATERIALS

Technical application guide	• Document
Application brief	• Document
Video	• Commercial • Success story • How it's used
Case Studies	• Robai Corporation • Genesis Systems Group
Referenced processes	• Best Practice: Assemblies • Best Practice: Varying Part Density • Best Practice: Embedding Hardware into FDM Parts • Best Practice: Inserting Hardware into FDM Parts • Best Practice: Orienting for Strength, Speed or Surface Finish

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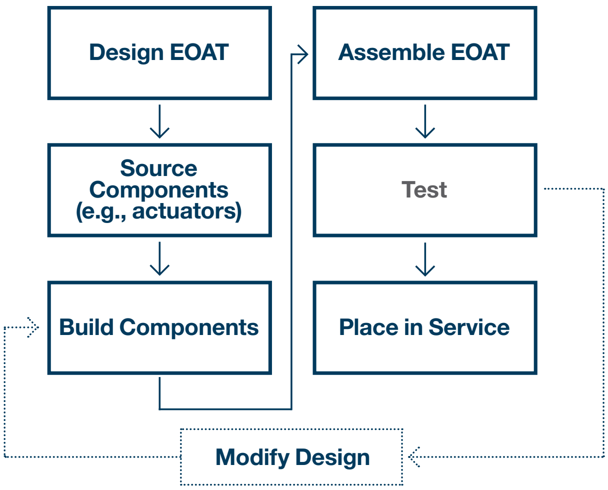
FDM For Robotic End Of Arm Tooling

1. PROCESS OVERVIEW

Robotic end of arm tools (EOAT) may be standard, general-purpose endeffectors or custom-built tools made for a specific application. FDM technology replaces machining when custom EOATs are needed



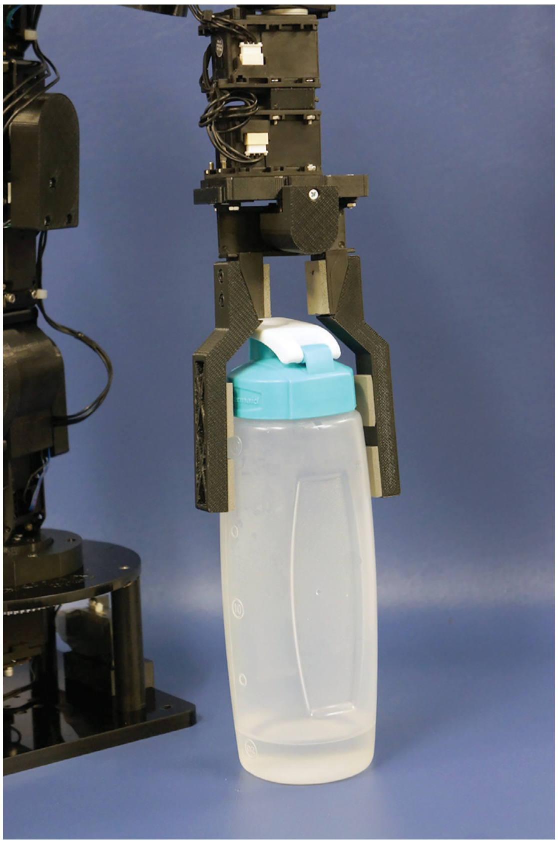


Figure 2: Off-the-shelf EOAT (ABS-M30 black).

2. DESIGN FOR FUNCTION (CAD)

A simple approach to apply FDM technology to EOAT construction is to use existing designs and traditional design rules. However, this may be an inefficient approach that does not capitalize on the advantages of additive manufacturing. If left unchanged, the rules that govern designs for conventional processes are artificially imposed on FDM EOATs and may negatively affect performance, time and cost (Figure 4).

