



Surrogate Parts for Design, Manufacturing, Training and Support

Surrogate parts are purpose-driven, non-functional substitutes for components and sub-assemblies with high value, long lead times and complex interfaces. These components directly affect the cost, schedule and success of the products in which they are installed. Using surrogate parts manufactured to current revision levels can help identify critical installation issues early, even before production components are available, without incurring the cost of production units early in the production cycle.



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1. Overview

1.1. Application:

FDM® (Fused Deposition Modeling) parts may be used when assessing assembly, installation, serviceability, routing and interfaces. It is also used when manufacturing training aids for assembly and service technicians. FDM's role is to produce surrogate components that are substituted for production components and sub-assemblies. 5S organizational aids.

1.2. FDM is a best fit when:

- The end product has:
 - Closely packed installations with tight interfaces and clearances. Complex designs.
 - Complex routing paths for wiring harnesses and fluid conduits.
 - Long-duration manufacturing, assembly or engineering cycles (typically greater than six months).
 - Risk of damage to component or neighbors during assembly or removal. Small to moderate size.
- Components and sub-assemblies have:
 - High-value (typically greater than \$5,000)
 - Long lead times (greater than two months)
 - Complex configurations or interfaces
 - The possibility of design modifications — of the component or those it interfaces with.
 - Desired part annotation, such as “Remove before flight.”
 - Needs that overly simplified mock-ups can't fulfill.
- Training aids have:
 - High-value components that are non-functional.
- Applications include:
 - Space claim: evaluation of the envelope of the component with respect to its neighboring sub-assemblies.
 - Interface: evaluation of the physical interfaces with mating items such as fluid fittings, electrical connectors, ducting and attachment hardware.
 - Training: representative models used to instruct technicians on assembly, operation and service.

2. Traditional Process Overview

2.1. The steps in the traditional assembly assessment process are:

- Procure production component or subassembly (Figure 4).
 - Manufacture in-house.
 - Purchase from supplier.
- Alternative — fabricate mock-up (Figure 5).
 - Fabricate or machine a simplified substitute in wood, metal or other material.
 - Omit features that increase fabrication time or cost. Eliminate assembly time.

2.2. To use FDM parts as surrogates:

- Simply substitute FDM part for the manufactured, purchased or fabricated item.



Figure 1: CH-53E Super Stallion is an ideal candidate for surrogate parts. Photo: Lance Cpl Steve Acuff.

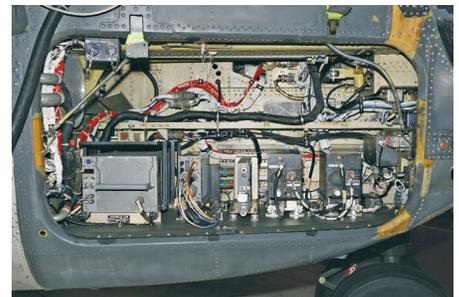


Figure 2: Super Stallion's avionics bay houses high-value, closely packed components with complex routing paths.



Figure 3: Prodrive's MINI WRC car used surrogates to validate ease of replacement.



Figure 4: Assembly assessment may be done with production units, such as this avionics control.

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- No design modifications required or FDM process adjustments needed. However, options are available if desired.

3. File Preparation

3.1. Create CAD model:

Build or acquire the CAD model of the surrogate to the design specifications of the production component or sub-assembly. No modifications are required, but options are available. Using the fully detailed CAD model allows complete assessment of all assembly, performance and serviceability issues, such as:

- Functional clearance requirements (air flow, cooling zones, sway clearance)
- Routing paths (wiring harnesses, fluid conduits, ducting)
- Installation and service access

If the size of the surrogate exceeds the build envelope of the FDM System, section the CAD model to create individual pieces that will be assembled in post processing.

Options for surrogate design include:

3.1.1. Type 1 – Envelope surrogate.

Remove or omit any internal features or internal components. The resulting CAD model will have all external, bounding surfaces with a solid core. Additionally, remove elements of the surrogate that are unnecessary for assessment or unwanted in a training aid.

This may decrease the build time by reducing internal supports if the sparse fill option (see section 3.3.3) is used. Also, it may decrease the time needed to remove supports.

3.1.2. Type 2 – Interface surrogate.

To evaluate interfaces, modify the CAD model to include representations of the attachment hardware (Figure 6). Alternatively, add design features that allow the production hardware to be mounted to the FDM surrogate.

