Detailed Manufacturability

User Tutorial for the Detailed Manufacturability Test Bench and Tool

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1.0 Purpose

The purpose of the Detailed Manufacturability Analysis Test Bench and Tool is to provide the designer with information on cost, lead time, and design feasibility. This test bench extends the fidelity of the cost and lead time estimates of the Concept-Level Manufacturability Test Bench by including custom manufactured components and also adds feasibility analysis, i.e. verifies that the design can be manufactured/assembled.

2.0 Procedures

The instructions in this manual assume that the user has installed the latest version of GME and has access to Creo, either locally or via the remote server.

2.1 Installation

Initial installation of the Detailed Manufacturability Tool will be provided with the installation of the CyPhy tool suite. Future editions of the tool may be packaged as a standalone or combined test bench installation package.
The test bench in GME that engages this tool is provided as a separate download from VehicleForge.

2.2 Tool

The Detailed Manufacturability Analysis Test Bench is the test bench in GME that the designer uses to interface with and the Manufacturability Tool, which is a server-based software system that accepts a design, analyzes it, and returns a result. Manufacturability analysis is an automated process to determine if the design is manufacturable. If the design is manufacturable, the analysis will determine the cost and lead-time to make the design. If it is not manufacturable with the capabilities available in the iFAB Foundry, feedback will be provided as to why it is not. Several analysis tools are employed to determine the feasibility and metrics for the purchase or manufacture and the assembly of the individual components. A high-level process flow of the tools and capabilities is shown in Figure 1.

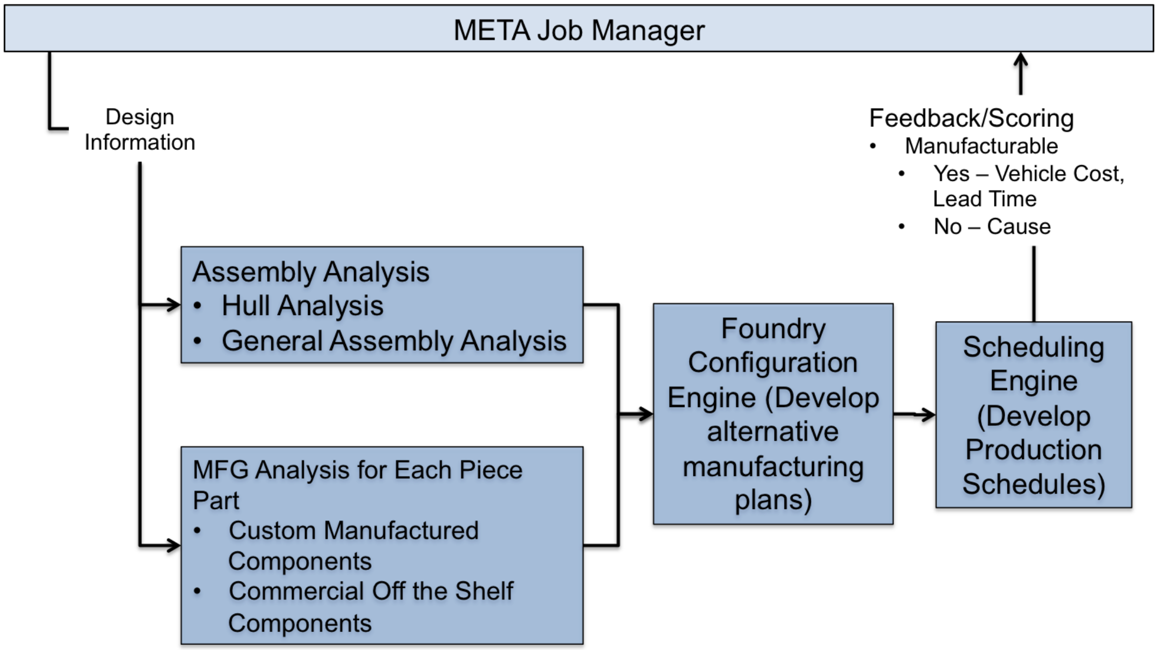


Figure 1: High-Level iFAB Foundry Analysis Tool Flow.

For additional detail and guidelines regarding the Detailed Manufacturability Tool please see this document.

3.0 Requirements Tested

- **Manufacturing Lead Time (days):** Time required to manufacture the first vehicle, from design release to build completion.
- **Vehicle Unit Cost ($):** Vehicle unit cost based on component costs (purchased and manufactured) and production of one vehicle.
- **Manufacturing Feasibility (true/false):** The design shall be manufacturable.

4.0 Required Components

There must be at least one component in the system under test, however this component can be of any type.

5.0 Theory of Operation

The system (design) is assembled into a 3D CAD representation, including the customization / generation of any parameterized components. Data about the purchasing and procurement is also assembled together for analysis by the iFAB

Foundry. This information is packaged up and sent via remote server to the iFAB Information System for processing.

6.0 Test Bench Structure

This test bench contains a system under test that is to be assembled and analyzed for its manufacturability.

The Detailed-Level Manufacturability test bench is included in the Official Test Benches located on gamma.vehicleforge.org. Steps 1-5 below show how to instantiate the test bench if the designer would like to re-create the test bench. Steps 6-7 discuss running the test bench and viewing the output from the tool.

Step 1

In the GME Browser, within the "Testing" Test Bench folder insert a new Test Bench subfolder ("Detailed Manufacturing"). Then insert a new Test Bench model ("Foundry"). Figure 2 shows the new test bench and model.

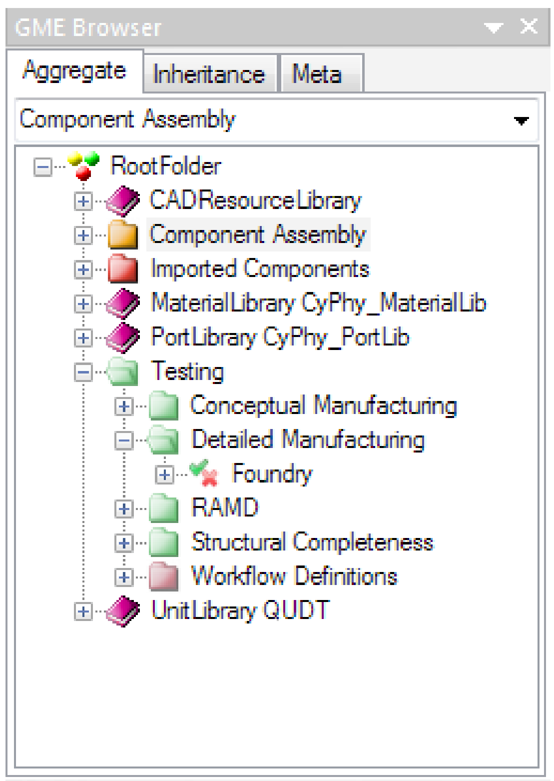


Figure 2: Detailed Manufacturing Test Bench (Foundry).