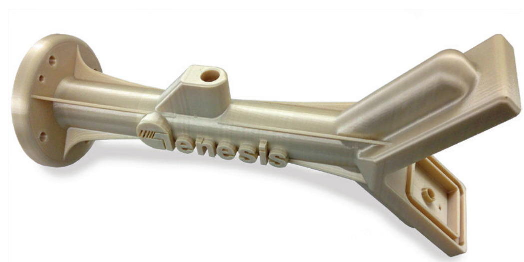


Figure 3: Custom EOAT with internal vacuum channels made with FDM material (ULTEM™ 9085 resin tan).

FDM For Robotic End Of Arm Tooling

Whenever time allows, it is best to start with a fresh design that builds on the design freedoms offered by additive manufacturing processes (Figure 5).

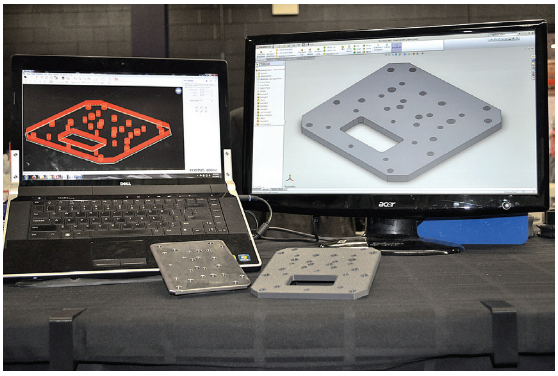


Figure 4: CAD model (right) of EOAT component (bottom right) using conventional design practices (ABS-M30 gray).

2.1. INTEGRATED DESIGN (CONSOLIDATION)

Convert assemblies into single parts. Often, EOAT components are dissected into many pieces in order to make conventional manufacturing processes feasible and affordable. This is unnecessary with FDM EOATs.

If reproducing an existing EOAT, start with a redesign that consolidates as many components as possible into one piece. If designing a new item, create it as one piece. Only split off parts when it is advantageous to the operation of the EOAT (Figures 6 and 7).

Integrated design has many advantages, including:

Figure 5: Example of EOAT (black) that leverages FDM's design freedoms.

- **Design for function**
  Focus on the task that the EOAT will perform. Optimize the design for its function rather than the processes used to make it.

- **Eliminate tolerance challenges**
  Holding tight tolerances is costly but avoidable. If two mating parts are combined into one, all concerns about controlling tolerances and costs are eliminated.

- **Eliminate assembly time**
  Consolidate all parts into a single piece to eliminate the time needed for assembly.

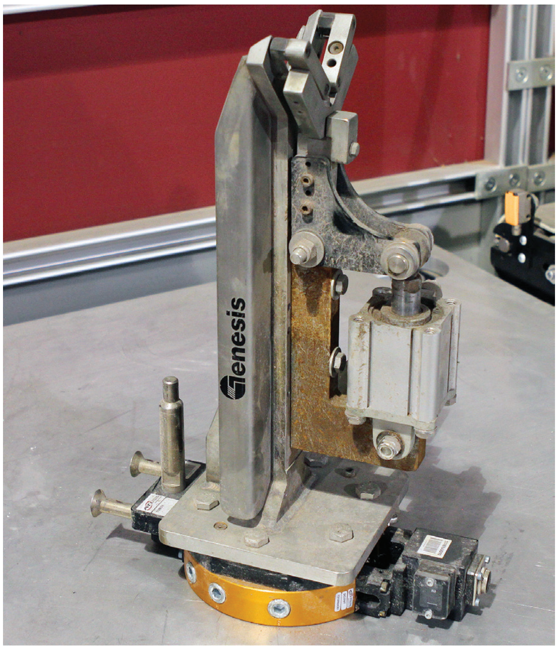


Figure 6: Multi-component EOAT that is CNC machined.

2.2. WEIGHT

The payload weight, which includes the EOAT and the item it manipulates, cannot exceed the payload rating for the robot. Doing so will cause excessive wear, requiring frequent maintenance. Additionally, the payload weight will affect the acceleration and speed of the robot.

