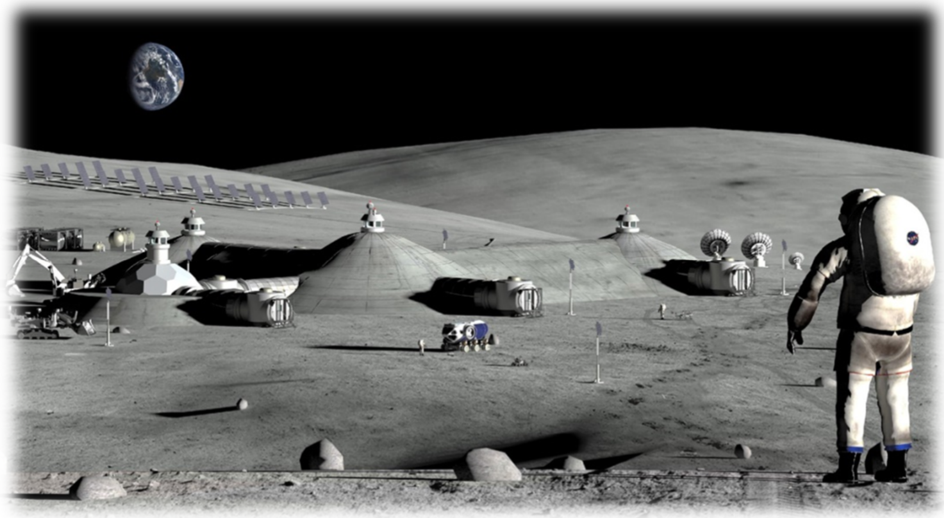
# HabSim v6.3 User Manual

*Resilient Extra-Terrestrial Habitats Institute (RETHi)*



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# Abbreviations

| | |
|---|---|
| AG | Agent system |
| CDHS | Communication and data handling |
| CPT | Cyber-physical testbed |
| ECLSS | Environmental control and life support system |
| FDD | Fault detection and diagnosis system |
| IE | Interior environment |
| IL | Intensity level |
| MCVT | Modular coupled virtual testbed |
| NASA | National Aeronautics and Space Administration |
| PW | Power system |
| RETHi | Resilient extra-terrestrial habitat |
| SPD | Smart power distribution |
| SPL | Structural protective layer system |
| ST | Structural system |

# Introduction

HabSim, formerly known as the Modular Coupled Virtual Testbed (MCVT), is a lunar habitat simulation platform based on RETHi's Reference Habitat Concept (RHC). The RHC is a conceptual habitat design created to inform the development of simulation tools, consisting of a dome with Environmental Control and Life Support System (ECLSS), power equipment, and an airlock. HabSim is a 1/5$^{th}$ scaled model of the RHC to achieve real-time simulation. HabSim simulates the subsystems required for a habitat to function and their interactions. The platforms can run nominally, or users can input disruptions to see how the habitat responds to different disruptions.

# Use of HabSim

## HabSim Visualization

HabSim supports the modeling of disruption scenarios which include both environmental and operational hazards to the system, the propagation of the system into hazardous states, and the implementation of safety control activities to enable recovery from these hazardous states. The physical distribution of the subsystems in HabSim is shown in Figure 1. The image on the left shows the outside view, with the habitat in the middle (orange circle) and the surrounding buildings and panels. The image on the right shows the habitat zoomed in with all of its internal systems.

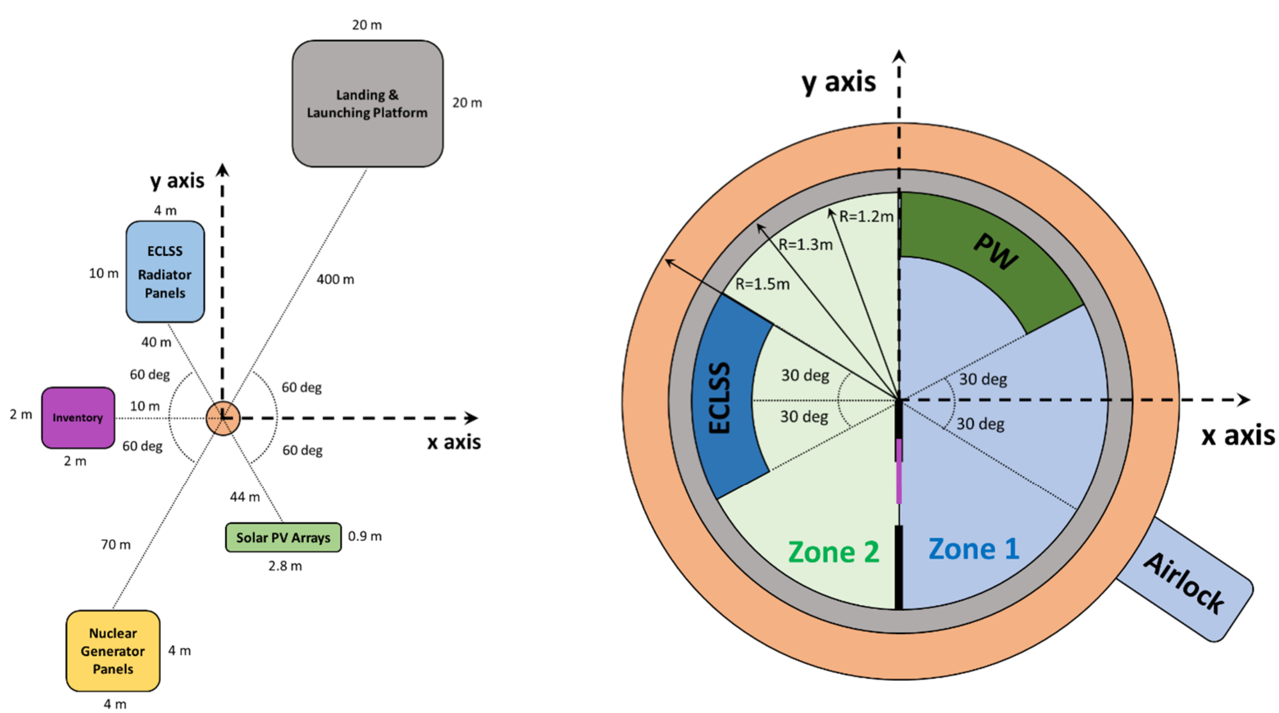



**Figure 1: HabSim v6.3 Subsystem Layout**

## Disruption Scenarios

Currently, HabSim v6.3 supports seven disruption scenarios:

1. Dust accumulation
2. Micrometeorite impact
3. Moonquake
4. Fire
5. Sensor failure
6. Cooling system cascade
7. Airlock leakage

For a micrometeorite impact, the exterior components can be impacted in three locations and the structure can be impacted in four different locations. These can be specified in the input file. For a visual of those locations, see Figure 2. For the exact values of the locations, see Table 1.

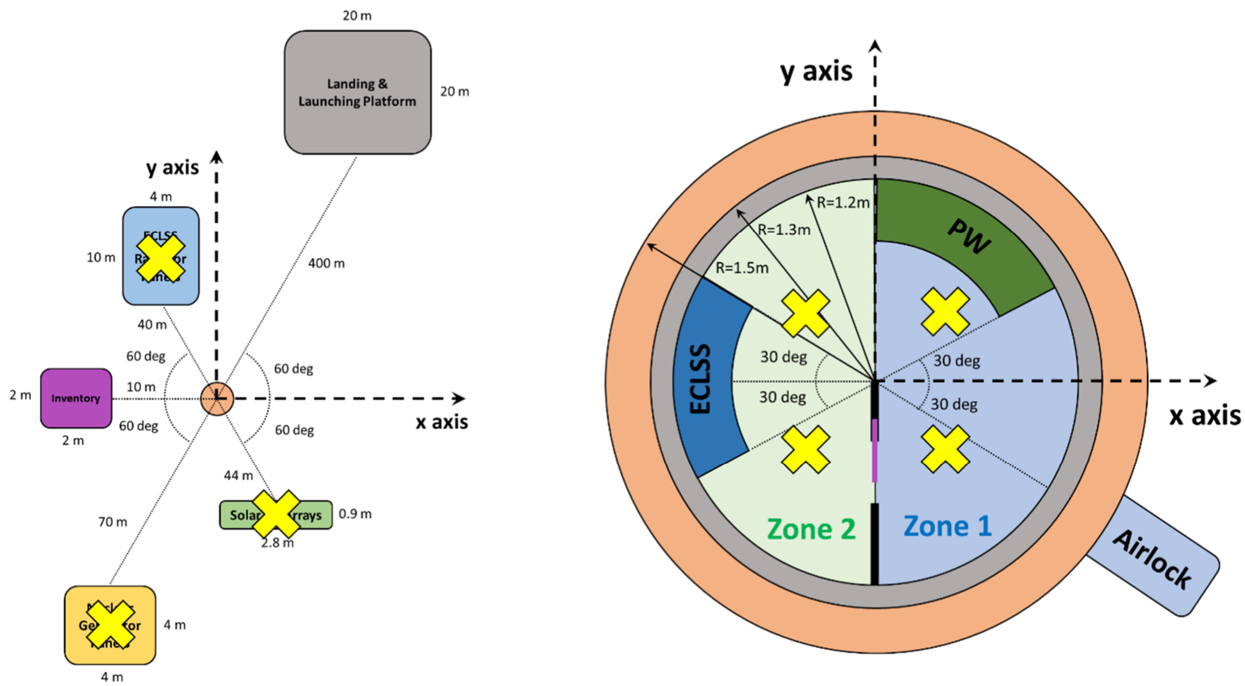



**Figure 2: Micrometeorite Impact Locations Visual**

**Table 1: Micrometeorite Impact Coordinates**

| | |
|---|---|
| On Solar Array | [+23.38, -38.92] m |
| On Nuclear Panels | [-33.80, -63.57] m |
| On ECLSS Radiator | [-22.26, +35.62] m |
| Above Power in Z1 | [+0.54, +0.54] m |
| Above ECLSS in Z2 | [-0.54, +0.54] m |
| Z1 | [+0.54, -0.54] m |
| Z2 | [-0.54, -0.54] m |

A fire in the interior environment can start anywhere within the habitat and extend radially outward as shown in Figure 3. The user can specify the starting location in the input file as [R, θ], where R is the radial location (0 < R < 1.2 m) and θ is the angle from the origin (0 < θ < 360 deg, θ ± 90, 270 deg).

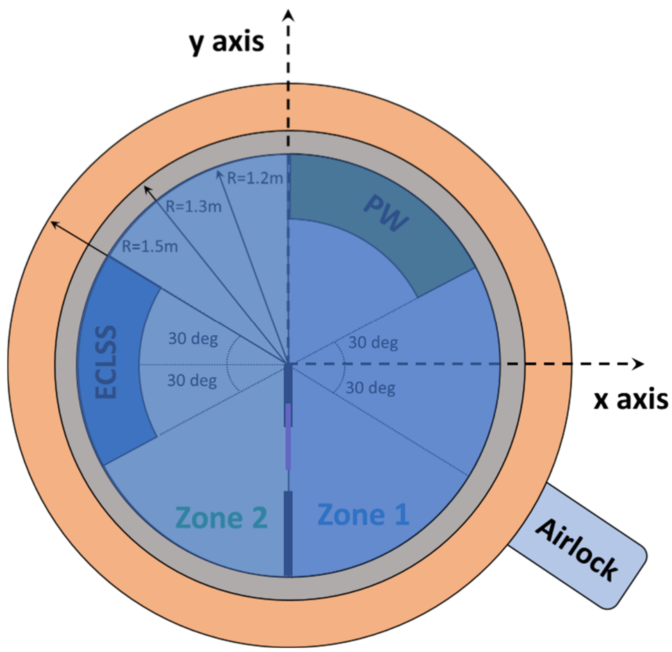



**Figure 3: Fire Start Locations in the Interior Environment (blue)**

Disruptions can originate in one or more subsystems in HabSim and potentially impact secondary subsystems, depending on the intensity of the disruption. The intensity of each disruption is controlled by a user through an Intensity Level (IL) setting in the input. These intensity levels are 1, 2, 3, 4, or 5, with severity of the disruption and resulting hazardous states increasing with the intensity. An IL of 1 means no disruptions, while intensity level of 5 is the maximum disruption effect. Users can control the intensity of each disruption, except for the launch/landing event and nominal dust accumulation. These disruptions do not have an associated intensity, but a user can specify the timing of these events and severity of dust accumulation on relevant subsystems. Those disruptions with intensities propagate differently for each intensity level.

To visualize the physical interdependencies in HabSim, Figure 4 is a matrix to show where each disruption can originate and how the disruption effects can propagate to other subsystems. Notice that there are four levels to the propagation to indicate four levels of cascading effects. Each lower-level effect cascades from the level directly above. A more in-depth flow chart of each disruption and their resulting hazardous states can be found in the Appendix section List of Disruption Scenarios.

| | 11 - SPL | 2 - Structure | 3 - Power | | | | 8 - Interior Environment | 5 - ECLSS | | | | Sensors | Appendix Figure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Solar | Nuclear | Energy Storage | Power Distribution | | Temperature | Pressure | Air | Radiator | | |
| Meteorite Impact - Structure | | | | | | | | | | | | | Fig. 10, 11, 12 |
| Meteorite Impact - Solar | | | | | | | | | | | | | Fig. 8 (left) |
| Meteorite Impact - Nuclear | | | | | | | | | | | | | Fig. 8 (right) |
| Meteorite Impact - ECLSS | | | | | | | | | | | | | Fig. 9 |
| Moonquake | | | | | | | | | | | | | Fig. 16, 17 |
| Fire | | | | | | | | | | | | | Fig. 13, 14, 15 |
| Sensor Failure | | | | | | | | | | | | | Fig. 18 |
| Launch/Landing Event | | | | | | | | | | | | | Fig. 19 (left) |
| Nominal Dust Accumulation | | | | | | | | | | | | | Fig. 19 (middle) |
| Airlock Leakage | | | | | | | | | | | | | Fig. 19 (right) |
| Cooling System Cascade | | | | | | | | | | | | | Fig. 20 |

| | |
|---|---|
| First | Initiation of disruption in HabSim model |
| Second | Potential system that can be impacted by the disruption originating in the first subsystem based on cyber or physical interdependencies |
| Third | Potential system that can be impacted by the hazardous state occurring in the second subsystem based on cyber or physical interdependencies |
| Fourth | Potential system that can be impacted by the hazardous state occurring in the third subsystem based on cyber or physical interdependencies |

**Figure 4: General Disruption Propagation Matrix for HabSim v6.3**

## Hazardous States and Safety Controls

Since each disruption can cause one or more hazardous states in the system, we further identified the hazardous states for the first subsystem where the disruption originates and the second, third, and fourth subsystems to which effects can propagate. Then, we must identify appropriate safety controls to address the original disruption and subsequent hazardous states in all subsystems. The relevant hazardous states and safety controls for the considered disruptions/failures in HabSim v6.3 are provided in the Table 1. Users will have the ability to modify the input parameters to simulate each disruption scenario and its intensity, as well as the specifications for the safety controls.

