Spacecraft Design Study with OpenMETA

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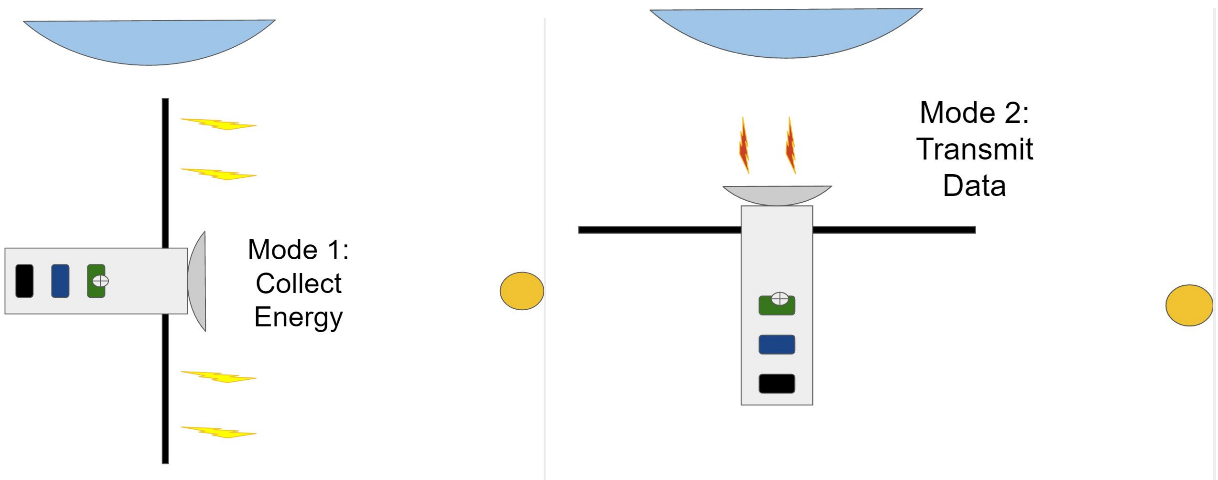
Design Challenge Description

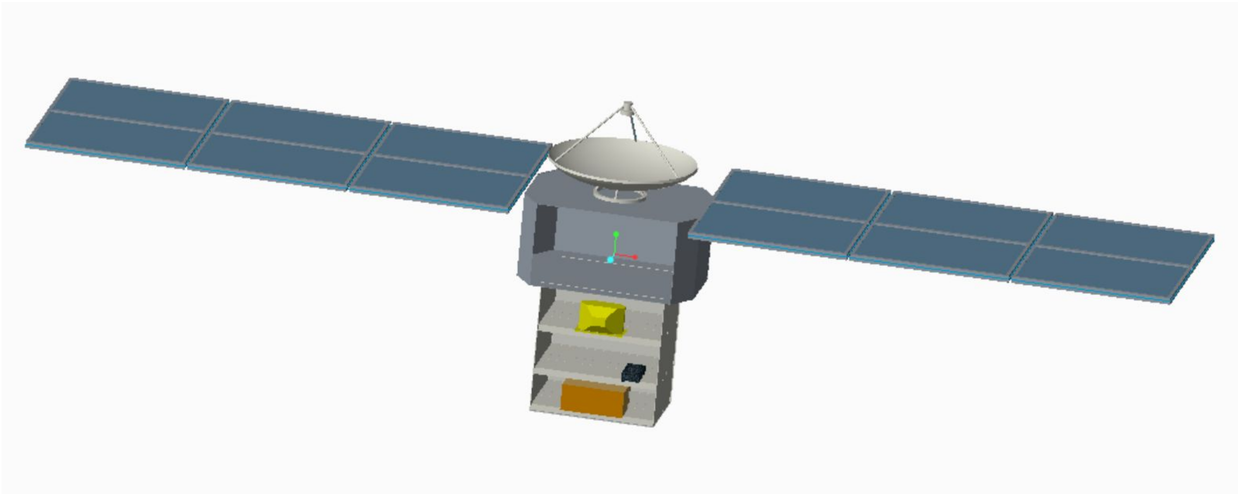
This tutorial reviews a moderate-level of complexity system: using the OpenMETA design process for a spacecraft



Simple Mission Specification

The mission cycle is intentionally simplified. The spacecraft will spend the majority of time in an energy collection mode, where the solar cells are pointed at the sun. During this time, any data collection and processing is done. Periodically, the craft will rotate 90 degrees to point the antenna at a receiving station on earth and transmit data. During this time, the system will operate from stored power.

Basic System Architecture:



The core system is shown in the figure above. It consists of the following parts:

- Cargo Bay (Dark Grey): This is the central mounting point, and contains space for mission equipment.
- PV Arrays: Designated as A and B, the left and right PV arrays generate electricity for both attitude control and mission electronics.
- Antenna: a dish antenna for transmission to the earth stations
- Body: This is structure for mounting the core subsystems for maintaining spacecraft functions. The body allows adjustment of mounting points, to permit core subsystems to be adjusted in XYZ within the body.
- Core subsystems, consisting of:
    - Control Gyroscope, for adjusting the attitude of the system. For simplicity, we consider only one axis.
    - Computer, executing all mission software and attitude control algorithms
    - Battery, to provide continuous power over mission cycles.

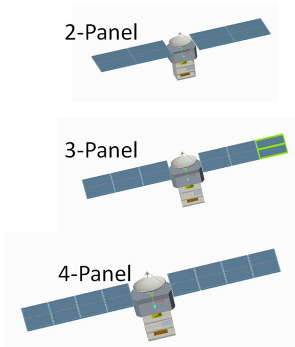
Design Task

The design tasks are to achieve the mission objectives, while minimizing cost, and not violating any of the specifications of components and subsystems.

Design Variables

The design choices and variables are as follows:

Photovoltaic Panel Subsystem (PV Panel): **Discrete Choice**



Three panel options are available. The individual segments are identical, but the designer can choose 2, 3 or 4 segments to make up a panel.

Design Constraint: In order to keep the spacecraft balanced, the same size panel must be used for both sides.

Battery Sizing: **(Continuous Variable)** The battery subsystem can be scaled almost continuously.

Controls: **(Continuous Variable)** The computer system implements a PD controller. Both the Proportional and Differential parameters are available for specification.

Placement: **(Continuous Variable)** Each of the core systems are attached to a mounting shelf. Shelf mounting heights are adjustable, as well as the XY locations on a shelf.

Design Requirements and Goals

The following set of properties must be maintained:

Requirement: Feasibility of Assembly. The final assembled system must not have any parts that intersect.
Method of Analysis: The solid model of the system must have no interferences between parts.

Requirement: All parts must survive launch loads.
Method of Analysis: Structural Finite Element with a specific load.

Requirement: Power Bus Voltage must remain within the range of 15V to 18V.
Method of Analysis: Electrical Stimulation of Mission Cycle.

Requirement: Maximum Temperature must not exceed 350K
Method of Analysis: Thermal Simulation of Mission Cycle

The following are goals of the design, to be minimized or maximized:

Goal: Pointing Error Max - the maximum deviation of the craft's actual angle vs. the setpoint, in absolute value.

Method of Analysis: Physical Simulation, 1D.

Goal: Pointing Error Average - the average deviation of the craft's actual angle vs. the setpoint, in absolute value.
Method of Analysis: Physical Simulation, 1D.

Goal: Thermal Variation - the max/min temperature during a mission.
Method of Analysis: Thermal Simulation.

Goal:.
Method of Analysis:.

The OpenMETA tools support each of these analysis, based on a single model. The tutorial will describe the process of modeling the system, mathematically analyzing it in the context of a scenario, and reviewing the data to find viable and good solutions, subject to the requirements listed.

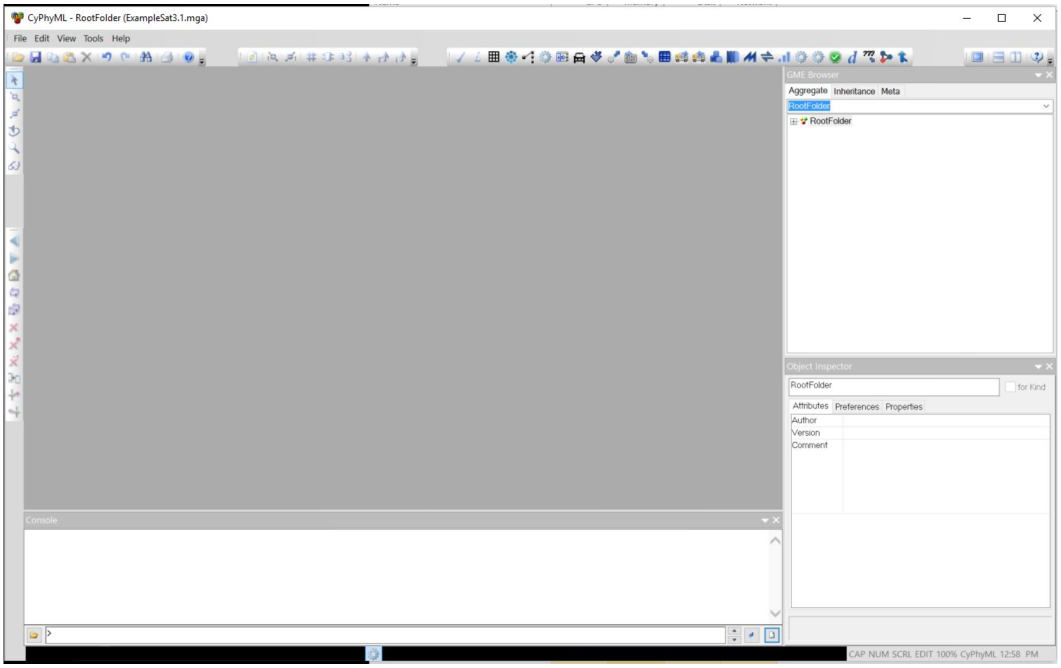
System Modeling

Assumptions: This tutorial assumes a basic familiarity with the OpenMETA tools, so will pass over may of the basic operations. For details on the tool, its installation, and modeling specifics, please refer to the OpenMETA Tutorial, found here:
Top level documentation:
file:///C:/Program%20Files%20(x86)/META/Documentation/HtmlDoc/index.html
Or a tutorial here:
http://www.isis.vanderbilt.edu/openmeta

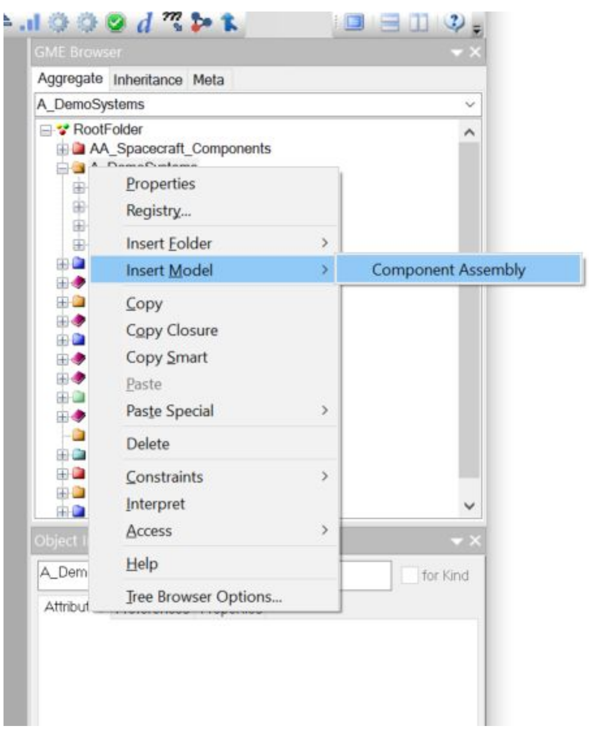
To accelerate the process, the components have been prepared and imported into an OpenMETA project. Working from an empty project is feasible as well, but this tutorial will begin from a functional project. The prepared project is found within the Example Models folder in Satellite_Example.zip which can be found HERE: http://www.isis.vanderbilt.edu/openmeta

Open the ExampleSat3_3 project:

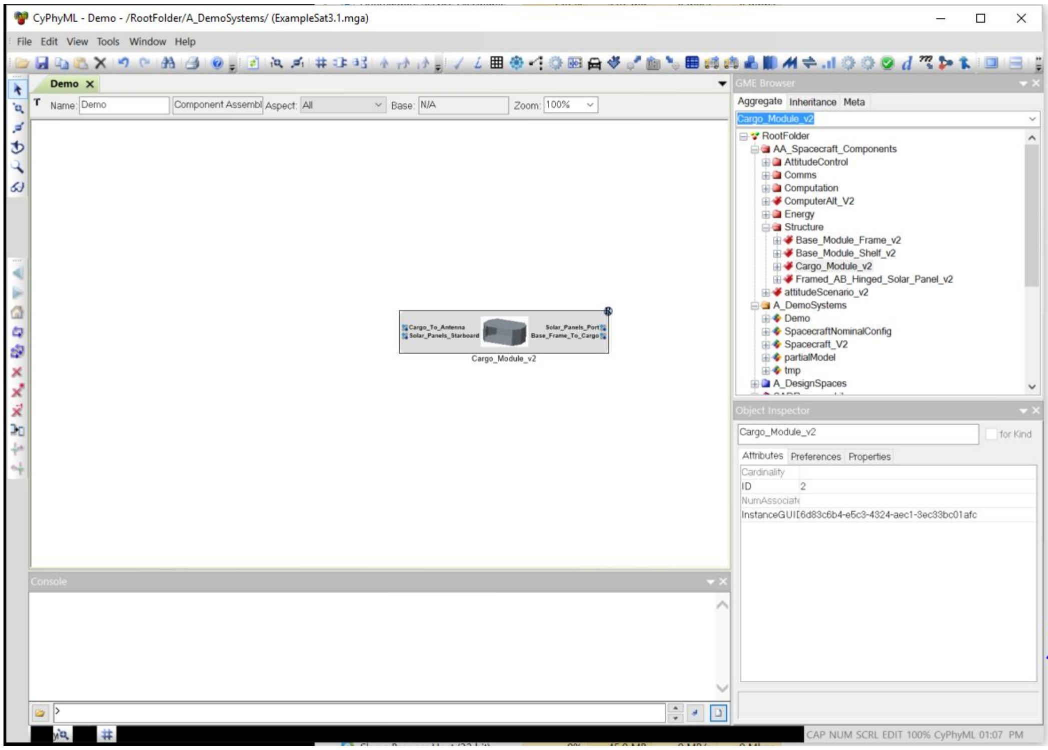
You will need to open ExmpleSat3_3.xme to start with the prepared project.



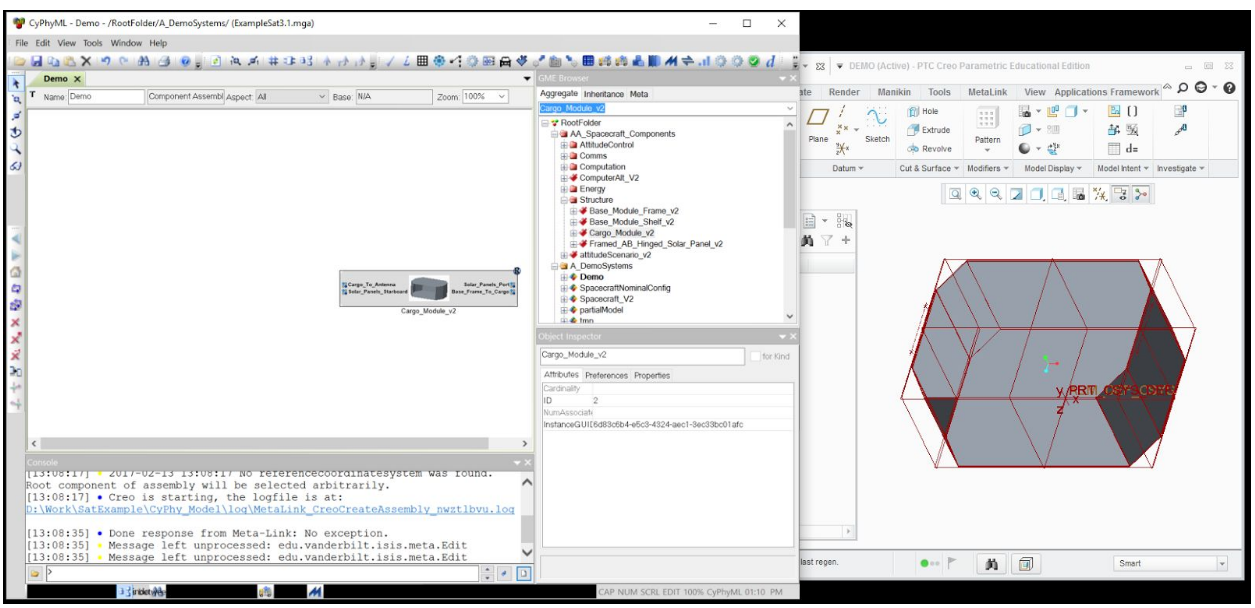
From the ground up, you can construct a system by creating a new Component Assembly, Open up the DemoSystems folder, and right click - Insert Model → ComponentAssembly. Rename the model to Demo.



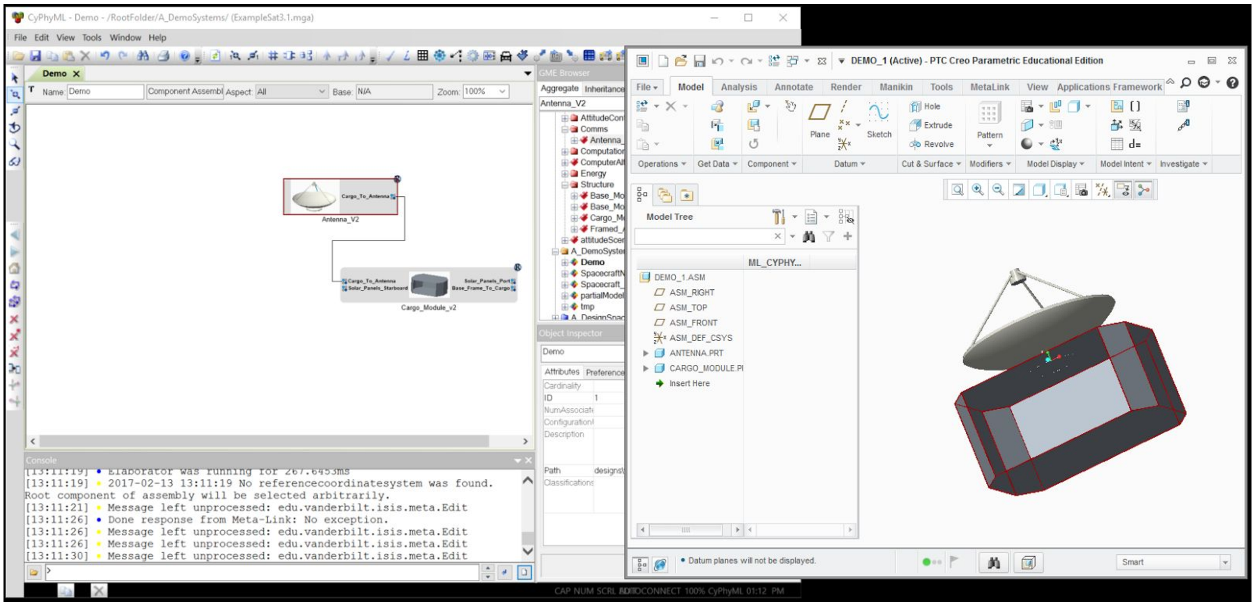
Open the Demo model, then navigate down to the AA_Spacecraft_Components folder. We begin by adding the CargoModule, which is in the Structure Folder.



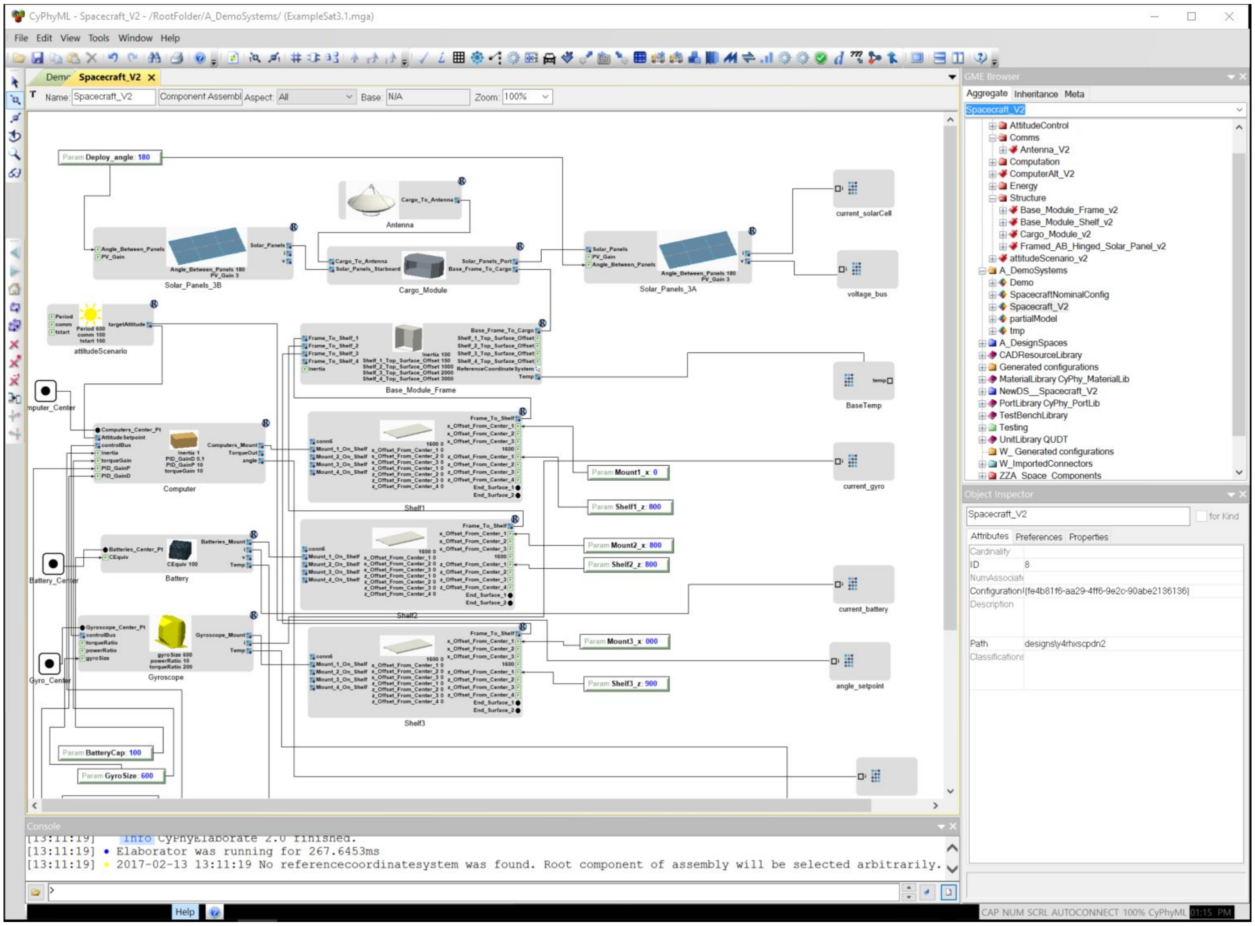
We can now open the model in METALink mode, to visualize the system as we build (provided you have Creo 3.0 installed). You should see something like the figure below:



Adding the Antenna, and connecting the components shows the next step of assembly.



Progressing thru the assembly of all parts and connectors will complete the system. A completed model is provided in A_DemoSystems/Spacecraft_V2.

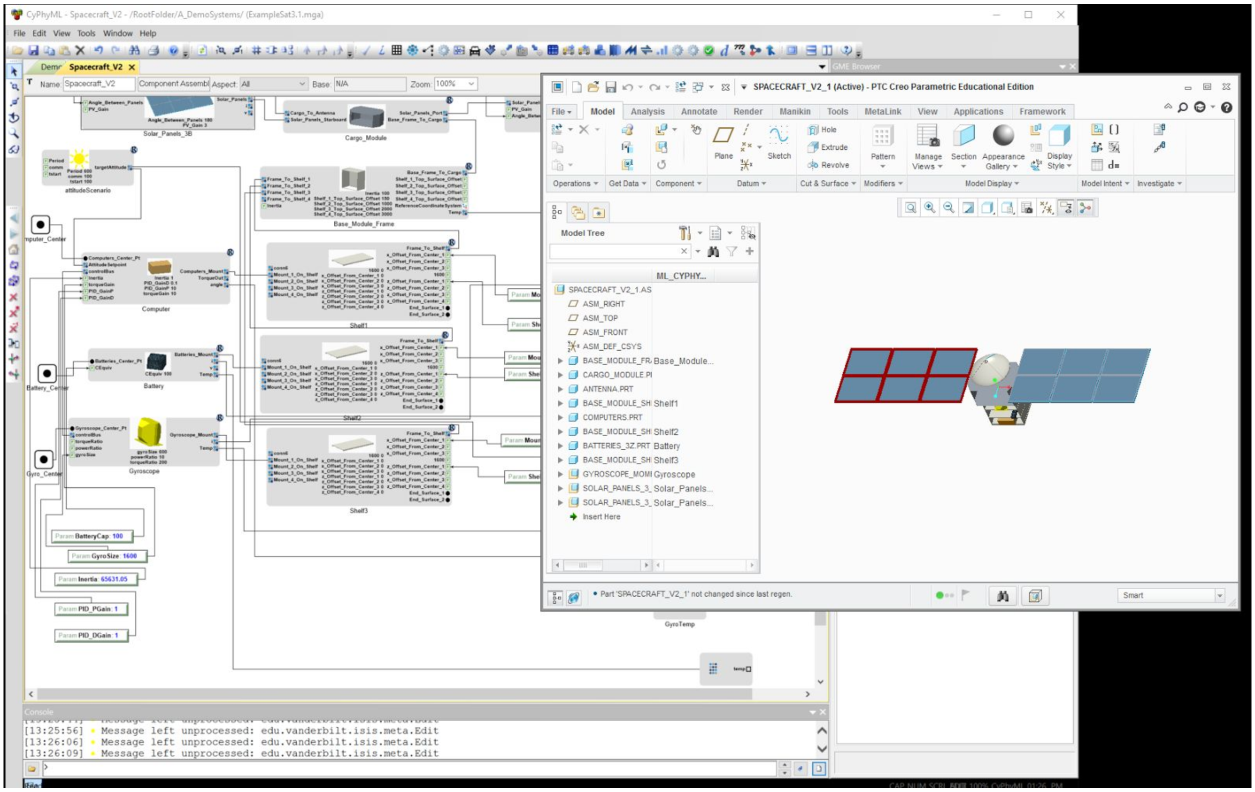


This model has added the PV array, Base_Module_Frame, 3x Shelf, and a Computer, Battery, and Gyroscope. With each of these components, a single connector captures the physical connection (3D solid), the electrical connection (Positive and Ground Power Bus), and a thermal path.