When designing an EOAT, incorporate weight-reducing features (Figure 8). This lowers the cost and time to produce a lightweight, wellbalanced EOAT.

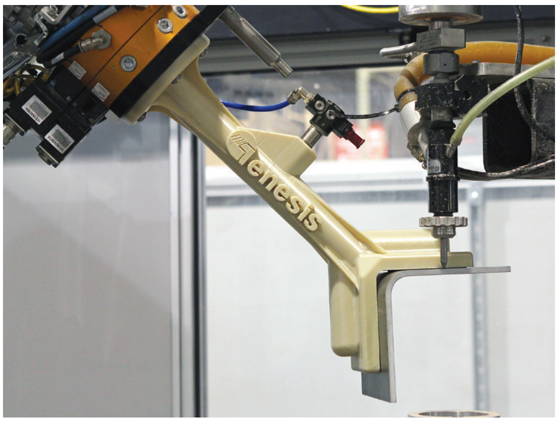


Figure 7: Single-piece FDM EOAT consolidates all components (ULTEM™ 9085 resin tan).

2.3. INTEGRATED FEATURES

There are two aspects to integrated features: adding features and inserting hardware.

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2.3.1. ADDING FEATURES

With traditional manufacturing processes, there is usually a cost associated with every feature added to a part. This is not true with additive manufacturing, especially when material is removed.

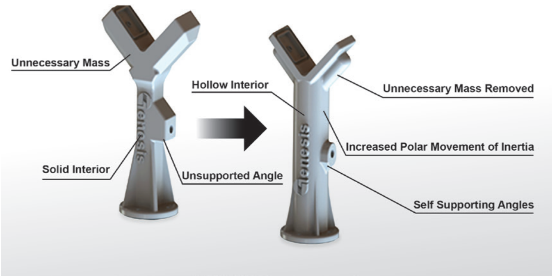

Figure 8: EOAT designed for machining (left) versus the weight-reducing design that is possible with FDM.

In the design of an FDM EOAT, consider adding features that aid its operation and reduce build times and material costs. For example:

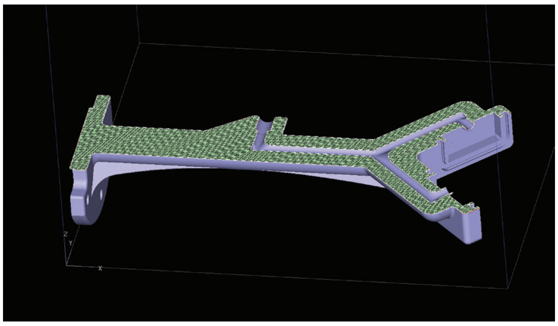

Figure 9: Cross-section of FDM EOAT showing internal vacuum channels.

- **Add internal vacuum channels.**
  Integrating vacuum channels eliminates external vacuum hoses (Figure 9).

  Note: The porosity within FDM parts can be overcome by compensating for vacuum loss or by sealing the port with an epoxy.

- **Add pockets, ribs and holes.**
  Removing mass will decrease weight, material consumption and build time. This is an especially important modification for large, bulky components, such as mounting bases

- **Add embellishments.**
  Incorporate job numbers, part numbers, storage locations or operational instructions directly on the EOAT (Figure 10).

2.3.2. INSERTING HARDWARE

Hardware may be added to FDM EOATs in a secondary operation. For example, threaded inserts can be press-fit into holes, which are added to the CAD model, following an FDM build (Figure 11). Other examples include inserting metal rods that act as stiffeners, or magnets for grasping metal parts. For details, see the *Best Practice: Inserting Hardware into FDM Parts*.