# Running Scenarios

## Installation and Access Instructions

### *MATLAB Requirements and Set Up*

Install MATLAB 2020a (link). For colleagues who are not familiar with Simulink, please check the website (link) to learn about it. After installation, check that there is a proper compiler installed (link). To check the current version of compilers in your PC, please run the command: mex-setup. If no compiler shows, click the down arrow on Add-Ons Icon, select Get Add-Ons, search for MinGW (available at no charge for Windows users) and install it. For Mac users, please install Xcode 12.x or later (link). The model can be run by using the online MATLAB version. Once MATLAB is installed, open MATLAB. In the Toolbar, click the down arrow on Add-Ons Icon and select Manage Add-Ons. See Figure 5.

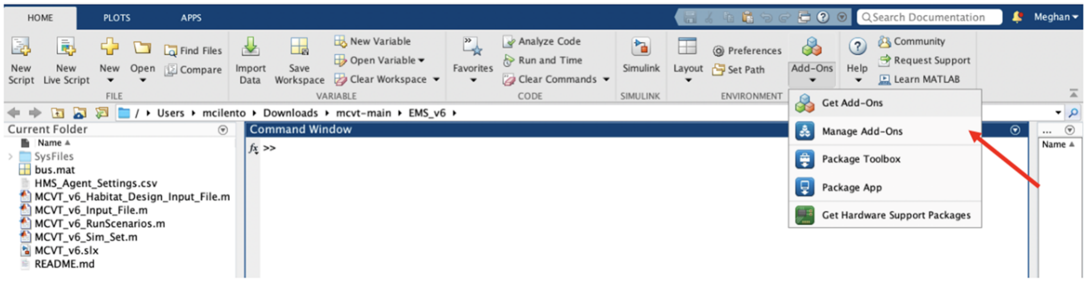



**Figure 5: Add-On Icon Selection in MATLAB Toolbar**

An Add-On Manager window will open, and in that window click Get Add-Ons. An Add-On Explorer window will then appear. Use the search bar in this window to find and install the following toolboxes:

(1) Signal Processing Toolbox
(2) DSP System Toolbox
(3) System Identification Toolbox
(4) Control System Toolbox
(5) Statistics and Machine Learning Toolbox
(6) Simulink Real-Time
(7) Simscape Electrical Toolbox
(8) Stateflow Toolbox
(9) Optimization Toolbox

If there are any errors, install the following toolbox as well:

(10) Deep Learning Toolbox

When installing these toolboxes, MATLAB will restart for each one. The installation process takes time to complete, and some toolboxes will take longer than others. You do not have to purchase any toolbox if using a university license of MATLAB. If this issue occurs, contact your advisor and/or university technology services. When all toolboxes are installed, close out of the Add-On Manager window.

## *Accessing HabSim v6.3*

Using the PCs on Purdue Campus

The RETHi offices on Purdue University campus have six PCs set up to run HabSim v6.3. The office is in the Hall for Discovery and Learning Research (DLR) 228C. The HabSim v6.3 on these computers is a baseline integrated version that is not undergoing development or testing. Log onto a PC using the provided username and password on the desk.

Ask for the most recent version of the code via Slack with the naming scheme *MCVT_v6 - ###*. Make a new desktop folder with your name and create a copy of the HabSim v6.3 folder there. Only modify the version in your folder.

Downloading on GitHub

Sign into GitHub and download the HabSim repository. Do not clone, push, or pull from this repository. A frozen version of HabSim v6.3 will be shared. Modifications to input files must be made on your local computer when running simulations.

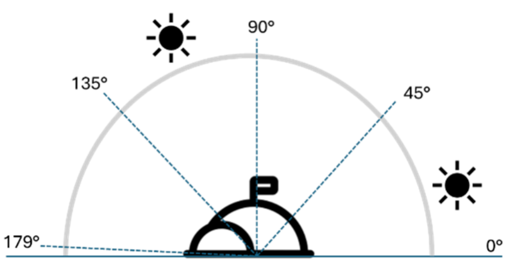
# Input Configuration

HabSim users will need to properly configure two different files to run simulations. The first is a MATLAB script titled MCVT_v6_Input_File.m. The second is an Excel spreadsheet titled Simulink_Agent_Settings.csv. Instructions on modifying each file are provided below.

## *MCVT_v6_Input_File.m*

This file houses input parameters for the HabSim simulations. Input variables are available for users to configure design specifications for several core systems, as well as disruptions that can damage the system. Table 2 provides the input parameters listed in this file as well as descriptions and units for reference.

**Table 2: Parameters Available in MCVT_v6_Input_File.m**

| | Variable Name | Accepted Values | Description | Units |
|---|---|---|---|---|
| Configuration Settings | SysFilePath* | 'SysFiles' | Where the system files are stored | N/A |
| | T_end | Any number from 1 – 2500<br>Default = 100 | Total simulation time | Seconds |
| | T_One_Earth_Day** | 24*60*60; | Length of a day on Earth | Seconds |
| | T_One_Lunar_Day** | 29.5306*24*3600 | Length of a day on the Moon | Seconds |
| | T_One_Lunar_Day_Time** | 0.5*T_One_Lunar_Day | Length of lunar daytime | Seconds |
| | dt_Saving_Data | 1 | Sampling rate for data saving | N/A |
| Nominal Condition Settings | norminal_dust_accum_rate | Any number in each index<br>Default: [0,0,0] | Dust accumulation rate without meteorite impact events on [Nuclear Radiators, Solar PV Arrays, ECLSS Radiators] | g/cm^2/s |
| | Dust_cleaning_thresholds | Any number in each index<br>Default: [13,16,50] | Agent will not be scheduled to clean the panels until the amount of dust reaches these values<br>[Nuclear Radiators, Solar PV Arrays, ECLSS Radiators] | g/cm^2 |
| | Nominal_air_leak | Any number in each index<br>Default: [2.65e-5, 2.65e-5] | Nominal air leakage in [Zone 1, Zone 2] | Meters |
| | Maint.Sys5. Fan | 0.0 | Dust accumulation rate on the fan in ECLSS | %/s |
| | Sun.Start_angle   | 0, 45, 90, 135, or 179 | Specify the start angle of solar radiation | Degrees |
| | Delay_Closing_Pocket_Door | Any number >= 0 | This can model the time it takes to evacuate one zone before closing the door or it can reflect the delay due to detecting the hazard or malfunction of the door. | Seconds |

| | | | | |
|---|---|---|---|---|
| **Nominal ECLSS Settings** | Target_Point_cooling | 1 | Cooling setpoint margin | K |
| | Target_Point_heating | 1 | Heating setpoint margin | K |
| | ECLSS_radiatorLoop_discreteNumber | Default = 50 | Number of elements in finite volume method of the radiator along its length | N/A |
| | ECLSS_radiatorLoop_LengthPerPanel | Default = 0.01 | Length of one radiator | Meter |
| | N_natural_dust | Default = 50 | Number of the panels that get nominal dust accumulation | N/A |
| **Nominal PW Settings** | solar_PV_capacity | 5.7 | Array power generation capacity | kW |
| | solar_DRatio_ini | Any value [0, 1]<br>Default = 0 | Initial dust cover ratio | N/A |
| | nuclear_power_multiplier | 1 | Nuclear power scaling factor<br>Maximum power is 5.8 | N/A |
| | ES_number_of_cells | Default = 1000 | Number of battery cells | N/A |
| | cell_energy | 0.15 | Max energy per battery cell energy | kWh |
| | Maximum_energy | ES_number_of_cells * cell_energy | Maximum energy that can be stored | kWh |
| | energy_stored_initial | 0.2*(ES_number_of_cells * cell_energy) | Initial energy stored | kWh |
| **ECLSS Settings** | ECLSS_Diameter_Relief_Valve | Default = 0.01 | Diameter of the ECLSS relief valve | Meter |
| **Agent Settings** | Sim_Agent.Ititial_Prep | Any number >= 0 | The time that takes to call and prepare Agent after a disruption scenario occurred | Seconds |

| | | | | |
|---|---|---|---|---|
| | Sim_Agent.Travel_Speed | Any number > 0 | The speed that Agent travels to go from the location of one damaged component to the location of the other damaged component | Meter/second |
| | Sim_Agent.Distance_Type | 1, 2, or 3 | 1 -> Distances all the same constant<br>2 -> Distances not including traveling to the inventory<br>3 -> Distances including traveling to the inventory | Meter |
| **Deterministic vs. Stochastic** | SD_Toggle.PW | 1 or 2 (1 is default) | (1) Deterministic, (2) Stochastic | N/A |
| **Micrometeorite Effects on PW** | SD.Sys3.Cov_3 | [1 2 3] | Number of converters damaged in case of micrometeorite impact IL 4 | N/A |
| | SD.Sys3.Cov_5 | [1 2 3 4 5] | Number of converters in case of micrometeorite impact IL 5 | N/A |
| **Decision-Making Settings** | Sys6U.agent_operational_mode | 1 | Operational mode of the agent | N/A |
| | Sys6U.settings_csv | "HMS_Agent_Settings_User.csv" | Specify PATH to the settings CSV for HMS and Agents | N/A |
| | Sys6U.test_settings_file | "Diagnostic_Test_Settings_User.csv" | Specify PATH to the settings CSV for Diagnostic Tests | N/A |
| **ECLSS** | SD_Toggle.ECLSS | 1 or 2 (1 is default) | (1) Deterministic, (2) Stochastic | N/A |
| | SD.Sys5.Dmg_fire | [3,4,5,6,7] | 3-7 can be damaged in a fire | N/A |
| | SD.Sys5.Dmg_mi | [1,2,3,4,5,6,7] | 1-7 can be damaged in a micrometeorite impact | N/A |
| | SD.Sys5.Dmg_mq | [1,2,3,4,5,6,7] | 1-7 can be damaged in a moonquake | N/A |
| | N_dmg_fire | Any integer 1-5<br>Default = 2 | The number of damaged components initially due to fire | N/A |
| | N_dmg_mi | Any integer 1-7<br>Default = 5 | The number of damaged components initially due to micrometeorite impact | N/A |
| | N_dmg_mq | Any integer 1-7<br>Default = 3 | The number of damaged components initially due to moonquake | N/A |

| | | | | |
|---|---|---|---|---|
| **Micrometeorite Disruption** | meteorite.IL | 1, 2, 3, 4, or 5 | Meteorite impact Intensity Level | N/A |
| | meteorite.impactStart | Any number > 0 | Meteorite impact start time | Seconds |
| | meteorite.coordinates | Exterior Components:<br>[+23.38,-38.92]<br>[-33.80,-63.57]<br>[-22.26,+35.62]<br><br>Dome/Interior Components:<br>[+0.54,+0.54]<br>[-0.54,+0.54]<br>[+0.54,-0.54]<br>[-0.54,-0.54] | [x ,y] meteorite impact cartesian coordinates.<br>Refer to Figure 1 and Table 2. | Meter |
| | meteorite.holeRadius_IL4 | Any number >=0<br>Recommended Range: [0 0.15] | Hole size in case of meteorite disruption with IL 4 | Meter |
| | meteorite.holeRadius_IL5 | Any number >=0<br>Recommended Range: [0 0.15] | Hole size in case of meteorite disruption with IL 5 | Meter |
| | meteorite.dustDuration | Any number > 0 | Duration of dust accumulation on exterior components | Seconds |
| | meteorite.dustAccumRate | Any numbers > 0<br>[0.9,0.5,0.2] | (1) Nuclear Radiators (2) Solar PV Arrays (3) ECLSS Radiators | g/cm^2/s |
| | SD.Sys3.ES_damage_Meteorite_IL_4 | Recommended Value: 0.3 | Remaining energy storage in case of meteorite impact IL = 4 | N/A |
| | SD.Sys3.ES_damage_Meteorite_IL_5 | Recommended Value: 0.1 | Remaining energy storage in case of meteorite impact IL = 5 | N/A |
| | SD_Toggle.ECLSS | 1 | (1) Deterministic, (2) Stochastic | N/A |
| | SD.Sys5.Dmg_mi | [1, 2, 3, 4, 5, 6, 7] | ECLSS components damaged by micrometeorite impact | N/A |
| | N_dmg_mi | 5 | The number of damaged components initially due to meteorite impact | N/A |

| | | | | |
|---|---|---|---|---|
| **Fire Disruption** | fire.IL | 1, 2, 3, 4, 5 | Fire Intensity Level | N/A |
| | fire.tStart | Any number >= 0 | Fire start time | Seconds |
| | fire.tDetection | Any number >= 0 | The time that the fire is detected | Seconds |
| | fire.polar_coordinates | [$0 \le R \le 1.2$, $0 \le \theta \le 360$] | [R, θ] R is the radial location and θ is the angle from the origin of fire initiation point. Refer to Figure 3. | [Meters, Degrees] |
| | SD.Sys3.ES_damage_Fire_IL_4 | Recommended: 0.3 | Energy storage left when fire IL 4 occurs | N/A |
| | SD.Sys3.ES_damage_Fire_IL_5 | Recommended: 0.1 | Energy storage left when fire IL 5 occurs | N/A |
| | fireSpreadRate | 0.001<br>Max: 0.007 m/s | Fire spread rate | m/s |
| | SD.Sys5.Dmg_fire | [3,4,5,6,7] | ECLSS components damaged by fire | N/A |
| | N_dmg_fire | 1, 2, 3, 4 or 5 | The number of damaged components initially due to fire | N/A |
| | fireSpreadRate | 0.001 | Fire spread rate | m/s |
| **Moonquake** | moonquake.IL | 1, 2, 3, 4, or 5 | Moonquake Intensity Level | N/A |
| | moonquake.tStart | 5 | Moonquake start time | Seconds |
| | moonquake.Duration | Any number > 50 | Moonquake duration (must be greater than 50) | Seconds |
| | SD.Sys3.ES_damage_Moonquake_IL_5 | 0.89 | Remaining energy storage after moonquake affects ES | N/A |
| | SD.Sys5.Dmg_mq | [1, 2, 3, 4, 5, 6, 7] | ECLSS components that can be damaged by moonquake | N/A |

| | | | | |
|---|---|---|---|---|
| | N_dmg_mq | 1, 2, 3, 4, 5, 6, or 7 | The number of damaged components initially due to moonquake | N/A |
| **Airlock** | airlock.IL | 1, 2, 3, 4, or 5 | Airlock failure Intensity Level | N/A |
| | airlock.tStart | Any number > 0 | Airlock start time | Seconds |
| | airlock.tDetection | Any number > 0 | Airlock fault detection time | Seconds |
| **Shuttle Launch** | launch.tStart | Any number > 0 | Start of dust accumulation due to launch/landing event (place after simulation to indicate no launch) | Seconds |
| | launch.Duration | Any number > 0 | Duration of launch | Seconds |
| | launch.Exhaust_Intensity | 50 | Dust intensity parameter for engine exhaust | mg/cm^2/s |
| **Nuclear Cooling leak** | CoolantNuclear.IL | 1, 2, 3, 4, or 5 | Nuclear cooling intensity level | N/A |
| | CoolantNuclear.tStart | Any number > 0 | Nuclear cooling leak start time | Seconds |
| | CoolantNuclear.tDetection | Any number > 0 | Nuclear cooling detection time | Seconds |
| **Sensor failure** | sensorFault.*generalsensor*_IL | 1, 2, 3, 4, or 5 | Sensor failure Intensity Level | N/A |
| | sensorFault.*generalsensor*_tStart | Any number > 0 | Sensor failure start time | Seconds |

* = Do not change.