Step 2

Now that the test bench container has been created, the design can be added. In the "Detailed Manufacturing" test bench, Copy/Paste... As Reference your assembly into the test bench workspace in GME, as shown in Figure 3. ***Note that there should be no spaces in the name of the assembly.***

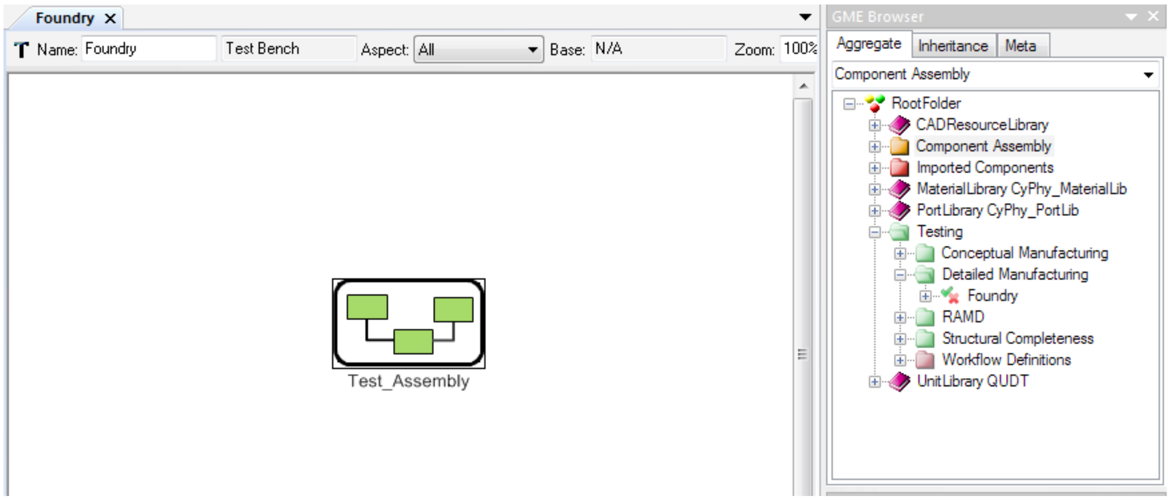


Figure 3: Copy/Paste...As Reference the Design Assembly into Test Bench.

Step 3

In the GME Browser, in the "Workflow Definition" subfolder create a new Workflow Model ("Detail_Mfg") as shown in Figure 4.

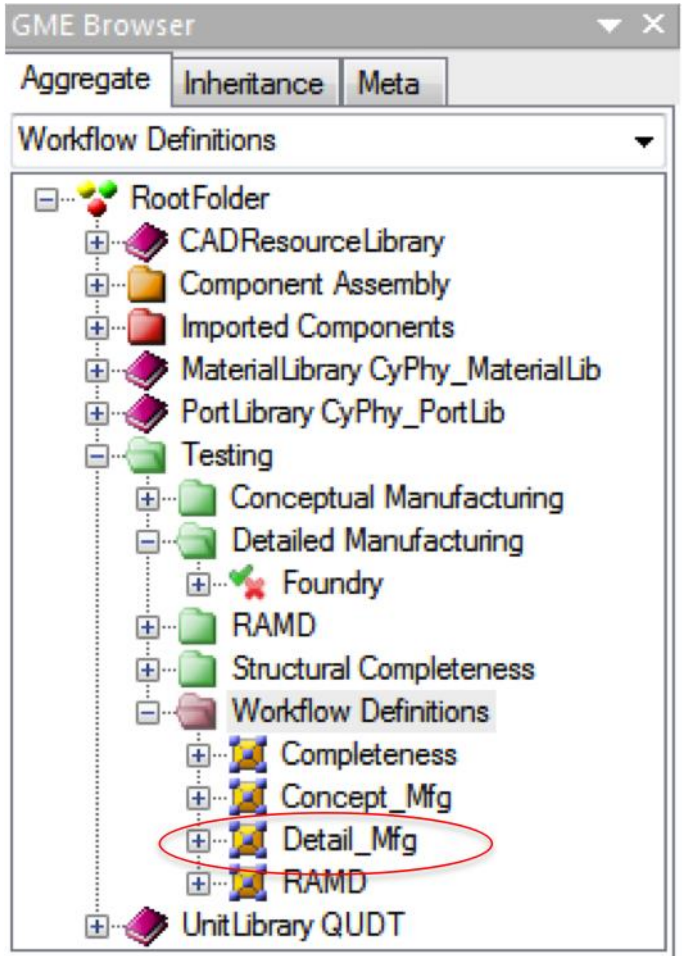
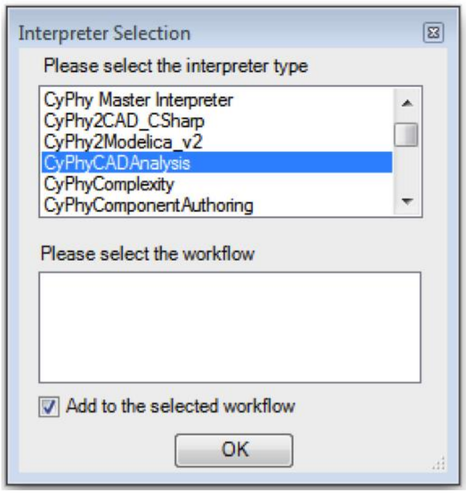


Figure 4: Insert Detail_Mfg Workflow into GME Browser.

Step 4

Open the “Detailed_Mfg” Workflow Model, drag a "Task" element into the workspace window, and select "CyPhyCADAnalysis" as the interpreter from the pop-up window. Double-click on “Task” and select "Detailed_mfg" as analysis tool. The pop-up dialog boxes should mimic Figure 5.