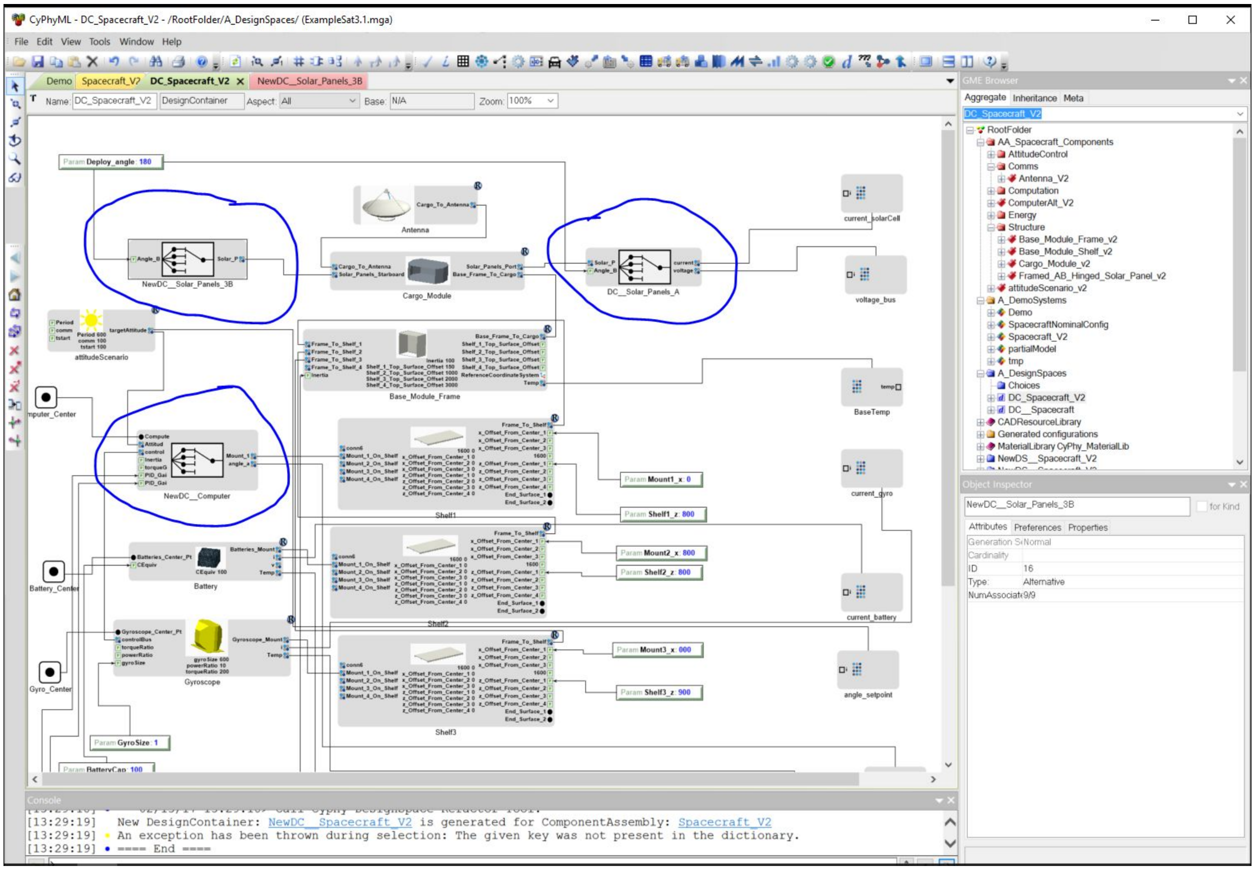
Also of note, several sensors from within the component have been added and brought out to as system connections. These include Current and Voltage on the bus, the temperature of the Base_Module, The current in/out of the Battery, Gyro, and the angular measurements and setpoints. Connecting these allow access to these data from the dynamics simulations.

The parameters for design exploration are also specified, including Battery Capacity (BatteryCap), the Inertia about the rotation point, the size of the Control Moment Gyroscope, and the control system parameters, proportional and derivative. There are also a set of parameters for adjusting the mounting positions.

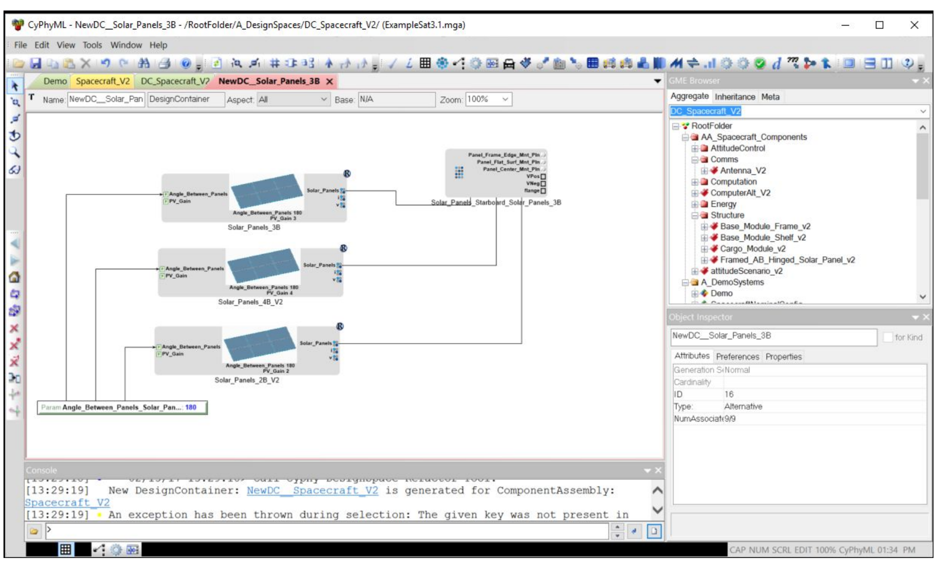
Take a moment to explore the models of the system, including using MetaLink to view the 3D solid model. Note that selecting a component in OpenMETA will highlight the solid model component.



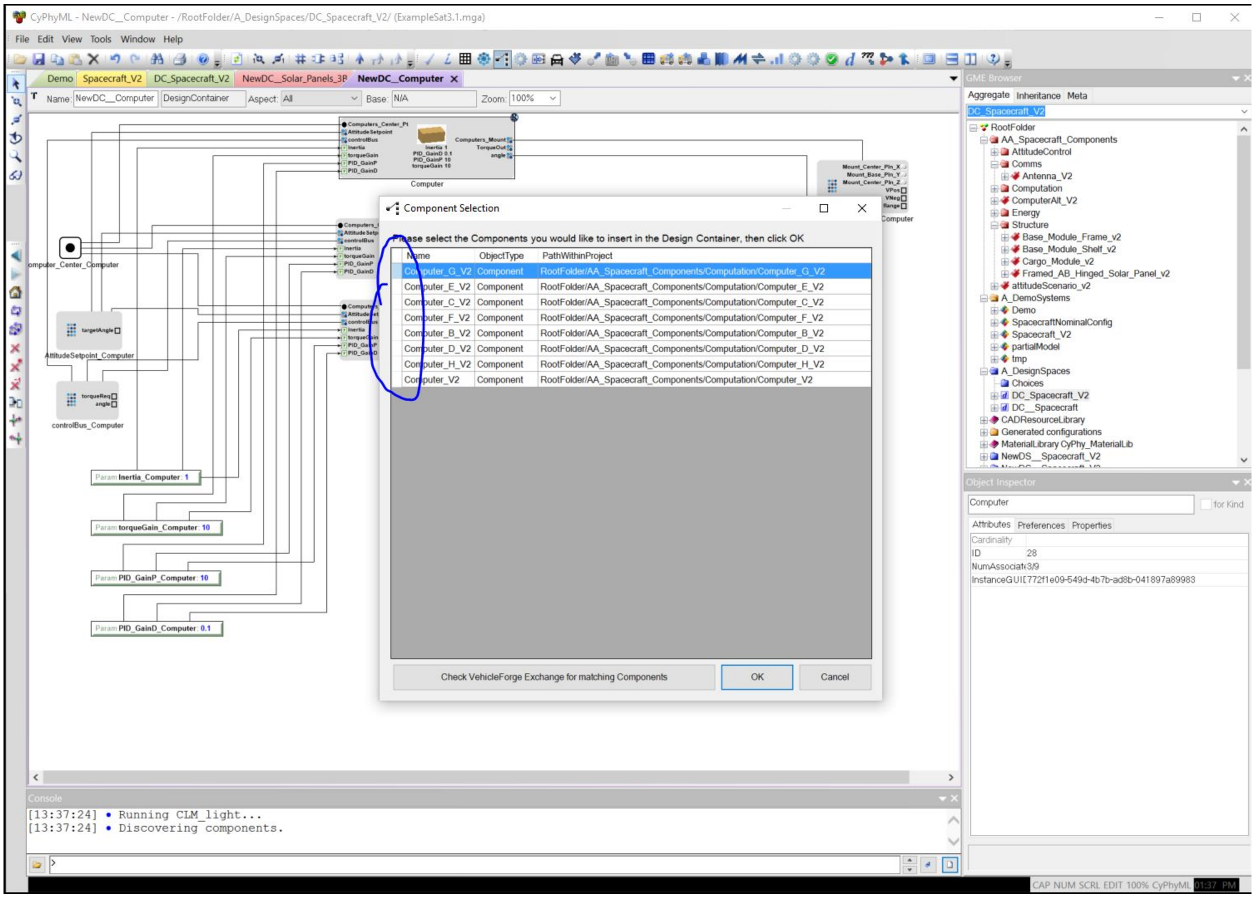
Using the OpenMETA Design Space Refactorer and Design Space Refinement Tools, the model can be rapidly evolved into a Design Space, which will permit representation of discrete design choices, e.g. PV Panel sizes. Please see the tutorial for a further explanation of this process.



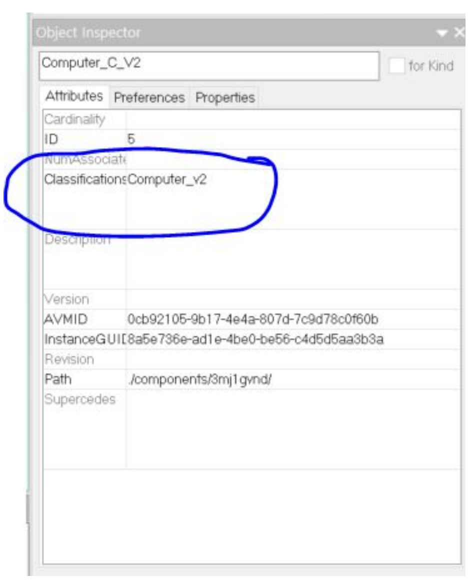
A Design Container with choices preconfigured is available in the A_DesignSpaces folder. Open DC_Spacecraft_V2, as above. Three design containers are included. Two for each of the left and right PV panel choices, and another example for options on computers.



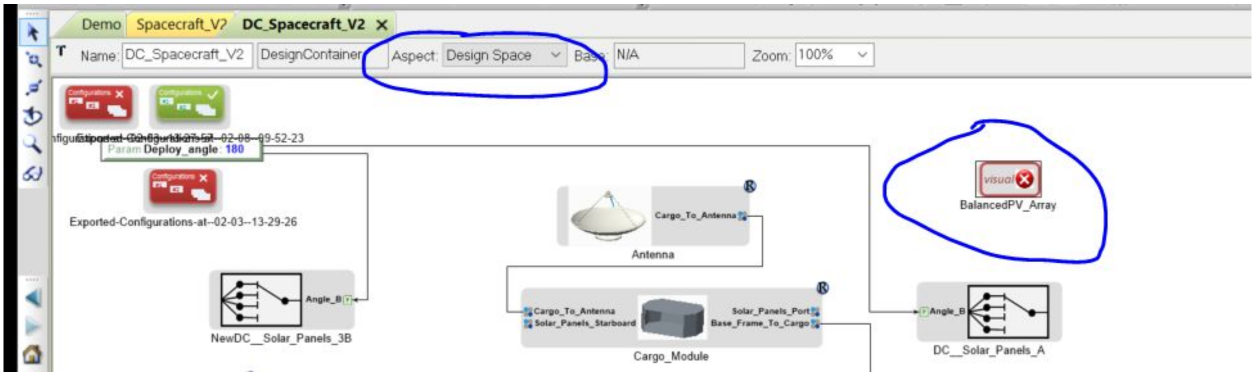
The design container for the PV arrays is shown above. A built-in tool allows the designer to rapidly add/wire up all components that are compatible with a component already in the design container. This tool is shown below. Individual component options can be selectively added, via the check-box circled.



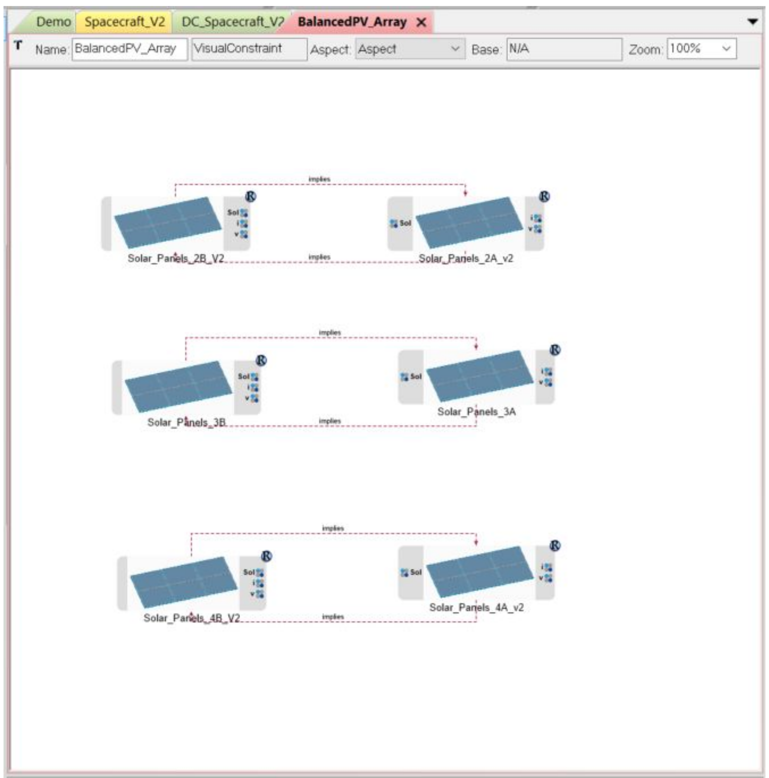
Compatibility is established via the component attribute called Classification, which can be filled with an Ontology Tag, in this case “Computer_V2”.



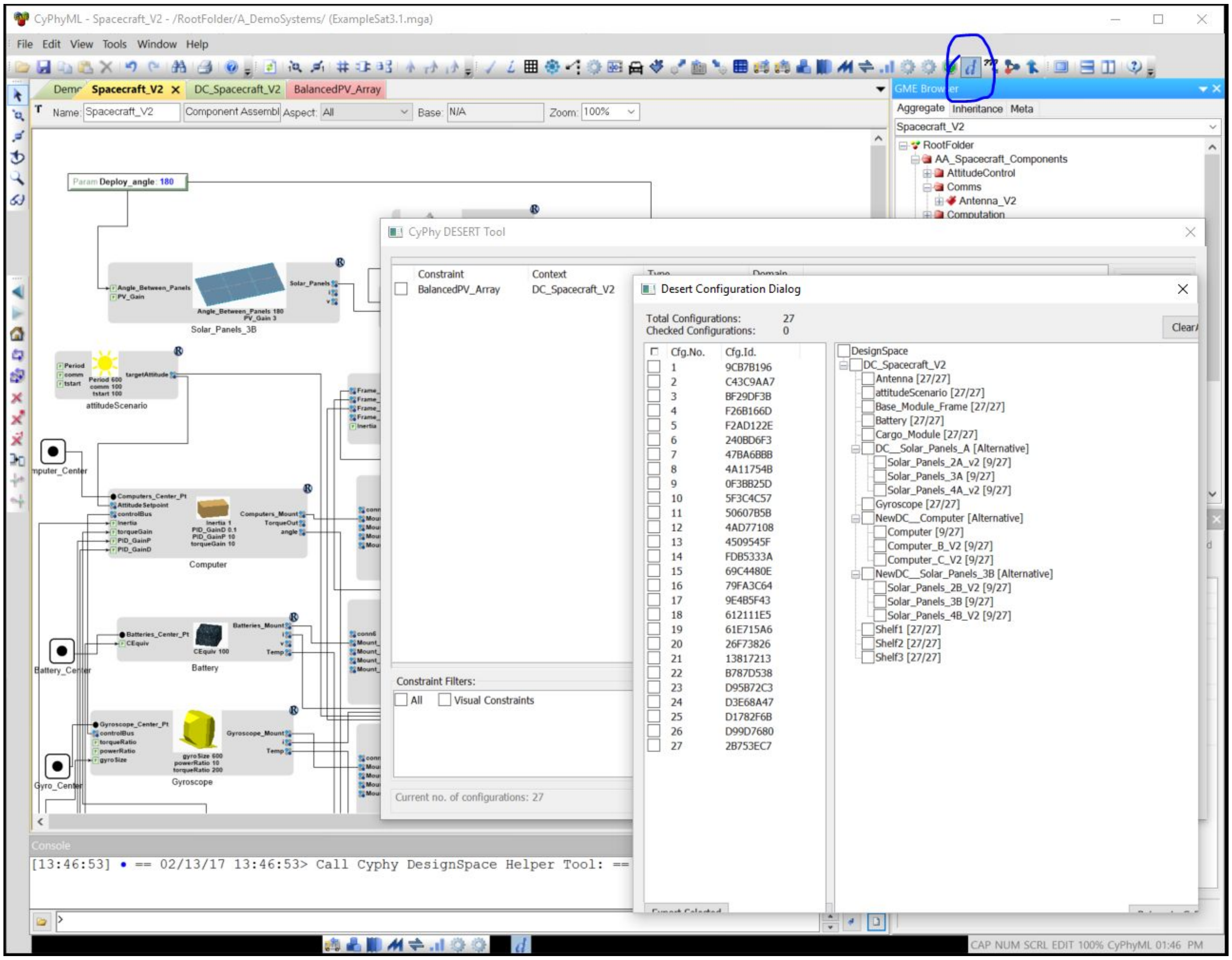
One last feature is used to complete the model: a Design Constraint, visible with the Design Space Aspect.



The BalancedPV_Array constraint, shown below:

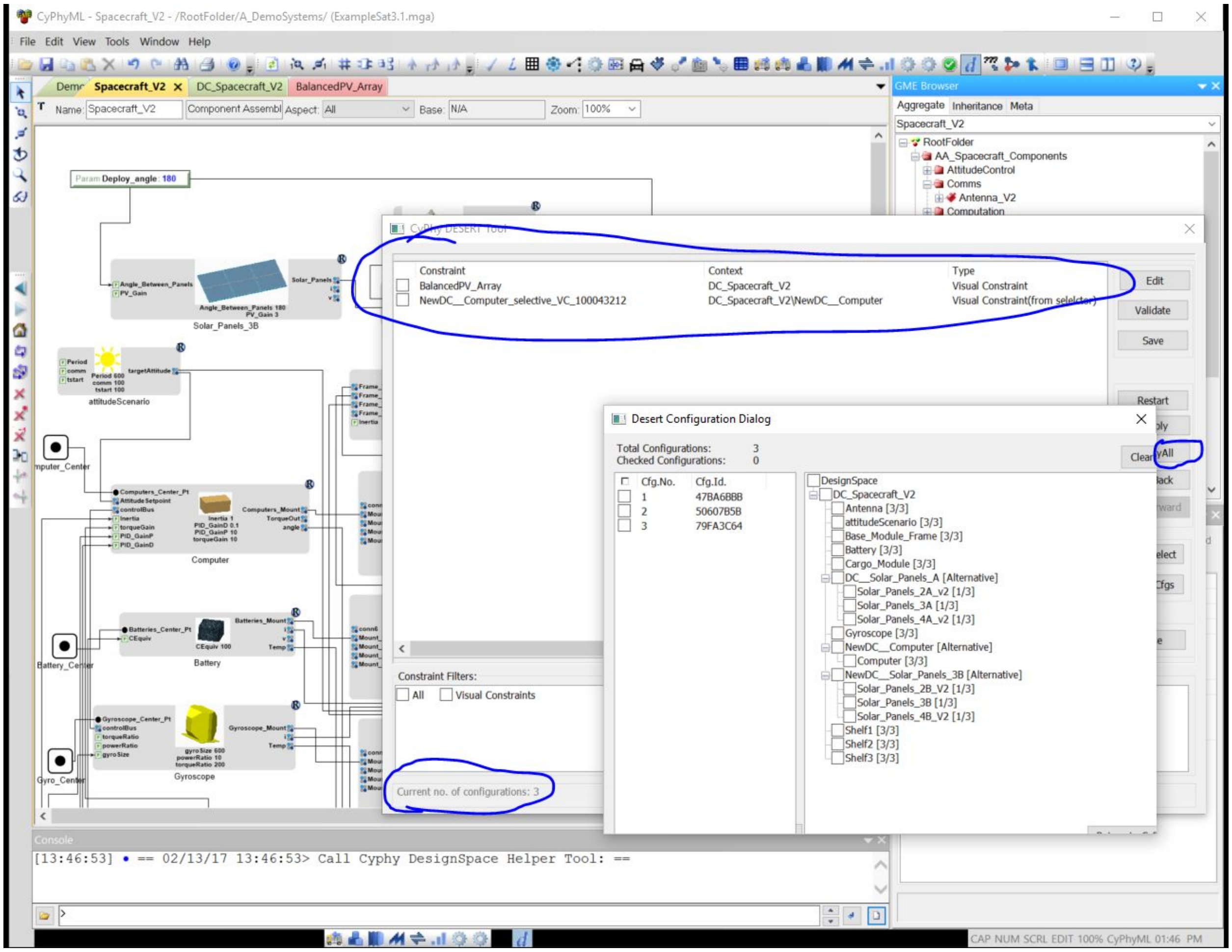


This specifies dependencies with the design choices, literally “If we choose Solar_Panels_2B, we must choose Solar_Panels_2A” (top “implies” link) and vice versa (bottom “Implies” link.) This is repeated for 3A/3B and 4A/4B.



Using the Design Space Exploration Tool on the DC_Spacecraft_V2 model, we can see the unconstrained space (27 options).

Applying the constraints, along with a manual selection of a single computer choice, we get 3 system options, shown below.



Exporting all of the constraints will allow us to further analyze just these choices.

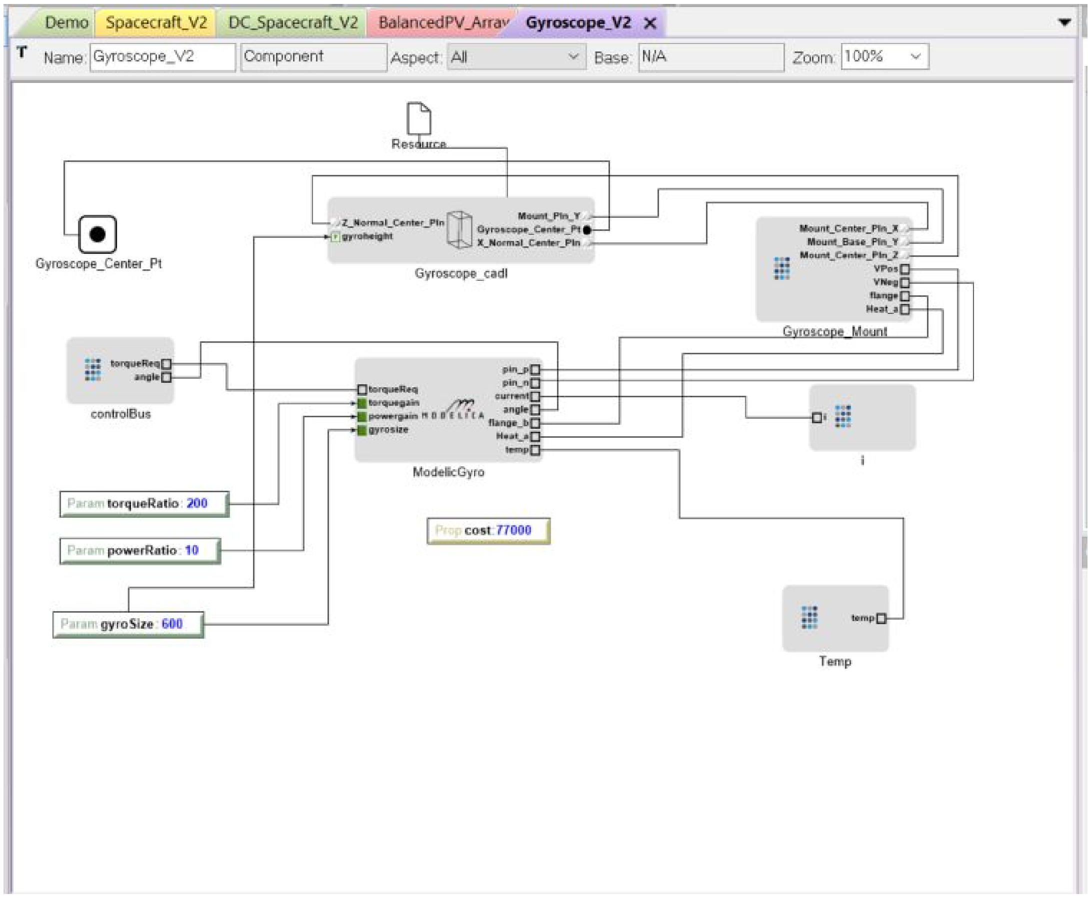
The system architecture modeling is now complete. To understand the underlying models, we will now browse thru a selection of components.