** = Added for debugging purposes. Use this scaling feature at your own discretion.

### *Simulink_Agent_Settings.csv*

This spreadsheet houses the input parameters that configure how an agent responds to the hazardous states that occur during HabSim simulations. Each hazardous state has an associated agent safety control to repair the damage and enable recovery back to a nominal state. Table 3 provides descriptions, units, and appropriate values for the relevant columns that users must modify to configure the repairable features in the HabSim.

The first four columns identify the subsystem and what needs to be fixed. System/Subsystem/Component, Location, Index, and Failure Mode (ID) are for identification purposes and do not need to be changed. T2F schedules the agent. The user lists the first component they want repaired with "1," the second with "2," and so on. All boxes do not need to be filled, only as many as the user wants to fix. If no columns of T2F are filled, there will be no agent action.

Repair Rate allows the user to change the rate of the repair activity. This can be changed to reflect different safety controls or implementation strategies in use. Depending on the repair rate, the task may or may not be completed to enable full recovery, but only repair partially during the set time frame. Some trial and error might be necessary to determine the repair rate that will be appropriate to enable the desired repair behavior.

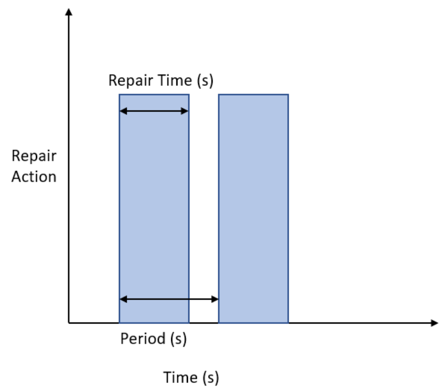
Repair Time reflects how long the agent is available to repair the damaged component. If the agent is set to stochastic, the agent will work for specified Repair Time. During the repair time frame, the agent will complete the task at the set Repair Rate. These will determine the time an agent works to complete the corresponding repair activity. This time frame is not how long it takes to have full recovery, but rather how long the user allows the agent to work on that activity.

The Period is the repair time plus the amount of time the agent is waiting to start the next operation. It can be seen visually in the Agent Repair Action plots as the distance between the two rising edges of agent action (see visual in table column). The period must be larger than the Repair Time.

**Table 3: Parameters Available in Simulink_Agent_Settings.csv**

| **Column Name in Spreadsheet** | **Parameter Description** | **Units** | **Acceptable Values** | **Comments** |
|---|---|---|---|---|
| **System/Subsystem/ Component** | The affected system | N/A | Do not change | Lists the top system. |
| **Location** | Affected system component | N/A | Do not change | Lists the component and/or what is wrong with it. |
| **Index** | List from top to bottom of everything | N/A | Do not change | List 1-119 items in order. |

| | | | | |
|---|---|---|---|---|
| **Failure Mode (ID)** | Used to identify the failure mode within repair actions | N/A | Do not change | Identification numbers starting with:<br>5 = ECLSS<br>3 = Power<br>2 = Structure<br>11 = SPL<br>8 = Interior Environment |
| **T2F** | Repair Priority | N/A | Nonnegative integers | Sets the scheduling of the agent repair activities. They are scheduled based on the chronological order of values in this column.<br><br>Repair activities with the smallest integer values will be scheduled first by command and control.<br><br>1 = repaired first<br>2 = repaired second<br>3, 4, 5… |
| **Repair Rate** | The rate of the repair activity | Depends on repair type | Depends on repair type | Use different repair rates for each safety control. |
| **Min Repair Rate** | The minimum value for the repair activity | Depends on repair type | Do not change | Suggested value for the minimum possible repair rate. |
| **Max Repair Rate** | The maximum value for the repair activity | Depends on repair type | Do not change | Suggested value for the maximum possible repair rate. |
| **Repair Time** | Time the agent is available to repair the damaged component. | Seconds | Nonnegative | The width of the square wave we are seeing in the agent repair action plot. |
| **Period** | The repair time + the time the agent is waiting to start the next operation. | Seconds | Nonnegative, Period > Repair Time | The distance between two rising edges in the agent repair action plot. |




| | | | | |
|---|---|---|---|---|
| **Recommended Repair Time** | The recommended time for the agent to be available for. | Seconds | Do not change | Suggested value for the agent to be available. |

## How to Run a Simulation

HabSim is composed of many MATLAB, Simulink, and Excel files. Table 4 shows the three most important files for the regular user:

**Table 4: Files for Using HabSim**

| **File Name** | **Description** |
|---|---|
| MCVT_v6.3_Input_File.m | MATLAB script is used to change the inputs of HabSim to represent different habitat settings and disruptions |
| MCVT_v6_3_RunScenarios.m | MATLAB script is used to start the entire simulation, give updates throughout, and plot data. |
| Simulink_Agent_Settings.csv | Excel spreadsheet that tells the agent what to fix and when. |

When the input files are configured to run your desired scenario, you should first make sure that you **save** the updated input files (MCVT_v6_Input_File.m and Simulink_Agent_Settings.csv). Then, open the script MCVT_v6_RunScenarios.m. This script is set up to call the two input files already modified. The simulation will continue with the status printing out at your set print interval. Monitor the command window in case any errors are thrown. Otherwise, once the simulation is complete, the output data will be written to the output folder specified in the input file. See the next section for information on the output data from HabSim v6.3 and which variables are relevant for each disruption scenario.

# Quick Start

1. Open two MATLAB files: MCVT_v6.3_Input_File.m and MCVT_v6_3_RunScenarios.m.
2. In the Input File script, uncomment lines 18-19. This will save your data.
3. In the Run Scenarios script, uncomment lines 34-46. This will run the code.
4. Chose a plotting script to write in line 44 to replace the Plot_Data placeholder.
5. Delete lines 43 and 46.
6. Click the green arrow to run the Run Scenarios script.

Figure 6 shows the updates printed in the command window as the HabSim code is running:

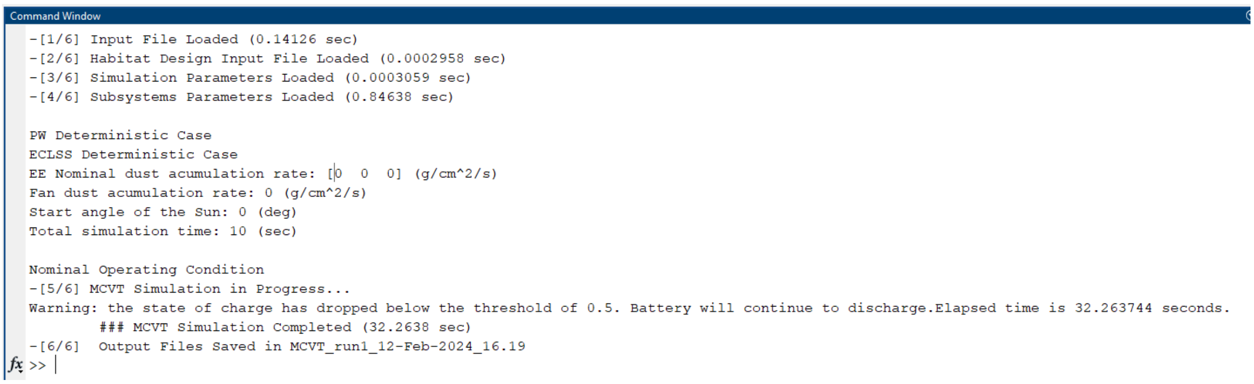



**Figure 6: Example Command Window Updates**

Plots will open automatically. Running HabSim for the first time shows no disruptions and no agent repairs for a 250 second simulation.

# Output Configuration

Output data for each HabSim simulation are provided in .mat files corresponding to each core subsystem. The core subsystems are each assigned a unique number in Simulink, and therefore, the output files are named by this unique number. See Table 6 in the Appendix for each subsystem and its corresponding number. All output variables accessible to users in each subsystem are listed in Table 6 in the Appendix.

Not all output data are needed by a user, and not all data needed are accessible to a user in the output folder. Table 5 lists the relevant performance metrics that a user might want to observe to understand the damageable/repairable behavior for each disruption scenario. Table 6 includes the general performance metric name and the variable name in the output data tables if they are available. Otherwise, the output data that users can directly access are plotted in a script, and the plots are specified in Table 7 in the Appendix. This file automatically reads the available data for all subsystems and plots the data as a function of simulation time.

**Table 5: Performance Metrics for Disruption Scenarios**

| **Hazardous State** | **Safety Control** | **Affected Performance Metrics** |
|---|---|---|
| Solar PV arrays are covered by dust (**HS100**) | Ability to remove dust from solar PV arrays (**SC798**) | 1. Solar power output<br>2. Solar irradiance |
| | Ability to activate secondary power generation system (**SC11**) | 1. Power supplied to all subsystems requesting<br>2. Solar power output<br>3. Nuclear power output |
| | Ability to activate battery power as power generation source (**SC822**) | 1. Currently stored energy<br>2. Maximum available energy storage<br>3. Power supplied to all subsystems<br>4. Solar power output<br>5. Nuclear power output |
| Nuclear radiator panels are covered by dust (**HS213**) | Ability to remove dust from nuclear radiator panels (**SC799**) | 1. Nuclear power output |
| | Ability to activate secondary power generation system (**SC11**) | 1. Power supplied to all subsystems requesting<br>2. Solar power output<br>3. Nuclear power output |
| | Ability to activate battery power as power generation source (**SC822**) | 1. Currently stored energy<br>2. Maximum available energy storage<br>3. Power supplied to all subsystems<br>4. Solar power output<br>5. Nuclear power output |
| ECLSS radiator panels are covered by dust (**HS216**) | Ability to remove dust from ECLSS radiator panels (**SC785**) | 1. Secondary loop fluid temperature |
| Paint degradation on ECLSS radiator panels (**HS217**) | Ability to repair paint damage on ECLSS radiator panels (**SC786**) | 1. Secondary loop fluid temperature |
| Habitat structural mechanical layer is breached (**HS127**) | Ability to repair the structural mechanical layer (**SC795**) | 1. Interior environment temperature<br>2. Interior environment pressure<br>3. Hole radius<br>4. Total volume removed |

| | | |
|---|---|---|
| | Ability to regulate temperature of interior environment (**SC823**) | 1. Interior environment temperature |
| | Ability to regulate pressure of interior environment (**SC824**) | 1. Interior environment pressure |
| Habitat structural protective layer is breached (**HS38**) | Ability to repair the structural protective layer (**SC796**) | 1. Interior environment temperature<br>2. Interior environment pressure<br>3. Volume of hole in regolith (per panel)<br>4. Number of SPL elements damaged<br>5. Damage level (per panel) |
| Solar PV arrays are damaged (**HS41**) | Ability to replace solar PV arrays (**SC799**) | 1. Solar power output<br>2. Solar irradiance |
| Nuclear radiator panels are damaged (**HS134**) | Ability to replace nuclear radiator panels (**SC801**) | 1. Nuclear power output |
| Solar power distribution converters are damaged (**HS227**) | Ability to repair individual power converters (**SC802**) | 1. Power output of converter 1<br>2. Power output of converter 2<br>3. Power output of converter 3<br>4. Power output of converter 4<br>5. Power output of converter 5<br>6. Power output of converter 6 |
| Solar power distribution main generation bus is damaged (**HS228**) | Ability to repair main power generation bus (**SC803**) | 1. Power output of the main generation bus |
| Energy storage system is damaged (**HS35**) | Ability to repair battery cells (**SC355**) | 1. Number of battery cells available<br>2. Currently stored energy<br>2. Maximum available energy storage |
| Solar power distribution converters are damaged (**HS227**) | Ability to repair individual power converters (**SC802**) | 1. Power output of converter 1<br>2. Power output of converter 2<br>3. Power output of converter 3<br>4. Power output of converter 4<br>5. Power output of converter 5<br>6. Power output of converter 6 |

| | | |
|---|---|---|
| Solar power distribution main bus is damaged (**HS228**) | Ability to repair main power generation bus (**SC803**) | 1. Power output of the main generation bus |
| Energy storage system is damaged (**HS35**) | Ability to repair battery cells (**SC355**) | 1. Number of battery cells available<br>2. Currently stored energy<br>2. Maximum available energy storage |
| Open fire in interior environment (**HS71**) | Ability to extinguish active fire in interior environment (**SC797**) | 1. Interior environment temperature<br>2. Interior environment pressure |
| ECLSS air tank has a leak (**HS219**) | Ability to repair piping between the air tank in ECLSS pressure system and interior environment (**SC788**) | 1. Air tank pressure<br>2. Upstream flow rate<br>3. Downstream flow rate |
| ECLSS compressor performance is decreased (**HS222**) | Ability to repair the compressor in ECLSS thermal system (**SC791**) | 1. Requested RPM for compressor<br>2. Actual RPM of compressor |
| Sensor(s) in Subsystem X* experience sensor drift | Ability to repair sensor drift in sensor(s) in Subsystem X* | |
| Sensor(s) in Subsystem X* fail | Ability to repair failed sensor(s) in Subsystem X* | |
| Sensor(s) in Subsystem X* experience simultaneous drift and failure | Ability to repair sensor(s) in Subsystem X* | |
| ECLSS fan is nonfunctional (**HS218**) | Ability to repair fan damage in ECLSS pressure system (**SC787**) | 1. Flow rate of the fan |
| ECLSS air supply valve is malfunctioning (**HS220**) | Ability to repair the air supply valve in ECLSS pressure system (**SC789**) | 1. Downstream flow rate |

| | | |
|---|---|---|
| ECLSS evaporator has air side leak (**HS223**) | Ability to repair the evaporator air side leak in ECLSS thermal system (**SC792**) | 1. Upstream flow rate<br>2. Downstream flow rate |
| ECLSS pressure system consumes excess power (**HS221**) | Ability to repair power consumption fault in ECLSS pressure system (**SC790**) | |
| ECLSS thermal system consumes excess power (**HS225**) | Ability to repair power consumption fault in ECLSS thermal system (**SC794**) | |
| ECLSS heater performance is decreased (**HS224**) | Ability to repair the heater in ECLSS thermal system (**SC793**) | 1. Requested heat<br>2. Actual heat provided |

* = General or any system

## *Data Inspector*

To access the data inspector, open the MATLAB Simulink file titled MCVT_v6.slx. The Simulink window will appear and in the top toolbar, there is a data inspector icon. Click on that icon, and the data inspector window will appear as seen in Figure 7. On the left side of the window, all output variables logged in the data inspector are listed with a check box next to them. You can use the Filter Signals bar to look for the relevant performance metrics listed in Table 6 that you want to view for your simulations.