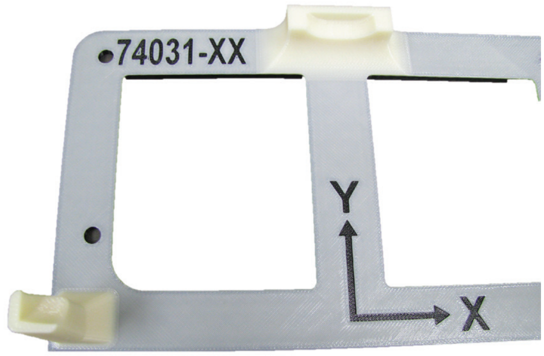

Figure 10: Text embellishments are added to identify EOATs and provide usage instructions (ABS-M30 ivory).

Another alternative is to mimic insert molding. In the CAD model, add a pocket or hole that will contain the appropriate hardware. During the FDM build process, pause the job, place the item in the part and resume the build. The hardware is now integrated within the FDM tool (Figure 12). An embedded magnet, for example, will be encased within the FDM plastic so there will be no metal-on-metal contact that can scratch part surfaces. For details, see the *Best Practice: Embedding Hardware into FDM Parts*.

Figure 11: Press-fit brass bushings in an FDM EOAT component (ABS-M30 black).

2.4. OPTIMIZE FDM EOAT PERFORMANCE.

CAD design may also be used to improve dimensional accuracy and strength while further decreasing build times.

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2.4.1. FEATURE ADJUSTMENTS

- **Offset surfaces.**
  For high-precision features, consider building a sample and inspecting it for adherence to dimensional requirements. Since FDM proves to be repeatable from build to build, adjustments in the CAD model may provide tighter tolerances than those expected from FDM.

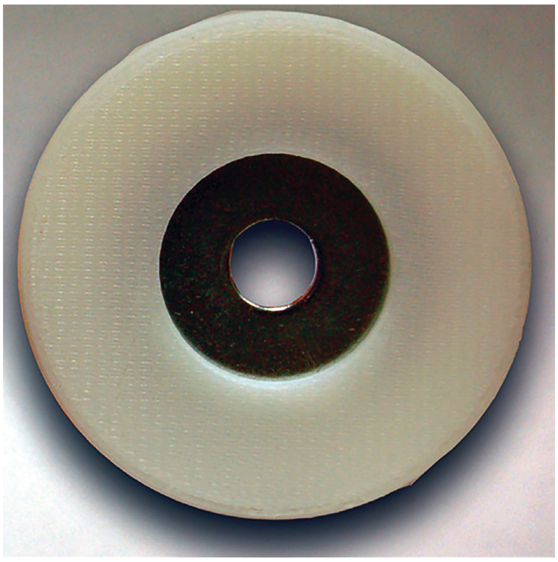

Figure 12: Magnet embedded during the FDM build (ABS-M30 ivory).

  - Build and measure a sample part.
  - Calculate the required adjustment.
  - Where oversized, offset the feature's surfaces inward. Where undersized, offset the feature's surfaces outward.

- **Adjust wall thicknesses.**
  For thin sections, interior gaps may result if the thickness is not evenly divisible by the contour width of the FDM toolpath. These may be eliminated through custom groups in Insight™ software (see Section 3.3) or by adjusting the feature's wall thickness in CAD.

- **Eliminate tapered walls.**
  Features that taper in the Z axis will have wall thicknesses that vary by elevation. This may cause interior gaps because the wall thickness can't be adjusted to match the contour thickness on thin-wall parts. Where possible, make all surfaces perpendicular to the XY plane when the part is oriented in its build position.

- **Eliminate supports.**
  Supports are added to the bottom of a part and to all features with an angle, as measured from the XY plane, which is less than the self-supporting angle in Insight software (Figure 13). Since supports increase build times and material expense, it is advantageous to minimize them. One option is to modify the CAD model so that features exceed the self-supporting angle.

2.5. DESIGN ITERATIONS

This design consideration is more of a reminder than a design technique. View each build as a "prototype." Continue to revise an EOAT's design to optimize its performance (Figure 14).