Component Models

Component models are captured in OpenMETA, with the component specification language that is part of CyPhyML. The external models and the associated artifacts are shown in the section below.

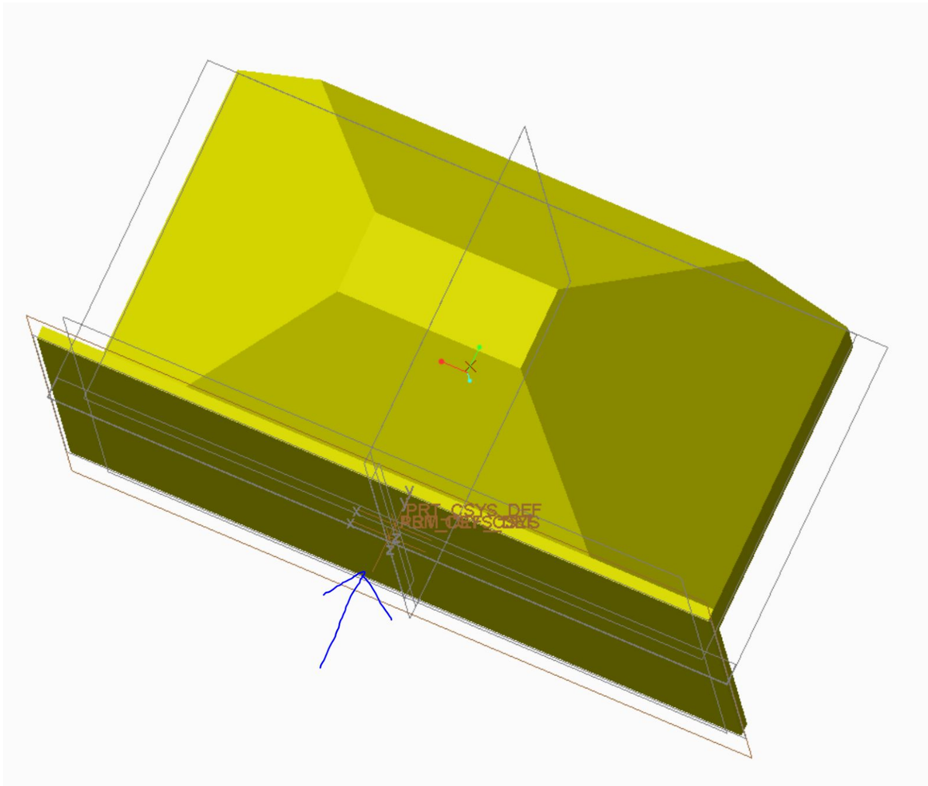
Control Moment Gyroscope

Clicking thru the system model to a component, we select the Gyroscope_V2

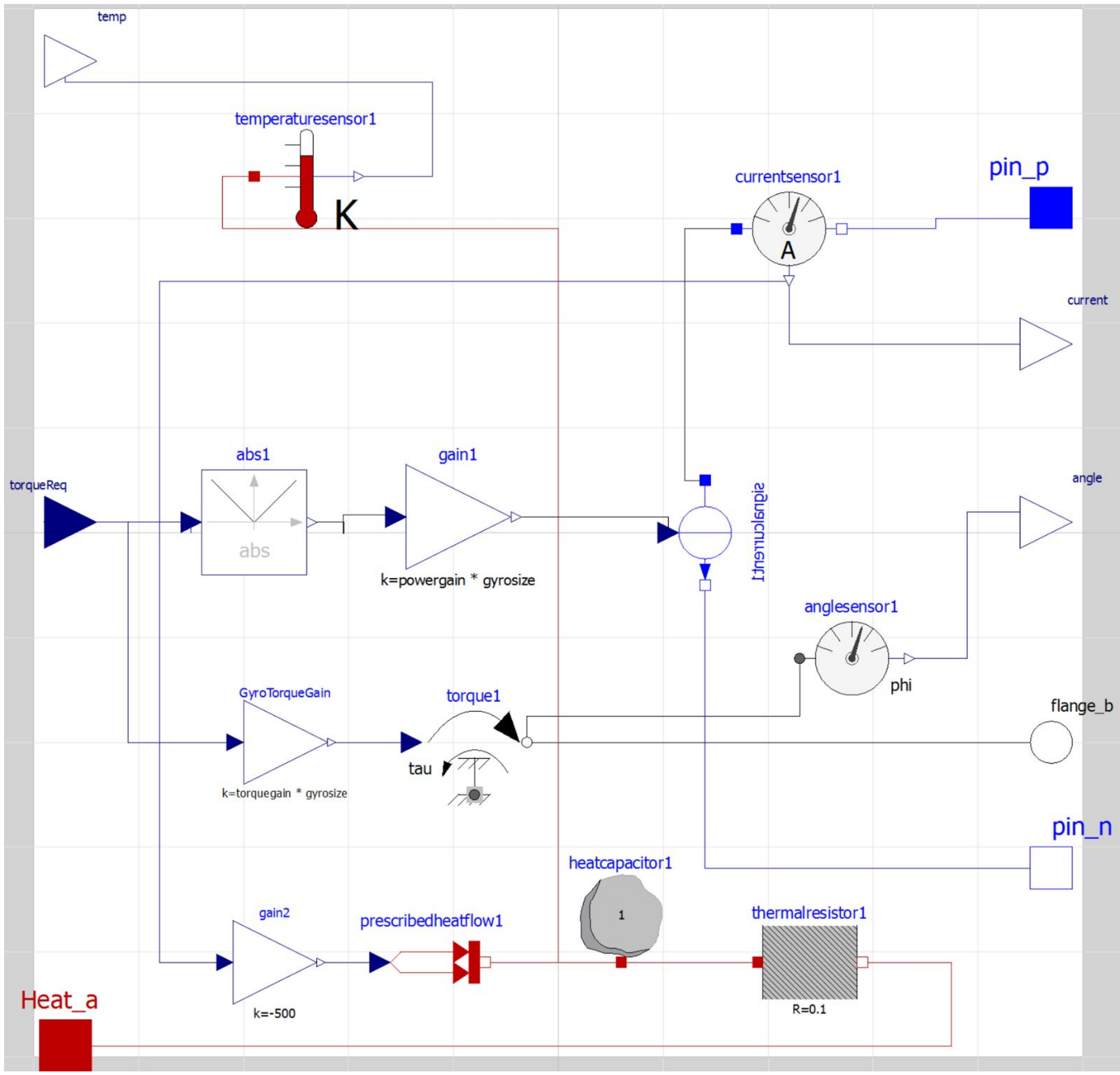


This model contains two domain artifacts:

- Gyroscope_cad is a reference to the solid geometry model. Current tools support only PTC Creo models, but other CAD tool support is planned. The relevant aspects of the CAD model are:
  - Datum Planes: these refer to three (orthogonal) planes on the surface of the Gyroscope. Axes and Coordinate Systems are also supported. The mounting point, and axes are shown in the figure below.
  - Datum Points: these are used to provide a 3D measurement point for determining the location of the part in the final assembly. These can also be used in FEA, for adding constraints and loads.
  - Parameters: The gyroHeight controls the CAD part's dimension, which will reflect the mass and inertia of the physical part.



- The relevant parts of the Simulation are captured in the ModelicaGyro model:
  - torqueReq is a signal requesting a torque from the controller. This is a Causal signal, input only
  - Angle is the current angle, measured at the gyroscope. This is an output-only signal
  - pin_p and pin_n are the positive and negative electrical connections. These are acausal signals.
  - Flange_b captures rotational power transfer. This is a causal signal.
  - Heat_a captures thermal power. This is a causal signal.
  - Temp, and Current are both signals measured within the components. These are output-only.



To implement the behavior of the control-moment gyroscope, the above Modelica model was created. At the edge of the Modelica model are the matching pins within the OpenMETA model. The basic theory of operation of the CMG is:

- Torque request is an input, from the system controller. After applying a gain, this is used to set the input to a torque source (torque1). The gain is related to a constant * the parametric size of the gyroscope.
- Torque is transmitted to the acausal port called flange_b. Angle is measured at the torque source.
- Electrical energy is consumed, simulated by a current source, that draws current from the pin_p to the pin_n output. The amount of current is programmed from the torque request, scaled by a constant multiplied by the gyroscope size.

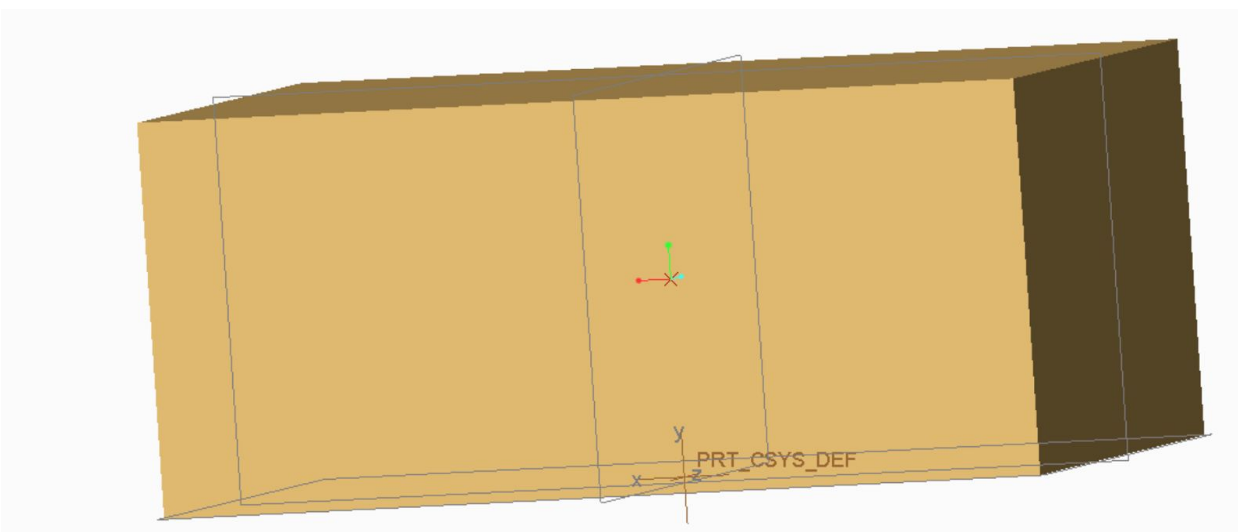
- Thermal behavior is simulated by a thermal source, with output scaled by the amount of current used by the gyroscope motors. Thermal energy is retained via the inherent thermal mass, and impeded to the mechanical interface by a thermal resistor.

Note that none of the constants has been calibrated to actual components, rather the values are for illustration only. We welcome any input on matching these values to actual component properties.

For the remainder of the components, we discuss the the modelica model. The OpenMETA models match the interfaces exactly.

Computer

The CAD model of the computer is a simple solid box, with density representative of an electronics assembly, and a 3 plane mounting datum set:



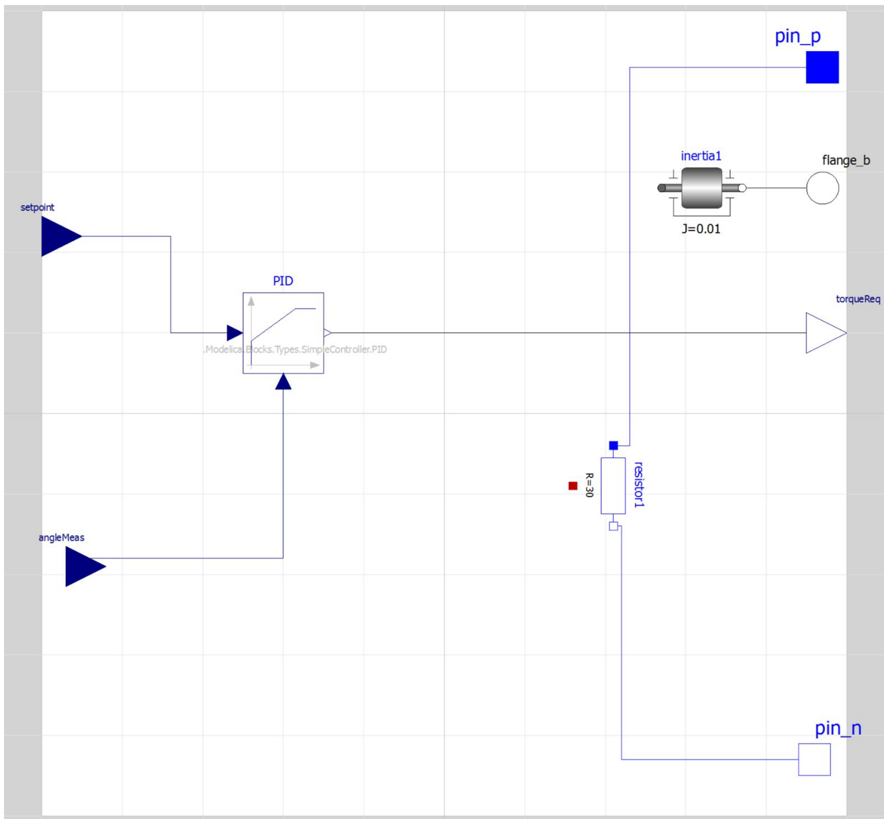
The behavioral model of the computer implements a simple PID controller, direct from the Modelica Standard Library.

The PID uses a setpoint for the target value, and “angle” for the feedback/actual value. The control signal is sent to a causal, output value.

Power consumption is modeled as a fixed resistance. Note that this is a potential area for fidelity improvement.

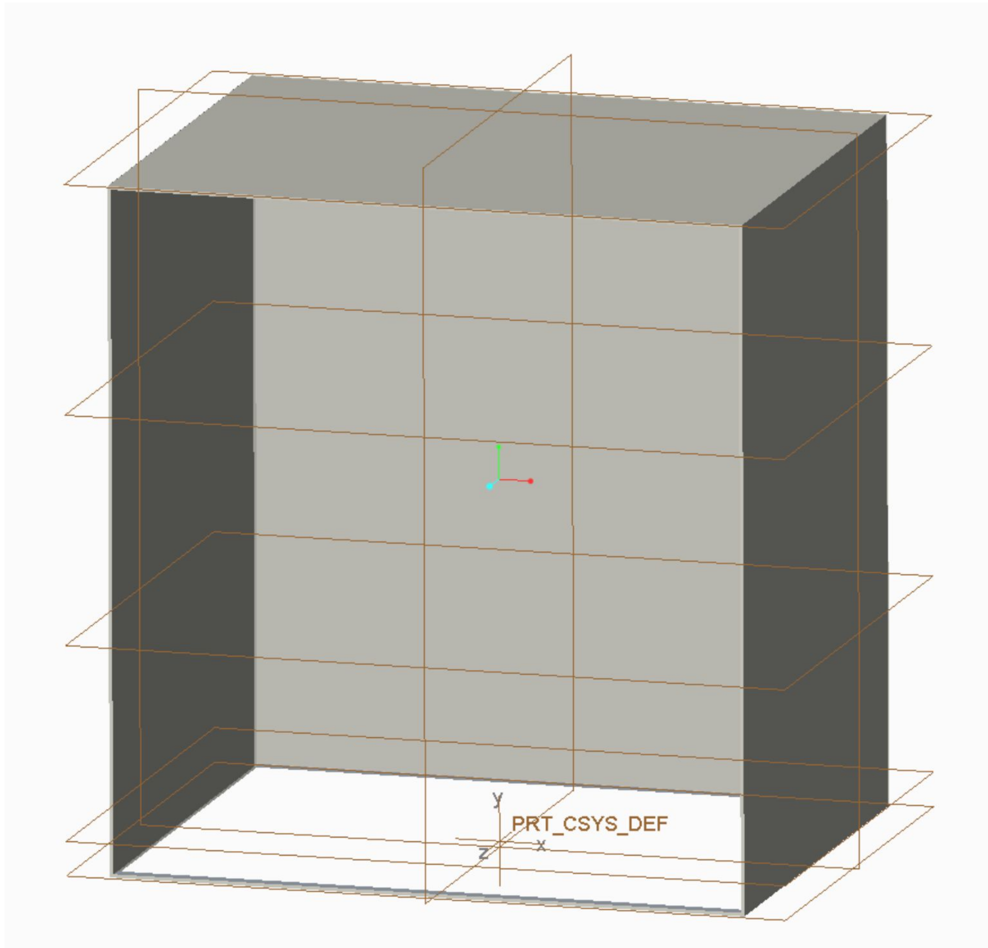
The connection flange has a nominal inertia term, to satisfy the simulation tool. Torque is transmitted thru the flange port.

Parameters for proportional gain and derivative gains are set within the OpenMETA system, and can be used in design studies.



Base Module Frame

The base module frame is a flexible, parametric box with a set of movable datum planes for mounting the shelf components. The model his shown below, with the shelf mounting planes clearly visible. The adjustments are available at the OpenMETA component model.

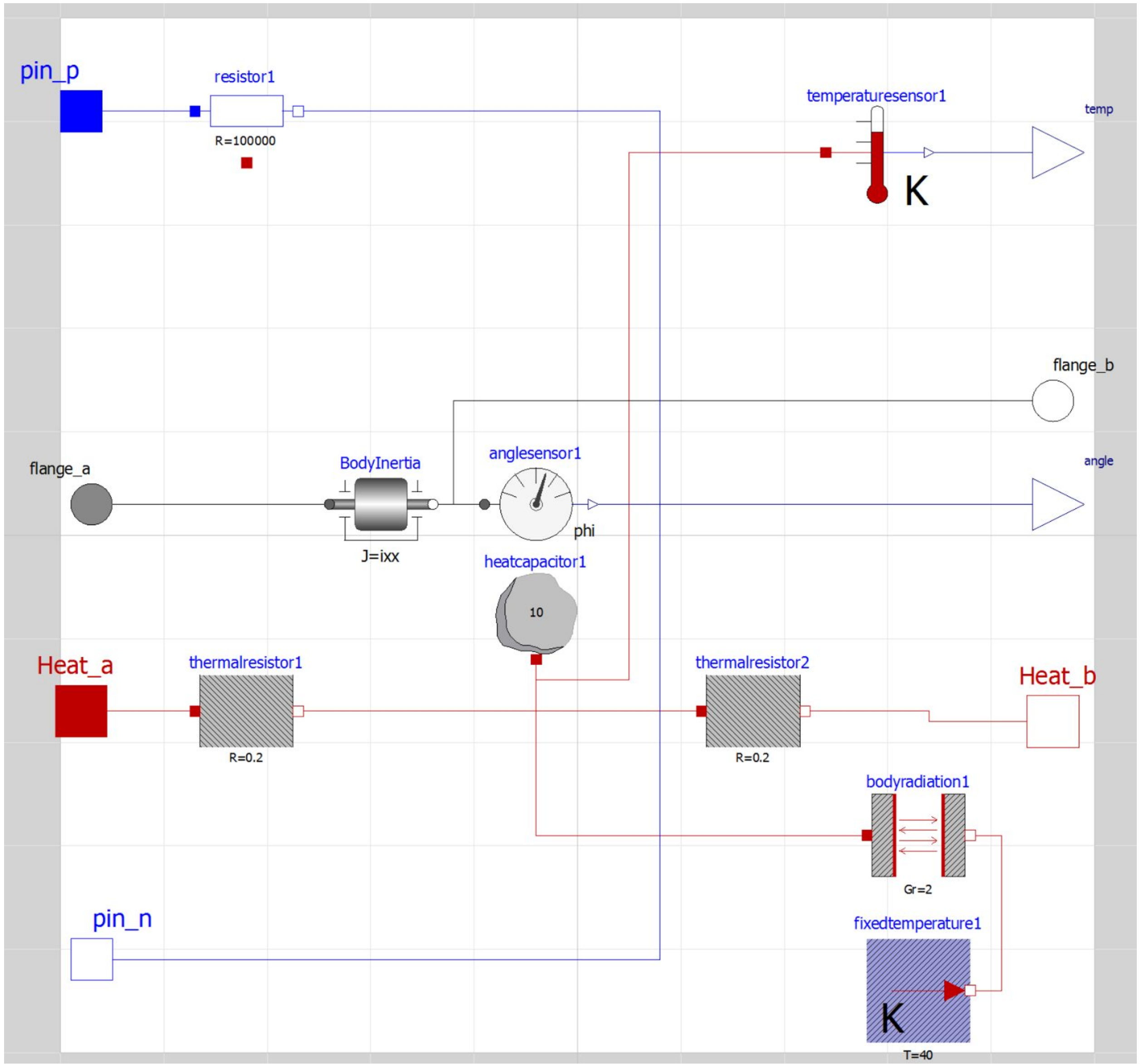


The behavioral model of the Base Frame is shown below.
A simple electrical circuit represent a small current leakage, which should be insignificant in the circuit model. Future versions could contain a heater for critical subsystems.

The BodyIntertia is the main inertial property of the system. This is parametric, to be programmed by the computed inertia of the CAD assembly in the design study. This will create the main force resisting the torque generated by the gyroscope.

Two flanges allow the connection of internal components separate from the components outside of the base module.

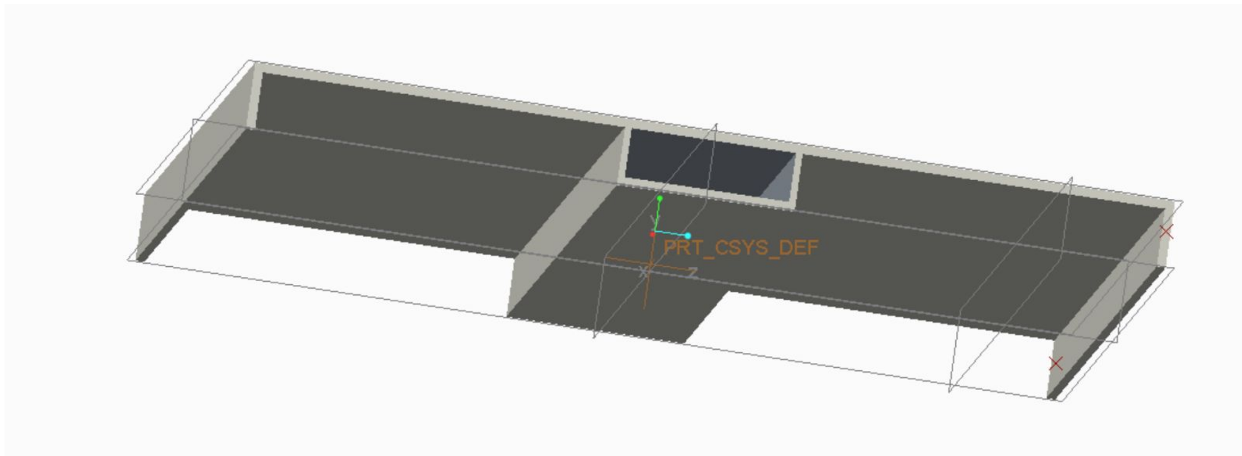
The base module also contains the main thermal radiator for the system. This is modeled as a fixed temperature (the temperature of open space) with a programmable body radiation. In this case, the radiation is fixed. Added fidelity could take parameters of the CAD model into account (Materials and surface area).
Thermal resistors account for the conduction of heat thru materials. A temperature sensor allows the readings to be used in the design study.



Base Module Shelf

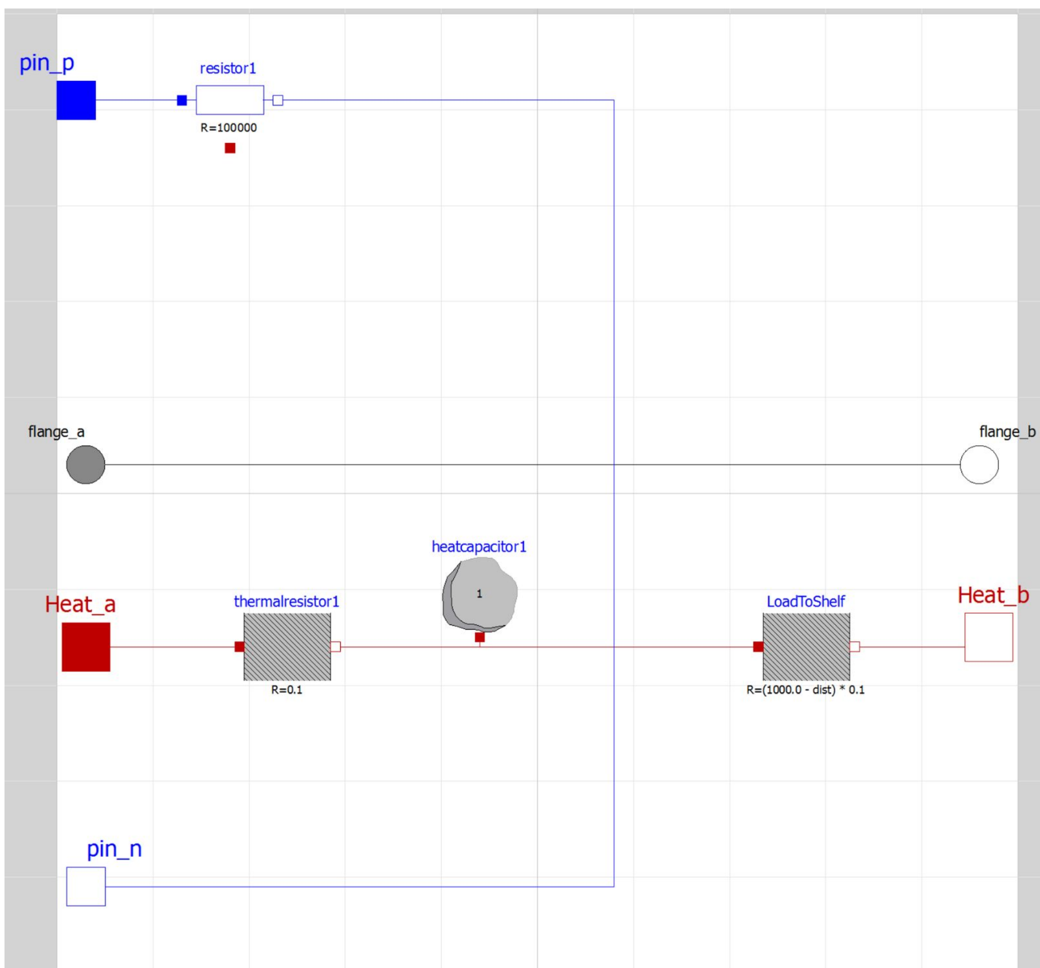
The base module shelf is used as an example for finite element analysis within the study. The CAD model is adjustable in material thickness and in the geometry of the supporting flanges. Its critical functions are to support the subsystems, and to transfer heat. There is also an assumed electrical bus built-in.