Including interfaces ensures that routings are correctly terminated before the production component is installed. This prevents last-minute rework during final product assembly.

Typical interfaces include:

- Fluid fittings
- Electrical connectors
- HVAC ducts
- Mechanisms (actuators, latches)

3.1.2.1. Option 1 – integrated hardware.

Add simplified representations of the connection hardware to



Figure 5: Alternatively, simple mock-ups are machined.

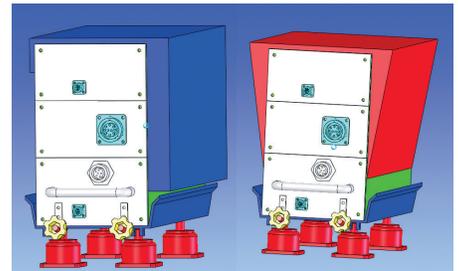


Figure 6: For interface surrogates, include attachment hardware in the CAD model.

the CAD model (Figure 7). For example, if the component has a 25-pin computer connection, model the metal flange but eliminate the pins.

3.1.2.2. Option 2 – assembled FDM hardware.

Use the approach in 3.1.2.1, but create the interface hardware as a separate CAD model. This option allows the connector to be made of an FDM material other than that used for the surrogate. Select the FDM material to match the mechanical, electrical and thermal properties needed for assessment.

These components are attached to the surrogate after post processing.

3.1.2.3. Option 3 – assembled production hardware.

This alternative combines an FDM surrogate with purchased hardware and fittings that will be used in the final product. Modify the CAD model to receive and hold the connector or fitting. For example, create a pocket in which the hardware will be nested or add holes for fasteners such as bolts.

3.1.3. Type 3 – Ergonomic surrogate.

In the case of training aids, an accurate representation of weight and balance may be desired. With an adjustment to the CAD model and addition of ballast to the FDM surrogate, the component will be an accurate representation of the production part.

3.1.3.1. Determine the mass properties of the production component.

Use the CAD program's mass properties function to calculate weight and center of gravity. Alternatively, request this data from the supplier.

3.1.3.2. Determine the mass properties of the FDM surrogate.

If applying a Part interior style of Solid – normal, use the CAD model to calculate weight and center of gravity. Reference Stratasys' material specification documents for the appropriate material density.

If using a Sparse style, accurate weighting and balance will require the production of a sample FDM surrogate. Physically measure the surrogate to calculate both values.

3.1.3.3. Create ballast pockets.

Determine the type of ballast and its density. Next, calculate the volume of ballast needed to increase the weight of the FDM surrogate to that of the production assembly. Then, create a strategically placed pocket in the model where the ballast will be located. Determine the resulting weight and center of gravity through mass properties function. Adjust as necessary.



Figure 7: FDM surrogate with simplified interface connections.

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To conceal and contain the ballast, create a cover plate with matching recessed mounting surfaces on the surrogate model. The cover plate will be constructed separately and bonded to the surrogate after the ballast has been loaded.

3.1.4. Type 4 – Smart surrogate.

FDM surrogates can be loaded with identification and sensing devices. For example, RFID tags may be embedded in the surrogate. These are used for sweeps at the final assembly stage to locate any surrogates that may have been accidentally left behind in the installation. Alternatively, sensors may be integrated within surrogate parts to provide data during functional inspections. Examples include simple harness installation checks (e.g., power or ground pin circuit validation), pressure transducers and flow-rate sensors to confirm fluid routing connections.

To accommodate the RFID tags and sensors, create pockets for the devices in the CAD model (Figure 8). Optionally, RFID tags may be fully contained and completely concealed in the FDM surrogate. In this case, create an enclosed cavity in the model. During the FDM build process, the job will be paused, RFID tag inserted and the job resumed. Prior to insertion, confirm that the RFID tag is rated for temperatures that exceed those of the FDM process (FDM material dependent).

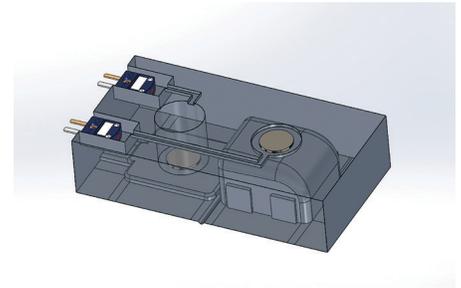


Figure 8: Add pockets in the CAD model to receives sensors or RFID tags.