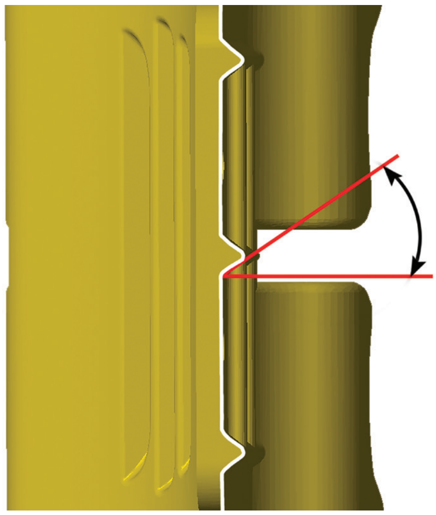

Figure 13: Angled feature is within self-supporting angle limits so that supports are unnecessary.

Because the FDM process works directly from the CAD data, it is both quick and economical. It is quite practical to gather feedback from the first iteration and make adjustments, considering the speed of the process and elimination of overhead (e.g., detail drawings or purchase order approval). With a simple adjustment of the CAD model and few minutes in the Insight software to prepare the job, a new revision is ready to build.

Figure 14: EOAT design progression from first (left) to last (right) (FDM Nylon 12 black, PC white and ULTEM™ 9085 resin tan).

Many companies that use FDM technology to produce EOATs have found that they are able to continually improve their operations by implementing changes discovered after the tool has been put into service.

2.6. VARIABLE DENSITY

A unique characteristic of FDM technology is that a single part can have regions with different build styles. The advantages include:

- Varying density for optimal strength and weight
- Varying density for optimal time and cost

To some degree, this can be achieved in the Insight software by using custom groups. But for advanced control, create a CAD model with separate bodies for each variable density region so that they can be processed with different toolpath options (Figures 15 and 16). For details, see the *Best Practice: Varying Part Density*.

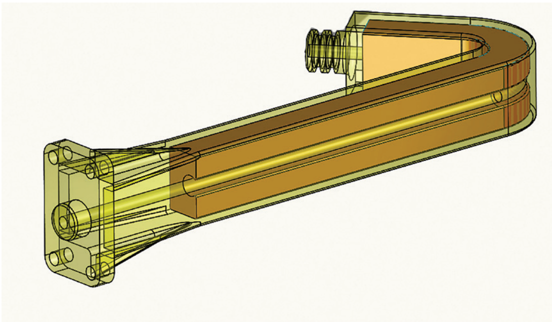

Figure 15: CAD model of an EOAT component divided into two bodies to create variable density.

2.7. GENERATE STL FILES.

When the EOAT design is complete, export the STL file from the CAD model. Ensure that settings, such as chord height, deviation and angle will produce a fine mesh with small facets. This will minimize postprocessing efforts and preserve accuracy. For details, see the *Best Practice: CAD to STL*.

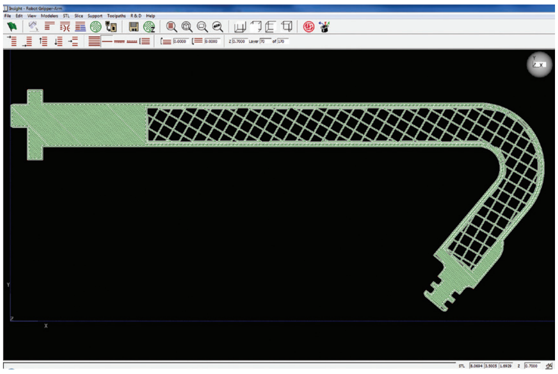

Figure 16: Variable density component that combines solid and sparse fills.

3. FILE PREPARATION

Import the STL file for the EOAT and prepare it for building as usual. To improve EOAT performance and FDM efficiency, consider the following recommendations.

3.1. ORIENT THE EOAT.

Select an orientation for the STL file that balances strength, surface finish, feature resolution and build time. For details, see the *Best Practice: Orienting for Strength, Speed or Surface Finish*.

