Institute for Software-Integrated Systems

Technical Report

TR#:	**ISIS-15-112**
Title:	**META Toolchain Interface to Manufacturing**
Authors:	**Jason Scott, Ted Bapty and Robert Boyles**

Table of Contents

VANDERBILT
UNIVERSITY

List of Figures

Tel (615) 343-7472 Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu

VANDERBILT
UNIVERSITY

1. Interface to Manufacturing

The META toolchain generates digital blueprints for design candidates in successively increasing detail as the design moves from a conceptual design to a highly detailed design. These META designs flow to the iFAB Foundry tool chain, where the goal of the iFAB Foundry is to automatically configure a digitally programmable manufacturing facility for the selection of manufacturing equipment, the sequencing of product flow into the planning of assembly process steps, and the automated generation of machine and human instruction sets needed. The iFAB tool chain, in support of the above goals, provides feedback to META informing the designer of the manufacturability of the design, known as Manufacturability Feedback Analysis (MFA).

MFA provides the following manufacturability analysis to the designer:
- Cost/Schedule: Total estimated cost of manufactured product and schedule required. Includes cost of procuring component items and end to end manufacturing of the design.
- Conceptual Manufacturing Analysis: Provides quick, design-time feedback to the designer about the validity of the design with respect to manufacturability (e.g. completeness of design).
- Detailed Manufacturing Analysis: Provides highly detailed feedback as to the manufacturability of both (1) CyPhy components (such as machinability), as well as (2) manufacturability of the entire design, considering availability of manufacturing equipment, dependencies encountered in sequencing of product flow, etc.
- RAMD Analysis: Reliability, Availability, Maintainability, & Durability (RAMD) of the design.

iFAB has created two design helper tools that are integrated into the OpenMETA toolchain: Hull Design Assist Tool (HuDAT) and the Manufacturing Analysis Augmentation Tool (MAAT) tool, described below.

1.1. HuDAT Creo Plugin

The purpose of the Hull Design Assist Tool (HuDAT) is to provide the designer with the capability to fully define the hull of an armored military vehicle with the information needed to perform detailed analyses including blast, ballistics, and manufacturability, and also the detailed manufacturing-related information needed to manufacture the designed hull. The HuDAT tool assists the user in adding manufacturing detail to CyPhy components including fully specifying the hull plates of a vehicle, internal hull structure, and specifying the weld geometry joining these structures and hull plates. HuDAT is

ISIS

VANDERBILT
UNIVERSITY

implemented as a plug-in to the PTC Creo Parametric CAD authoring tool that provides an additional set of functions to help the designer move from a concept level design to a fully detailed design. These added functions are provided in the form of two additional ribbons in the Creo environment. The HuDAT toolbar is a ribbon is shown in Figure 1.

In the AVM process, the hull design process begins with a concept level hull that has been analyzed using CyPhy to determine a suitable length, width, height, configuration, thickness, and material type for the hull items. The tool inputs a CAD assembly of a CyPhy hull component and performs a check to confirm that the component contains all of the prerequisite information to be converted to a detailed assembly. The plates and welds are then created programmatically via HuDAT with the user specifying the weld material. The detailed hull information is then updated in the CyPhy hull component via the Meta-Link live-link connection between the CyPhy editor and Creo.

Figure 1: HuDAT Creo Plugin

1.2. MAAT tool Creo Plugin

The purpose of the Manufacturing Analysis Augmentation Tool (MAAT) is to provide a mechanism for designers to supply additional CyPhy component information for custom manufactured components, i.e. components that are made in the iFAB Foundry distributed manufacturing environment. This data (e.g., part class selection, material specification, and general tolerance definition) is required in order for the detailed manufacturability CyPhy Test Bench to return an associated cost and lead time for a submitted part or assembly. All custom designed components (e.g., brackets, weldments, etc.) need to be augmented using the MAAT for a submitted design to be considered manufacturable.

The MAAT tool enables designers to identify non-manufacturable designs before incorporating these components into their design. Also, the evaluation of independent custom component designs (parts or assemblies) is, during the component validation phase, more efficient than receiving this feedback by submitting an entire vehicle design. Designers can also use the detailed manufacturability test bench results to improve their designs in an effort to reduce cost and/or lead time.