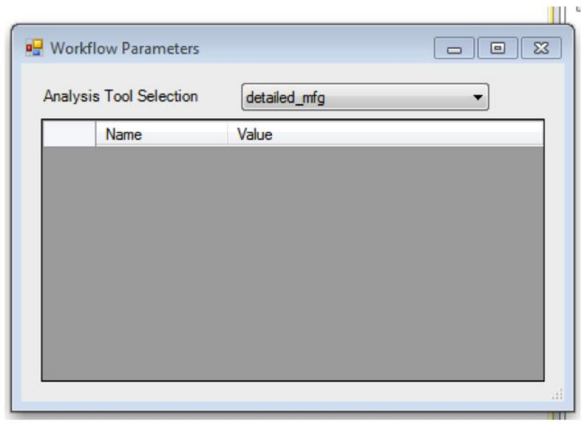


Figure 5: Detailed_Mfg Workflow.

Step 5

Now open the "Detailed_Mfg" test bench and right click drag/drop ... As Reference the "Detailed_Mfg" workflow definition and three (3) metrics (from Part Browser) into test bench. Metrics must be renamed "Vehicle_Unit_Cost", "Manufacturing_Lead_Time", and "Manufacturable." Once this step is complete, the main window in GME looks like the graphic shown in Figure 6 below.

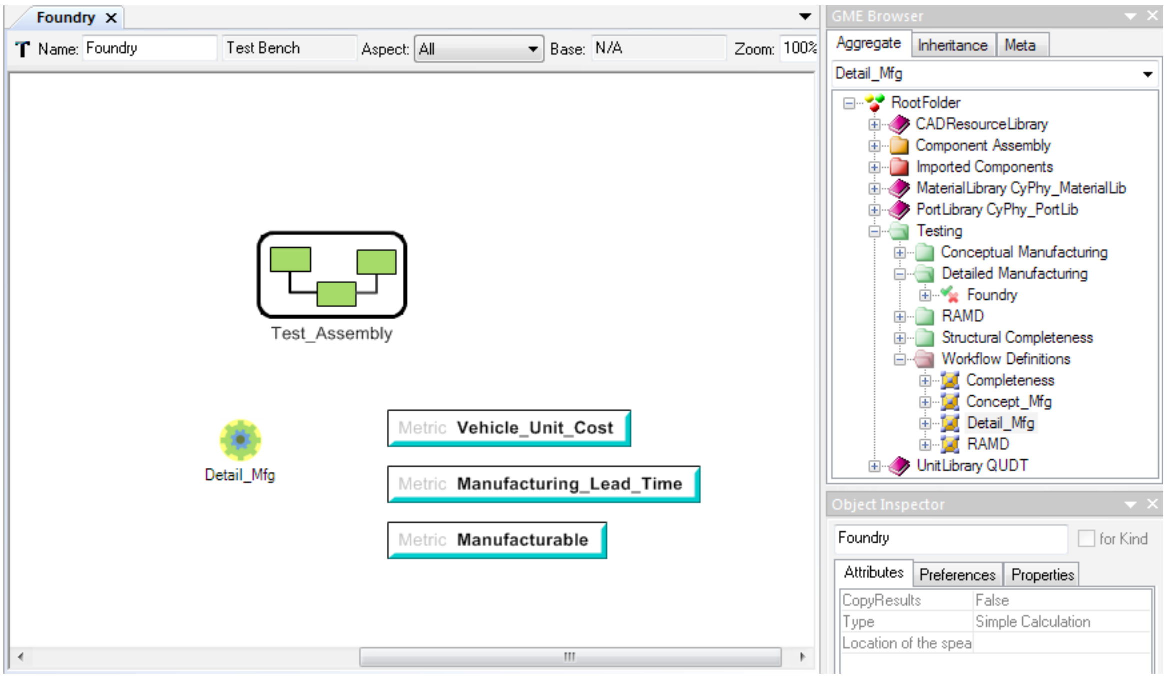


Figure 6: GME Interface with Detailed Manufacturability Test Bench.

Step 6

To exercise the test bench, run the Master Interpreter (highlighted in task bar). Check the “Post to META Job Manager” box as shown in Figure 7.

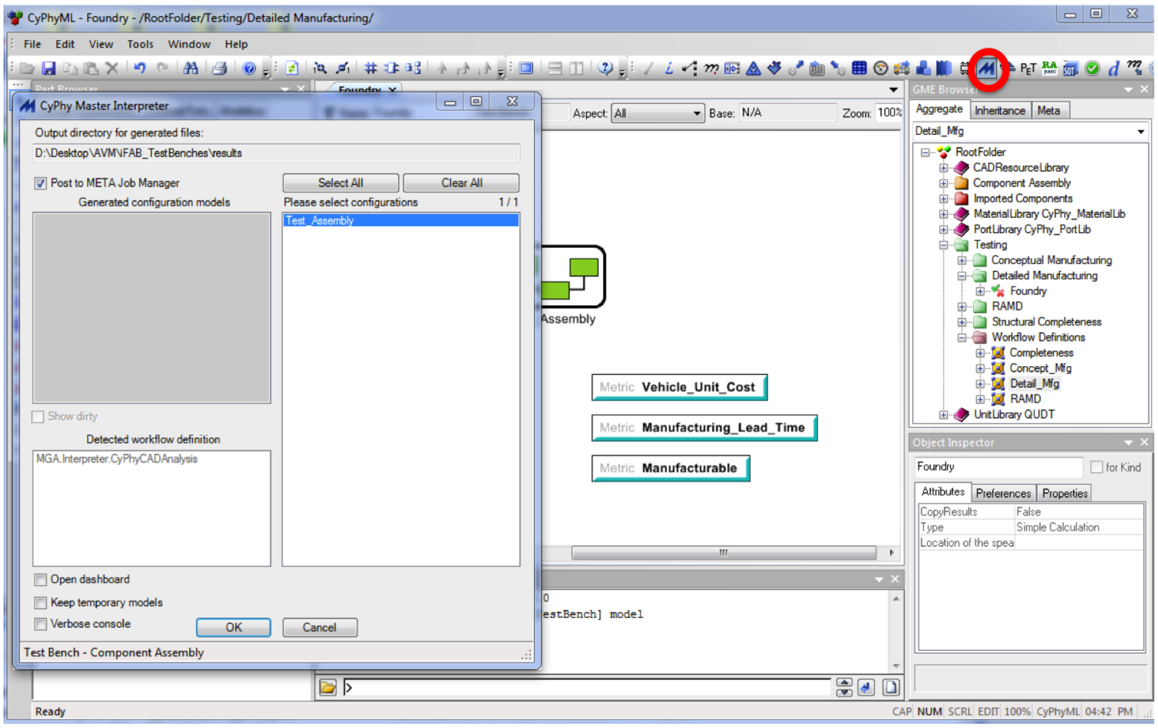


Figure 7: Running the Test Bench.