3.2. SELECT FILL STYLE.

Strength and weight are important factors for EOAT performance. Considering the FDM material that will be used and the robot arm's performance demands, select ***Solid – normal***, ***Sparse*** or ***Sparse – double dense*** fill style (Figure 17).

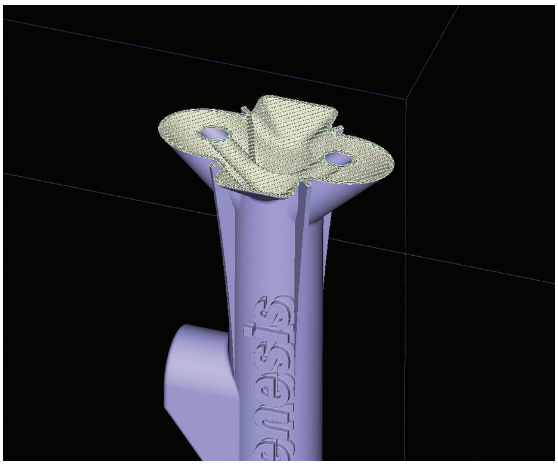

Figure 17: FDM EOAT processed with a Sparse-double dense fill to create a semi-hollow interior.

Optionally, modify toolpath settings through ***Advanced parameters*** (Toolpath > Setup… > Toolpath Parameters). By adjusting these settings, weight and build time can be reduced, porosity minimized and strength increased. For example, customize the ***Sparse fill air gap*** to increase strength by reducing the air gap, or decrease weight by increasing it.

3.3. CREATE CUSTOM GROUPS (OPTIONAL).

Custom groups can be used in many ways to selectively modify toolpaths for EOATs. Following are three of the most common uses when build FDM EOATs.

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- **Use variable density.**
  Variable densities are applied to regions of a part to allow optimization for strength, weight, build time and cost (Figure 18). For details, review the *Best Practice: Varying Part Density*.

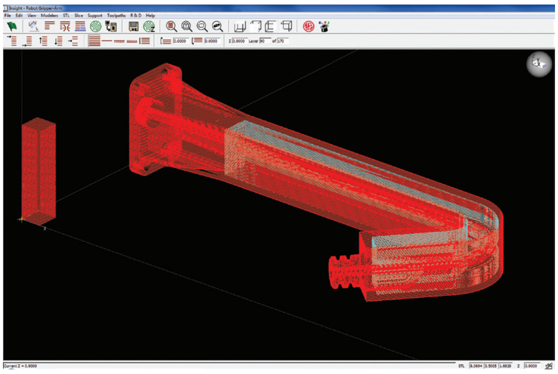

Figure 18: Variable density part in Insight software shows sparse fill interior (cyan) and solid exterior (red).

- **Reduce porosity.**
  Reducing porosity around critical locations such as mounting holes is critical to ensure the overall success of the tool (Figure 19). For details, review the *Best Practice: Applying Custom Toolpaths for Thin Walls and Bosses.*

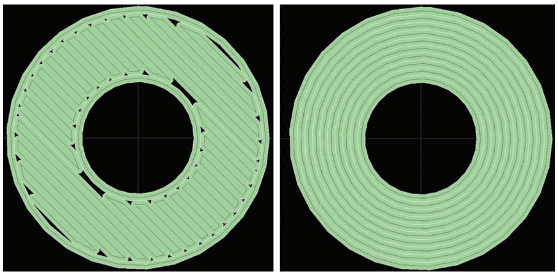

Figure 19: Porosity (left) before applying a custom group to make a solid feature (right).

- **Adjust wall thickness.**
  For thin sections, interior gaps may result if the thickness is not evenly divisible by the contour width of the FDM toolpath. These may be eliminated through custom groups in the Insight software or by adjusting the feature's wall thickness in CAD (Section 2.4). For details, review the *Best Practice: Applying Custom Toolpaths for Thin Wall and Bosses*.