Note that this is not necessarily representative of a lightweight design.



The behavioral model is shown below. It has a small amount of heat capacitance representing the mass of the shelf, and a variable heat conductance from the component mounting point to the edge of the shelf. This accounts for the placement location.

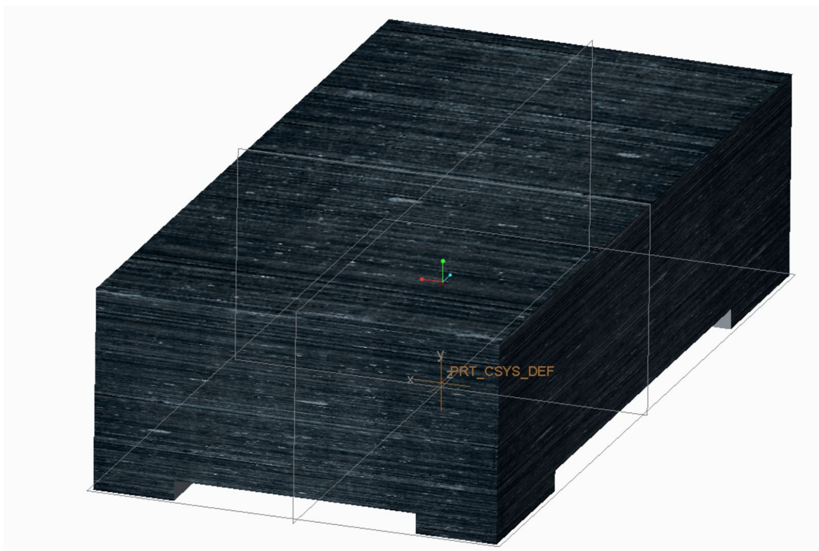
All rotational forces are directly passed through the component.



Battery

The battery component's function is to store electrical energy to power the system while the PV array is pointed away from the sun. The CAD model is represented below.

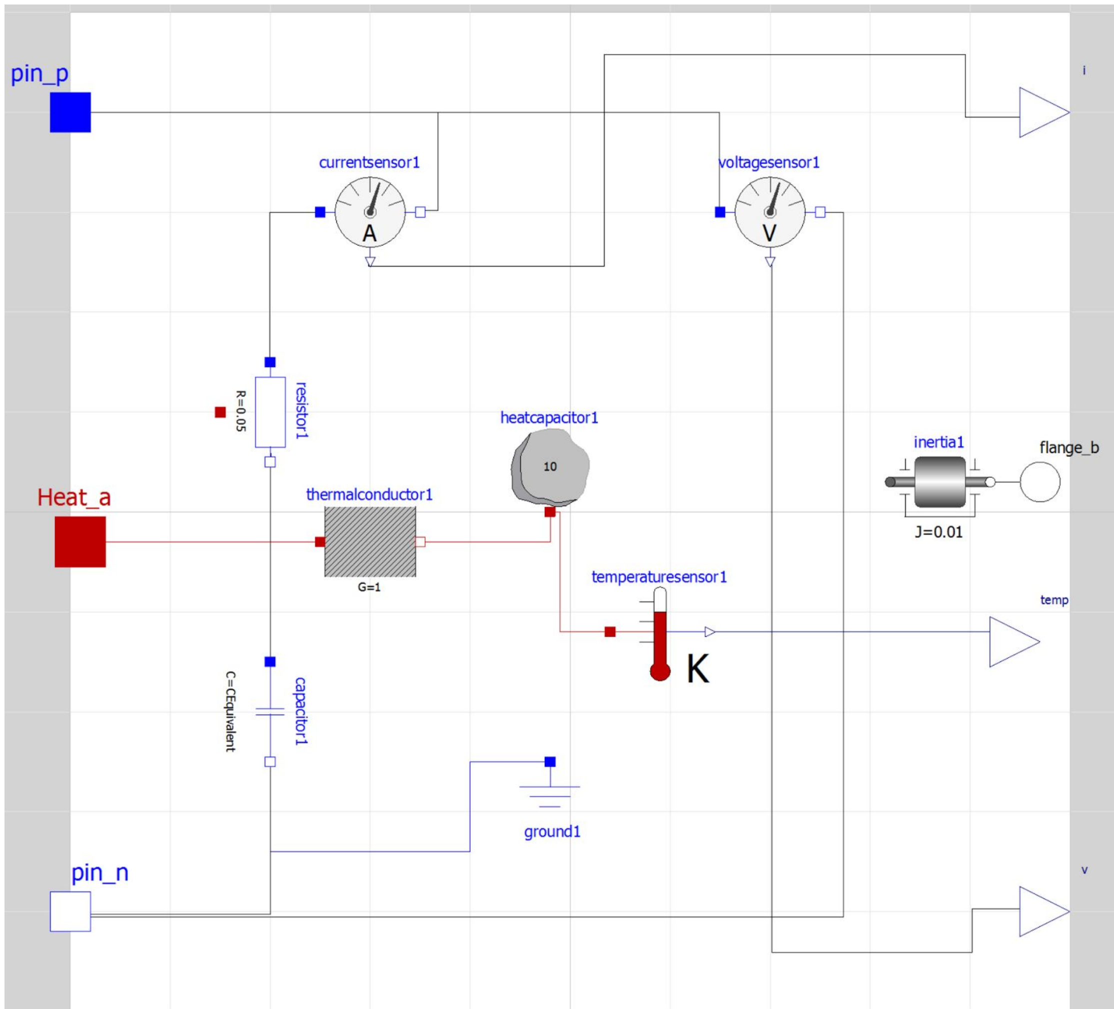
The CAD solid object is scaled in length, width, and height based on the requested battery capacity.



The battery simulation behavior is represented as a simple capacitor, with value related to the StorageCapacity parameter, and a small resistance.

The thermal circuit is a simple thermal mass, with a fixed conductance to/from the component edge. A temperature sensor reports the internal temp.

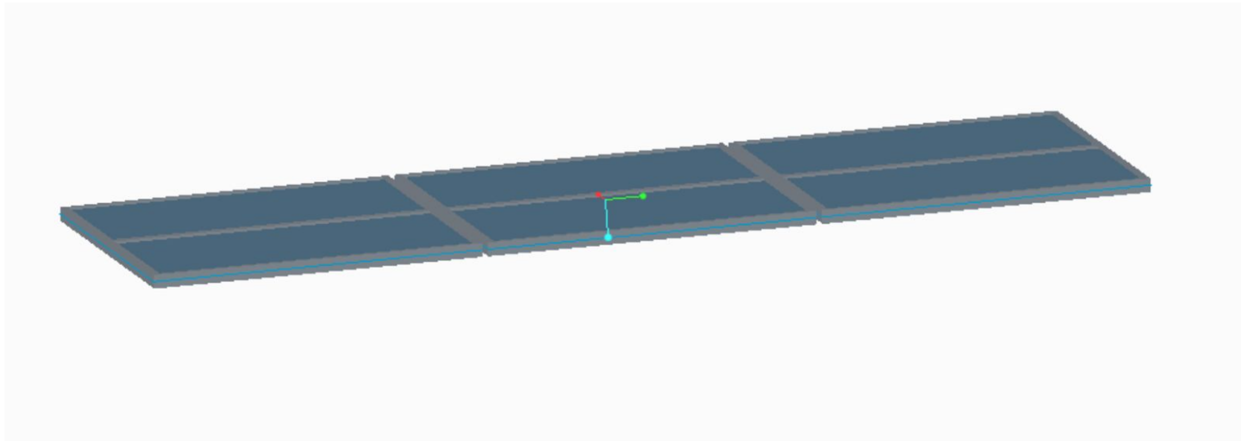
A higher fidelity model could capture the charging/discharging losses and convert to thermal waste heat.

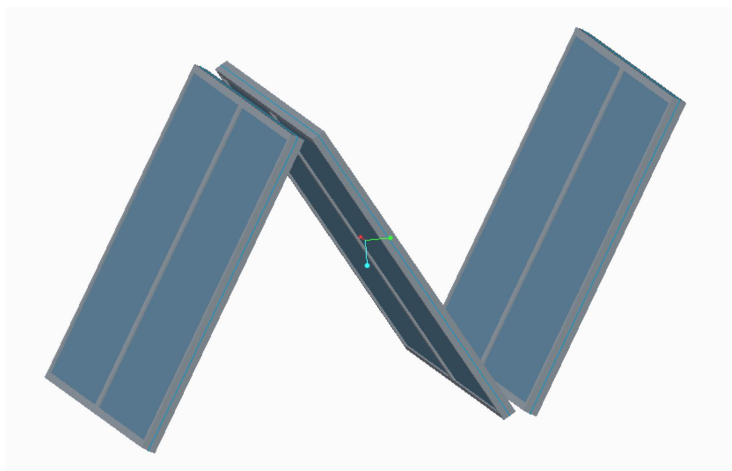


Photovoltaic Array

The PV component's function is to generate electrical energy to power the system. The PV array generates current in proportion to the angle to the sun.

The CAD model is represented below, for the 3 panel array. Similar models are included for the 2 panel and 4 panel array. The model is parameterized with a folding angle, ranging from 0 to 180. This allows the model to be evaluated in the launch configuration (0 deg) and deployed configuration (180)

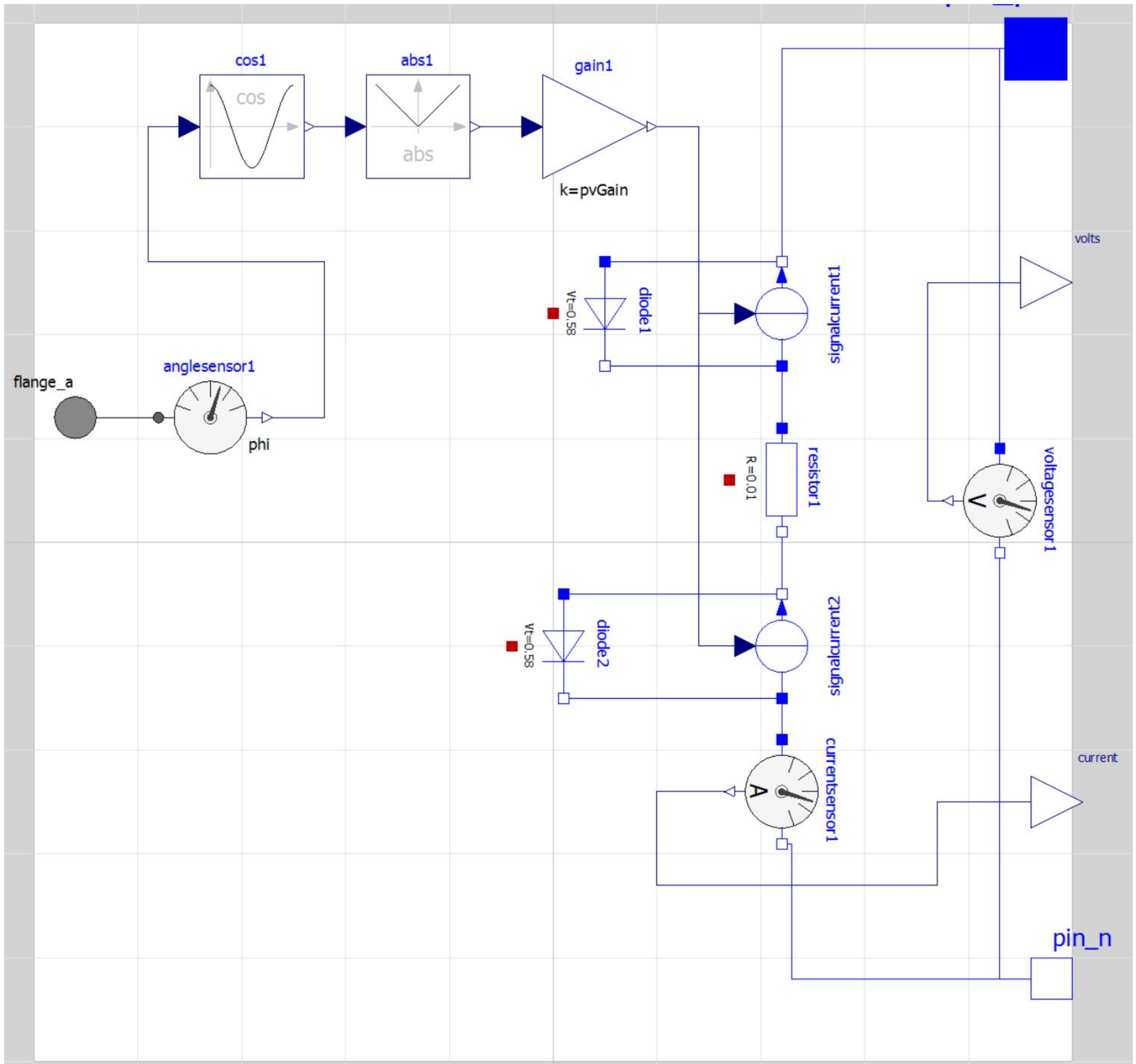




The behavioral model is shown below. This is a simplified version of a PV array stack. The model has a maximum voltage output of approximately 18 V, programmed by the forward bias voltage of the diodes (in series)

Energy generation is modeled with a current source, and small forward resistance. The amount of current is parameterized by the fixed size of the array, and the cosine angle of the PV array with respect to the sun.

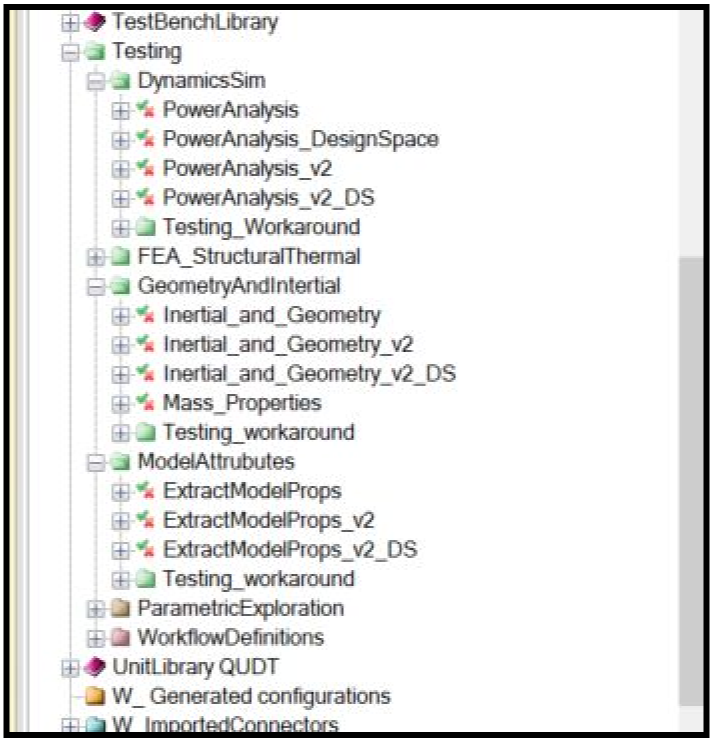
Current and voltage sensors make the data available to the test simulation.



System Requirements Evaluation

The system is evaluated with a series of test benches. These are described below.

Test benches are accessed in the Testing folder. We will walk thru 3 of them for illustration, starting with the Dynamics Simulation, followed by Geometry and Inertial. The FEA will be discussed at the end.



Dynamics Simulation

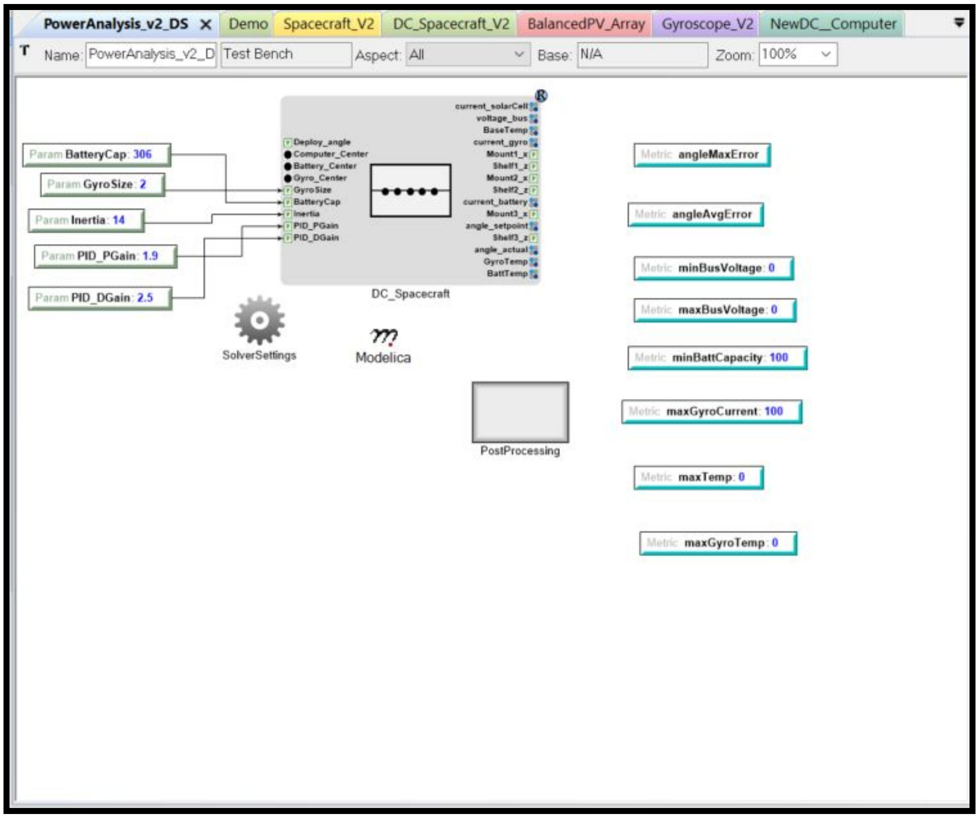
Dynamics simulation is performed in Modelica. An example testbench is shown below, with the purpose of simulating a series of maneuvers of the spacecraft as it rotates from 0 to 90 degrees.

At the core is the system-under-test model. This is a reference to the design space discussed earlier. The meaning of this model w.r.t. A design space is to execute the test bench on all valid configurations (in this case, 3).

Parameters allow the user (or external study) to define Battery Capacity, Gyro size, system intertia, and the controller gains.

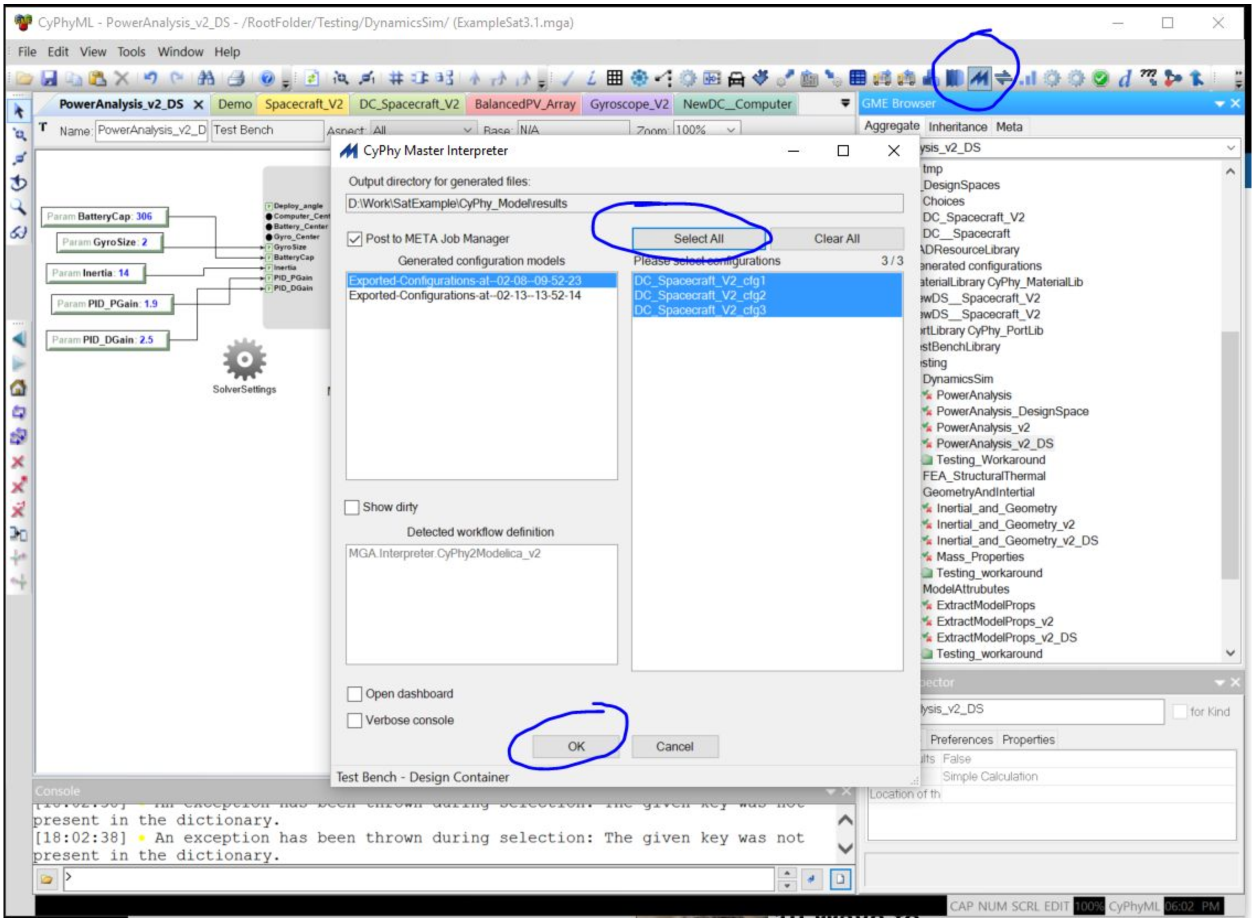
Metrics define the computed data. These correspond directly with the design study objectives and requirements. Due to this, we refer to a testbench as an Executable Requirement:

- AngleMaxError is the maximum delta between setpoint and actual angle
- AngleAvgError is the maximum delta between setpoint and actual angle
- MinBusVoltage is the minimum measured voltage on the system
- MaxBusVoltage is the maximum measured voltage on the system bus
- MaxGyroCurrent is the maximum instantaneous current consumed by the gyroscope
- MaxTemp is the maximum temperature of the base module
- maxGyroTemp is the maximum temperature internal to the Gyroscope.

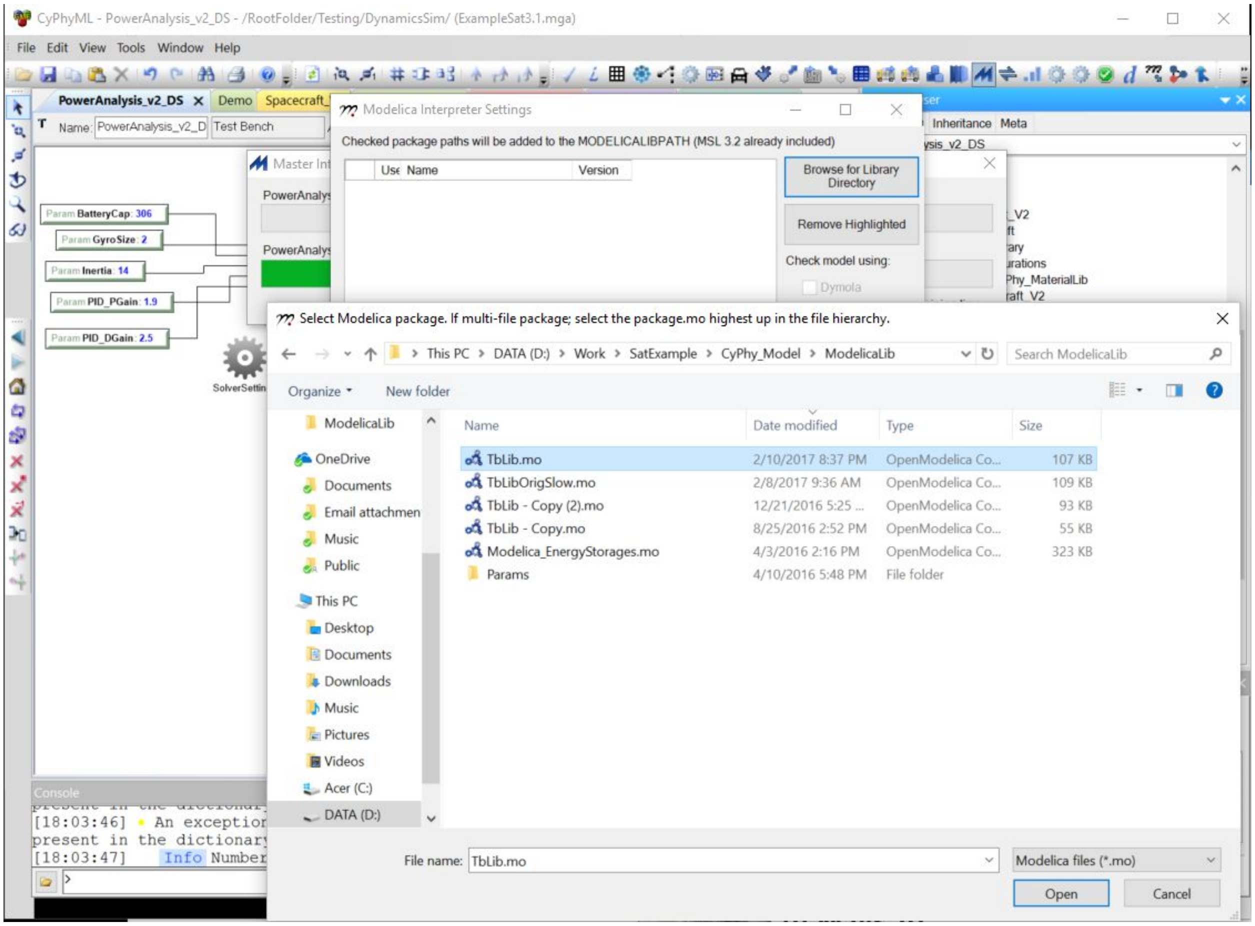


Other objects in the Test bench allow setting the simulation time (3000 seconds, in this case) along with a postprocessing script (in Python) that will compute all the max, avg, etc from the raw data.