The iFAB MAAT tool is implemented as a Creo plugin, in a manner similar to HuDAT, supporting the specification of manufacturing data for both components and assemblies. In an assembly, this specification includes describing contact interactions between parts

VANDERBILT
UNIVERSITY

such as welds and fasteners. For components that need to be fabricated, the part material and type of stock that will be used are compared against the iFAB stock database to confirm that such a sized raw stock part exists. Types of stock include flat plates, square pipes, and circular pipes. After comparing against this database, the parts can be individually checked for manufacturability. If a given part is unable to be fabricated due to the material and process used (e.g., casting), an error is presented to the user. This is particularly useful to analyze one questionable part to avoid submitting a large, complex design that can take hours to analyze. This tool can also be used to directly submit a manufacturability analysis, although it will not be viewable in the dashboard as the test bench manifest results file is not created/updated in this process. Figure 2 shows an example of defining a part class and material for a given component using the MAAT tool.
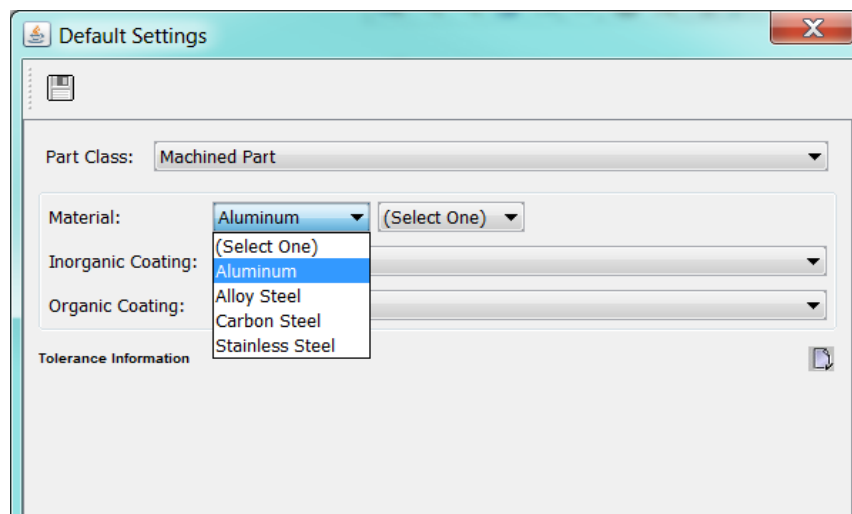

Figure 2: MAAT Tool

Since both the HuDAT and MAAT tools are implemented as Creo plug-ins, they are easily accessible as part of the design process using Meta-Link, which provided real-time interaction between the CyPhy design and component editor and the Creo CAD tool. The manufacturing information for components as provided by HuDAT and MAAT is captured as an iFAB-specified data structure that is incorporated into the CyPhy Component definition. The OpenMETA tool chain extracts from a candidate design a Technical Data Package (TDP) as required by iFAB for analysis as described in the next section.

VANDERBILT
UNIVERSITY

2. TDP Synthesis

The OpenMETA toolchain generates a digital specification of a CyPhy design providing design contents, physical assembly, and information necessary for manufacturing. This information is collectively referred to as the Technical Data Package (TDP) and serves as the data interface between the OpenMETA toolchain and the iFAB Foundry toolchain. The META team supported the generation of the TDP package, as well as the integration of third-party Creo plugins discussed in the previous section, to facilitate the authoring of components with the necessary manufacturing information.

2.1. Objective

One of the major assets that the OpenMETA toolchain brought to design analysis was the ability to interface with a manufacturing foundry to accurately estimate a design's cost of production and lead time to assemble said design. Providing enough information about a design to paint an accurate picture regarding its manufacturability is crucial when discerning between various designs. As the capabilities of iFAB increased, the META team supported the generation of artifacts to use these features. Information included in the TDP ranged from CAD model STEP files, component manufacturing information, and weld information. Integration between the OpenMETA tools and Creo plugins developed by iFAB allowed for the user to provide more in-depth component information using a user-friendly interface. The capture of detailed information directly results in a higher completion rating during the manufacturing analysis. The completion rating signifies how complete a design is in terms of assembly specification, and therefore the weight with which the metrics returned by iFAB can be trusted. As the design process progresses from conceptual to detailed, the amount of manufacturing information increases allowing the iFAB manufacturing analysis to provide increasingly accurate results.