Select “OK.”

Select “Use Project Manifest” as well as the “AP203_E2_Single_File” and “AP203_E2_Separate_Part_Files” boxes. For user-created components that are not imported into GME, point to the Creo file location (the CAD folder in your project directory) for the “CAD Auxiliary Directory” field as shown in Figure 8, otherwise the project.manifest.json file should contain the information to point to the correct CAD files.

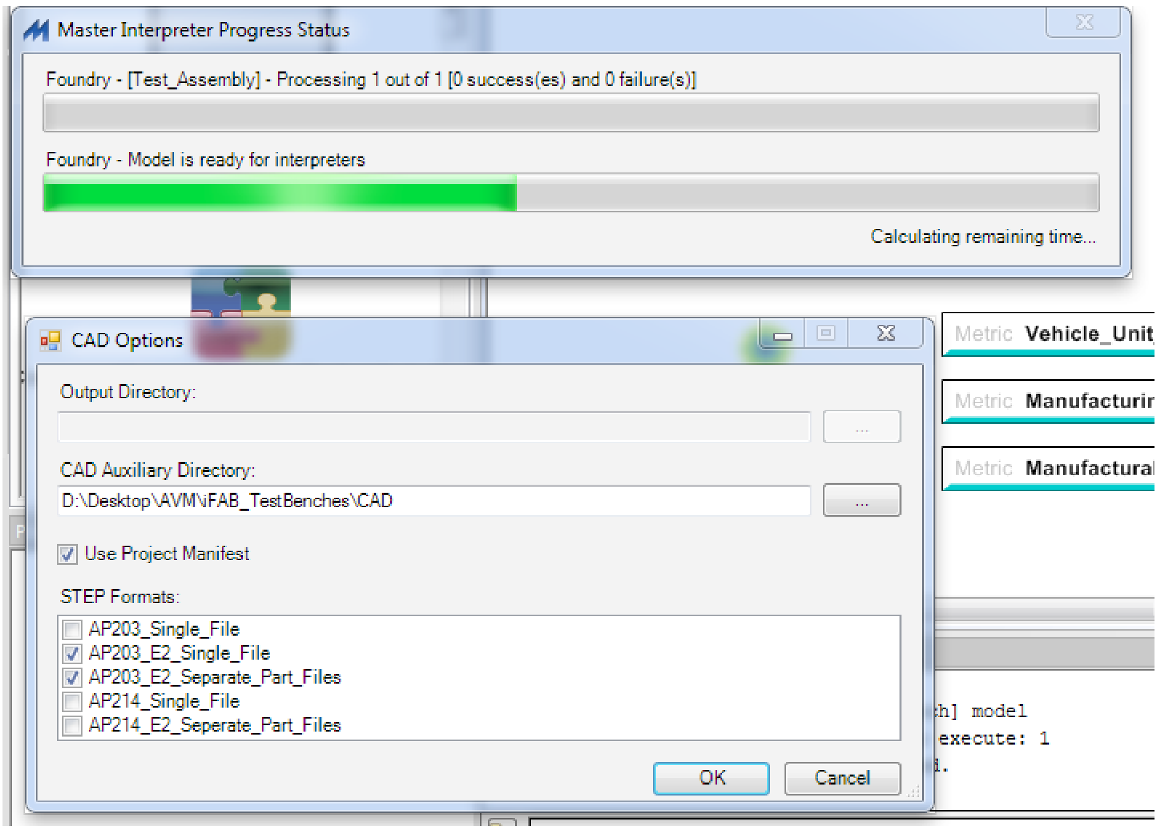


Figure 8: Use Project Manifest and Selection of STEP File Formats.

Step 7

Select “Remote Execution” from the JobManager Configuration pop-up since the Detailed Manufacturability test bench is a server only test bench and cannot be run on the designer’s machine because the analysis tool is instantiated only on the server. You will be prompted to enter your VehicleForge username and password as shown in Figure 9.