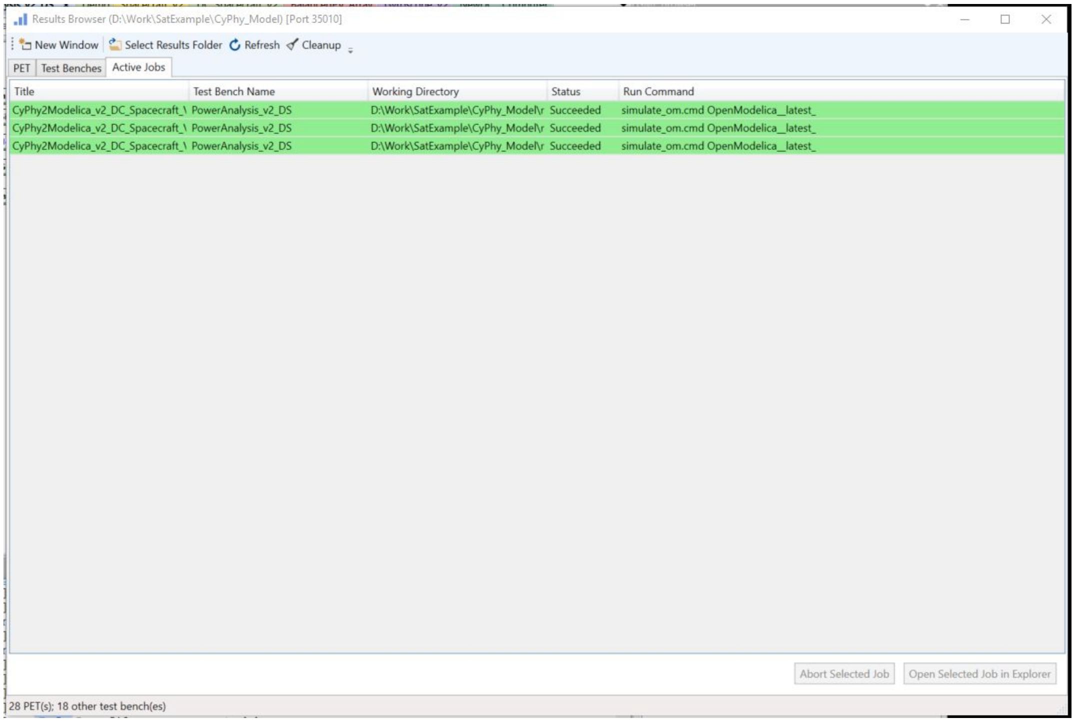
This tesbench can be directly executed by pressing the M button, selecting configurations or selecting All configurations, followed by OK.



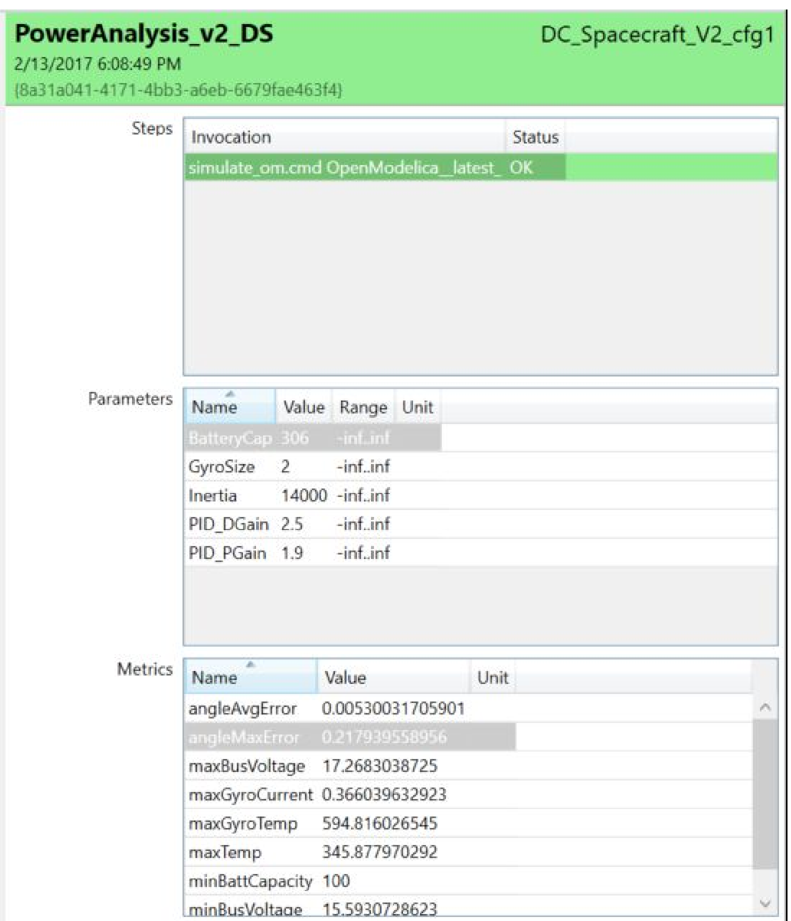
For dynamic simulation, often a library is needed. This is selected in the next frame. TbLib.Mo is located in the ModelicaLib directory.



After hitting OK, OpenMETA will iterate through each of the design configurations, elaborate all component behavior models, connect all ports, and create a valid simulation model. These models are submitted to the Job Manager, shown below, which will execute them in parallel on the host computer:

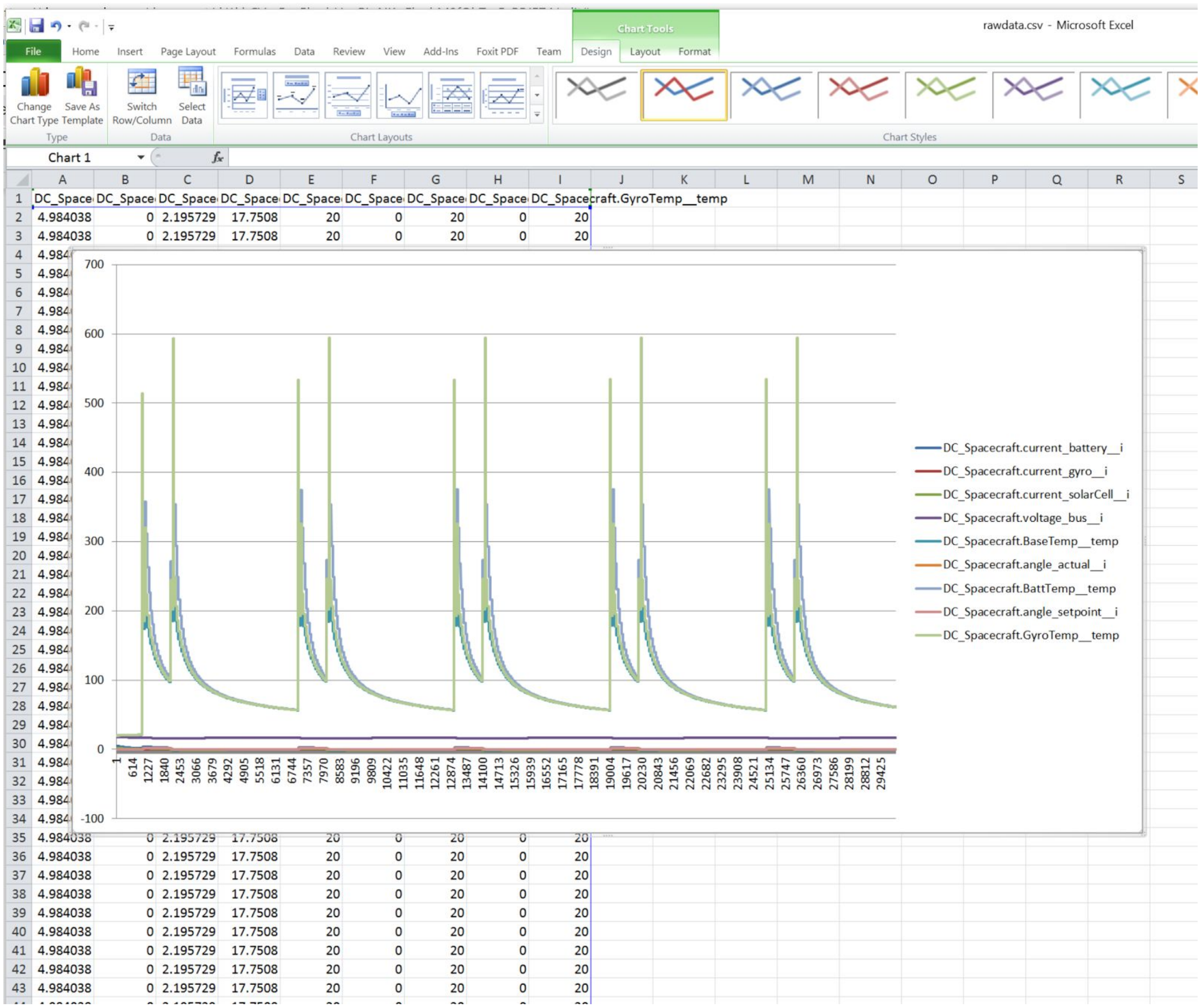


Selecting the Test Benches tab, you can view the metrics:



Here we can see that the overall temperature is 345, while the gyro spikes to nearly 600K.

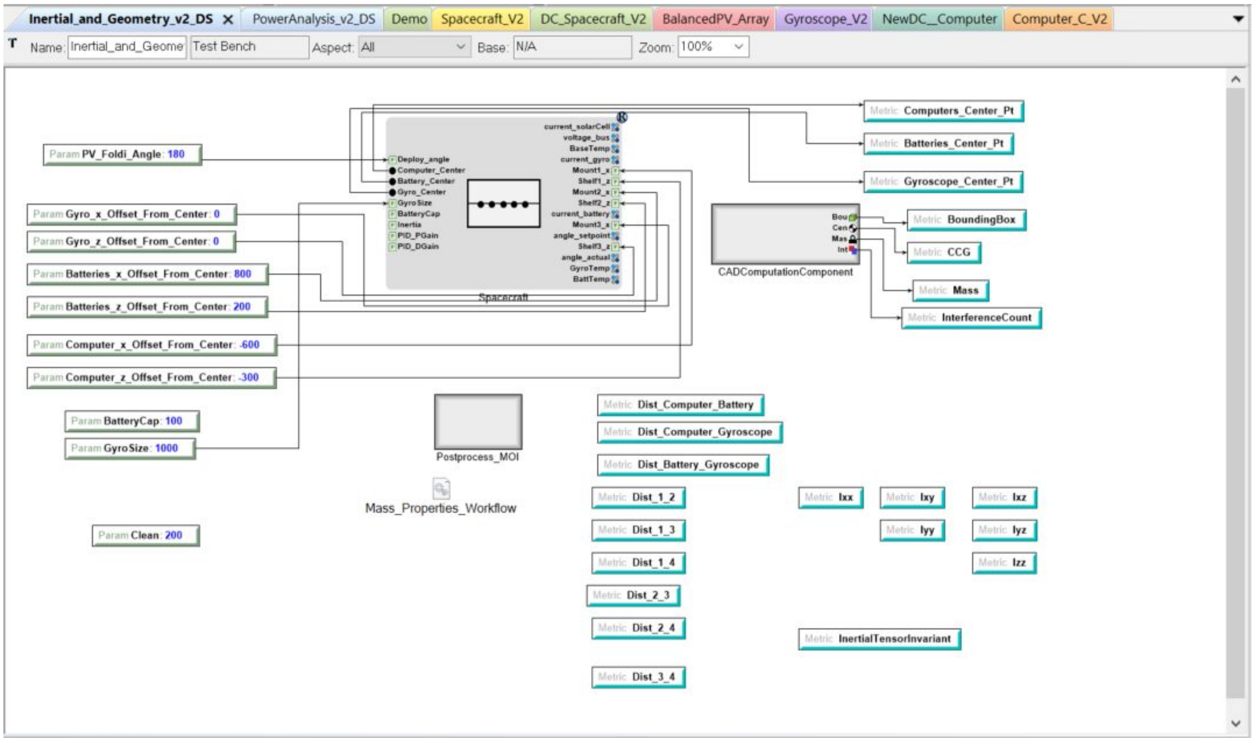
The postprocessing also generates a CSV of the raw data, suitable for plotting in excel, as below.



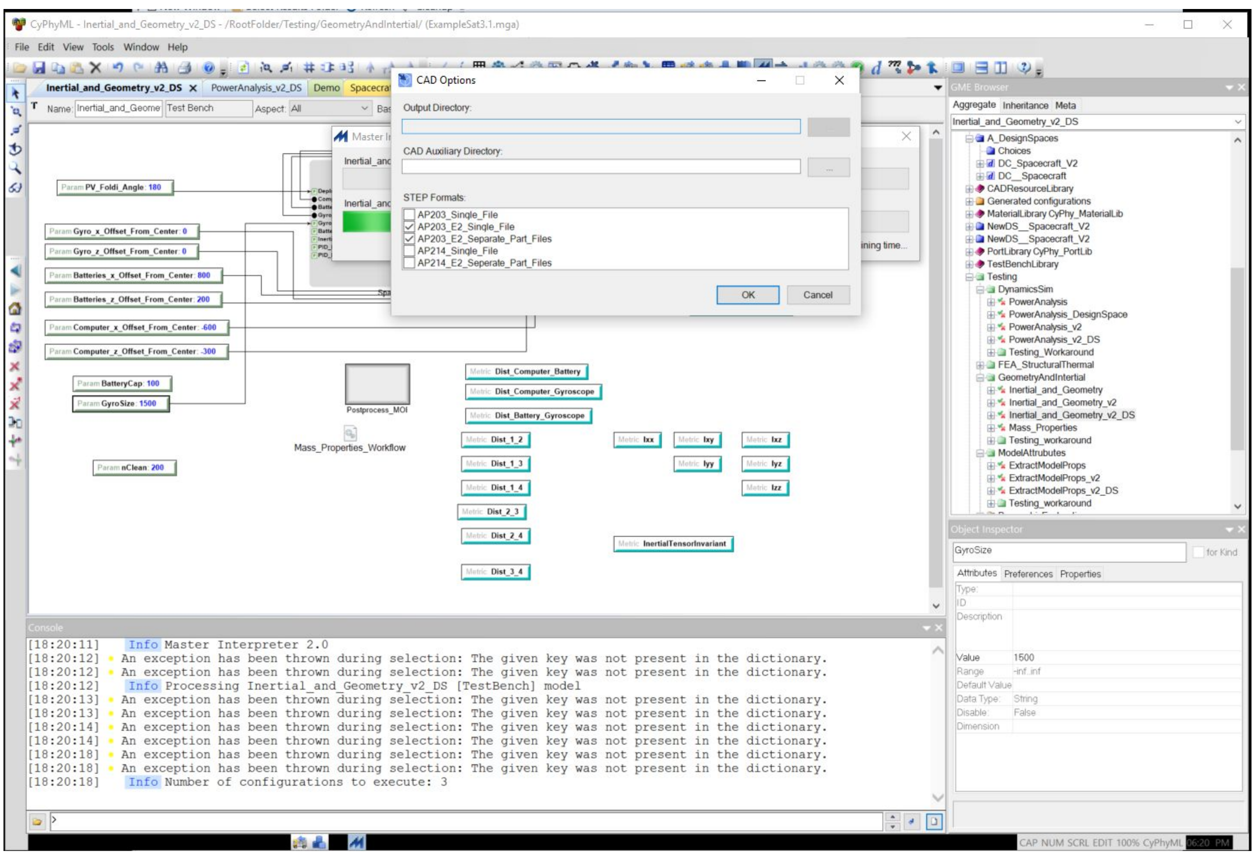
Geometry Analysis

Geometry analysis is performed in Creo. The CAD testbench, shown below, enacts creation of the fully assembled CAD model.

In addition to creating the CAD model, a standard set of metrics can be computed, including bounding box, mass, center of gravity, and a count of interferences.



Executing the test bench, via the M button, allows the user to select which STEP file formats will be generated.



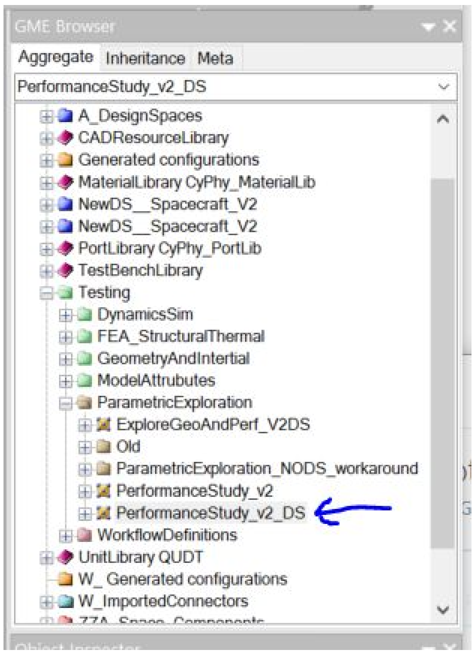
The results from the CAD testbench are shown in the table below. Of primary interest in the context of the analysis is the intertia (Ixx) and Mass of the system.

Design Studies in OpenMETA

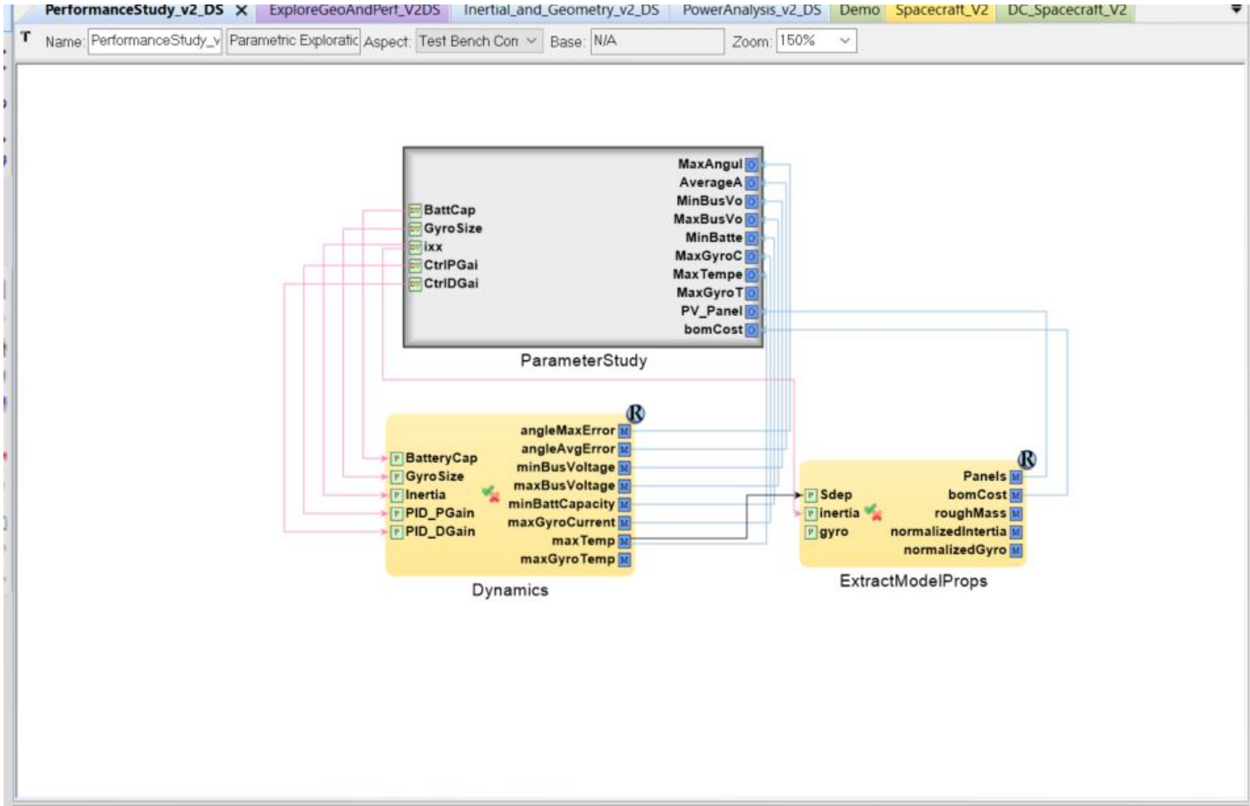
The combination of a design space and the Parametric Execution Tool allows the user to perform a Multi-Disciplinary Optimization/Analysis on the system.

Design Study Models

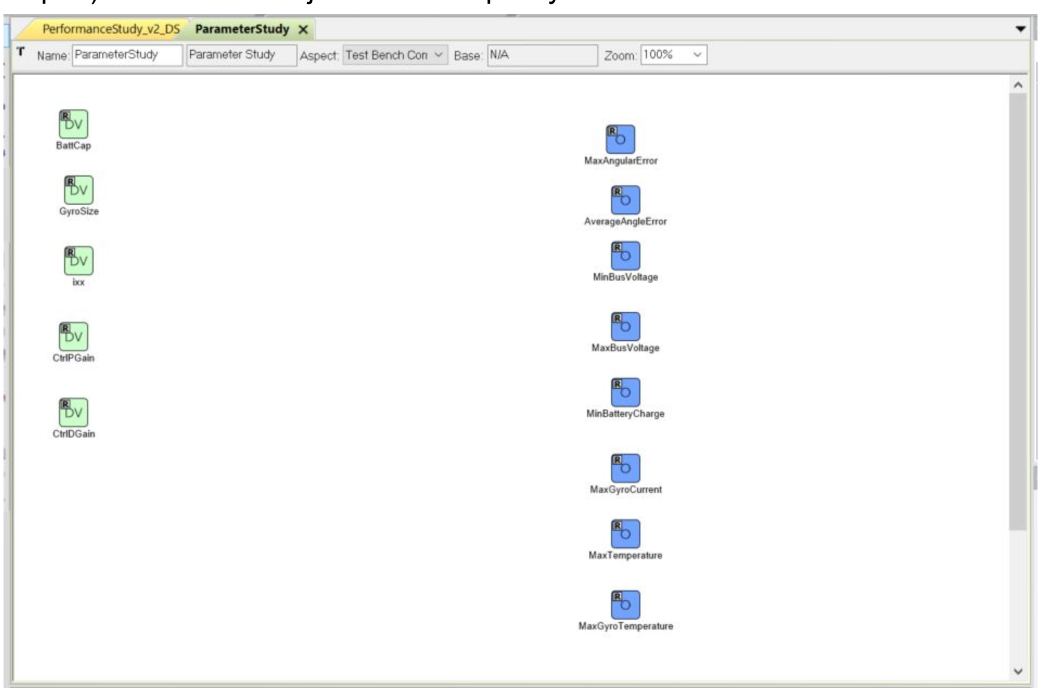
A typical PET model is shown below. This model can be found here:



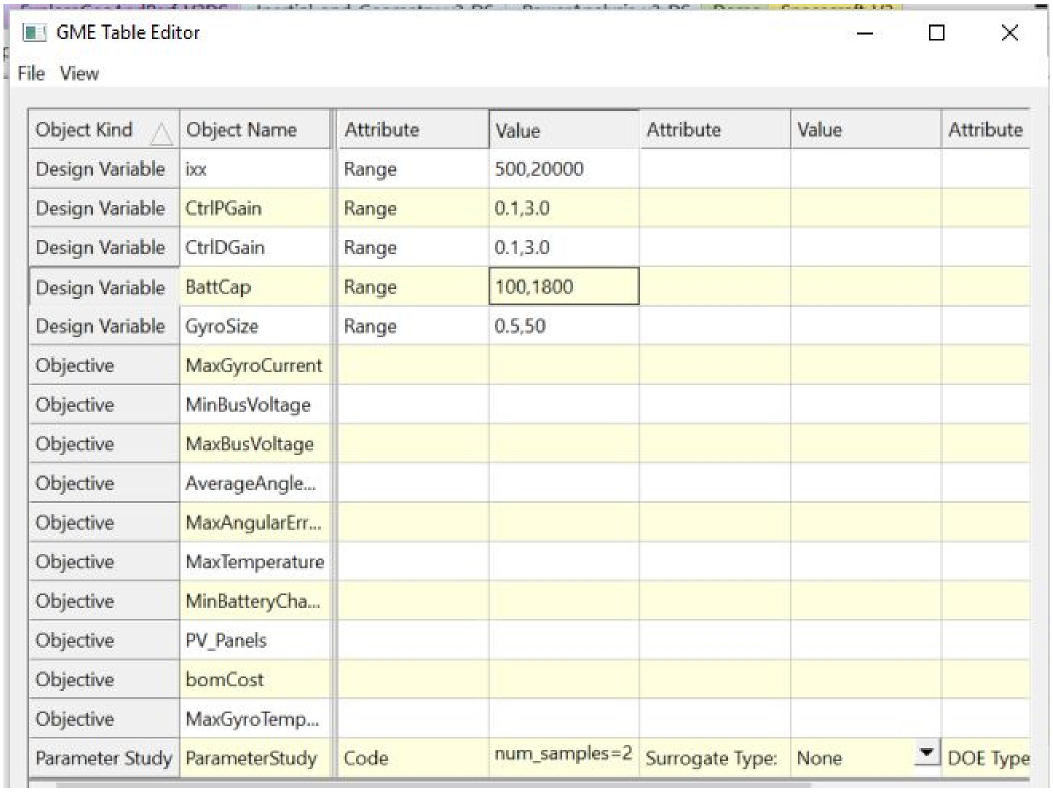
This model consists of a set of test benches, in yellow (see System Requirements Evaluation), an analysis Driver, in gray, and a connectivity of parameters and metrics.



The contents of the ParameterStudy are a set of Design Variables(variable ranges speciifed as a “from,to” pair) and a set of Objectives that specify data to be collected.