2.2. Architecture

The following diagram (see Figure 3) details the architecture of the generation of the TDP artifacts:
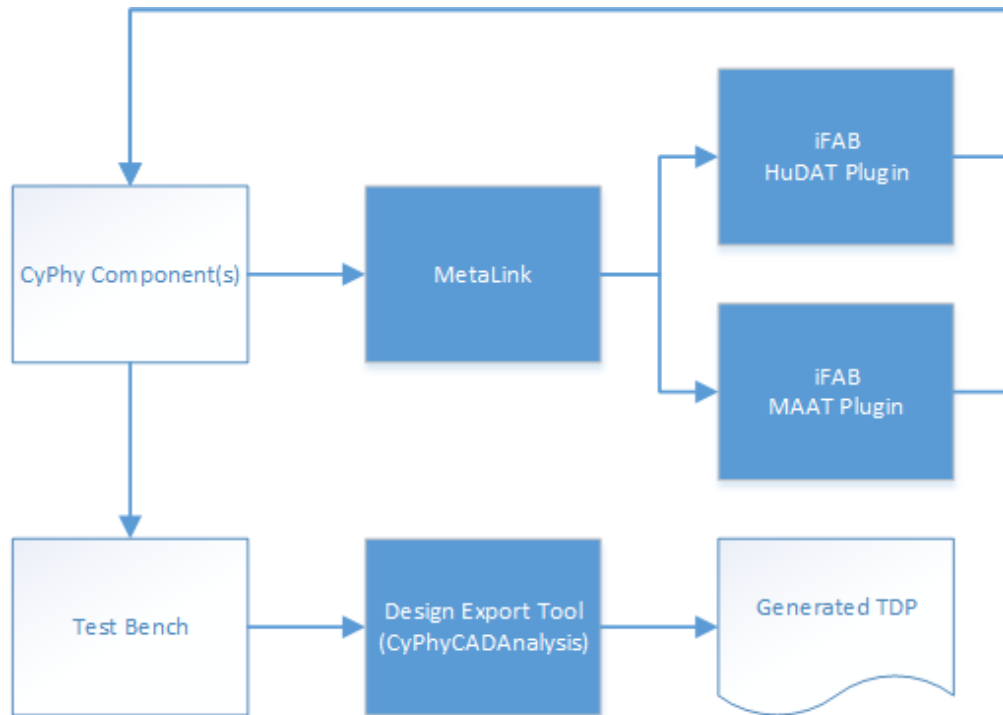
Figure 3: Architecture describing the workflow of at the design export tool.

At the core, the TDP consists primarily of information regarding components in the CyPhy design. The components' CAD models can be modified via the Meta-Link interpreter. The CyPhy component can then be updated to reflect any changes made within Creo (including the update of the ACM component description file). Manufacturability assessments can be conducted on components or assemblies within Meta-Link using the MAAT plugin. To create welds and detailed plates for components such as a hull, the HuDAT plugin can be invoked.

Once the component and assembly CyPhy design definition is complete, a Test Bench can be created to execute the design export tool. For the iFAB manufacturing analyses, the design export tool is invoked through the CyPhyCADAnalysis interpreter. The interpreter interrogates the CyPhy design and builds the CAD assembly, as well as generates/copies the desired artifacts into the results directory. This results directory, once populated, is the TDP.

2.3. Data Flow

Figure 4 details the data flow of the TDP generation.
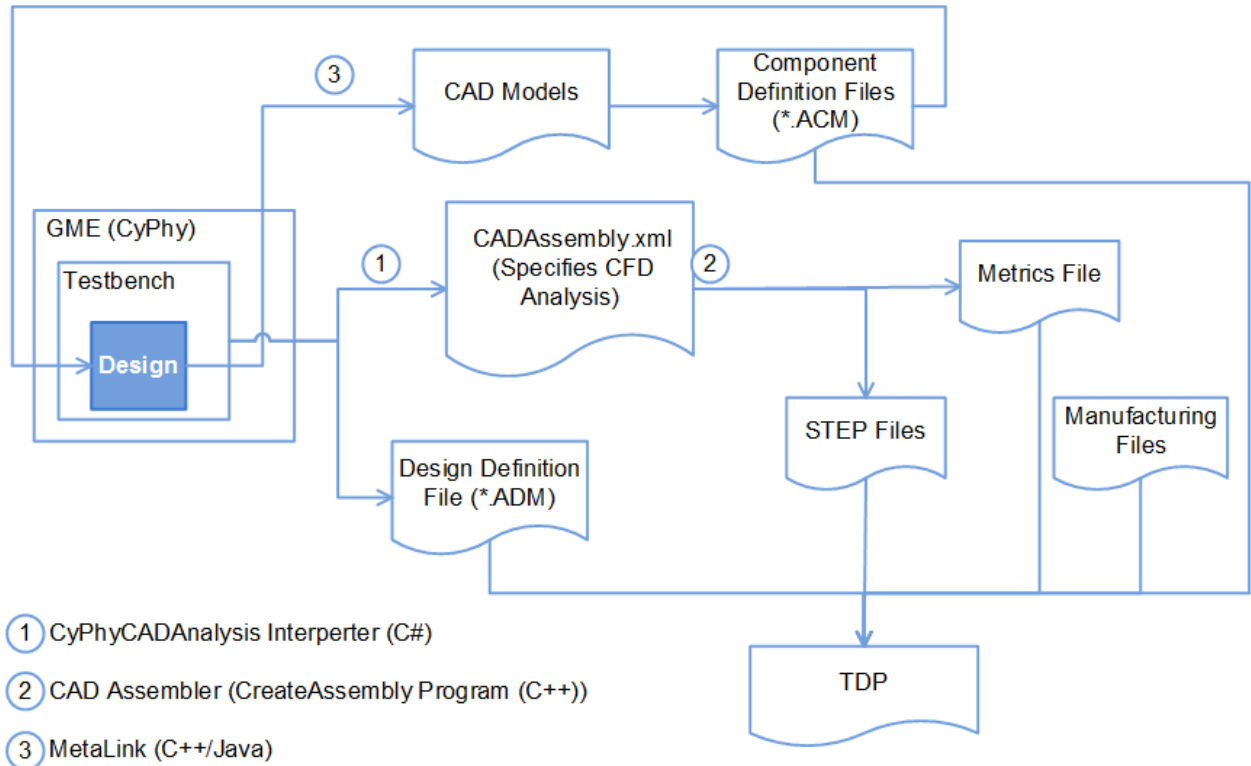
VANDERBILT
UNIVERSITY