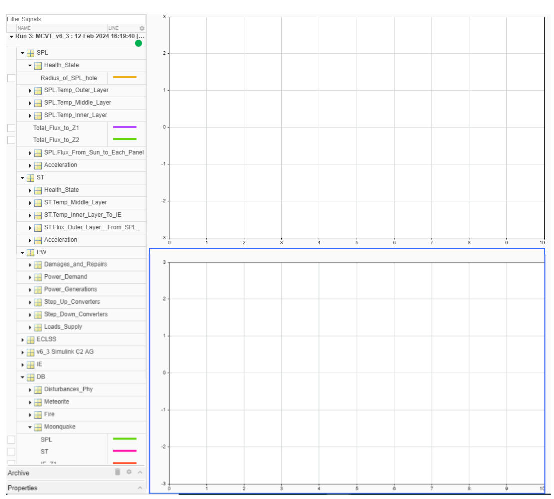



**Figure 7: Data Inspector Window from Simulink**

# Example Simulations

## *Example 1: Micrometeorite Impact*

**Description:** In the first scenario, a micrometeorite at IL 5 hits the habitat on zone 2, at coordinates [-0.54,0.54] m, damaging ST and SPL, together with converters 1 and 2 and 90% of the available battery cells. Converters 1 delivers the generated nuclear power to the smart power distribution, and converter 2 delivers the generated solar power. The simulation happens during a lunar night; therefore, no solar power is generated. Nuclear generation is fully working, and the energy storage is charged at 20% of the maximum storage.

```
Command Window
-[1/6] Input File Loaded (0.2414 sec)
-[2/6] Habitat Design Input File Loaded (0.0020364 sec)
-[3/6] Simulation Parameters Loaded (0.0011086 sec)
-[4/6] Subsystems Parameters Loaded (4.1344 sec)

PW Deterministic Case
ECLSS Deterministic Case
EE Nominal dust acumulation rate: [0  0  0] (g/cm^2/s)
Fan dust acumulation rate: 0 (g/cm^2/s)
Start angle of the Sun: 90 (deg)
Total simulation time: 120 (sec)

Meteorite Disruption Scenario
                IL: 5
       impactStart: 10
       coordinates: [-0.5400 -0.5400]
    holeRadius_IL4: 8.0000e-04
    holeRadius_IL5: 0.1000
      dustDuration: 30
     dustAccumRate: [0 15 0]
    impactDuration: 1

fx -[5/6] MCVT Simulation in Progress...
```

Figure 8 provides information on the health state of the habitat components.

- **2D** and **2E** show that in this scenario, ST and SPL are pierced by the micrometeorite, resulting in a hole in ST and SPL.
- **4A, 4B,** and **3G** show that the debris caused by the micrometeorite impact damage some of the components in the PW system. including power converter 1, power converter, 2, and some of the battery cells, respectively.
- All the other signals are zero because the other habitat components are not affected by the micrometeorite impact.
- As long as these signals are zero the corresponding components are healthy, but the battery shows the percentage of the healthy (not damaged) number of the batteries.
- **3G** shows that after the batteries are repaired, the final percentage of the healthy batteries is less than 100%.

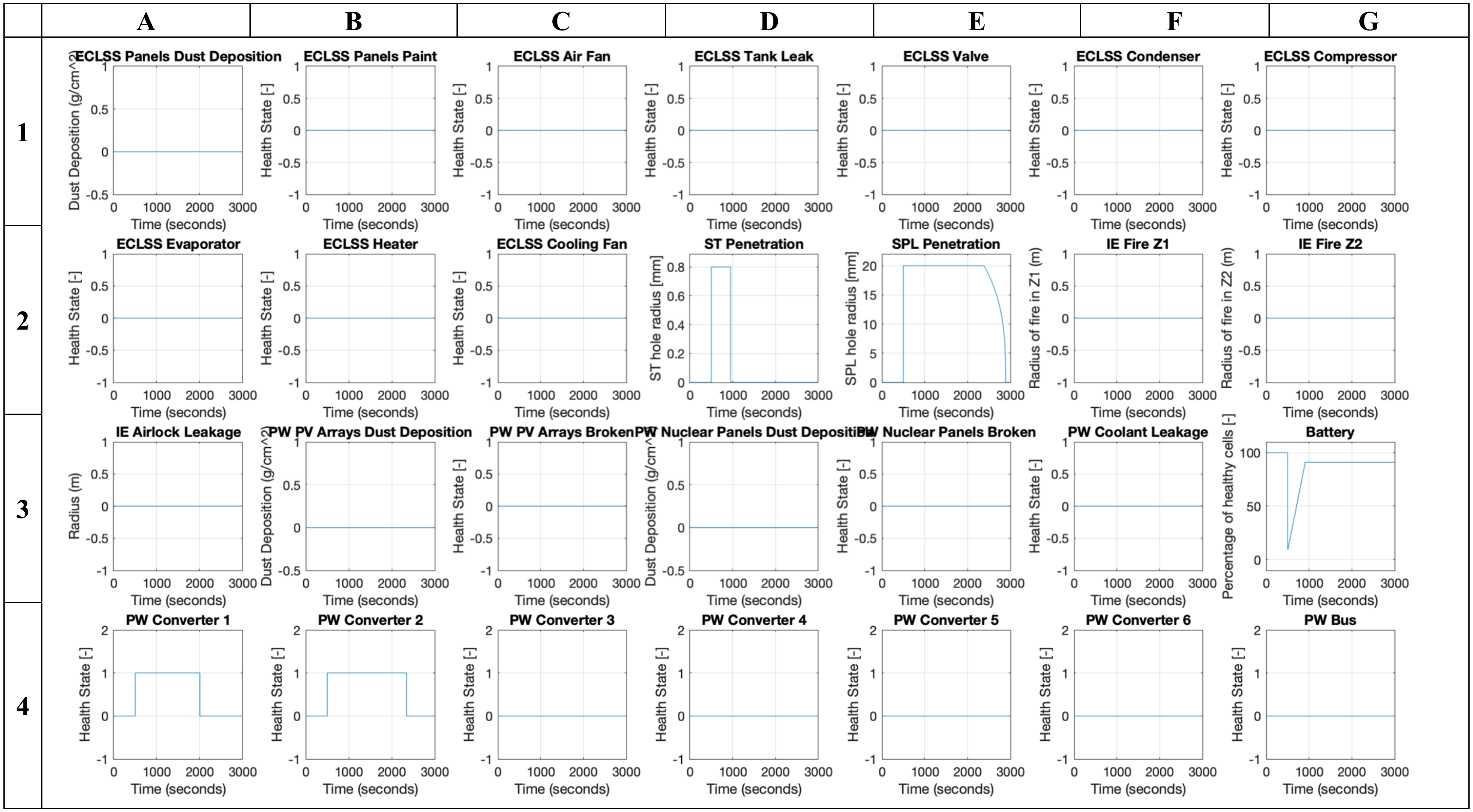



**Figure 8: Health States**

Figure 9 shows the agent's interventions. Each component has a unique code associated to the agent repair action shown on y-axis.

- **3E** shows that the battery cells are the first component to be repaired by the agent. The repair order is set by the user before the simulation starts.
- **2D** show that the ST is being repaired as second. The hole size is 0.8 mm, and it is patched in 500 seconds. The repair is instantaneous, and once the agent patches the hole, its radius goes to zero. After that, the agent repairs converter 1 and 2 (**4A** and **4B**, respectively).
- **2E** show that SPL is the last component to be repaired.

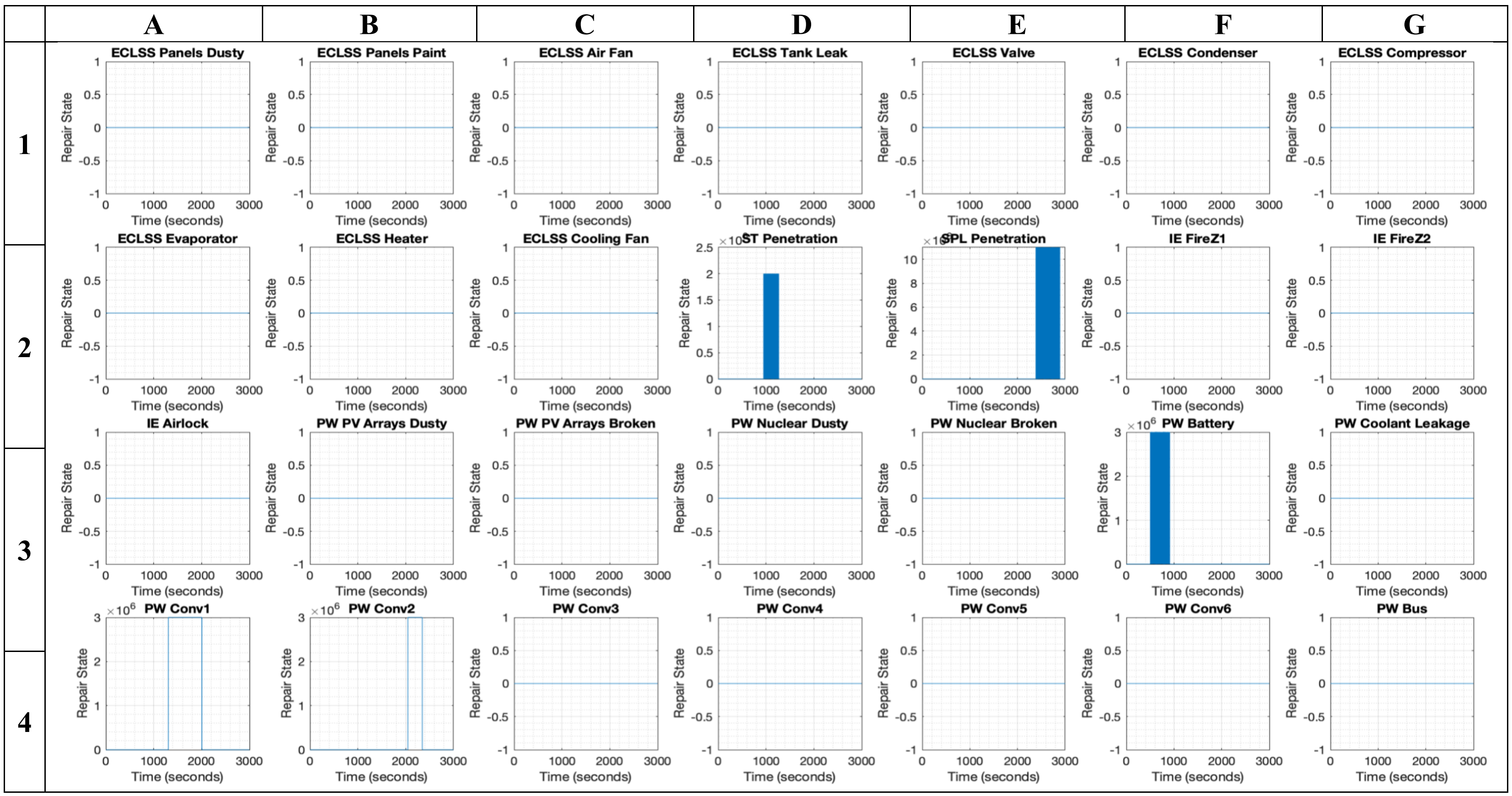



**Figure 9: Repair Actions**

Figure 10 is demonstrating all the interventions on one figure, where the repairs are done this order; battery cells, ST, PW converter 1, power converter 2 and finally SPL.

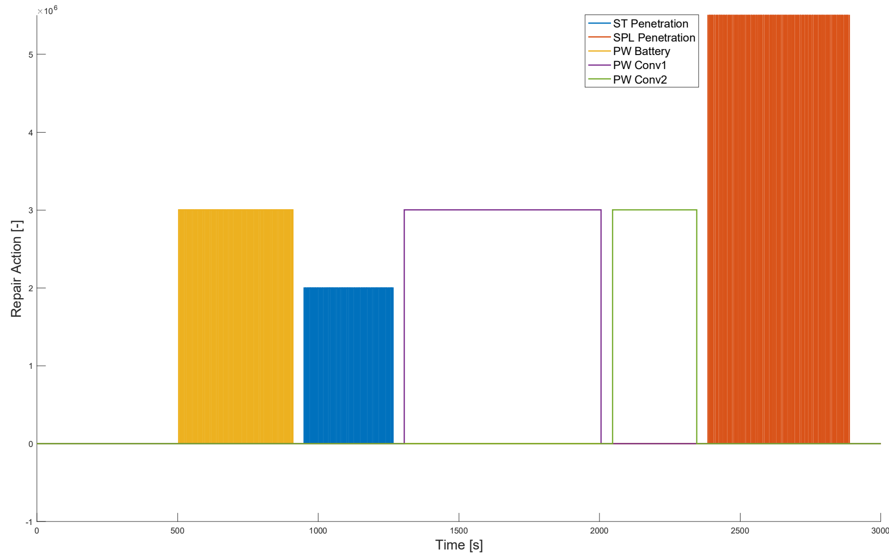



**Figure 10: Repair Sequence**

Figure 11 shows the PW loads and output of the converters. In particular, the ECLSS load.