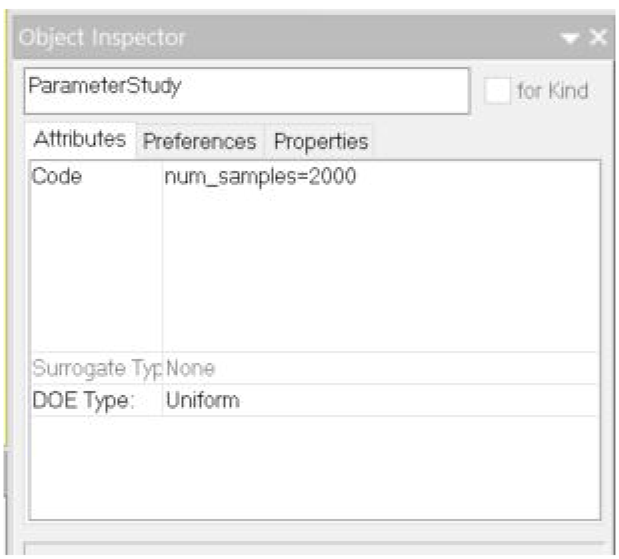


It is often more convenient to view a study in the table editor, as below.



Object Kind	Object Name	Attribute	Value	Attribute	Value	Attribute
Design Variable	ixx	Range	500,20000			
Design Variable	CtrlPGain	Range	0.1,3.0			
Design Variable	CtrlDGain	Range	0.1,3.0			
Design Variable	BattCap	Range	100,1800			
Design Variable	GyroSize	Range	0.5,50			
Objective	MaxGyroCurrent					
Objective	MinBusVoltage					
Objective	MaxBusVoltage					
Objective	AverageAngle...					
Objective	MaxAngularErr...					
Objective	MaxTemperature					
Objective	MinBatteryCha...					
Objective	PV_Panels					
Objective	bomCost					
Objective	MaxGyroTemp...					
Parameter Study	ParameterStudy	Code	num_samples=2	Surrogate Type:	None	DOE Type

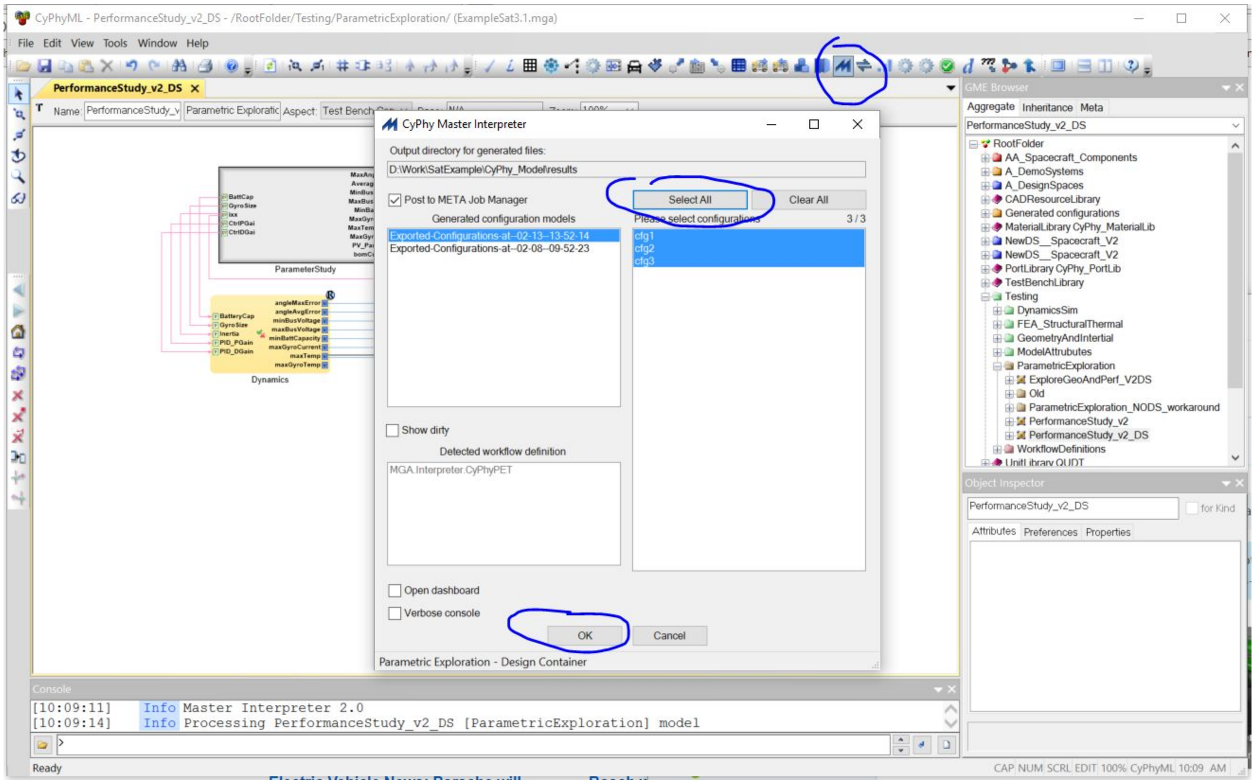
The type of sampling and number of samples are set in the properties of the ParameterStudy object:

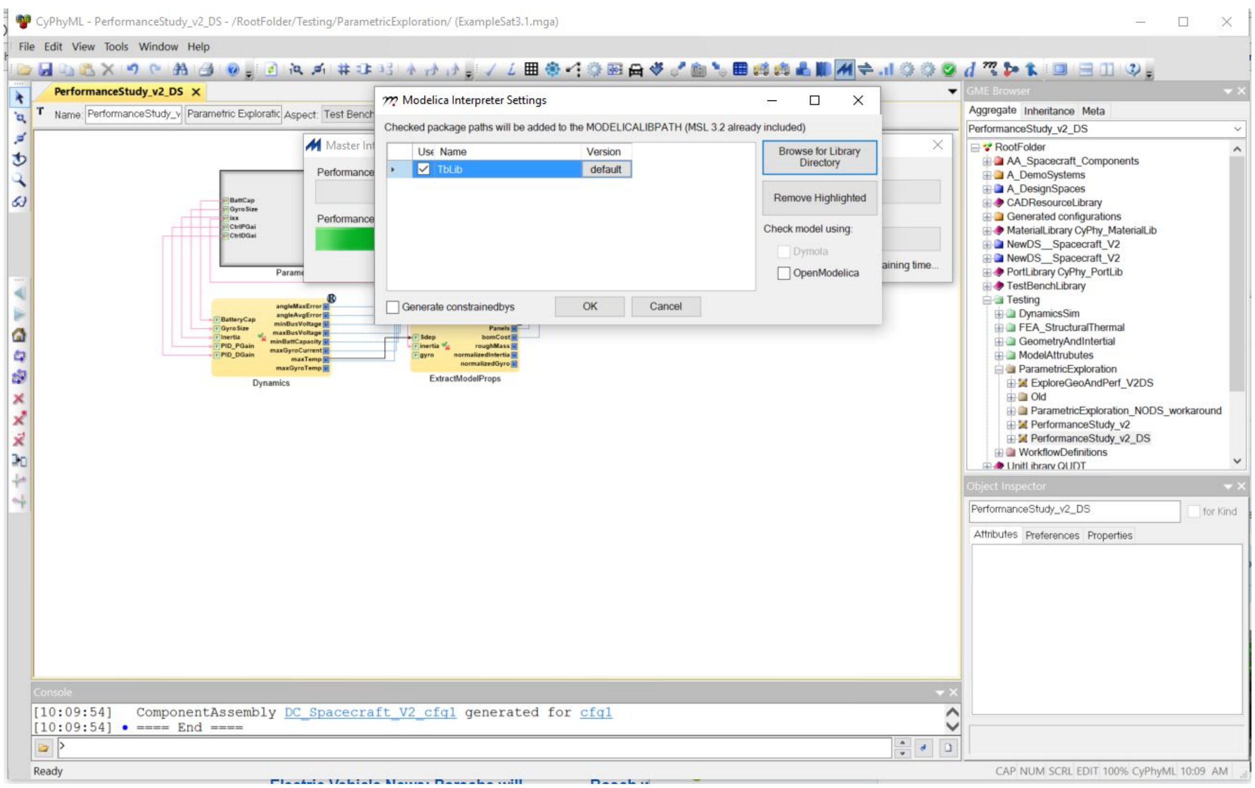


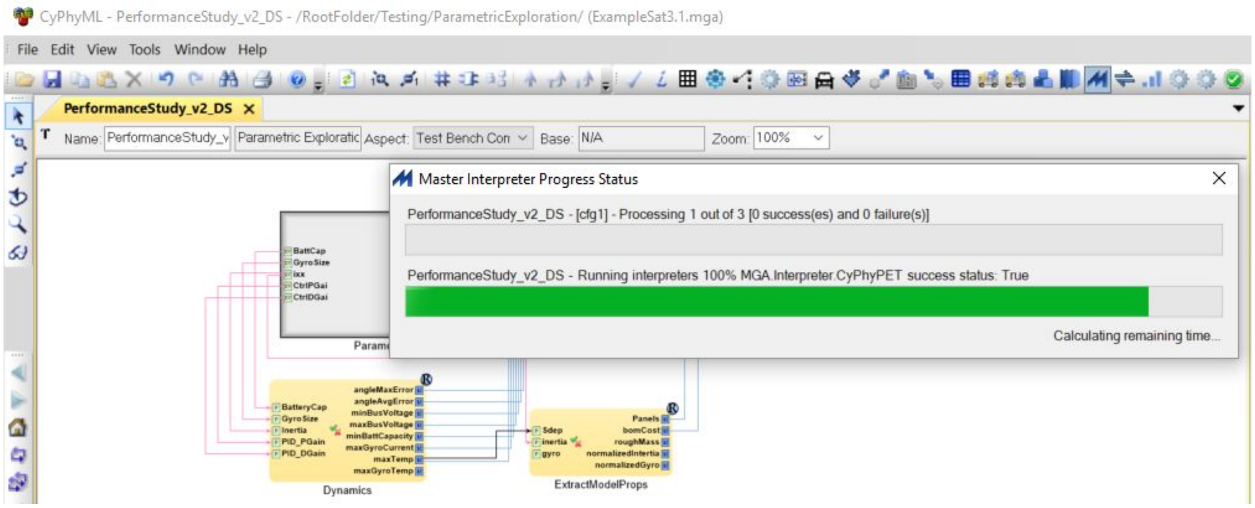
Here we request 2000 uniformly distributed samples.

Design Study Execution

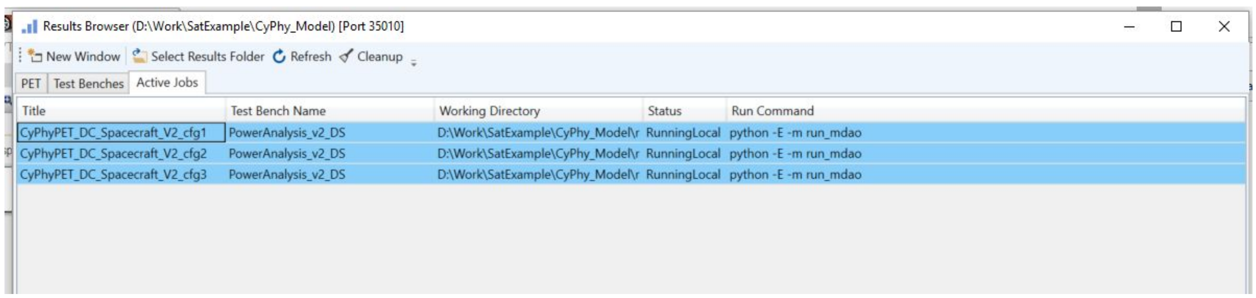
Execution is done with the “M” button, which will request the union of all the test bench queries, and allows selection of which (or all) of the design points to include in the study.


CyPhyML - PerformanceStudy_v2_DS - /RootFolder/Testing/ParametricExploration/ (ExampleSat3.1.mga)
File Edit View Tools Window Help
PerformanceStudy_v2_DS
CyPhy Master Interpreter
Output directory for generated files:
D:\Work\SatExample\CyPhy_Model\results
Post to META Job Manager
Select All
Clear All
Generated configuration models
Please select configurations
3 / 3
Exported-Configurations-at--02-13--13-52-14
Exported-Configurations-at--02-08--09-52-23
cfg1
cfg2
cfg3
Show dirty
Detected workflow definition
MGA.Interpreter.CyPhyPET
Open dashboard
Verbose console
OK
Cancel
Parametric Exploration - Design Container
ParameterStudy
Dynamics
GME Browser
Aggregate Inheritance Meta
RootFolder
AA_Spacecraft_Components
A_DemoSystems
A_DesignSpaces
CADResourceLibrary
Generated configurations
MaterialLibrary CyPhy_MaterialLib
NewDS__Spacecraft_V2
NewDS__Spacecraft_V2
PortLibrary CyPhy_PortLib
TestBenchLibrary
Testing
DynamicsSim
FEA_StructuralThermal
GeometryAndIntertial
ModelAttrubutes
ParametricExploration
ExploreGeoAndPerf_V2DS
Old
ParametricExploration_NODS_workaround
PerformanceStudy_v2
PerformanceStudy_v2_DS
WorkflowDefinitions
Object Inspector
PerformanceStudy_v2_DS
Attributes Preferences Properties
Console
[10:09:11] Info Master Interpreter 2.0
[10:09:14] Info Processing PerformanceStudy_v2_DS [ParametricExploration] model
Ready
CAP NUM SCRL EDIT 100% CyPhyML 10:09 AM

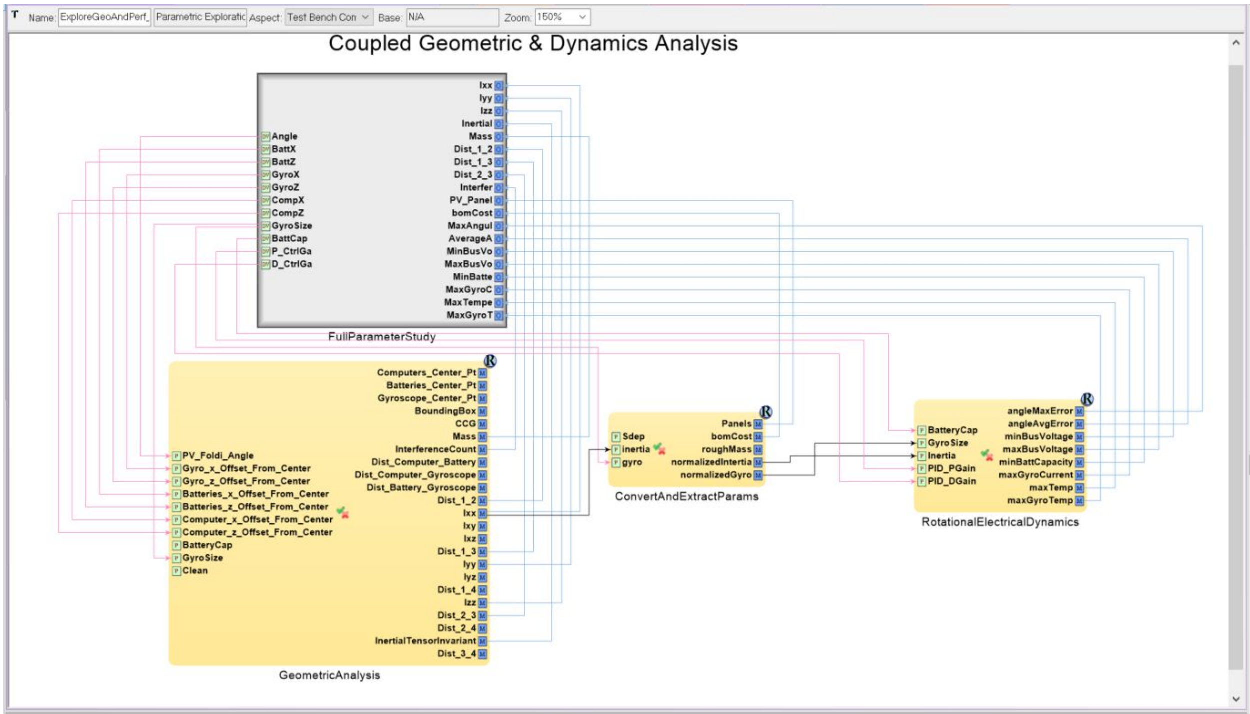

CyPhyML - PerformanceStudy_v2_DS - /RootFolder/Testing/ParametricExploration/ (ExampleSat3.1.mga)
File Edit View Tools Window Help
PerformanceStudy_v2_DS
Modelica Interpreter Settings
Checked package paths will be added to the MODELICALIBPATH (MSL 3.2 already included)
Use Name Version
TbLib default
Browse for Library Directory
Remove Highlighted
Check model using:
Dymola
OpenModelica
Generate constrainedbys
OK
Cancel
Master Int
Performance
Dynamics
ExtractModelProps
GME Browser
RootFolder
Object Inspector
PerformanceStudy_v2_DS
Console
[10:09:54] ComponentAssembly DC_Spacecraft_V2_cfg1 generated for cfg1
[10:09:54] ==== End ====
Ready
CAP NUM SCRL EDIT 100% CyPhyML 10:09 AM



Execution is performed under control of the Job Manager



A more comprehensive PET study is included, in the ExploreGeoAndPerf_V2DS.
This model, shown below, couples a the geometric test bench with the dynamics test bench.
Ths allows all positioning and sizing of components to impact the mass and inertial directly.



GME Table Editor

File View

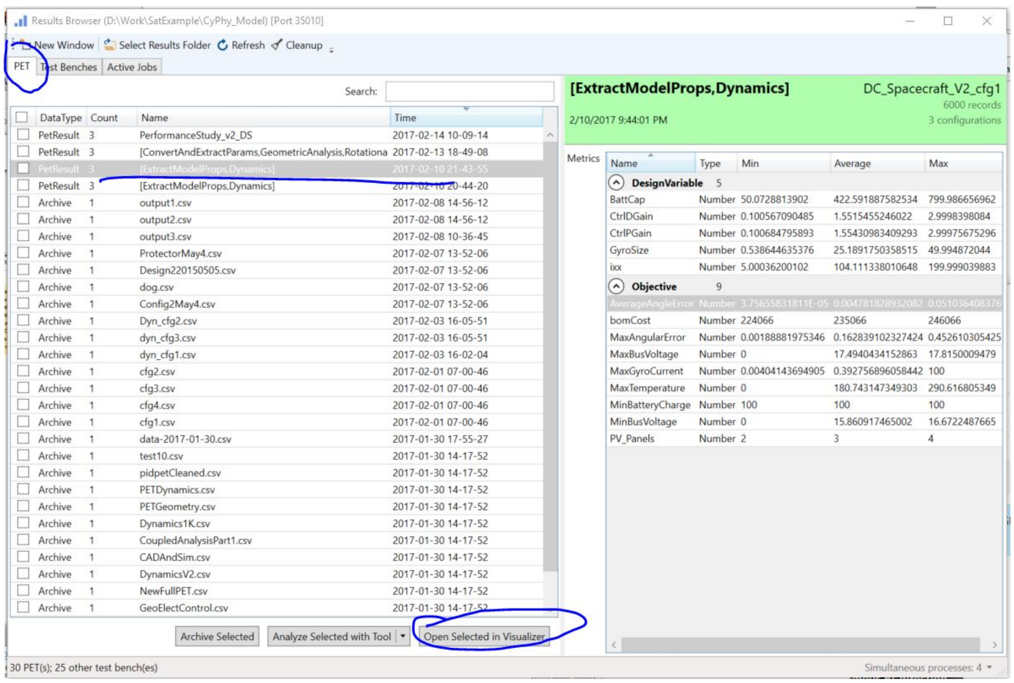
Object Kind	Object Name	Attribute	Value	Attribute	Value	Attribute	Value
Design Variable	BattCap	Range	20,800				
Design Variable	GyroSize	Range	600,3000				
Design Variable	P_CtrlGain	Range	0.1,3.0				
Design Variable	D_CtrlGain	Range	0.1,3.0				
Design Variable	BattZ	Range	0,300				
Design Variable	Angle	Range	179,180				
Design Variable	CompX	Range	0,1000				
Design Variable	CompZ	Range	0,500				
Design Variable	BattX	Range	000,1000				
Design Variable	GyroZ	Range	0,500				
Design Variable	GyroX	Range	00,1000				
Objective	Mass						
Objective	Dist_2_3						
Objective	Iyy						
Objective	PV_Panels						
Objective	bomCost						
Objective	Dist_1_3						
Objective	Dist_1_2						
Objective	InertialTensor						
Objective	Ixx						
Objective	MinBusVoltage						
Objective	Interference						
Objective	Izz						
Objective	AverageAngle...						
Objective	MaxGyroCurrent						

Design Study Visualization of Performance Study

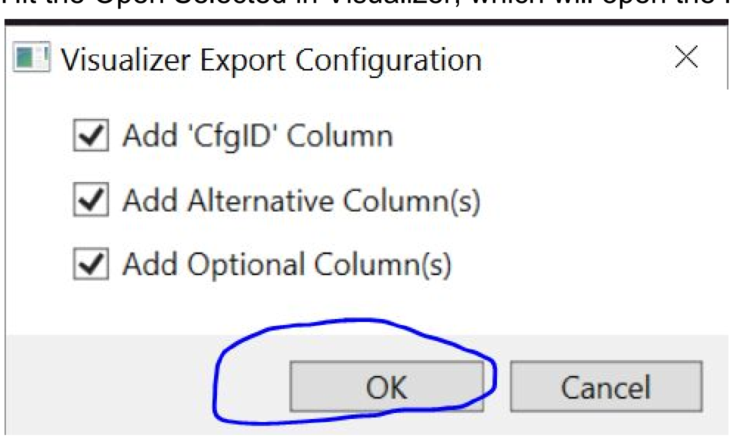
The visualizer documentation can be found here:
Visualizer Chapter:
file:///C:/Program%20Files%20(x86)/META/Documentation/HtmlDoc/visualizer.html

Start from the results browser, and select the PET tab at the top.

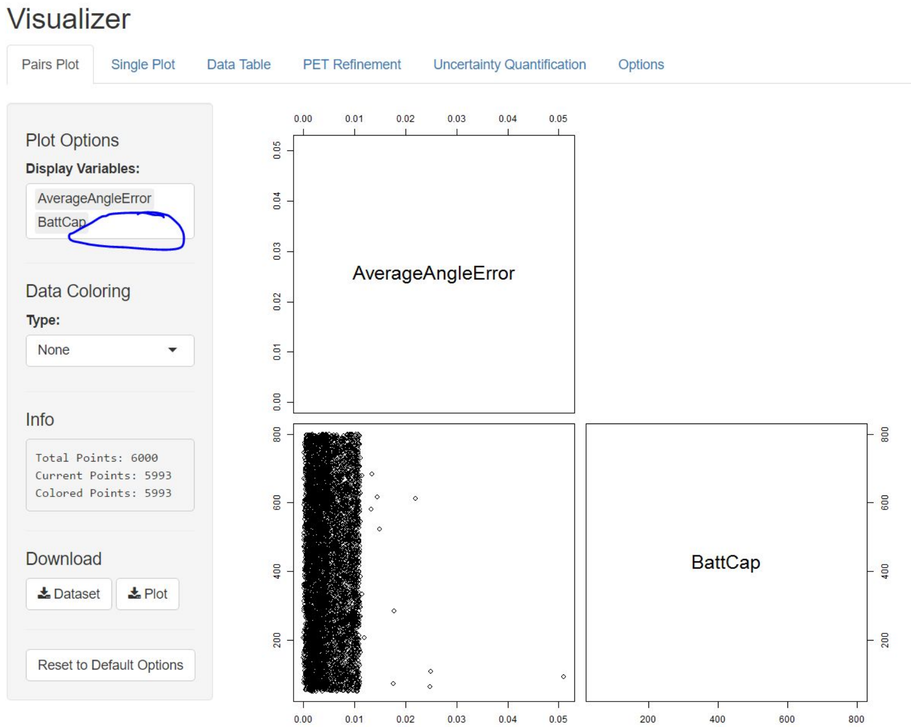
Next, pick a PetResult line. A summary of the design study is shown in the table on the right, including the design variable ranges, the number of records, and the number of design space configurations.



Hit the Open Selected in Visualizer, which will open the PET Visualizer window in a browser.



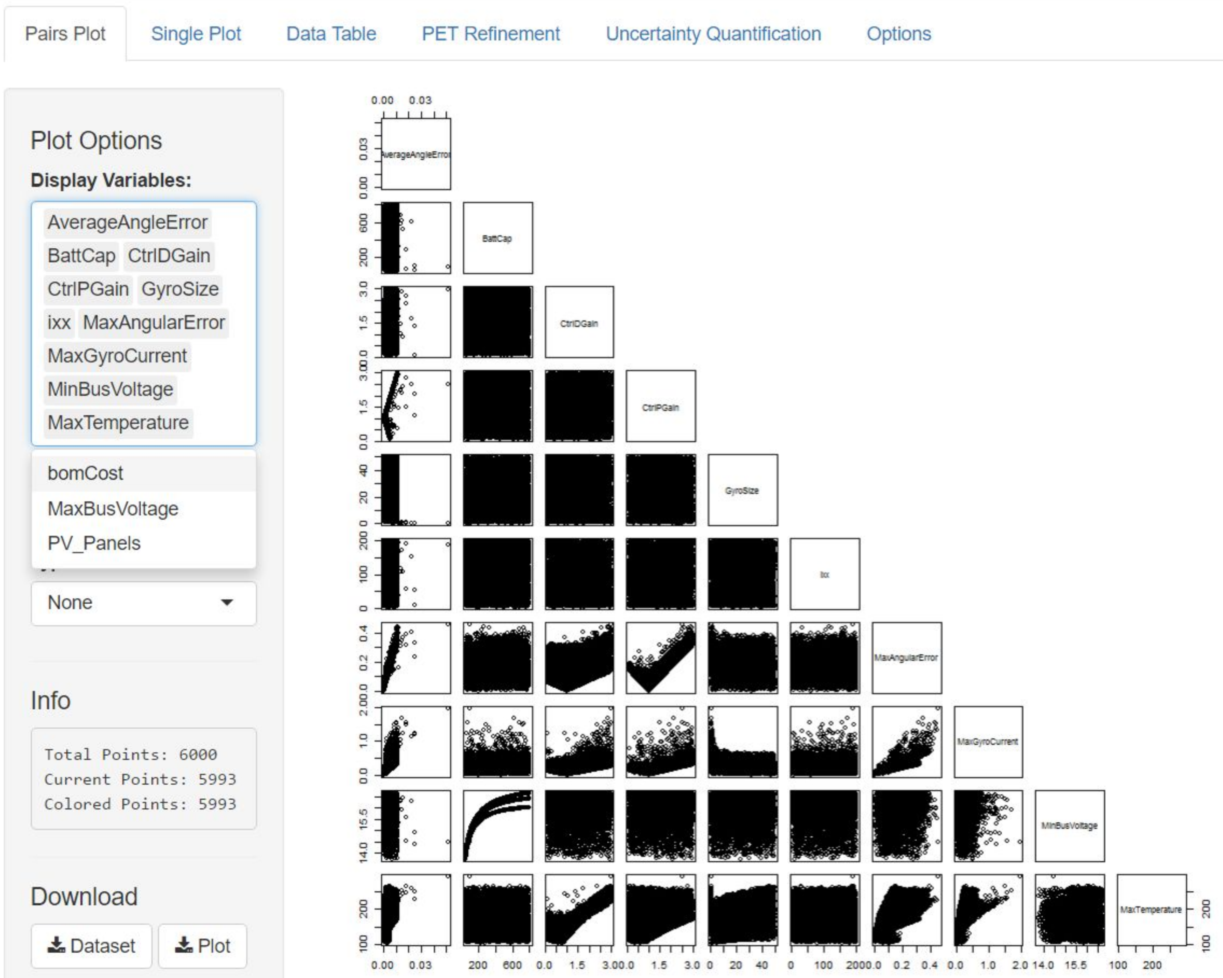
We recommend adding the extra columns, as it will permit PET data refinement features in the visualizer.