- **Swap support material.**
  For large, bulky EOATs with direct access to support structures, consider using model material for both the part and supports. This will reduce build times by eliminating the delay for heating and purging the support material extruder.
  Begin by generating SMART or Sparse supports. T hen create a custom group and change its Toolpath material to model material. Next, add the default support curves to this custom group.

4. MATERIALS

All FDM materials are suitable for EOAT production. Select a suitable material based on:

- Mechanical properties
- Chemical and solvent resistance
- Soluble support structures

5. SECONDARY PROCESSES

Secondary procedures such as assembly are typically required with many EOAT devices. However, the advantages of FDM technology greatly reduce the complexity of these procedures.

5.1. REMOVE SUPPORTS.

If the EOAT is made of an FDM material that uses breakaway supports, manually remove them. Otherwise, wash away the support material following the instructions supplied with the soluble support cleaning agent.

5.2. FINISH AND PREPARE COMPONENTS (OPTIONAL).

There are many options for finishing and preparing FDM parts prior to EOAT assembly (Figure 20). For details on these processes, see the best practices documents listed below.

- *Best Practice: Finishing*
- *Best Practice: Assemblies*
- *Best Practice: Inserting Hardware into FDM Parts*

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5.3. ASSEMBLE THE EOAT.

Assemble the FDM EOAT components with stock components, such as actuators, vacuum cups, regulators, framing and quick tool changers (Figure 21).

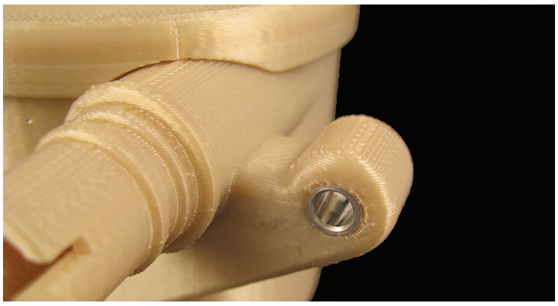

Figure 20: Compression-limiting bushing added to an FDM EOAT (PPSF Tan).

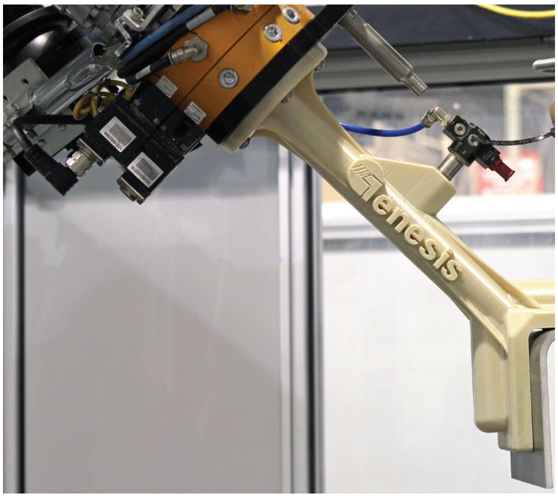

Figure 21: FDM EOAT assembly (ULTEM™ 9085 resin Tan) with base plate and vacuum line.

6. KEY PROCESS CONSIDERATIONS

OBSTACLE		RESOLUTION					
		LIGHTS-OUT OPERATIONS	DESIGN FOR FDM	PROCESS CONTROL	SECONDARY PROCESSES	PART ORIENTATION	MATERIAL SELECTION
Build time	Throughput not competitive with machining.	✓	✓	✓		✓	
Porosity	Not sealed, will not hold a vacuum.			✓			
Accuracy	Dimensional variance not to spec.		✓	✓	✓	✓	
Surface finish	Visible layers and toolpaths.			✓	✓	✓	
Material expense	Cost of raw material is high.		✓	✓			
Small features	Thin features may deflect or break.		✓	✓		✓	✓
Material properties	Plastics lack strength/durability of metal. Lower strength in Z axis.			✓		✓	✓
Supports	Support removal from cavities is difficult.		✓			✓	✓

Table 1: Common obstacles and resolutions

6.1. RESOLUTIONS

- Lights-out operations:
  - Increase throughput and efficiency by managing job scheduling to leverage “lights-out,” automated operations.
- Design for FDM (CAD):

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- Only build the critical/complex surfaces from FDM. Utilize standard purchased components like modular framing, valves, regulators and vacuum cups.