3.2. Export STL file.

When the CAD model is complete, export it as an STL file. Ensure that settings, such as chord height, will produce a file with very small facets. This will yield a surrogate that is a true representation of the finest details in the component.

Note that large models with numerous features may result in overly large, unmanageable files. In this case, adjust the setting to increase facet size, which will reduce the file size.

3.3. Prepare for FDM build.

Import the STL file into Insight and follow the standard workflow for job processing.

3.3.1. Orient STL file.

Orient the file for the best surface quality and feature definition.

3.3.2. Select Slice height. (**Modeler setup > Configure modeler**)

Considering the size of the typical surrogate, a Slice height of either 0.010 in. (0.25 mm) or 0.013 in. (0.33 mm) will yield the best combination of build time and part quality. However, for smaller surrogates, those less than 8 x 8 x 8 in. (203 x 203 x 203 mm), with small features, consider either 0.005 in. (0.13 mm) or 0.007 in. (0.18 mm) slices. The thinner slice improves feature resolution and surface finish but also increases build time.

Next, slice the file and proceed to **Toolpath > Setup**.

3.3.3. Define toolpaths.

Insight offers three Part interior styles: Solid-normal, Sparse and Sparse-double dense. Select the appropriate style for the following characteristics:

- Strength
- Weight
- Material consumption
- Build time

Part interior style may be selected from **Modeler > Setup or Toolpaths > Setup**.

Following are descriptions and characteristics of the fill styles:

- Solid-normal (Figure 9)
 - Dense fill with no gap between adjacent rasters
 - Rasters run perpendicular to those on the proceeding layer
 - Characteristics:
 - Strongest
 - Heaviest
 - Highest model material consumption
 - Longest build times
- Sparse (Figure 10)
 - Hollow interior with internal lattice for structural rigidity
 - Large air gap between rasters
 - Uni-directional rasters on each layer (Figure xx)
 - Alternating raster angles between layers
 - Characteristics:
 - Weakest
 - Lightest
 - Lowest model material consumption
 - Shortest build times
- Sparse – double dense (Figure 11)
 - Hollow interior with internal lattice for structural rigidity
 - Same as sparse, except bi-directional rasters on each layer
 - Characteristics (versus sparse):
 - Stronger
 - Slightly heavier

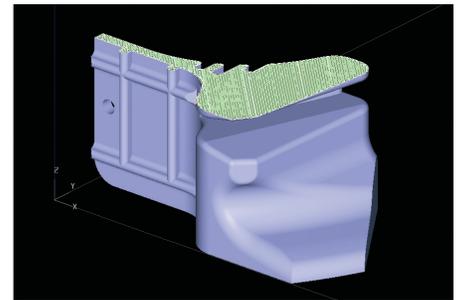


Figure 9: Solid-normal part interior style.

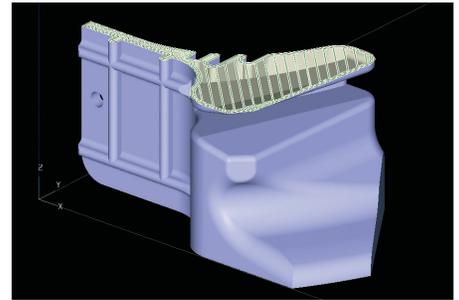


Figure 10: Sparse part interior style.



Figure 11: Sparse-double dense part interior style.

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- Slightly more model material
- Slightly longer build time

Considering that surrogates may be subjected to some mechanical load and mishandling and that a lower weight makes them easier to handle and transport, the most-recommended style is Sparse – double dense.

4. Systems And Materials

4.1. FDM systems.

Surrogate parts may be produced on the full line of FDM machines, including legacy systems and:

- Fortus® 3D Production Systems
 - 250mc
 - 360mc
 - 400mc
 - 900mc
- Dimension® 3D Printers
 - 1200es
 - Elite
- uPrint® 3D Printers
 - SE
 - SE Plus

4.2. Material options.

The full line of FDM materials is suitable for surrogate parts. Base a material selection on operational considerations and the environment in which the surrogates will be used.