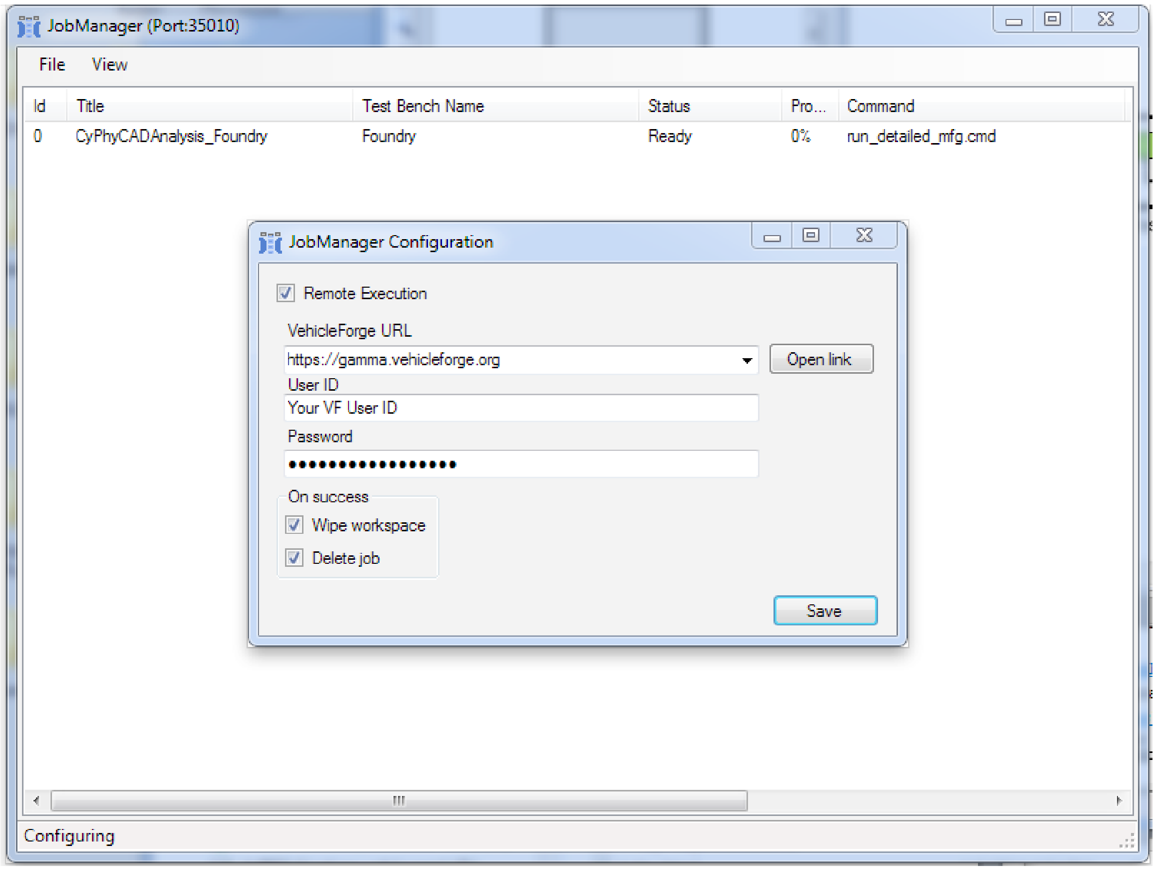


Figure 9: Authenticating VF Account Access.

Once the job has posted to the Job Manager, the design information will be uploaded to the server, the analysis will be run, and the results will be downloaded to the results folder.

In results folder, there will be two output files that contain manufacturing analysis information about the design: testbench_manifest.json and detailed.manufacturabilityResults.json. The information in these files can be used to modify the design to improve cost and lead time. To get to the results folder, right-click on the analysis in the job manager and select “Show in Explorer”.

Typical analysis times are between 0.5 and 1 hour and increase with the number of components in the design.

Figure and Figure show an example manufacturability output visualizer. There are two ways to use this visualization: on the user's local machine and through VehicleForge.

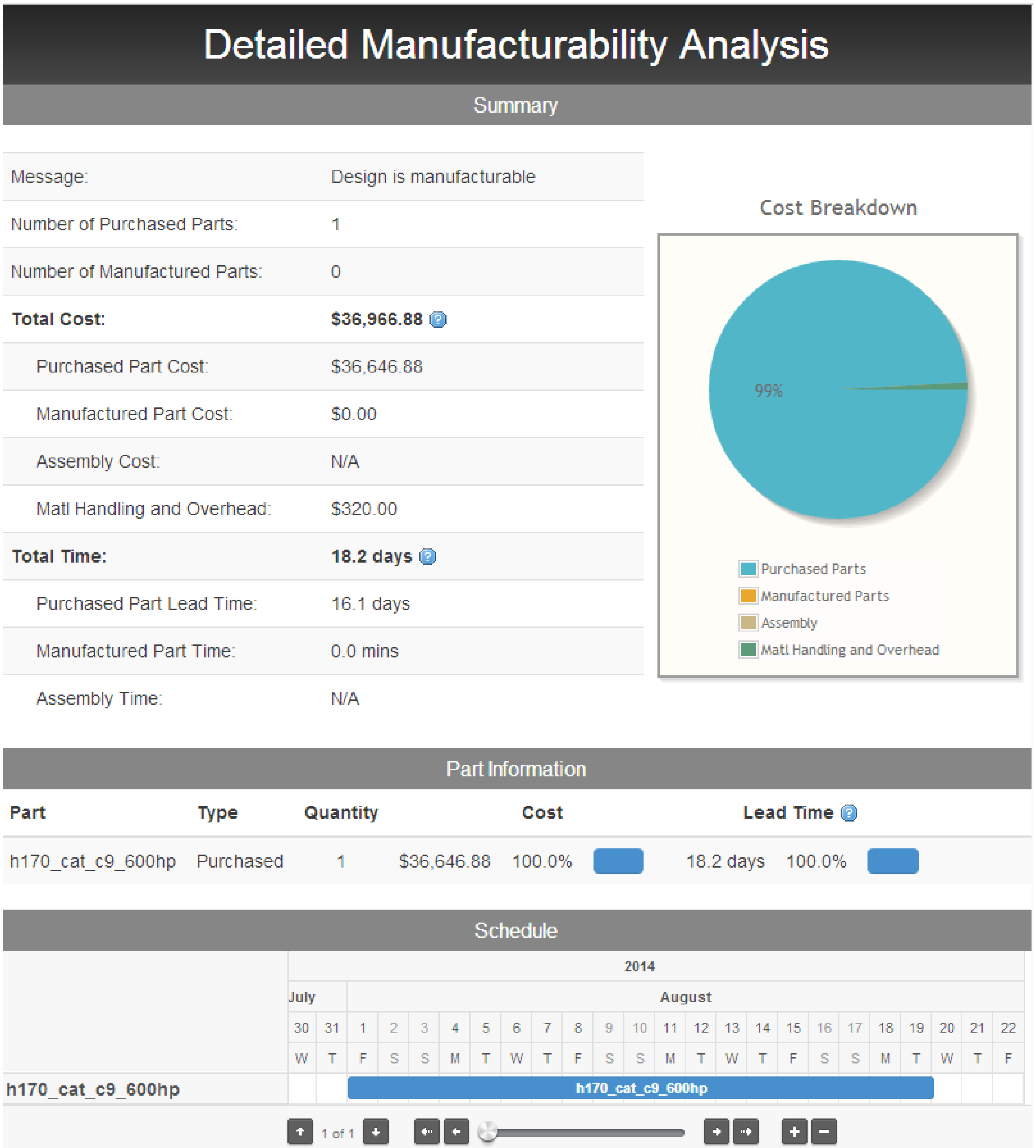


Figure 10: Detailed-Level Manufacturability Analysis Results in Local Visualizer (Manufacturable Design).