Figure 4: General overview of the TDP data flow for the design export tool.

A description of the major TDP data constructs follows:
- Design - CyPhy design assembly model to be analyzed.
- Test Bench – Description of the test to be conducted and the design(s) that will be analyzed.
- Design Definition File – Description of the CyPhy assembly including join information (*.ADM).
- Component Definition Files – Description of a CyPhy component in a single file (*.ACM).
- Metrics File - CyPhy generated file that extracts key properties from the CyPhy composed design: Mass properties of the parts, bounding boxes, locations of parts in 3D space.
- Manufacturing Files - Cost and lead time details for make or buy components.
- STEP files - CAD model geometry

2.3.1. TDP Export Tool

The input to the TDP export tool is the CyPhy Test Bench, as well as the following information for each component in the design:
- ACM component definition file

VANDERBILT
UNIVERSITY

- CAD model(s)
- Manufacturing XML (if applicable)

This collection of files is copied to a specified results directory, which represents the design TDP. In addition to component information, the TDP export tool generates an ADM file describing the assembly as a whole, including specifications as to how the design components are connected together.

2.3.2. Creo Plugins

The data contained in the TDP can be improved by specifying manufacturing data via Creo plugins. Each of the iFAB Creo plugins are launched by initializing Meta-Link from a CyPhy component with a CAD design. The plugins appear as items in the Creo ribbon, and facilitate the manipulation of a component's CAD solid model and/or manufacturing information. These changes can then be saved as an updated Creo CAD model, or an exported component definition ACM file. The modified files are saved to the component's specified directory in the 'components' subfolder where the CyPhy design is located.

2.4. Detailed Description

2.4.1. TDP Export Tool

The TDP export tool is called by running the CyPhyCADAnalysis interpreter. The CyPhyCADAnalysis interpreter generates required model information for a variety of mechanical analyses, including manufacturing. The interpreter traverses through each component assembly and component in the design. For each component, its associated CAD models, ACM component definition file, and manufacturing XML (if applicable) are copied from the 'components' subfolder in the META design project directory to the results directory.

The CAD models are used in the OpenMETA CAD Assembler utility, which will then export each file to the AP203 E2 STEP file format as part of the Manufacturability Test Bench execution. The ACM file fully describes the CyPhy component, including the various parameters and properties along with their values and units. During the CyPhyCADAnalysis interpretation process, the component's folder in the CyPhy design directory is checked for the presence of an ACM file. If no such file is located, the tool calls the component exporter to produce an ACM file. For fully elaborated components, a manufacturing XML may also be present. This XML provides information regarding the procurement of buy components. Such information may include cost per part, lead time per part, shipping costs, and supplier information. If this XML does not exist for a CyPhy component, it is assumed this component is a 'make' component.