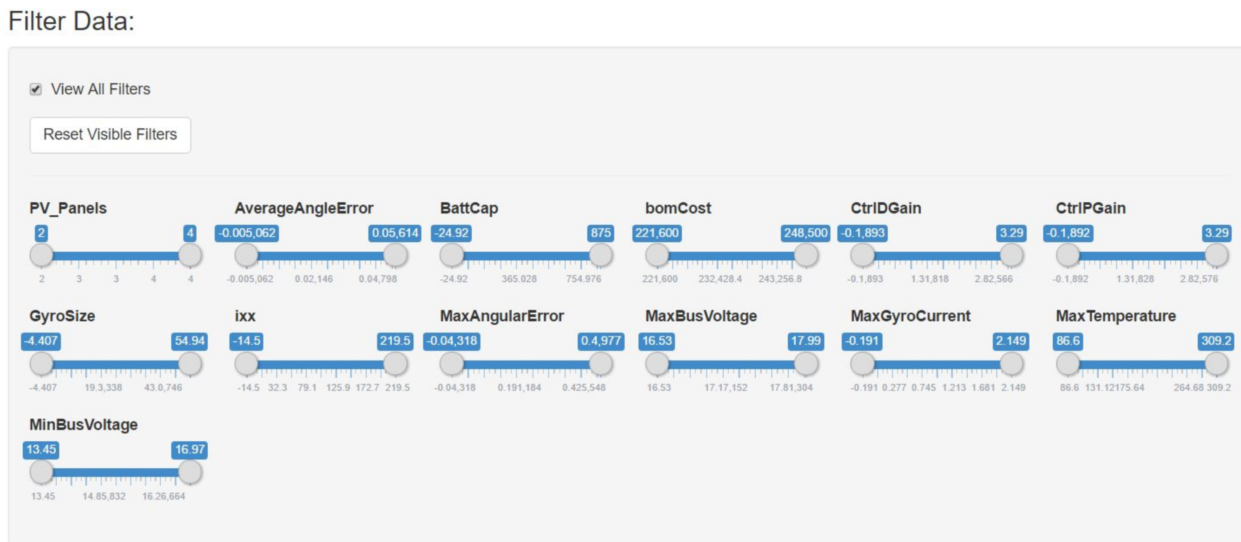
The visualizer opens with two default parameters selected. Click in the whitespace indicated to add more parameters. The figure below adds a set of interesting variables.

From the data, we can see general trends and interrelations between design variables and metrics. For example, we see a expected relationship between max Gyrocurrent and Max Temperature.

Viewing the full results set



To better explore the results, scroll down to the Filter Data section:

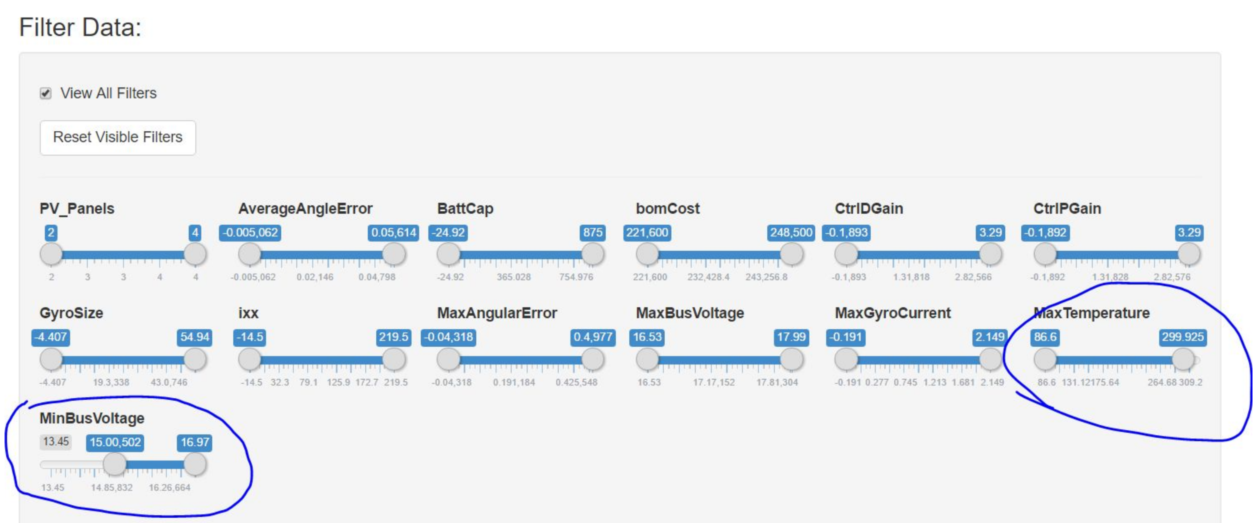


Applying Design Constraints

Here we can set constraints on data points based on metrics. Following the system requirements, we can filter out points based on temperature and bus voltage.

Requirement: *Power Bus Voltage must remain within the range of 15V to 18V.*
Method of Analysis: *Electrical Stimulation of Mission Cycle.*

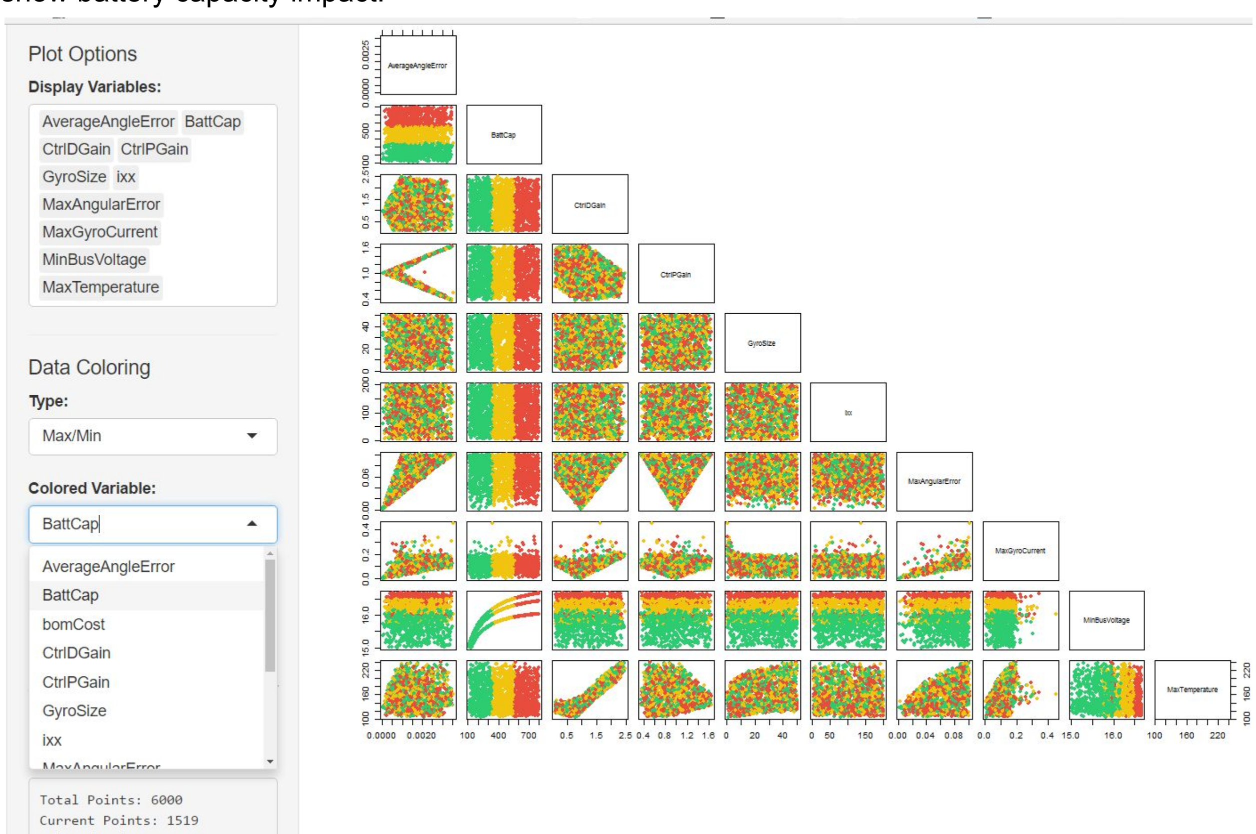
Requirement: *Maximum Temperature must not exceed 300K*
Method of Analysis: *Thermal Simulation of Mission Cycle*



The refined data set looks like this:

There are still many data points, 5388 points to be exact.

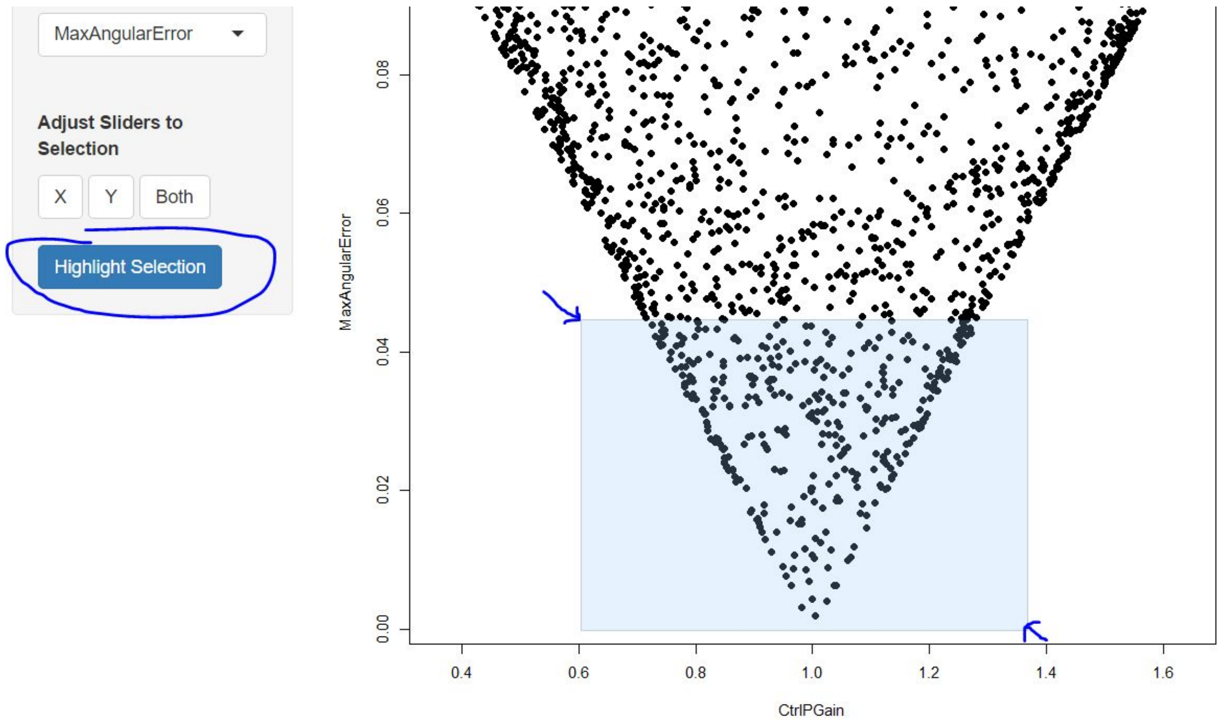
Now, we can refine to minimize max angle error. At the same time, we can adjust plot colors to show battery capacity impact:



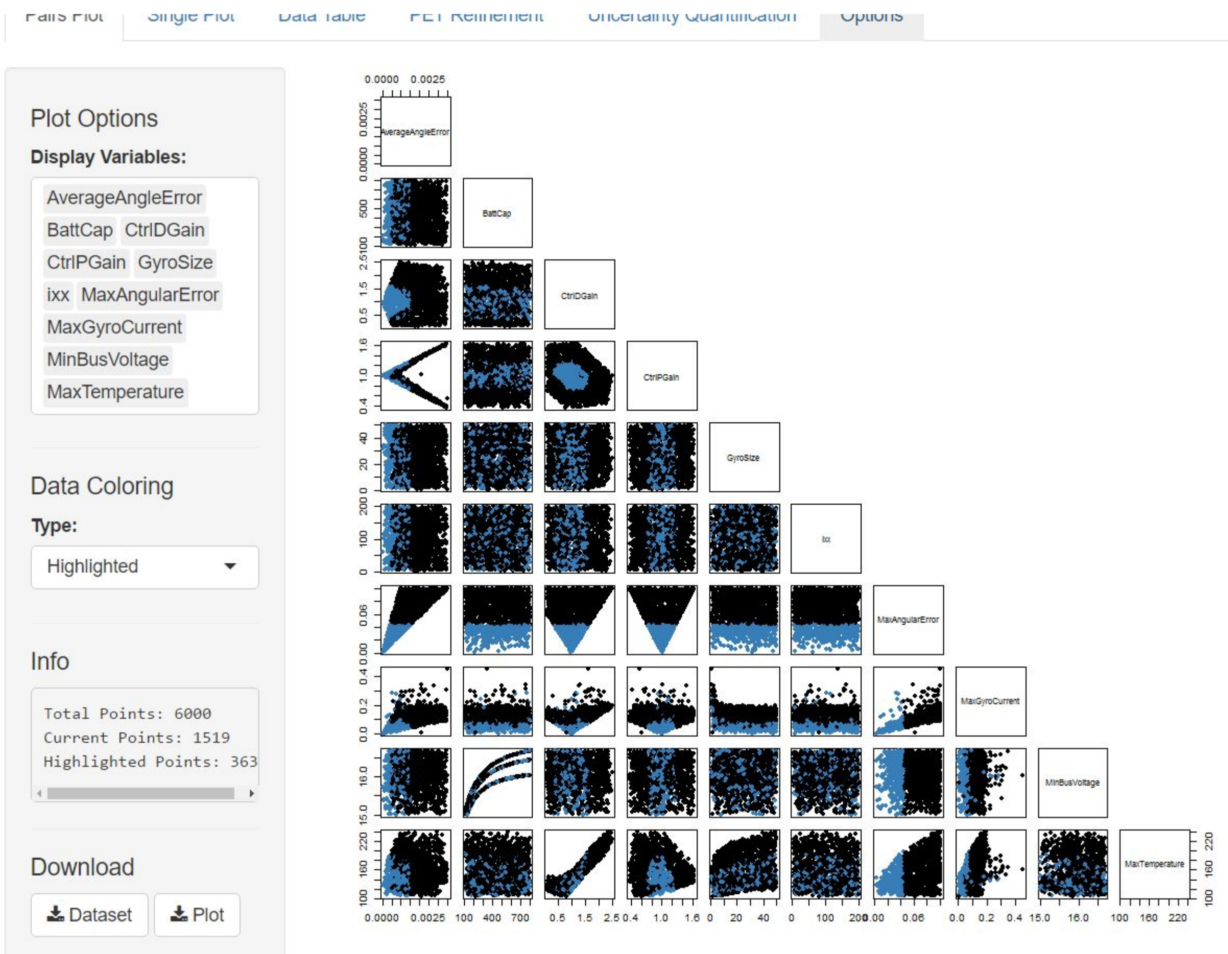
Refining to Design Goals

To focus on a single pair of parameters for example, Proportional gain vs Max Angle Error, double click on the plot at the intersection of CtrlPGain and MaxAngularError:

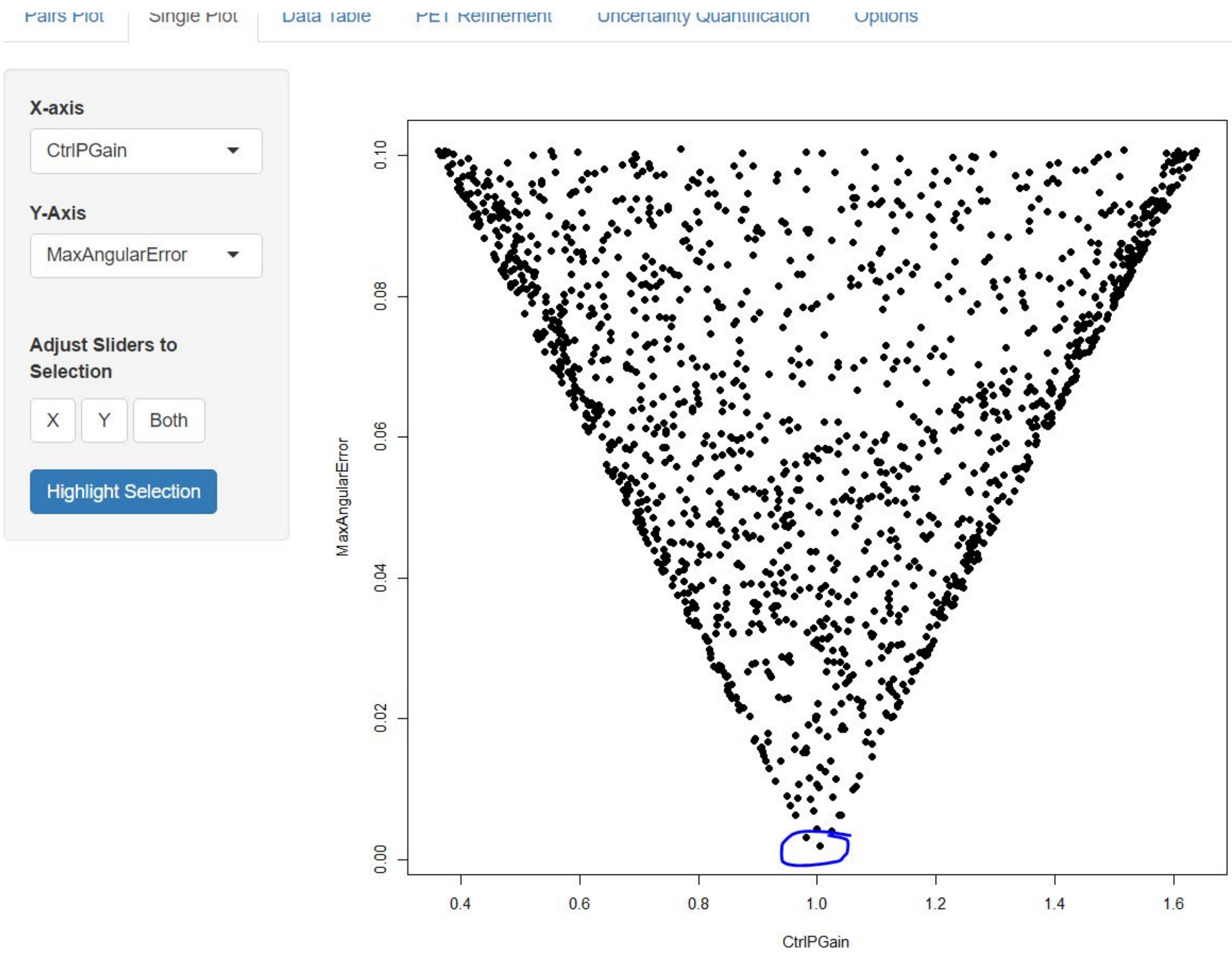
We can also select a set of points, and highlight them across the pairs plots:



And now we can view how these low-error points are distributed across other variables.


Pairs Plot
Single Plot
Data Table
PET Refinement
Uncertainty Quantification
Options
Plot Options
Display Variables:
AverageAngleError
BattCap
CtrlDGain
CtrlPGain
GyroSize
ixx
MaxAngularError
MaxGyroCurrent
MinBusVoltage
MaxTemperature
Data Coloring
Type:
Highlighted
Info
Total Points: 6000
Current Points: 1519
Highlighted Points: 363
Download
Dataset
Plot

Selecting a Design Point

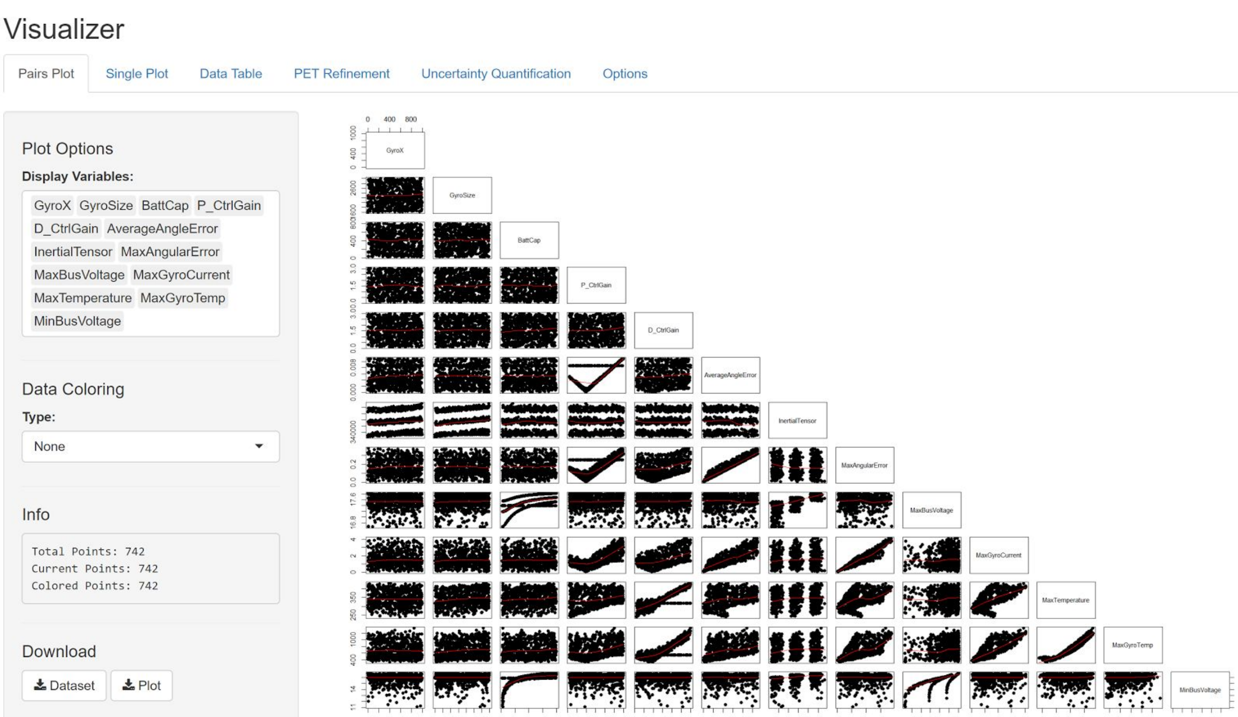


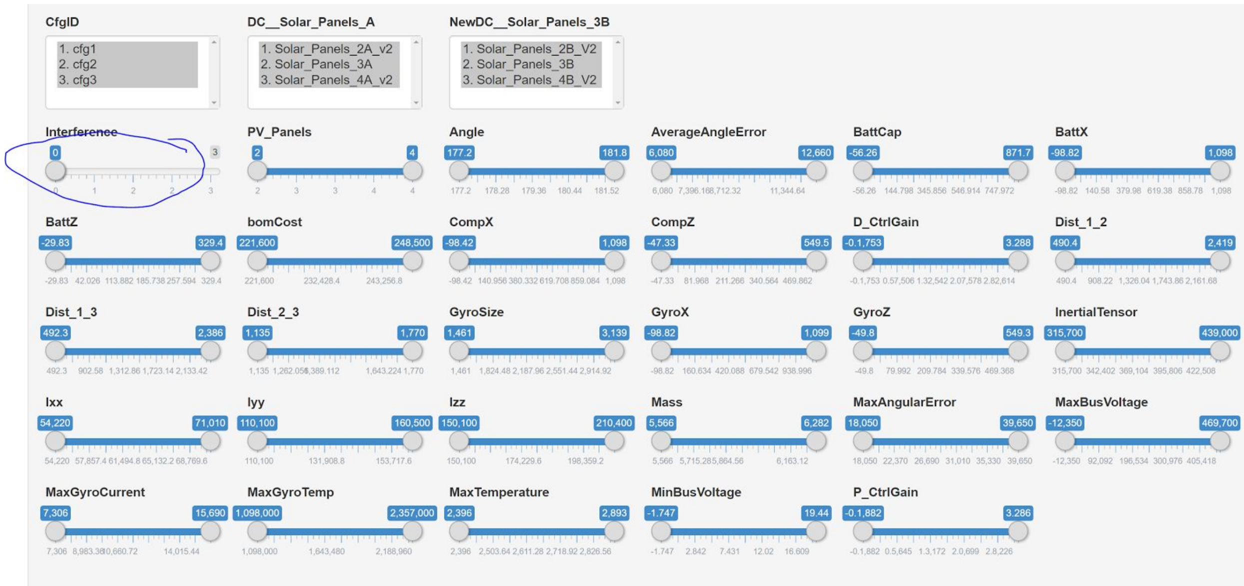
We an inspect the design values and objectives for any point by clicking on it, and scrolling down to the table:

```
                  5602
AverageAngleError "3.756558e-05"
BattCap           "206.8789"
bomCost           "246066"
CfgID             "Unknown"
CtrlDGain         "0.9633457"
CtrlPGain         "1.004439"
GyroSize          "31.49986"
ixx               "61.22731"
MaxAngularError   "0.00188882"
MaxBusVoltage     "17.6669"
MaxGyroCurrent    "0.004169783"
MaxTemperature    "129.2068"
MinBatteryCharge  "100"
MinBusVoltage     "15.74227"
PV_Panels         "4"
```

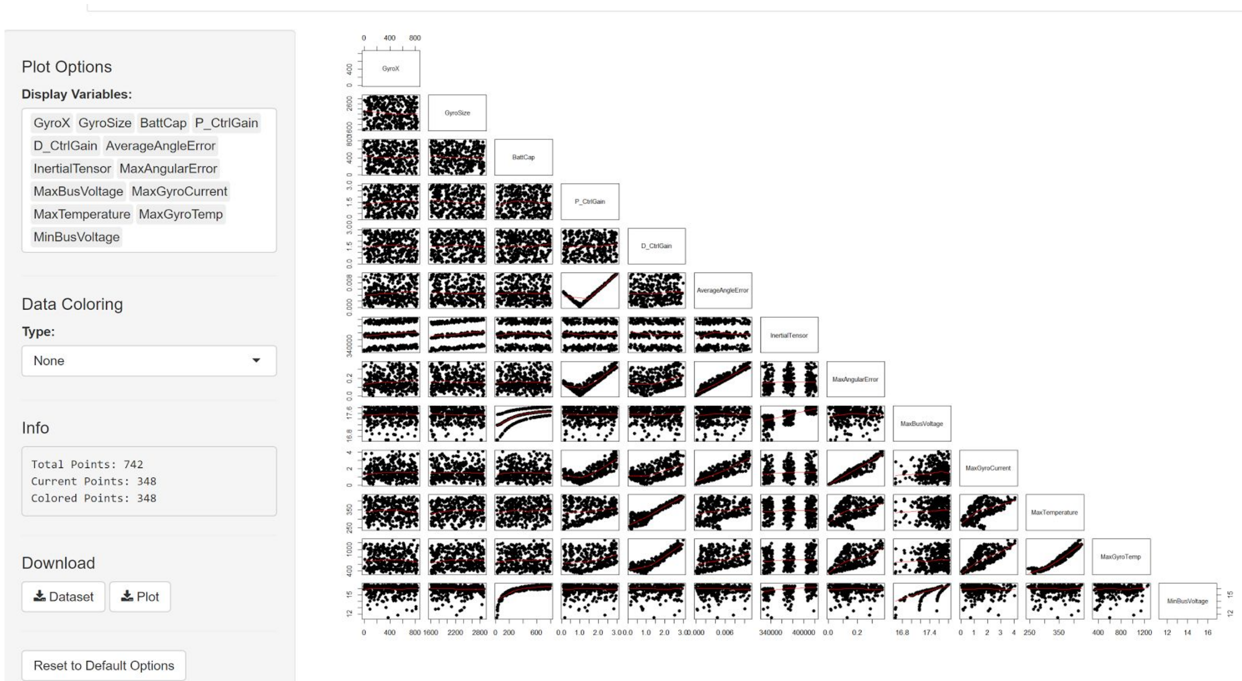
This is one of the points that warrants further inspection.