- Design the EOAT to optimize the FDM process: use selfsupporting angles (that eliminate the need for support), offset surfaces, utilize variable density, remove excessive material, and ensure the use of minimum wall thicknesses.

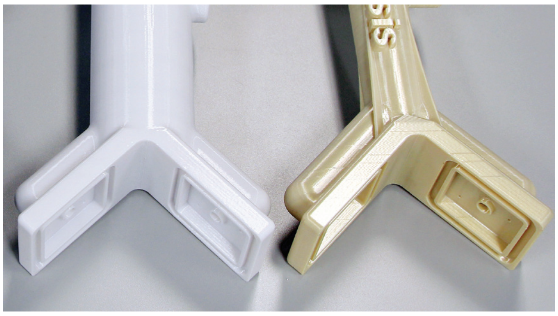

Figure 22: Genesis FDM EOAT iterations (left to right: PC White, and ULTEM™ 9085 resin tan).

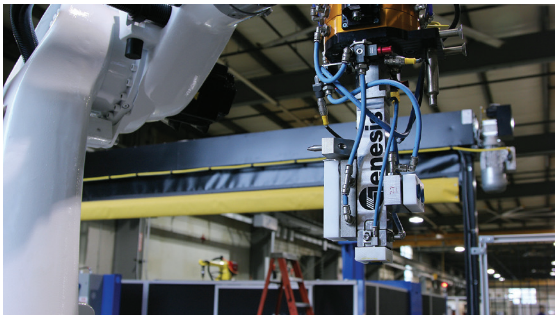

Figure 23: Conventionally made, multi-piece EOAT.

- Process control (Insight software):
    - Use advanced Insight software tools for fill styles and custom groups to adjust strength, porosity, material expense and build time.
    - Select appropriate slice heights for feature size, surface finish and build time.
- Secondary processes
    - For surface smoothness: solvent smoothing, secondary
    - machining, sanding, filling (body fillers) or coating (epoxy).
    - For accuracy: secondary machining (drill/tap/mill).
- Part orientation:
    - Position the part to improve feature accuracy, surface finish,

- build speed or strength.
- Orient for easy support removal.

- Material selection:
  - Select the best material to meet performance requirements (strength, chemical resistance, soluble supports and available slice height).

Figure 24: Single-piece, vacuum EOAT for waterjet cutting made with FDM material (ULTEM™ 9085 resin tan).

7. TOOLS AND SUPPLIES

7.1. REQUIRED ITEMS

- 3D CAD software
- Insight software (documented with Insight 9.0)

7.2. OPTIONAL ITEMS

- EOAT components such as:
  - Actuators (pneumatic, electric, hydraulic or spring)
  - Framing
  - Valves & regulators
  - Fittings
  - Sensors
  - Nippers
  - Rotaries

  - Gripper fingers
  - Sprue grippers
  - Vacuum cups
  - Suspensions
  - Quick changers
- Epoxy sealants
- Hardware:
  - Magnets
  - Inserts
  - Nuts and bolts

Figure 25: Vacuum FDM EOAT (ABS-M30 yellow).

8. RECAP – CRITICAL SUCCESS FACTORS

8.1. FOLLOW BEST PRACTICES.

- Optimize the EOAT by leveraging design freedoms.
- Minimize weight while maximizing strength.

8.2. ELIMINATE ADOPTION OBSTACLES.

- Use Insight software advanced controls for process improvement.
- Adopt FDM best practices and design for FDM guidelines.

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To obtain more information on this application, contact:

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www.stratasys.com/solutions-applications

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