- **1A** shows the sum of ECLSS heating and cooling loads. At 800 seconds, the air leaking out the habitat trough the puncture hole causes habitat temperature and pressure decrease. Therefore, the ECLSS thermal and pressure consumption is higher.
- **1B** represents the monitoring loads, which are constant since the sensor power consumption is constant.
- **1C** shows the power consumed by housekeeping loads and scientific instruments. In this simulation, the housekeeping and scientific instruments loads are considered constant.
- **1D** shows the pump power consumption, which is zero because the IE is not being cooled.
- **1E** shows the generated nuclear power, which is constant. The generated solar power is shown in **1F**, and it is slightly increasing because of the sun moving through the day.
- **2A** shows the currently stored energy plot, which compares the total storage capacity with the current one. In the beginning, the batteries are being charged. Then when the micrometeorite impact happens, the temperature drops and causes the energy storage efficiency to decrease. This causes a drop of both maximum and current available power. The energy storage then increases again after the repair action. then decrease since is being used because the converters one and two are damaged. Then increase again since the PW can rely again on nuclear power.
- **2B** shows the battery energy storage, which starts to discharge as soon as the nuclear power and solar power converters are damaged, since the converters are necessary to route the power to the habitat subsystems.
- **2C** shows the dumping loads, used to control the generated nuclear power which cannot be delivered through the converter and then needs to be dumped.
- **2D** shows the sum of the power generated by the nuclear, solar and the power stored into the PW energy storage.
- **2E and 2F** show the output of converter 5 and 6. Converter 5 delivers power to the monitoring loads, and converter 6 delivers power to housekeeping loads.  Output of power converter 6 drops when the converters 1 and 2 are damaged, because the SPD stops powering instruments to save power for ECLSS.
- The damage of converters 1 and 2, is confirmed by the subplot representing Output of step-up converters 1 and 2, which become zeros as soon as the meteorite impact happens. Output of step-up converter 3, **(3C)** is the same as discharge power, since after the meteorite impact the only source of power is the PW energy storage. Because of the temperature drop caused by the ST puncture, the stored energy efficiency decreases. About the step-down converters, necessary to power the system loads, the output of converter 4, (**3D**) is the same as ECLSS load, (**1A**) since this is the converter which delivers the power to ECLSS system, and the output of converter 5, **(3E)** is constant since the monitoring loads are constant. The output of power converter 6, **(3F)** drops when the converters 1 and 2 are damaged, because the SPD stops powering instruments to save power for ECLSS. Once the converters are repaired, the converter 6 is back to deliver the power to accessory loads.

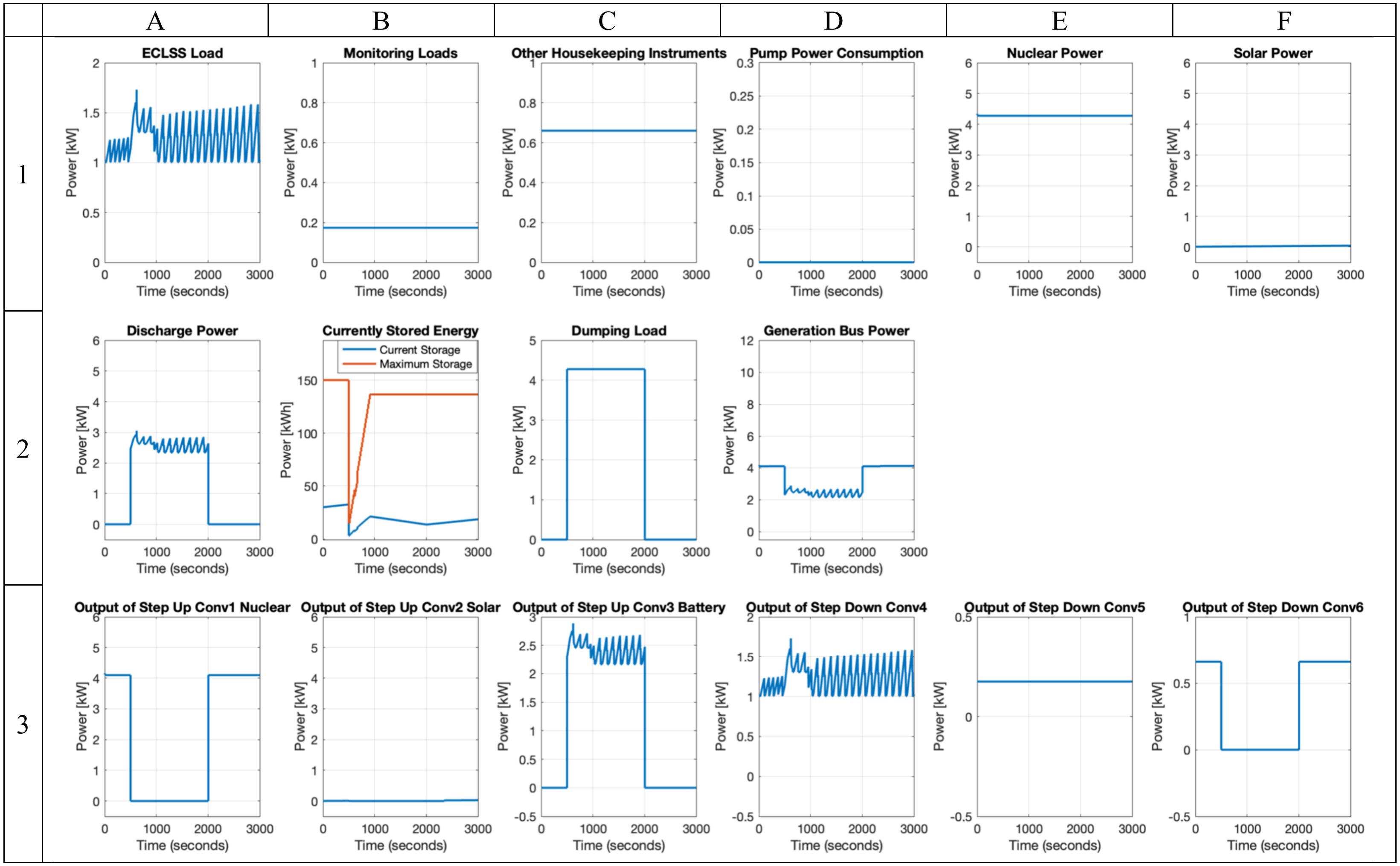



**Figure 11: PW Signals**

The plots in Figure 12 pertain to the ECLSS power consumption and air supply.

- **1A** shows the power consumed by the ECLSS compressor. The power request peaks when the temperature is at its minimum. This is because the temperature affects the compressor efficiency. Here the ECLSS power requested and power consumed are the same, because PW can provide energy to ECLSS systems.
- **1B** and **1C** present the power consumed by ECLSS heaters in zone 1 and zone 2. The power request by the heater in zone 1 is higher, because the temperature in zone 1 stays in the unsafe zone for more time (the micrometeorite impact happens in zone 1).
- **1D** and **1E** show the power consumed by ECLSS ventilation fans.
- **1F** shows the total ECLSS power consumption, which is the sum of power consumed by ECLSS heater, compressor, and fans.
- **2A, 2B, 2C,** and **2D** illustrate the ECLSS power request. In this simulation, the ECLSS power request equals the ECLSS power consumption. This is because the available power is enough to power the ECLSS loads.
- **2E** shows the heat gain, which is the heat generated by the PW components. For example, the energy storage dissipates heat into the IE when working. This is an example of heat gain.
- **3A, 3B,** and **3C** show the efficiency of ECLSS compressor and fans. In response to the temperature decrease, the fans and compressor efficiency decrease as well. This causes a higher power demand by the compressor and fans, **2A , 2D,** and **2E.**
- **3D** and **3E** are about the air flowing into zone 1 and zone 2. The ECLSS pressure control injects air when the IE pressure falls below the supply set point, shown in red in **1A** and **1B.**
- **3F** and **4A** illustrate the amount of air that is vented out the IE in case the pressure exceeds the discharge set point, shown in blue in **1A** and **1B**.
- **4B** and **4C** are about the air injected into the habitat when the IE pressure falls below the supply set point, shown in red in **1A** and **1B.**

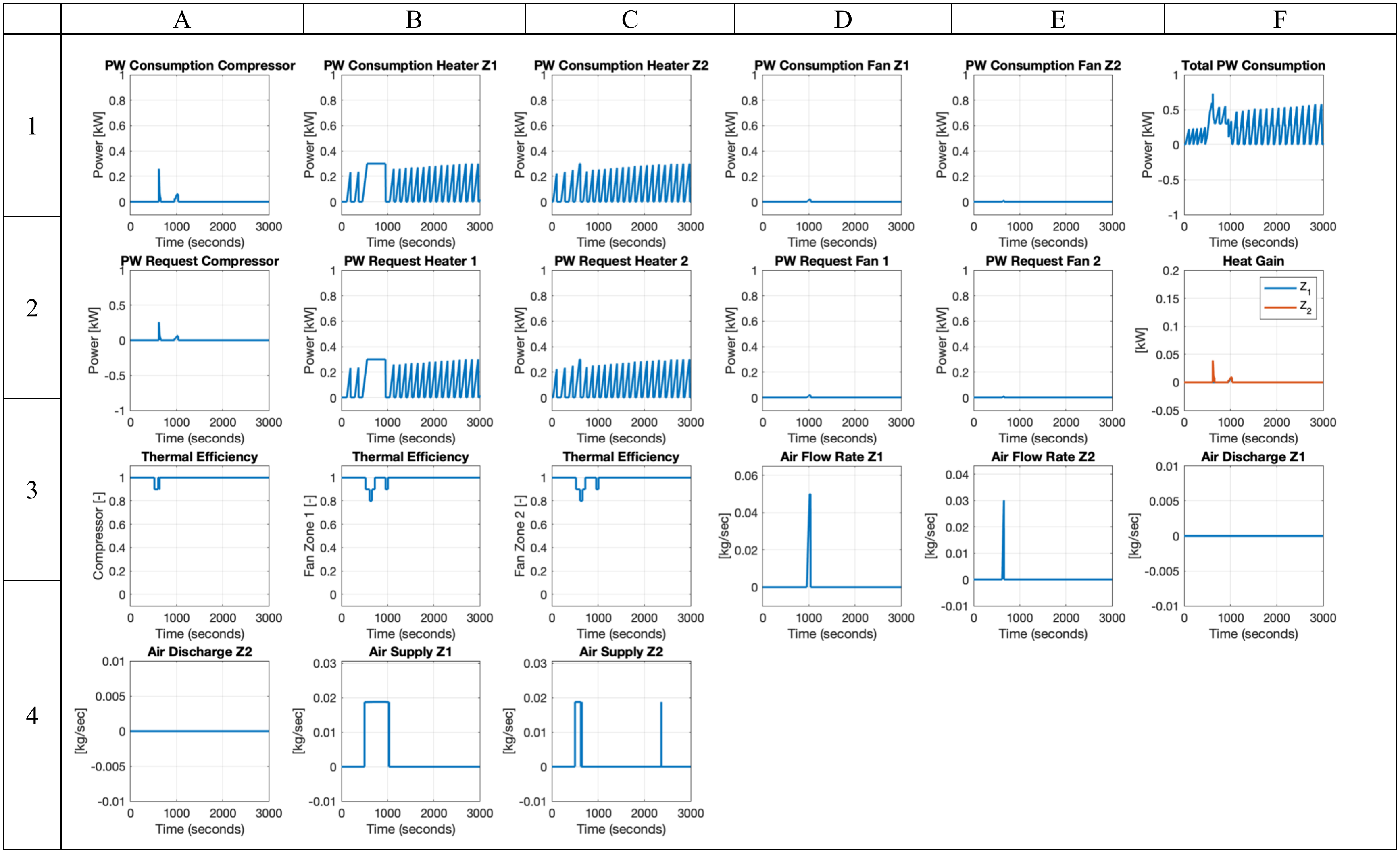



**Figure 12: ECLSS Signals**

Figure 13 shows the temperature and pressure inside the habitat, together with the thermal loads and the air circulation.

- **1A and 1B** demonstrate the pressure in zone 1 and 2, which is decreasing right after the micrometeorite impact, and is restored to the nominal value only after SPL and ST are repaired.
- **1C** and **1D** shows the temperature in zone 1 and 2 is decreasing as well as soon as the micrometeorite impacts on the habitat, because of the hole in ST and SPL. The pressure is restored after SPL and ST are repaired by agent.
- **1E** show the average wall temperature for zones 1 and 2. In this simulation, the air temperature is restored quickly and the wall temperature does not present any changes. This is because the wall temperature is increasing slower than the air temperature because of the high thermal inertia.
- **1F** show the heat gain due to the components present in zone 1 and 2. In particular, PW batteries and fan add heat to the zone 1. Compressor and cooling fan add heat to zone 2 when operating.
- **2A** presents the heating load, which is positive because heat is provided to the system by the ECLSS heaters to compensate the temperature drop due to the micrometeorite puncturing SPL and ST.
- **2B** shows the cooling load, which is considered positive as heat is removed from the habitat.
- **2C** is about the overall thermal load, obtained by the difference between heating and cooling thermal load. In this case, since the heater thermal load is positive and greater than the cooling load, the overall thermal load is positive as well.
- **2D** shows the wall temperature flux, due to convection. A positive heat flux means that the wall temperature is higher than the IE temperature, and vice versa.
- **2E** shows the heat flux due to fire. In this simulation, this signal is zero because no fire is initiated.
- **2F** is about the heat flux between IE and wall, considering a heat flux of the fire.
- **3A** shows the pocket door position. After the meteorite impact happens, initially the pocket door dividing the two zones stays open. At 700 seconds is closed, and this causes the pressure in zone 2 to go back to normality right after (**1B**). The same for the temperature in zone 2, shown in **1D**. About the pressure in zone 1, shown in **1A**, it takes more time to recover, since the air leaks out the habitat until the agent repairs it.
- **3B** shows that the air circulating in Z1 and Z2 is different than zero when the leak starts. This is because the ECLSS pressure controller commands the air injection into the two habitat zones.
- **3C** shows the air flow between the two zones. In this case, there is no air flow between the two zones.
- **3D** shows the air leaking from the habitat IE. Air leaking is decreasing during the time because of the pressure decrease, and the air supply, shown in **3E**. In this simulation, once the leak is detected, pressure controller commands maximum supplying of air in zones 1 and 2 to quickly reestablish the pressure.
- **3F** shows the discharge into the exterior environment. Air discharge can be due to nominal habitat air leaks or depressurization events caused by micrometeorite impact.