- Recommended:
 - ABS (ABS-M30, ABSplus)
 - Least expensive
 - Good mechanical properties
 - Simple processing—soluble supports
- For higher strength:
 - Polycarbonate (PC)
- For elevated temperature and chemical resistance:
 - Polyphenylsulfone (PPSF)
 - ULTEM 9085*
 - FST rated (flame, smoke and toxicity); suitable for applications where fire safety is a concern

After selecting the FDM material, review the color options. If available, consider using a color that will distinguish the surrogate from production components. For example, select red ABS (Figure 12), which communicates “remove before flight” in the aerospace industry. The contrasting color provides a visual indicator that a surrogate is installed in the product assembly (Figures 13 and 14). This approach eliminates painting, or other marking, to identify surrogates.

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5. FDM Process

The FDM process requires no file modification. However, if embedding or integrating RFID tags, sensors or interface hardware, the FDM process will be paused to allow hardware insertion and resumed. For details, see “Inserting Metal in FDM Parts.”

6. Surrogate Preparation

6.1. Remove supports.

Following the build process, remove supports from the surrogate. They may be removed manually or by dissolving in soluble-support solution (where applicable). If dissolved, thoroughly rinse surrogate and dry.

The surrogate is now ready for installation into the product assembly.

6.2. Optional preparation.

6.2.1. Oversized surrogates.

If the surrogate is constructed in sections (see 3.1), join them using a method suited to the FDM material. (See “Comparison of Bonding Methods for FDM Materials.”) Options include adhesives, solvents, hot air plastic welding, ultrasonic welding and mechanical fasteners.

6.2.2. Interface surrogates.

6.2.2.1. FDM representative fittings.

Attach the FDM fitting to the surrogate. Alternatives include bonding compounds such as epoxy, and mechanical fasteners. If both the surrogate and fitting are made of ABS or PC-ABS, solvent bonding is also an option.

6.2.2.1. Production fittings.

Insert commercial hardware into cavities or recesses in the surrogate or attach them to external surfaces. Join the fittings to the surrogate with mechanical fasteners, adhesives or epoxy compounds

6.2.3. Ergonomic surrogates.

To match the weight and balance of the production component, add ballast to the surrogate. Steel plate, cut to the size of the receiving cavities, is commonly used. For cavities that snake through the part, a mixture of steel shot and epoxy resin is effective.

Bond the ballast in the surrogate cavity with epoxy. Then place the FDM cover panel over the cavity and bond it to the surrogate.

6.2.4. Smart surrogates.

Sensors such as RFIDs can be epoxy bonded or mechanically fastened to the surrogate’s surfaces or embedded (see sections 3.1.4 and 5.0) so that they cannot be damaged or tampered with in production (Figure 15).



Figure 12: Use colored FDM materials to flag surrogates, such as “Red – remove before delivery.”



Figure 13: Color-code surrogates to indicate “Remove during installation.”



Figure 14: Yellow surrogates could indicate a safety warning.

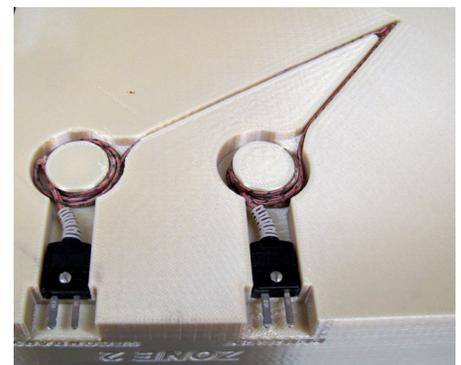


Figure 15: Place and bond sensors or RFID tags in FDM surrogate.

7. Tools & Supplies

7.1. Required items.

- None

7.2. Optional items.

- For ergonomic surrogates:
 - Ballast such as steel plate or shot
- For smart surrogates:
 - RFID tags
 - Sensors

8. Recap – Critical Success Factors

8.1. CAD model:

- Use current revision level.
- Alter, as needed, for:
 - Envelope, interface, ergonomic surrogates.
- Incorporate receiving cavities for RFID tags and sensors.

8.2. Part interior style:

- Select ***Solidnormal, Sparse or Sparse – double dense.***
 - Match assembly or training requirements while minimizing time and material consumption.

8.3. Material selection:

- Select for mechanical, thermal and chemical properties.
- Consider red (or other bright color) ABS-M30 or ABSplus (Figure 16).
 - Good, general-purpose material
 - Color flags component as a surrogate



Figure 16: Consider color-coded surrogates to flag for removal.

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