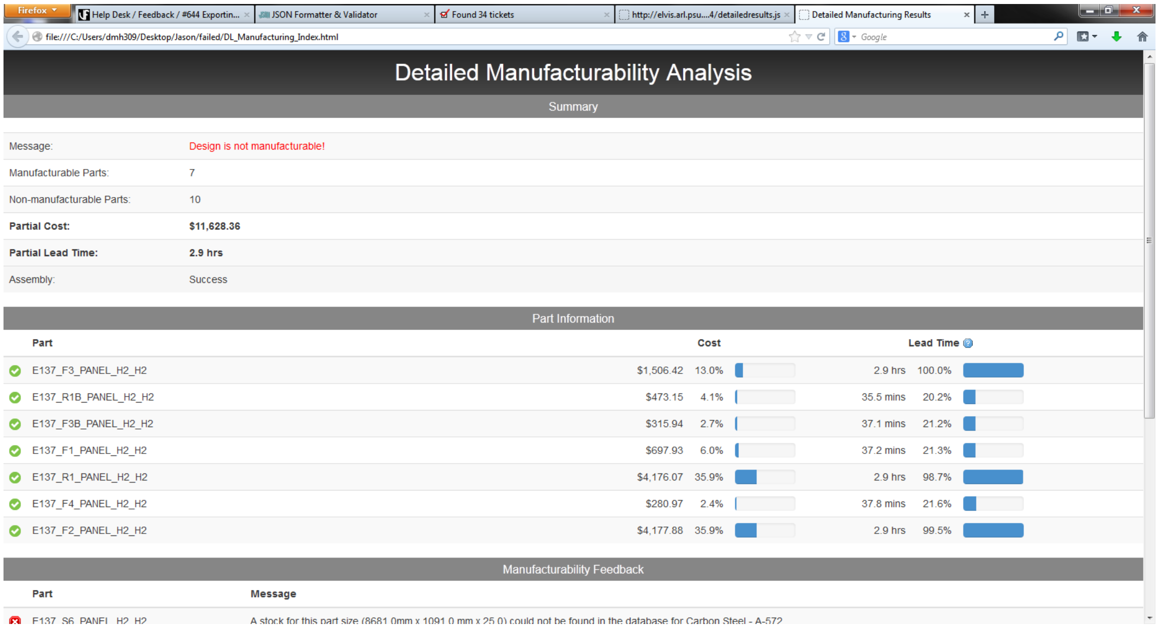


Figure 11: Detailed-Level Manufacturability Analysis Results in Local Visualizer (Non-Manufacturable Design).

To view the results locally, navigate to the results folder of the detailed level manufacturability test bench output and double click on the DL_Manufacturing_Index.html file. The html viewer works with Firefox and Internet Explorer browsers. Other browsers (Chrome) can be used by setting the “target” for the shortcut startup to: “C:\Program Files (x86)\Google\Chrome\Application\chrome.exe” –allow-file-access-from-files. You will need to change the file path of the installation location for Chrome is different on your machine.

To view the results through VehicleForge, check in the results folder to your SVN or GIT repository on VehicleForge and click on the testbench_manifest.json file to view summary data and the detailed.manufacturabilityResults.json to view the detailed results from this test bench. The view will be identical to the views shown above.

7.0 Description

Detailed Manufacturability analysis is an automated process to determine if the design is manufacturable. If the design is manufacturable, the analysis will determine the cost and lead-time to make the design. If it is not manufacturable with the capabilities available in the iFAB Foundry, feedback will be provided as to why it is not. Several analysis tools are employed to determine the feasibility and metrics for the assembly and the purchase or manufacture of the individual components.

The System Under Test is assembled in CREO and then each component making up the system is saved as an individual step file. Data about procurement for each component is also gathered. This information is packaged and sent (via remote server) to the iFAB Foundry information system for processing.

Results are returned in two files "testbench_manifest.json" and "detailed.manufacturabilityResults.json" containing summary results and more detailed results, respectively. The summary results can be viewed in the dashboard and in the local or VehicleForge manufacturability visualization tool.

8.0 Metrics

- **Manufacturing Lead Time (days):** Time required to manufacture the first vehicle, from design release to build completion.
- **Vehicle Unit Cost($):** Vehicle unit cost.
- **Manufacturing Feasibility (true/false):** The design shall be manufacturable.

Test Bench #	Metric	Description
61	Vehicle_Unit_Cost	Vehicle unit cost
66	Manufacturing_Lead_Time	Time required to manufacture the first vehicle, from design release to build completion
67	Manufacturable	The design shall be manufacturable

9.0 Required Connections to System Under Test

NONE

10.0 Outputs

The output of this test bench is two results files “testbench_manifest.json” and “detailed.manufacturabilityResults.json”. The summary results summarize the cost, leadtime, and manufacturing feasibility and can be viewed/interpreted in the dashboard. A portion of the summary results is shown in Figure 12.


```
"AnalysisStatus": "OK",
"Created": "2014-01-13T17:22:21.6702159Z",
"DesignName": "Meta_assembly",
"Metrics": [
    {
        "GMEID": "id-0067-00001910",
        "Description": "",
        "DisplayedName": null,
        "VisualizationArtifacts": [],
        "Value": "18.1951388889",
        "ID": "439152d9-4c77-4d46-98e6-1c857c331816",
        "Unit": "days",
        "Name": "Manufacturing_Lead_Time"
    },
    {
        "GMEID": "id-0067-0000190f",
        "Description": "",
        "DisplayedName": null,
        "VisualizationArtifacts": [],
        "Value": "true",
        "ID": "7600e4c7-e999-4885-8d8b-10174e69bbb6",
        "Unit": "",
        "Name": "Manufacturable"
    },
    {
        "GMEID": "id-0067-00001911",
        "Description": "",
        "DisplayedName": null,
        "VisualizationArtifacts": [],
        "Value": "36966.8831969",
        "ID": "df05fb93-1642-4f9d-a58a-6c0bd8fbf38d",
        "Unit": "dollars",
        "Name": "Vehicle_Unit_Cost"
    }
```


Figure 12: Portion of Summary Results.

The summary results can be seen and compared with other system metrics in the Dashboard. For further information on using the dashboard, please go to the appropriate page.