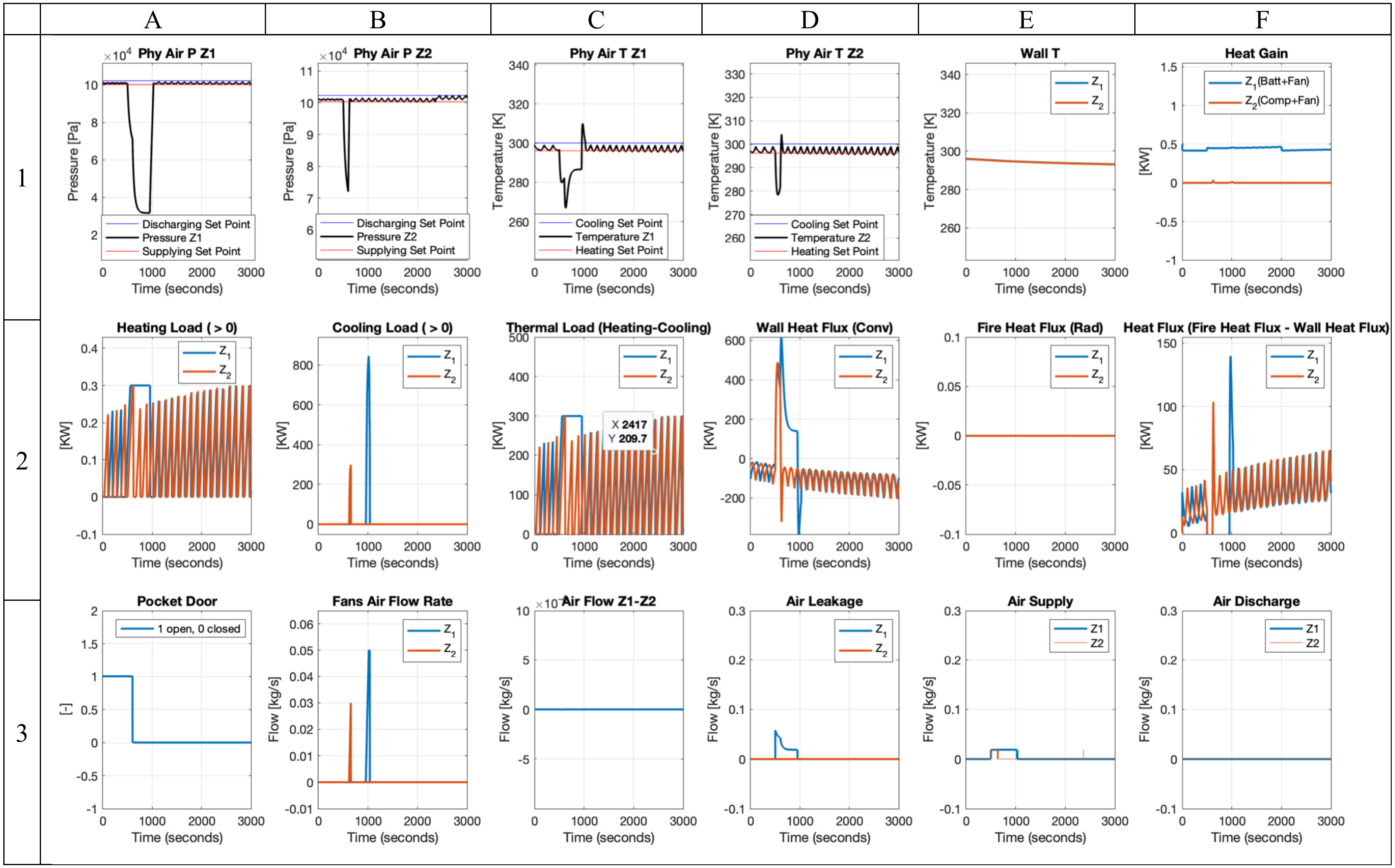



**Figure 13: IE Signals**

- **1A** is about the temperature of the ST middle layer, which is between the inner layer, shown in **2A**, and the outer layer, which is considered to be the SPL inner layer as well.
- **1B, 1C, 1D,1E,1F, 2B, 2C, 2D,2E,2F, 3B, 3C, 3D,3E,3F** shows the acceleration of the habitat ST at different locations and directions.
- **3A** is about the flux between the ST outer layer and the SPL inner layer. A positive flux means that SPL is colder that ST.

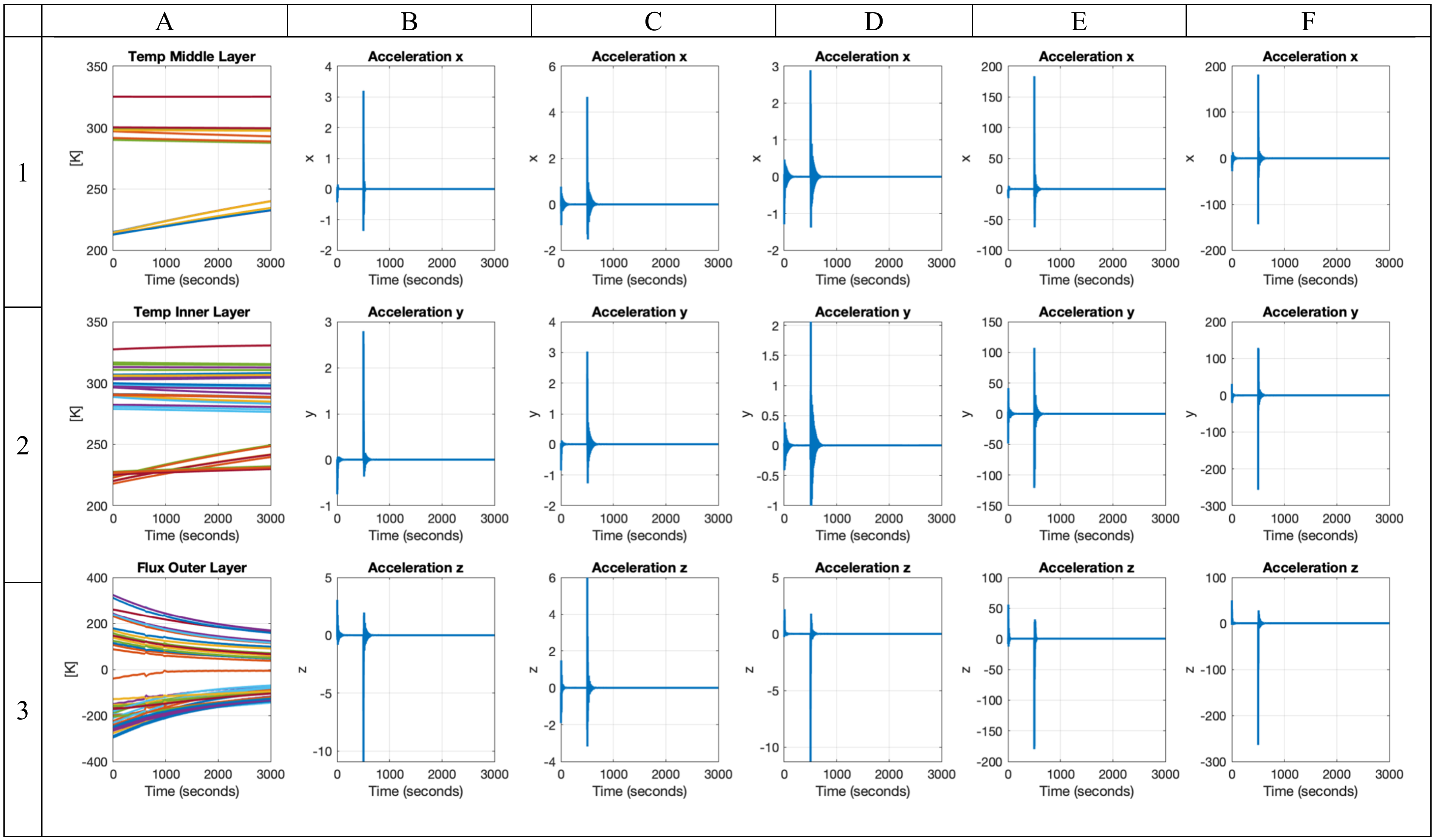



**Figure 13: ST Signals**

- **1A, 1B, and 1C** are about the temperature of the SPL outer layer, middle layer and inner layer, respectively.
- **1D** shows the flux from sun to external SPL. A positive flux means that the sun is heating a panel.
- **1E** represents the flux between SPL and ST. A positive flux means that the SPL temperature is greater that ST and vice versa. Blue line represents zone 1, and the orange line is zone 2.
- **1D, 1E, 2A, 2B, 2C, 2D, 2E, 3A 3B, 3C, 3D, and 3E** show the acceleration of the habitat ST at different locations and directions.

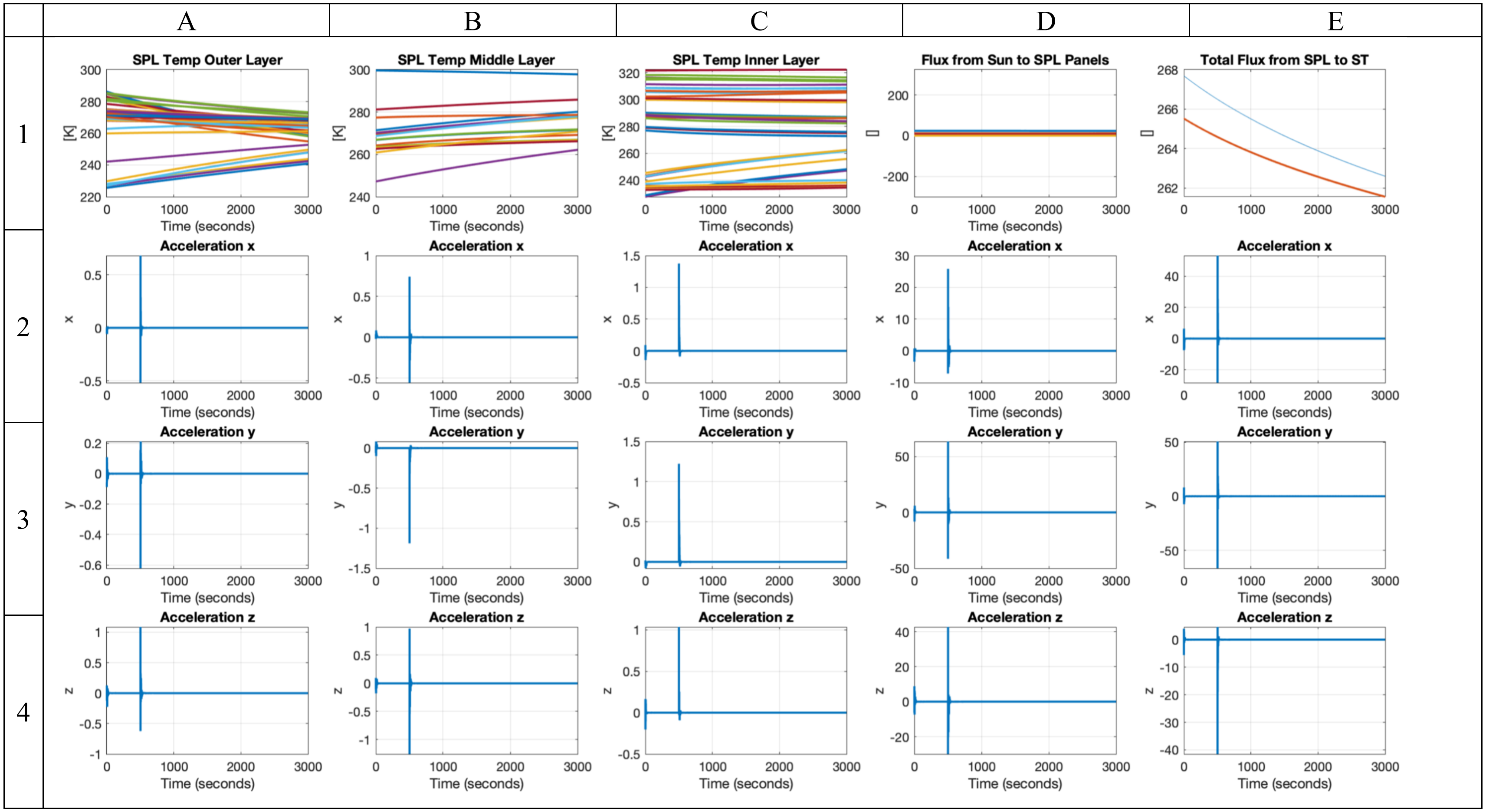



**Figure 14:SPL Signals**

*Example 2: Fire*

In this simulation, an IL 5 fire disruption is initiated in habitat zone 2. The fire will affect pressure, temperature and consequentially ECLSS and PW efficiency.

Command Window

```
-[1/6] Input File Loaded (0.12987 sec)
-[2/6] Habitat Design Input File Loaded (0.0003599 sec)
-[3/6] Simulation Parameters Loaded (0.0003926 sec)
-[4/6] Subsystems Parameters Loaded (0.96387 sec)

PW Deterministic Case
ECLSS Deterministic Case
EE Nominal dust acumulation rate: [0   0   0] (g/cm^2/s)
Fan dust acumulation rate: 0 (g/cm^2/s)
Start angle of the Sun: 90 (deg)
Total simulation time: 120 (sec)

Fire Disruption Scenario
                   IL: 5
               tStart: 20
           tDetection: 100
    polar_coordinates: [0.7000 180]
          coordinates: [-0.7000 0]

-[5/6] MCVT Simulation in Progress...
```

Figure 15 shows the health states of all the damageable components. Health state changes are initiated by disruptions.

- **2G** shows that the radius of the fire increases in a linear manner until the agent starts to extinguish it. In this version of HabSim, we assume that delay between detection and start of agent action is neglectable. Once the fire is detected, the repair action start, so the fire radius starts decreasing. The fire suppression takes four steps so in between there is a slight increase in the fire radius.
- All the other figures. show a zero-value signals as in this scenario the fire starts far from ECLSS and PW components, and it does not spread enough to reach them during the whole simulation. Therefore, all the other components have a health state value equal to zero. The battery health state is at 100% and indicates that all the battery cells are healthy.