Visualizing the Coupled Geometry/Performance Design Study

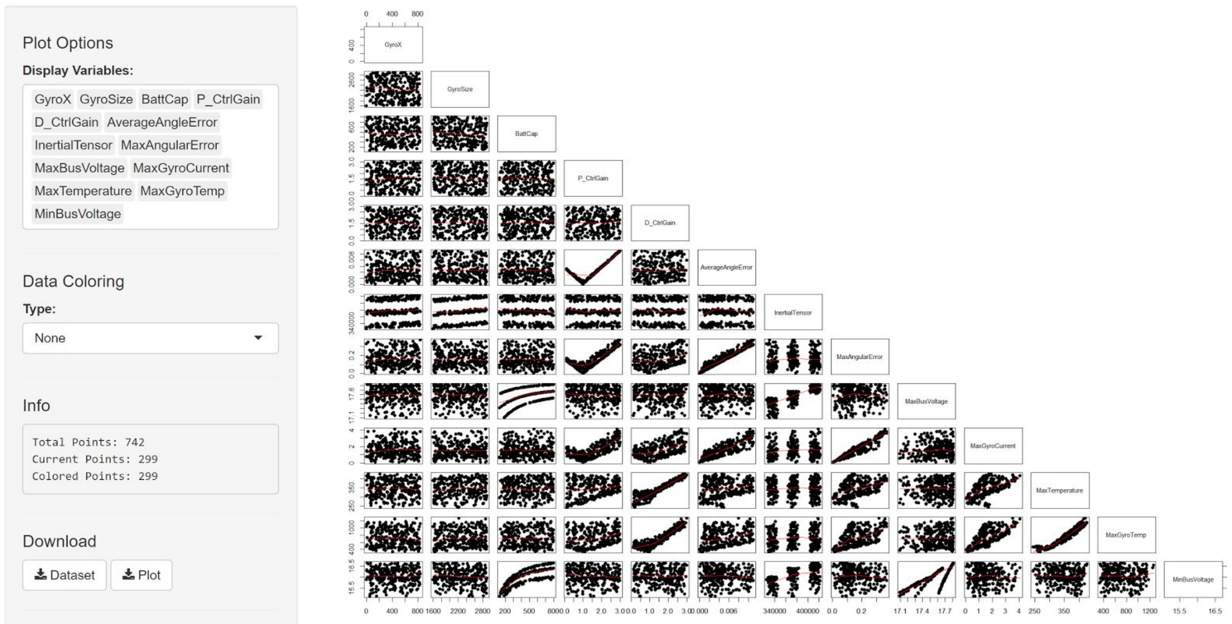




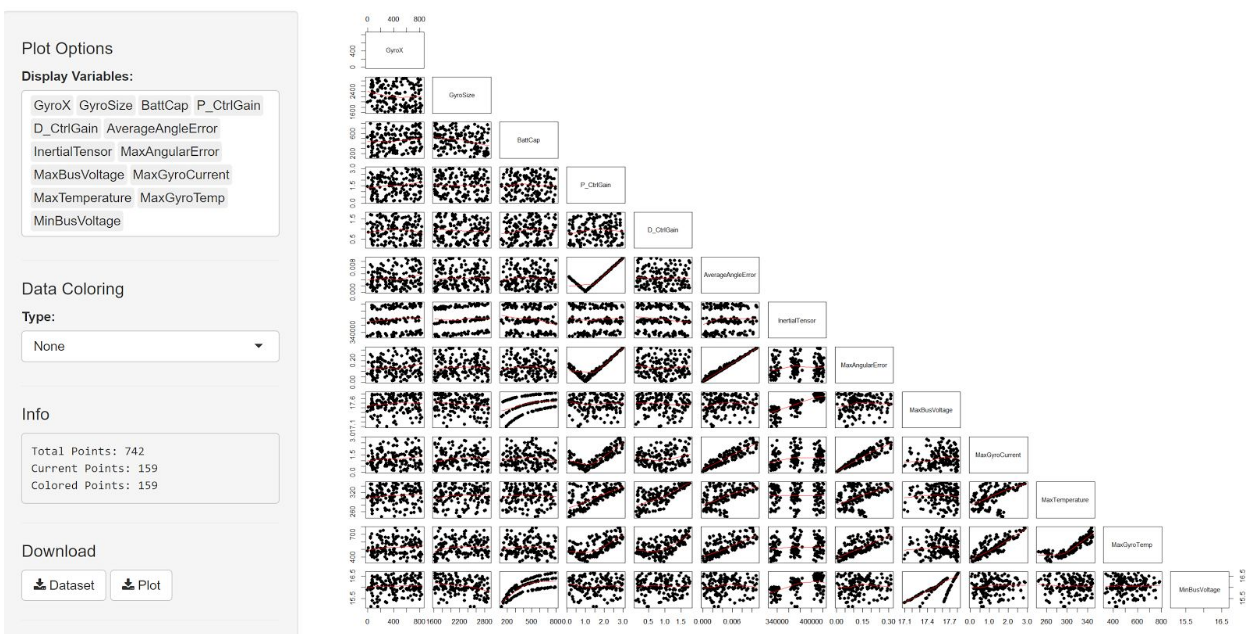
Removing all invalid physical configurations, based on interference…

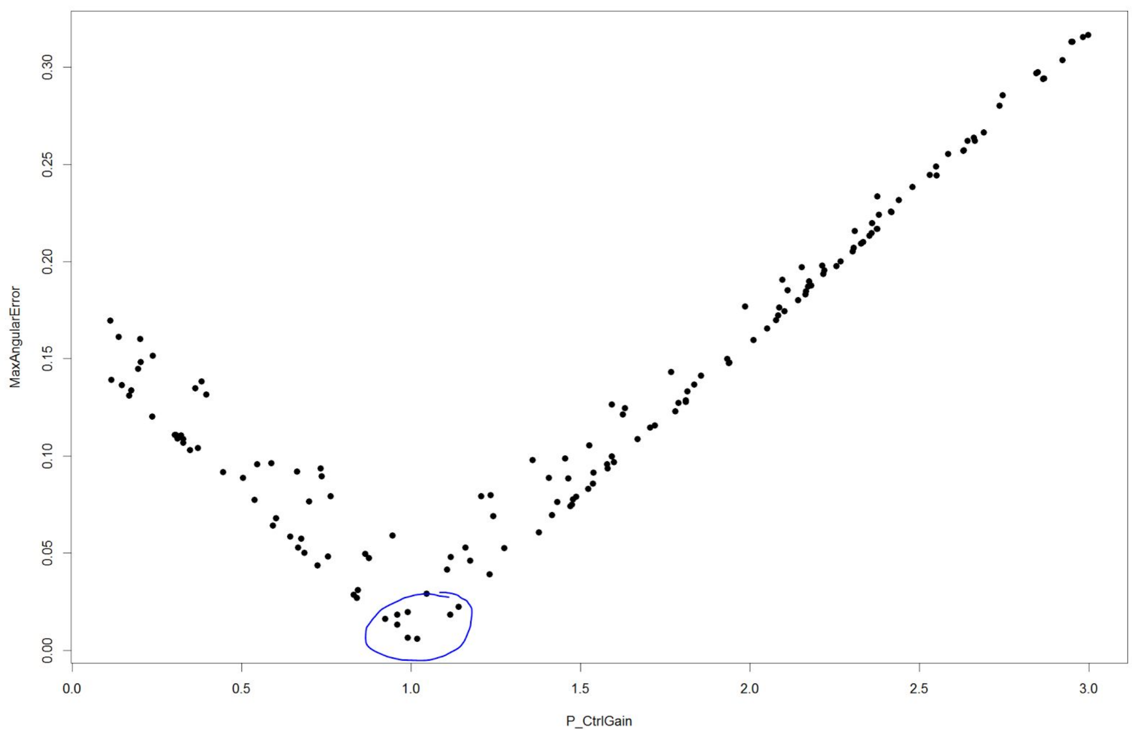


Applying minimum voltages….



Apply maximum temperature limits:



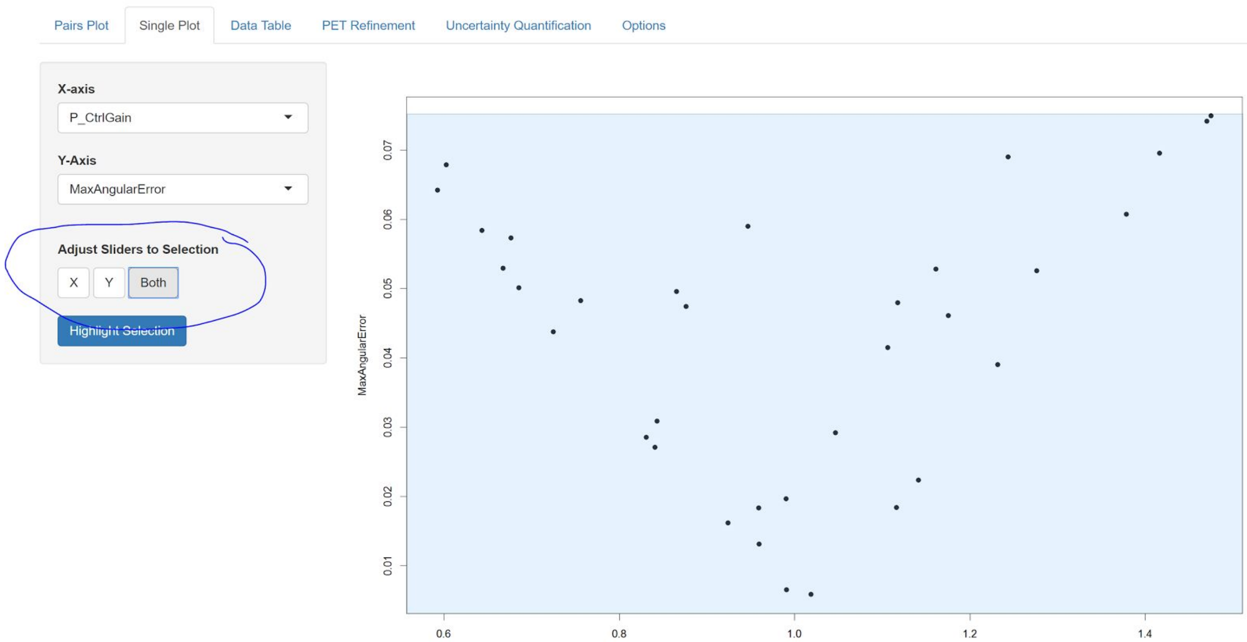


Two feasible options are shown below.

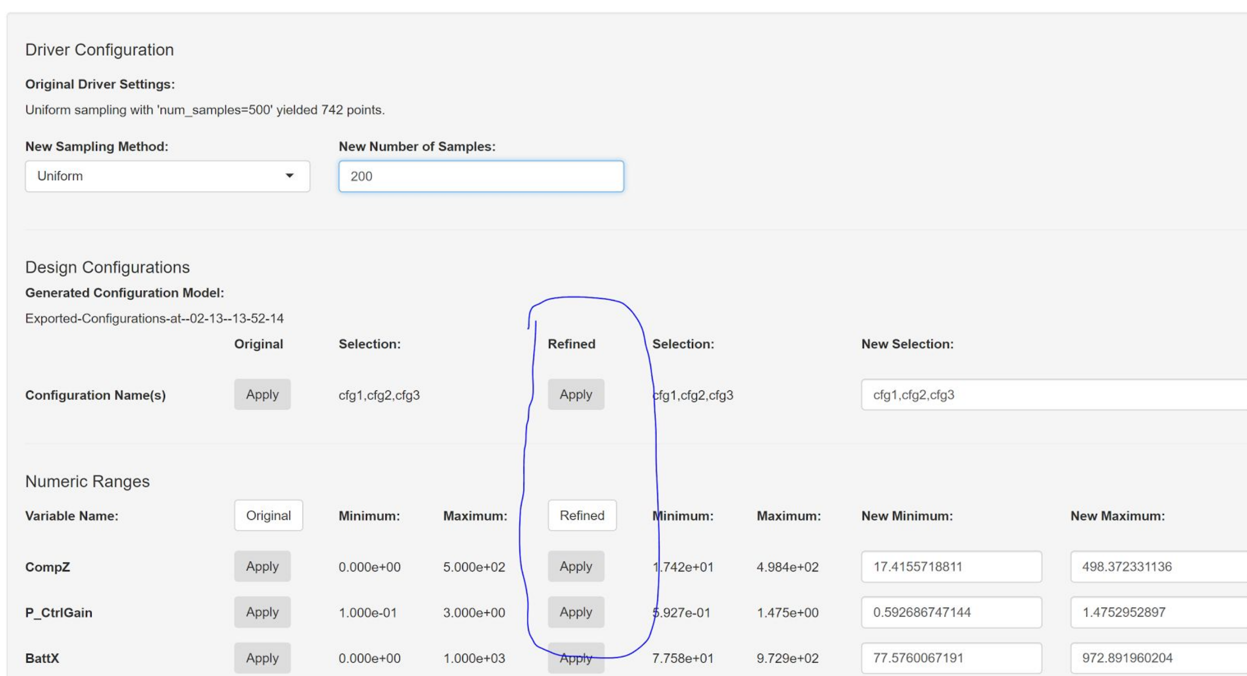
	698
Angle	"179.5801"
AverageAngleError	"0.0001193897"
BattCap	"455.243"
BattX	"719.5051"
BattZ	"151.8252"
bomCost	"235066"
CfgID	"cfg3"
CompX	"78.40062"
CompZ	"67.66559"
D_CtrlGain	"1.042488"
DC__Solar_Panels_A	"Solar_Panels_3A"
Dist_1_2	"1540.882"
Dist_1_3	"916.8412"
Dist_2_3	"2083.319"
GyroSize	"2864.49"
GyroX	"141.5065"
GyroZ	"447.5713"
InertialTensor	"378498.4"
Interference	"0"
Ixx	"66248.26"
Iyy	"132451"
Izz	"179799.1"
Mass	"5962.312"
MaxAngularError	"0.005812761"
MaxBusVoltage	"17.5767"
MaxGyroCurrent	"0.08584488"
MaxGyroTemp	"404.3577"
MaxTemperature	"297.2118"
MinBatteryCharge	"100"
MinBusVoltage	"16.16867"
NewDC__Computer	"Computer"
NewDC__Solar_Panels_3B	"Solar_Panels_3B"
P_CtrlGain	"1.018925"
PV_Panels	"3"

	483
Angle	"179.3654"
AverageAngleError	"8.525446e-05"
BattCap	"553.0887"
BattX	"972.892"
BattZ	"0.4865198"
bomCost	"246066"
CfgID	"cfg2"
CompX	"282.2916"
CompZ	"346.9657"
D_CtrlGain	"0.9125499"
DC__Solar_Panels_A	"Solar_Panels_4A_v2"
Dist_1_2	"2062.557"
Dist_1_3	"1009.691"
Dist_2_3	"1454.297"
GyroSize	"2748.022"
GyroX	"510.4951"
GyroZ	"48.19251"
InertialTensor	"418337.9"
Interference	"0"
Ixx	"67363.16"
Iyy	"150594.8"
Izz	"200380"
Mass	"6201.912"
MaxAngularError	"0.006483053"
MaxBusVoltage	"17.78314"
MaxGyroCurrent	"0.06222967"
MaxGyroTemp	"383.5365"
MaxTemperature	"288.8448"
MinBatteryCharge	"100"
MinBusVoltage	"16.4841"
NewDC__Computer	"Computer"
NewDC__Solar_Panels_3B	"Solar_Panels_4B_V2"
P_CtrlGain	"0.9909481"
PV_Panels	"4"

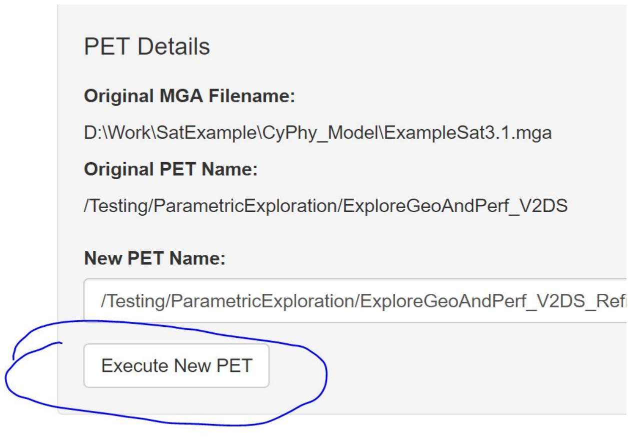
If we need more resolution in the design space, we can further restrict the ranges



And request a new design study run, via the PET Refinement Tab



After setting new ranges for the new PET study, we can request a new run



A new set of tasks will show up in the Results Browser/Job Manager's Active Jobs tab:

CyPhyPET_DC_Spacecraft_V2_cfg2	PowerAnalysis_v2_DS	D:\Work\SatExample\CyPhy_Model\r	Succeeded	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg3	PowerAnalysis_v2_DS	D:\Work\SatExample\CyPhy_Model\r	Succeeded	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg1	PowerAnalysis_v2_DS	D:\Work\SatExample\CyPhy_Model\r	RunningLocal	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg2	PowerAnalysis_v2_DS	D:\Work\SatExample\CyPhy_Model\r	RunningLocal	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg3	PowerAnalysis_v2_DS	D:\Work\SatExample\CyPhy_Model\r	RunningLocal	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg3	ExtractModelProps_v2_DS	D:\Work\SatExample\CyPhy_Model\r	RunningLocal	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg2	ExtractModelProps_v2_DS	D:\Work\SatExample\CyPhy_Model\r	QueuedLocal	python -E -m run_mdao
CyPhyPET_DC_Spacecraft_V2_cfg1	ExtractModelProps_v2_DS	D:\Work\SatExample\CyPhy_Model\r	QueuedLocal	python -E -m run_mdao

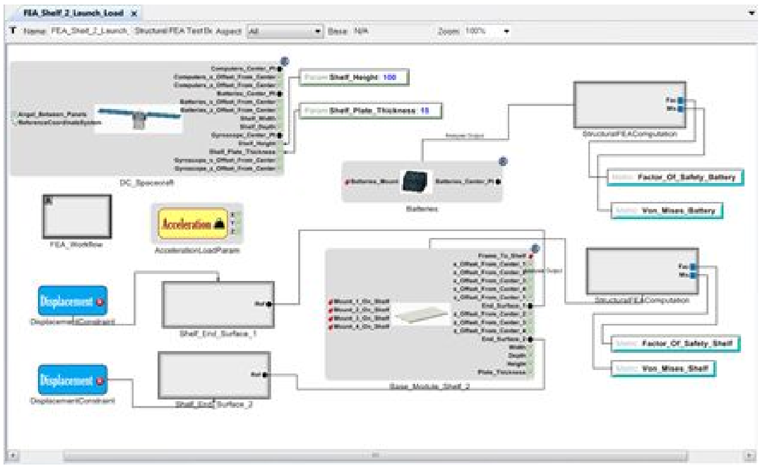
Here, we have added 3 new jobs to the currently running set. As the machine has 4 processors, one new configuration will run, while the other 2 are queued. After the jobs complete, we can view our refined design study data set.

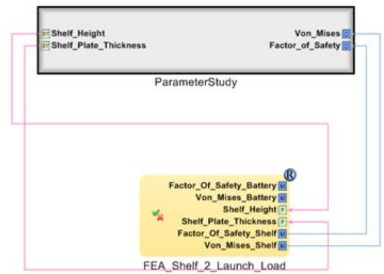
<< Add Refined Data Space>

Design Study at Deeper Abstractions: Finite Element Analysis

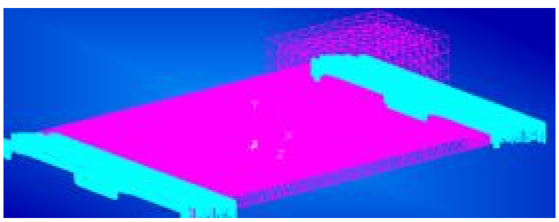
Given a design that meets all our performance and geometry requirements, we can then validate the structural integrity via a finite element

Drilling down to a deeper level of abstraction, we evaluate and optimize the design of a physical geometry component. The tools manage the execution of finite element analyses (FEA), in this case MSC NASTRAN. For the design study, a test bench and PET was created for the assessment of the battery load on the mounting shelf, based on launch acceleration loads. The test bench describes the loads and constraints on the sub-assembly (i.e. shelf and battery) and the PET iterates over dimensions (e.g. shelf height) of the shelf and submits an FEA for each dimensional variation. Figures showing the test bench and PET follow:

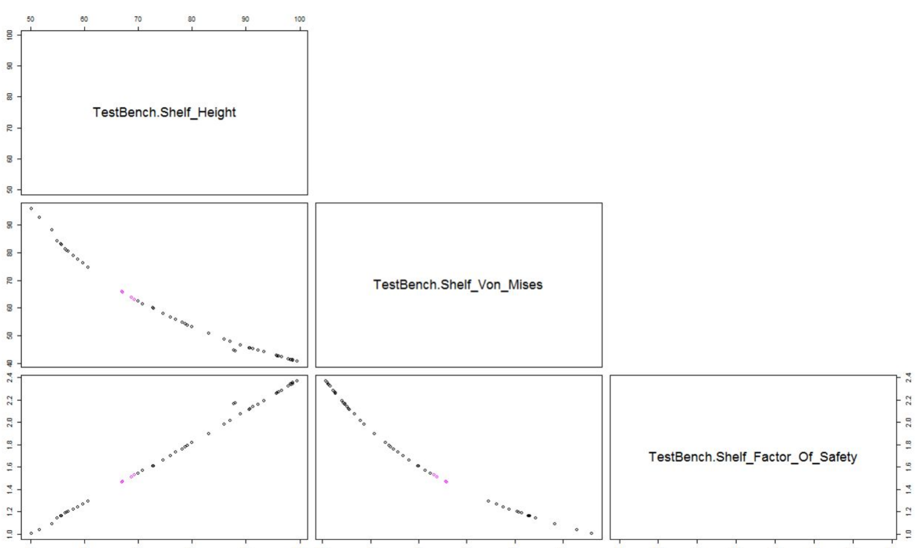




The following figures show the FEA mesh with loads/constraints and the resulting Von Mises stress contour plot for one dimensional variation:



The above FEA PET was run over 50 various shelf heights and the results are presented in the following diagram. The goal is to select the minimum shelf-height (and thus the minimum weight shelf) with an acceptable factor-of-safety.



The results show that a shelf thickness of 15 mm and height of 67 mm is sufficient to support the mass during launch, allowing the designer to minimize total system weight.

This design study shows a fully automated analysis of a complex system, using a single model, across multiple levels of abstraction. Geometric analysis was coupled with ODE-based dynamics models incorporating electrical, thermal, and mechanical analysis. These properties were evaluated over a broad design space, with a refinement into a small parametric range. Finally, the tools supported optimization of one of the components for lightweighting using detailed finite element analysis. Aside from execution time, engineering time and effort is minimized.