The ADM design file lists each component in the assembly, along with component-level data that is exposed at the design assembly level. These include exposed parameters, properties, and connector definitions. Also, assembly join information is given for each join specified in the assembly. A sample glued join is shown below (Figure 5). All

properties related to the join are listed along with the components to which the join is assigned (in this case, part1 and part2).

```xml
<JoinData d3p1:id="jdb537adc8-8f11-4376-9697-22d5253358aa" xmlns:d3p1="iFAB">
  <name>GluedJoin</name>
  <part1 />
  <part2 />
  <description />
  <glued>
    <length>1</length>
    <volume>1</volume>
    <material />
  </glued>
</JoinData>
```

Figure 5: Example XML description of join information

All of the information described above is placed in a single directory. Once the CAD assembly has been completed and STEP file exported, this directory is compressed. This compressed file is the TDP that will be sent to the iFAB servers for the manufacturability analysis.

2.5. Validation

2.5.1. Generate TDP with 90% completeness metric

In order to assess the completeness of a given design's TDP, a Completeness Test Bench was developed by Penn State University (PSU). This analysis tool examines the information provided in the TDP and returns a percent score between 0-100 describing the completeness of the model. For example, when welds and joins are excluded, the completeness score decreases. The lower a completeness score, the less confident a user can be in the results of the manufacturability analysis tools due to a lack of information.

The ability to provide a valid Test Bench with a certain level of completeness, however, varies with the design created by the user and the detail to which the assembly is modeled. It is not a function of the TDP export tool. An example is shown below for a basic assembly using one of the hull components from the FANG competition and a periscope. If the connection is made without a join specified, the completeness Test Bench returns a score of 0.0. When the connection between the two components is specified as a glued join (CyPhy assembly in Figure 6), a completeness score of 100.0 is returned, as shown in Figure 7. If this design was to be submitted to iFAB for a manufacturability analysis, one could be confident that the returned metrics would accurately reflect the actual costs. This demonstrates how the TDP export tool correctly packages the required data for iFAB. For each connection in a design, a join specified must be added or the completeness score will decrease. Depending on the type of join data missing or the number of welds missing, the manufacturability metrics will reduce in validity.

VANDERBILT
UNIVERSITY

Figure 6: CyPhy Assembly with Join

Structural Completeness Analysis

About

Structural completeness analyzes the join information in a design (fasteners, welds, adhesives, etc.) to ensure that:

1. all connections have join information; and
2. all joins are valid and complete.

Completeness is calculated as `[(# of connections) - (# of missing joins) - (# of incomplete joins)] / (# of connections)`. Therefore, a structurally complete design with all joins fully specified will receive a completeness score of 100%. A design lacking all join information will score 0%. The results below identify each connection with missing or invalid join information and provide a short description of the problem. These results also highlight any unattached components. A component is unattached if it is not connected to any other component, which may indiciate an issue in the design.

Summary

Completeness Metric:	100.00 %
Number of Components:	2
Number of Unattached Components:	0
Number of Connections:	1
Connections Missing Join Data:	0
Connections with Incomplete Join Data:	0

Identified Issues

No issues identified.

Figure 7: Structural Completeness Metric_Results

2.6. Results/Accomplishments

The TDP provides iFAB with a complete package of artifacts to fully describe a CyPhy design. The generation of the TDP takes only a few seconds, allowing for a shorter turnaround between manufacturing analysis execution and completion. Providing a TDP quickly and completely ensures a higher level of confidence can be assigned to an assessment's results.

2.7. AVM Involvement

The TDP was used extensively throughout the AVM project, including the FANG 1 competition, beta testing, gamma testing, and during validation exercises after gamma testing concluded. The package was generated as part of the manufacturability assessments required of the FANG competitors. In addition to the detailed manufacturing assessment, the TDP was used in AVM as the input to the other iFAB assessments, including completeness and RAMD (Reliability, Accessibility, and Maintainability of a Design) analyses.

2.8. Future Enhancements

The TDP will be improved upon in the future to contain more detailed information, as it becomes usable by iFAB. If used in future efforts, the TDP generation will continue to be supported to provide any usable additional information in the manufacturability assessment of a design.

VANDERBILT
UNIVERSITY

3. Conclusions

The TDP export tool provides a collection of data files to be used by iFAB for the manufacturability analysis and manufacturing of a CyPhy design. This includes information regarding each component in the design as a separate item, as well as data concerning the connectivity between components. The more detailed and more specific the information provided in the CyPhy model becomes, the more the returned cost and lead time metrics can be trusted to be accurate. The data included in the TDP became more detailed and realistic by integrating two iFAB Creo plugins related to material and join data specification.

VANDERBILT
UNIVERSITY