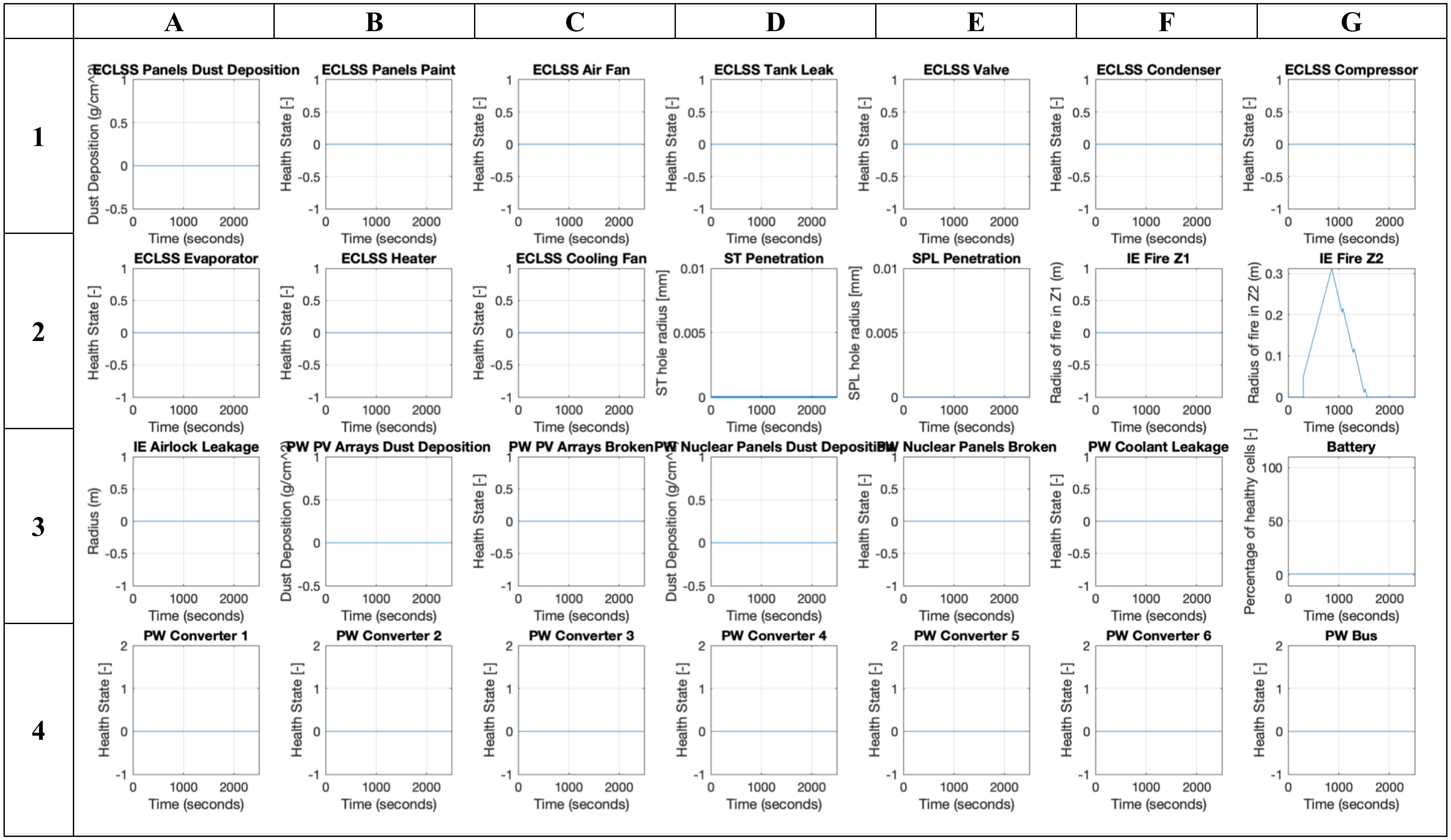



**Figure 15: Health States**

Figure 16 shows the agent actions used to repair the damaged components within HabSim.

- **2G** shows that it takes four steps to extinguish the fire which is consistent with the results demonstrated in **Fig. 15 2G**.
- All the other Figs. show a zero-value signal as no other intervention is necessary.

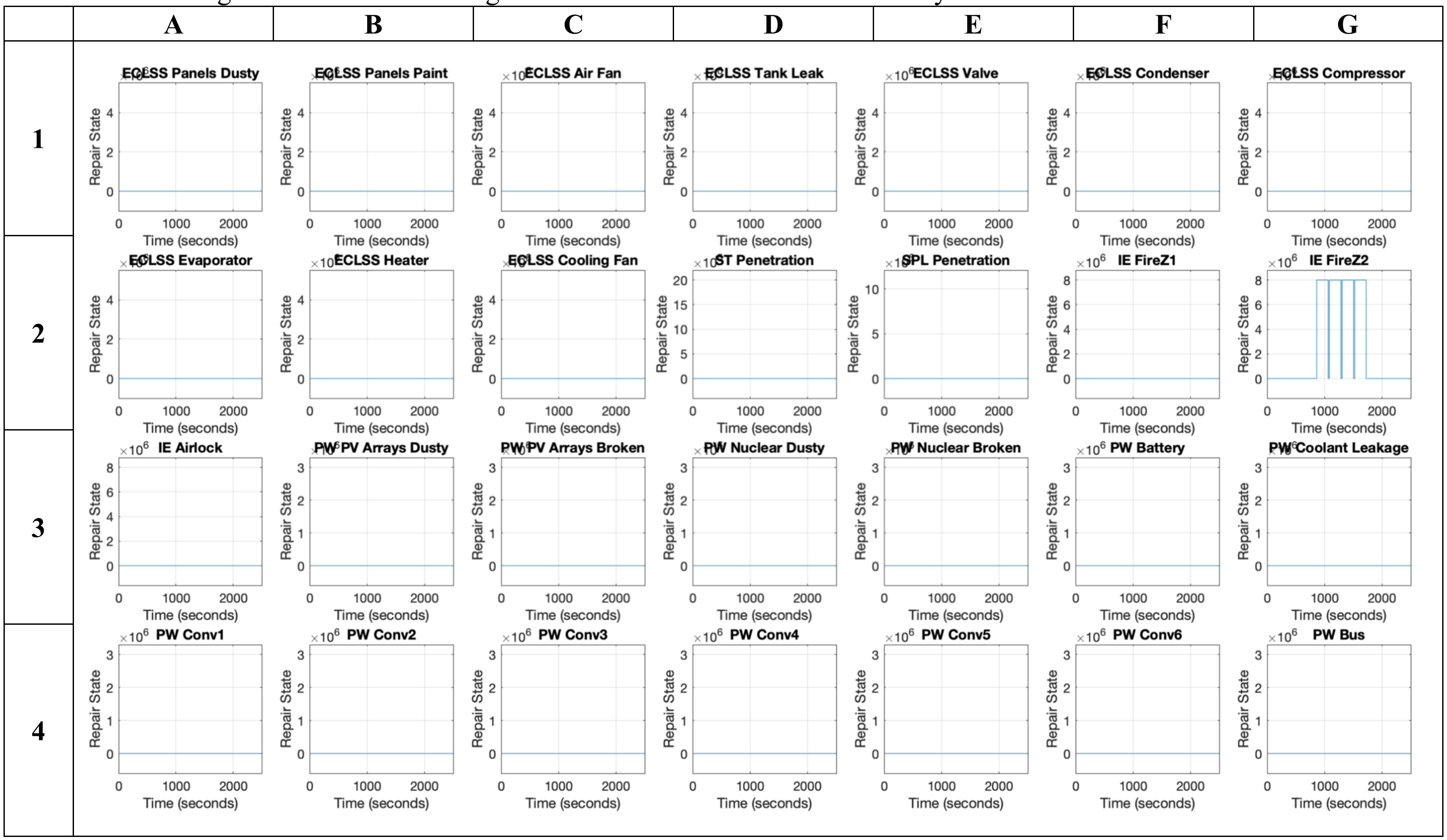



**Figure 16: Repair Actions**

Figure 17 shows the power signals.

- **1A** demonstrate that ECLSS load follows the trend observed on the radius of the fire in **Fig. 15 - 2G.**
- **2B** demonstrate that at time = 800 seconds, the stored energy in the batteries decreases by 40% as the efficiency of the batteries is a function of the environmental temperature
- **1C** shows the PW loads related to housekeeping instruments. For example, fridges, microwaves and all the appliances needed by the habitat crew during the crewed state.
- **1D** shows the PW loads related to ECLSS system pumps.
- **1E** shows the generated nuclear power. It is constant to 4.3 kW.
- **1F** shows the generated solar power. In this case we are considering a lunar night, therefore there is no generated solar power.
- **2A** presents the discharge power, which is the power that is drawn from the PW batteries when batteries are the only available power source. In this case, since nuclear power is available as well, the PW batteries are charging, as can be seen in **2B**.
- **2B** demonstrates that the generated nuclear power is used to charge the batteries. This explains the increase in current stored energy.
- **2C** shows the nuclear power dumping loads. Dumping loads are used to channel the nuclear power that cannot be correctly delivered to the power management system.
- **2D** shows the total generated power. In this case, the generated power is equal to the generated nuclear power, shown in **1D**.
- **3A** demonstrates that the output of the step-up converter 1 is equal to the generated nuclear power, shown in **1E**.
- **3B** shows that the output of step-up converter 2 is zero, same as generated solar power presented in **1F**.
- **3C** shows that the output of the converter 3 is zero, since in this scenario the batteries are not being used.
- **3D** shows that the output of stepdown converter 4 is equal to ECLSS power request. This is because the converter 4 delivers power supply for ECLSS heating and cooling systems.
- **3E** shows that the output of stepdown converter 5 is equal to ECLSS monitoring loads power request.
- **3F** demonstrates that the output of the converter 6 is zero is equal to zero similar to the housekeeping loads demonstrated in **1C**.

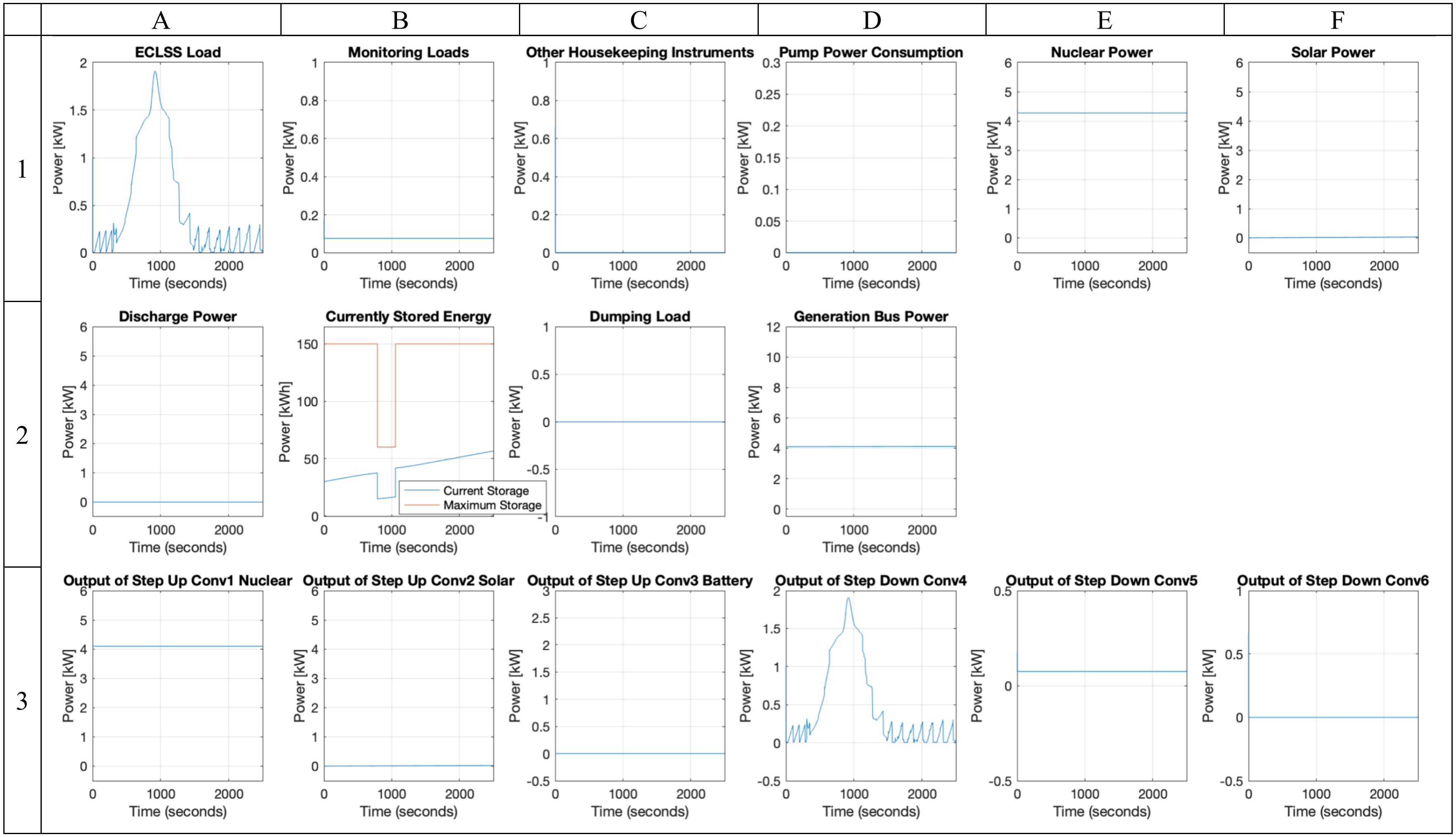



**Figure 17: PW Signals**

Figure 18 shows the ECLSS signals.

- **1A** shows the power consumed by the ECLSS compressor. The ECLSS compressor efficiency decreases with the temperature, as in **3D**.
- **1B** shows the power consumed by the ECLSS heater in zone 1. The heater is not activated when the fire is spreading and being suppressed.
- **1C** illustrates the power consumed by ECLSS heaters in zone 2. The heater is active in the beginning of the simulation to keep the temperature within the required range shown in **Fig. - 19 1D.**
- **1D** and **1E** shows the power consumed by ECLSS fans for zone 1 and 2, respectively. The fans efficiency decreases with the temperature, as shown in **3D** and **3E**.
- **1F** is about the total ECLSS power consumption. It is equal to the sum of power consumed by compressor, heaters and fans.
- **2A, 2B, 2C, 2D, and 2E** shows the power requested by ECLSS components. In this simulation, power request and consumption are the same. This means that the generated and stored energy is enough to power all the ECLSS loads.
- **2F** shows the heat gain for zone 1 and 2. The heat gain is the heat generated by all the powered components and crew. For example, heat generated by a computer is considered heat gain. Heat gain increases the load of ECLSS thermal and pressure management
- **3D** shows the thermal efficiency of the ECLSS compressor. The thermal efficiency decreases with temperature.
- **3E** and **3F** present the thermal efficiency for fan used to recirculate air in zones 1 and two.
- **4A** and **4B** shows the air flow used to cool zone 1 and 2.
- **4C** and **4D** shows the air vented out the habitat in case the pressure exceeds the discharge limit.
- **4E** and **4F** shows the air injected into the habitat when the pressure drops below the supply setpoint.