The detailed results file contains information about the overall design including detailed information about each component in the design. It also includes the schedule of the manufacturing and assembly of the components in the design.

11.0 Testbench Tier Information

Attribute	Tier 1 (Concept-Level Manufacturability)	Tier 2 (Detailed-Level Manufacturability)
Test Bench Name	Foundry_Conceptual	Foundry
Description	Concept-Level Manufacturability analysis calculates the cost and lead-time of the design under test. This tool analyzes the information provided in the design, specifically the components (engine, transmission, etc.) and the hull. The test bench is designed to analyze designs from initial conceptual hull through detailed design. This test bench is used as a tool to get a cost and lead time estimate of the design quickly, but lacks the detail analysis capability found in the Detailed Manufacturability Test Bench.	Detailed Manufacturability analysis is an automated process to determine if the design is manufacturable. If the design is manufacturable, the analysis will determine the cost and lead-time to make the design. If it is not manufacturable with the capabilities available in the iFAB Foundry, feedback will be provided as to why it is not. Several analysis tools are employed to determine the feasibility and metrics for the assembly and the purchase or manufacture of the individual components.
Estimate Run Time	~10min running CAD Assembly	~10min running CAD Assembly
	0.5s average run time (0.166s - 0.893s)	27min average run time (5min - 12hrs)
Error Margin	In-Process	This test bench is the Standard
Results Provided	Vehicle Unit Cost	Vehicle Unit Cost
	Manufacturing Lead Time	Manufacturing Lead Time
		Manufacturable
Local/Remote	local and remote	remote only
Tool Used	concept level mfg analysis (python)	detailed level mfg analysis (iFAB server)
How to Interpret Results	locally - CL_Manufacturing_Index.html	locally - DL_Manufacturing_Index.html
	VF - visualization	VF - visualization
		3D PDF for individual components
		3D PDF for detailed mfg report
Model Requirements	STEP AP203 separate files	STEP AP203 separate files
	.adm file - META design file	.adm file - META design file

Attribute	Tier 1 (Concept-Level Manufacturability)	Tier 2 (Detailed-Level Manufacturability)
	acm files - Component Definition Files	acm files - Component Definition Files
	manufacturing models (COTS and Custom)	manufacturing models (COTS and Custom)
	Manufacturing Manifest	Manufacturing Manifest
	Submission.json	Submission.json

12.0 Notes on Authored Components

If you have created custom components that you would like to submit for manufacturability analysis, a few things need to be included in the CyPhy component:

1. Make sure the component has a directory in the 'components' folder of your project directory. This is similar to all current C2M2L components. This is where the "CAD" & "Manufacturing" folders and ComponentData.xml are housed. Place the manufacturing xml file associated with the part in this component's “Manufacturing” folder. Examples of the manufacturing models are provided (<PurchasedPartExample.xml>, <Plate-SheetExample.xml>, < MachinedPartExample.xml>, <ComponentAssembly.xml>) and a screen shot of each of these is provided in Appendix A.
2. A ManufacturingModel block. Leave all attributes for this part blank.
3. A Resource block that is then connected to the ManufacturingModel. For the "Path (URI)" attribute, enter the path to the manufacturing xml relative to the specific component's folder created in (1). For example: If the manufacturing xml is located at "\components\Engine\Manufacturing\<xml>", the Path (URI) would be "Manufacturing\<xml>".

13.0 Troubleshooting

Common Manufacturability Test Bench Errors

- **ERROR:** No procurement/manufacturing information is associated with this part. If this is a COTS component, please ensure the ACM file defines the required procurement information. Otherwise, please ensure the manufacturing model is specified.
- **ERROR:** Model decomposition task: The manufacturing information for null is undefined. Please use the TDP Editor and ensure all components are defined.

These errors indicate that the component does not contain sufficient manufacturing data for the software to evaluate it. Please refer to the "Notes on Authored Components" section above and the example manufacturing model xml files in Appendix A.

- **ERROR:** Manufacturing E137_S1_PANEL_H5_H5: A stock for this part size (8288.0mm x 775.0 mm x 25.0) could not be found in the database for Carbon Steel - A-572

This error indicates that there is no plate stock size large enough to manufacture the plate. Please use the HuDAT tool (plug-in to Creo) to cut the plates to sizes that are within the raw stock size dimensions.

14.0 Future Work and Planned Enhancements

There is currently no easy way to generate the manufacturing related information described in the previous section. The project team is working on a solution that is integrated into the Creo environment that will enable the designer to generate the required information.

The current iFAB Foundry Tools assess welding for cost and lead time and assembly feasibility, however the tools do not currently check for compatibility between the materials. The iFAB Foundry team will be implementing a weld compatibility analysis tool to the tool chain once a feasible assembly sequence has been determined.

Reasoning about Geometric Dimensioning and Tolerancing (GD&T) has been implemented at a very basic level in the current release of this test bench. The team will be working on more advanced reasoning algorithms to further incorporate this aspect into the tools.

Appendix A: Manufacturing Model Examples

Purchased Part Example


```xml
<?xml version="1.0" encoding="UTF-8"?>

<part uuid="130eb4b9-3d37-41e8-bccd-8207ba773afc">
  <name>DAMPER</name>
  <length unit="mm">10.82392220292394</length>
  <width unit="mm">34.0000002</width>
  <height unit="mm">10.82392220292394</height>
  <volume unit="mm3">1415.7810285672138</volume>
  <weight unit="kg">0.011113881074252627</weight>
  <file type="STEP">DAMPER.stp</file>
  <manufacturingDetails>
    <purchased>
      <notes>none</notes>
      <NSN></NSN>
      <supplier>
        <CAGEIdentifier>
          <CAGECode>
            <code>N/A</code>
          </CAGECode>
        </CAGEIdentifier>
        <catalogNumber>3692K15</catalogNumber>
        <componentInfo>N/A</componentInfo>
        <FOB>Origin</FOB>
        <leadTime>2.0</leadTime>
        <leadTimeBasis></leadTimeBasis>
        <leadTimeUncertainty>0.0</leadTimeUncertainty>
        <packaging>Box</packaging>
        <partDescription>Damper Part</partDescription>
        <paymentTerms>30</paymentTerms>
        <price>34.71</price>
        <quantity>1</quantity>
        <shipmentDimensions>{0.05,0.05,0.05}</shipmentDimensions>
        <shippingMass>1.0</shippingMass>
        <shippingPointAddress>600 N. County Line Road, Elmhurst, IL 60126-2081</shippingPointAddress>
        <transportationNeeds/>
        <unitOfIssue>1</unitOfIssue>
      </supplier>
    </purchased>
  </manufacturingDetails>
</part>
```

Plate-Sheet Example


```xml
<?xml version="1.0" encoding="UTF-8"?>

<part uuid="69748e49-7174-47a5-a4c1-059258dffab5">
  <name>I215_STL_A572_GR50_1</name>
  <length unit="mm">700.0000002</length>
  <width unit="mm">163.5000002</width>
  <height unit="mm">15.875000200002098</height>
  <volume unit="mm3">744200.7477175256</volume>
  <weight unit="kg">5.841975869582575</weight>
  <file type="STEP">I215_STL_A572_GR50_1.stp</file>
  <manufacturingDetails>
    <plate>
      <notes></notes>
      <material>
        <carbonSteel>A-572</carbonSteel>
      </material>
      <planarFaces>
        <generalTolerance unit="mm">0.254</generalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
      </planarFaces>
      <bends>
        <bendAngleTolerance unit="degrees">0.1</bendAngleTolerance>
      </bends>
      <simpleHoles>
        <diametricalTolerance unit="mm">0.127</diametricalTolerance>
        <positionalTolerance unit="mm">0.127</positionalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
        <threaded>false</threaded>
      </simpleHoles>
      <complexHoles>
        <generalTolerance unit="mm">0.254</generalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
      </complexHoles>
      <inorganicCoatings/>
      <organicCoatings>
        <organicCoating>non-CARC</organicCoating>
      </organicCoatings>
    </plate>
  </manufacturingDetails>
</part>
```

Machined Part Example


```xml
<?xml version="1.0" encoding="UTF-8"?>

<part uuid="448de5cc-d9d4-42a5-8481-0005da612c3a">
  <name>STEEL_MASS</name>
  <length unit="mm">50.0000002</length>
  <width unit="mm">12.000000199999999</width>
  <height unit="mm">50.0000002</height>
  <volume unit="mm3">25000.0</volume>
  <weight unit="kg">0.19624999999999998</weight>
  <file type="STEP">STEEL_MASS.stp</file>
  <manufacturingDetails>
    <machined>
      <notes></notes>
      <material>
        <alloySteel>
          <hotRolled>4130</hotRolled>
        </alloySteel>
      </material>
      <planarFaces>
        <generalTolerance unit="mm">0.254</generalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
      </planarFaces>
      <curvedSurfaces>
        <generalTolerance unit="mm">0.254</generalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
      </curvedSurfaces>
      <curvedWalls>
        <generalTolerance unit="mm">0.254</generalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
      </curvedWalls>
      <simpleHoles>
        <diametricalTolerance unit="mm">0.127</diametricalTolerance>
        <positionalTolerance unit="mm">0.127</positionalTolerance>
        <surfaceRoughness unit="mm">0.0015880000000000002</surfaceRoughness>
        <threaded>false</threaded>
      </simpleHoles>
      <inorganicCoatings/>
      <organicCoatings/>
    </machined>
  </manufacturingDetails>
</part>
```

Component Assembly Manufacturing Model Example


```xml
<assembly>
  <name>custom_muffler_bolted_asm</name>
  <unusedParts/>
  <assemblyDetails>
    <assemblyDetail>
      <name>I215_STL_A572_GR50_1 - I215_STL_A572_GR50_2</name>
      <part1 id="e066d588-9d63-4687-ab7b-4892c8738c81">I215_STL_A572_GR50_1</part1>
      <part2 id="92d205a3-df38-4a0a-928c-83dc45f5ab2c">I215_STL_A572_GR50_2</part2>
      <mechanical>
        <linkingPart id="9b112ed7-6336-4a73-ab25-8d4290611950">C100_M6X1P0X30_10P9_BLO<
        <fasteningMethod>Bolted</fasteningMethod>
        <fasteningQuantity>3</fasteningQuantity>
        <torque unit="N m">60.0</torque>
      </mechanical>
    </assemblyDetail>
    <assemblyDetail>
      <name>I215_STL_A572_GR50_1 - I215_STL_A572_GR50_2</name>
      <part1 id="e066d588-9d63-4687-ab7b-4892c8738c81">I215_STL_A572_GR50_1</part1>
      <part2 id="d4a2cfb7-7d30-4300-a8a9-9f900c1d993e">I215_STL_A572_GR50_2</part2>
      <mechanical>
        <linkingPart id="9b112ed7-6336-4a73-ab25-8d4290611950">C100_M6X1P0X30_10P9_BLO<
        <fasteningMethod>Bolted</fasteningMethod>
        <fasteningQuantity>3</fasteningQuantity>
        <torque unit="N m">60.0</torque>
      </mechanical>
    </assemblyDetail>
    <assemblyDetail>
      <name>I215_STL_A572_GR50_2 - I215_STL_A572_GR50_3</name>
      <part1 id="92d205a3-df38-4a0a-928c-83dc45f5ab2c">I215_STL_A572_GR50_2</part1>
      <part2 id="51bb7a91-9c76-4760-9133-f7a36871e4a3">I215_STL_A572_GR50_3</part2>
      <welded>
        <length unit="mm">150.0</length>
        <jointType>Tee</jointType>
        <twoSided>True</twoSided>
        <weldType>Stitch</weldType>
        <weldPenetration>Partial</weldPenetration>
        <inspectionRequirement>Visual</inspectionRequirement>
        <part1Thickness unit="mm">15.875</part1Thickness>
        <part1Material>Steel</part1Material>
        <part2Thickness unit="mm">15.875</part2Thickness>
        <part2Material>Steel</part2Material>
      </welded>
    </assemblyDetail>
    <assemblyDetail>
      <name>I215_STL_A572_GR50_2 - I215_STL_A572_GR50_3</name>
      <part1 id="d4a2cfb7-7d30-4300-a8a9-9f900c1d993e">I215_STL_A572_GR50_2</part1>
      <part2 id="51bb7a91-9c76-4760-9133-f7a36871e4a3">I215_STL_A572_GR50_3</part2>
      <welded>
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