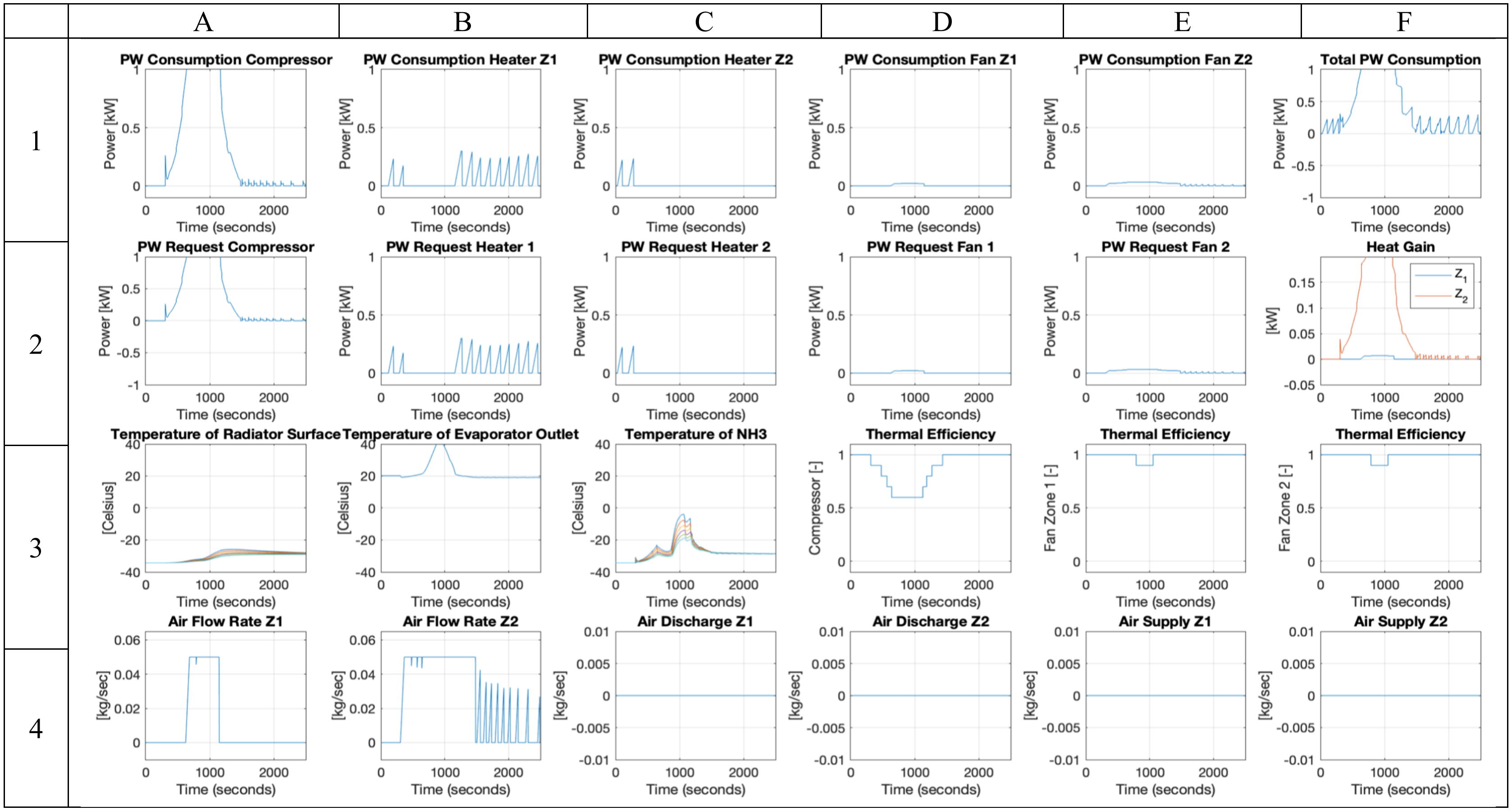



**Figure 18: ECLSS Signals**

Figure 19 shows the internal habitat signals.

- **1A** and **1B** show the pressure for habitat zone 1 and 2, respectively. The discharging set point, in blue in **1A** and **1B** is the higher allowed pressure before the ECLSS pressure control vents out the air to the exterior environment. The supply set point, in red in **1A** and **1B**, is the minimum allowed pressure before the ECLSS pressure control commands the air injection into the habitat zone.
- **1C** and **1D** show the temperature for habitat zone 1 and 2, respectively. The cooling set point, in blue in **1C** and **1D** is the higher allowed temperature before the ECLSS temperature control activates the ECLSS cooling system. The heating set point, in red in **1C** and **1D**, is the minimum allowed temperature before the ECLSS thermal commands the heater activation.
- **1E** show the average wall temperature for zones 1 and 2. In this case, the fire spreading in zone 2 causes an increase in wall temperature. The wall temperature is increasing slower than the air temperature because of the high thermal inertia.
- **1F** show the heat gain due to the components present in zone 1 and 2. In particular, PW batteries and fan add heat to the zone 1. Compressor and cooling fan add heat to zone 2 when operating.
- **3A** shows the heating load, which indicates the heat provided to the IE. In this simulation, heat is provided before and after the fire spreading and suppression. The peaks in the signals are due to the activation and deactivation of the heaters. When the temperature is equal to the cooling setpoint in **1C** and **1D**, the heater is deactivated, and the heating load decreases.
- **3B** shows the cooling load, which indicates the cooling activation.
- **3C** shows the difference between heating and cooling loads.
- **3D** is about the heat flux for heat due to convection between the habitat wall and IE. A positive heat flux means that the wall is providing heat to the IE. This happens when the wall temperature is higher than the IE temperature. In this simulation, the IE temperature is higher than the wall one, because of the fire. Therefore, the heat flux due to convection is negative.
- **3E** is about the heat flux generated by fire. In this case, since a fire is present, the fire flux is different from zero.
- **3F** is the difference between heat flux generated by fire and heat flux from wall to interior environment. A positive heat flux means that the wall is providing heat to the IE.
- **4A** shows the pocket door position. The pocket door divides IE zone 1 from IE zone 2. It can be closed to separate the two zones.
- **4B** shows the fans flow rate. In particular, the orange line is about the air flowing in zone 1, and the blue line is about zone 2.
- **4C** shows the flow between the two zones. In this simulation there is no zone ventilation.
- **4D** shows the air leaking from the habitat sealings. In this case, the leak has been set to zero (no air leak into the external environment)
- **4E** is about the air supplied to the habitat, to compensate pressure leaks due to sealings degradation or micrometeorite impacts.
- **4F** shows the air discharged into the exterior environment when the pressure exceeds the setpoint.

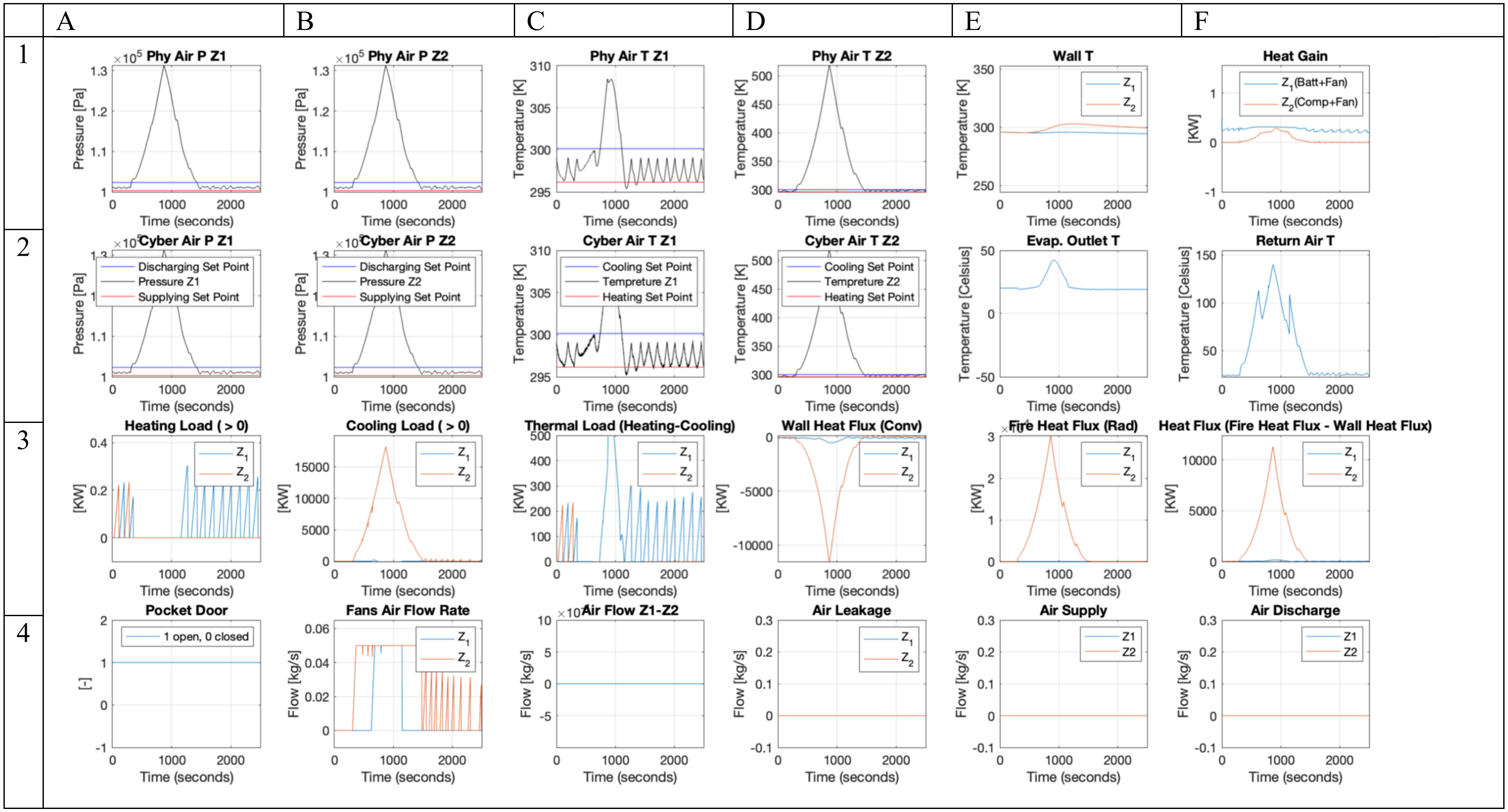



**Figure 19: IE Signals**

- **1A** is about the temperature of the ST middle layer, which is between the inner layer, shown in **2A**, and the outer layer, which is considered to be the SPL inner layer as well.
- **1B, 1C, 1D, 1E, 1F, 2B, 2C, 2D, 2E, 2F, 3B, 3C, 3D, 3E,** and **3F** shows the acceleration of the habitat ST at different locations and directions.
- **3A** is about the flux between the ST outer layer and the SPL inner layer. A positive flux means that SPL is colder that ST.

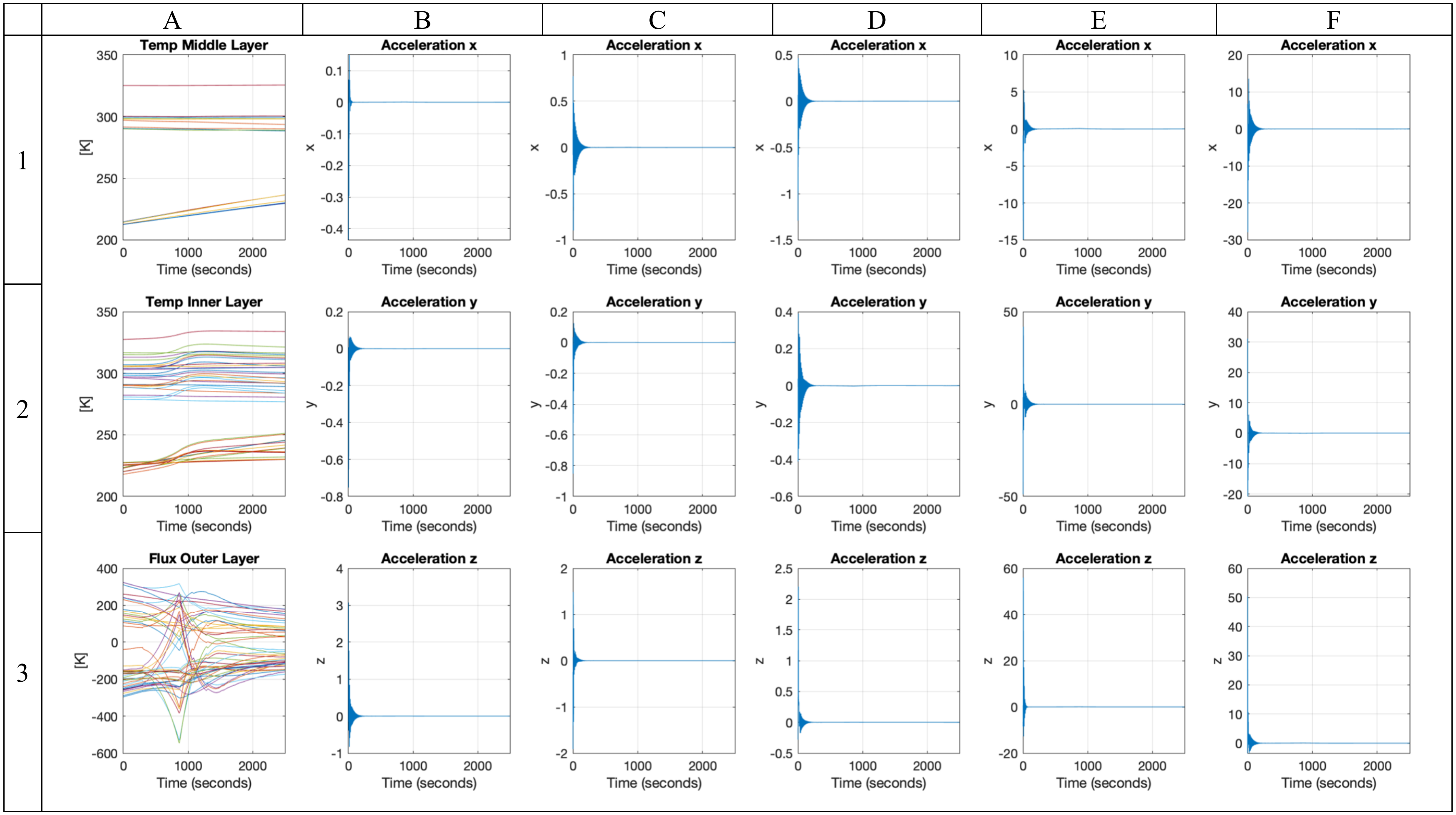



**Figure 20: ST Signals**

- **1A, 1B,** and **1C** are about the temperature of the SPL outer layer, middle layer and inner layer, respectively.
- **1D** shows the flux from sun to external SPL. A positive flux means that the sun is heating a panel.
- **1E** represents the flux between SPL and ST. A positive flux means that the SPL temperature is greater that ST and vice versa. Blue line represents zone 1, and the orange line is zone 2.
- **1D, 1E, 2A, 2B, 2C, 2D, 2E, 3A 3B, 3C, 3D,** and **3E** show the acceleration of the habitat ST at different locations and directions.

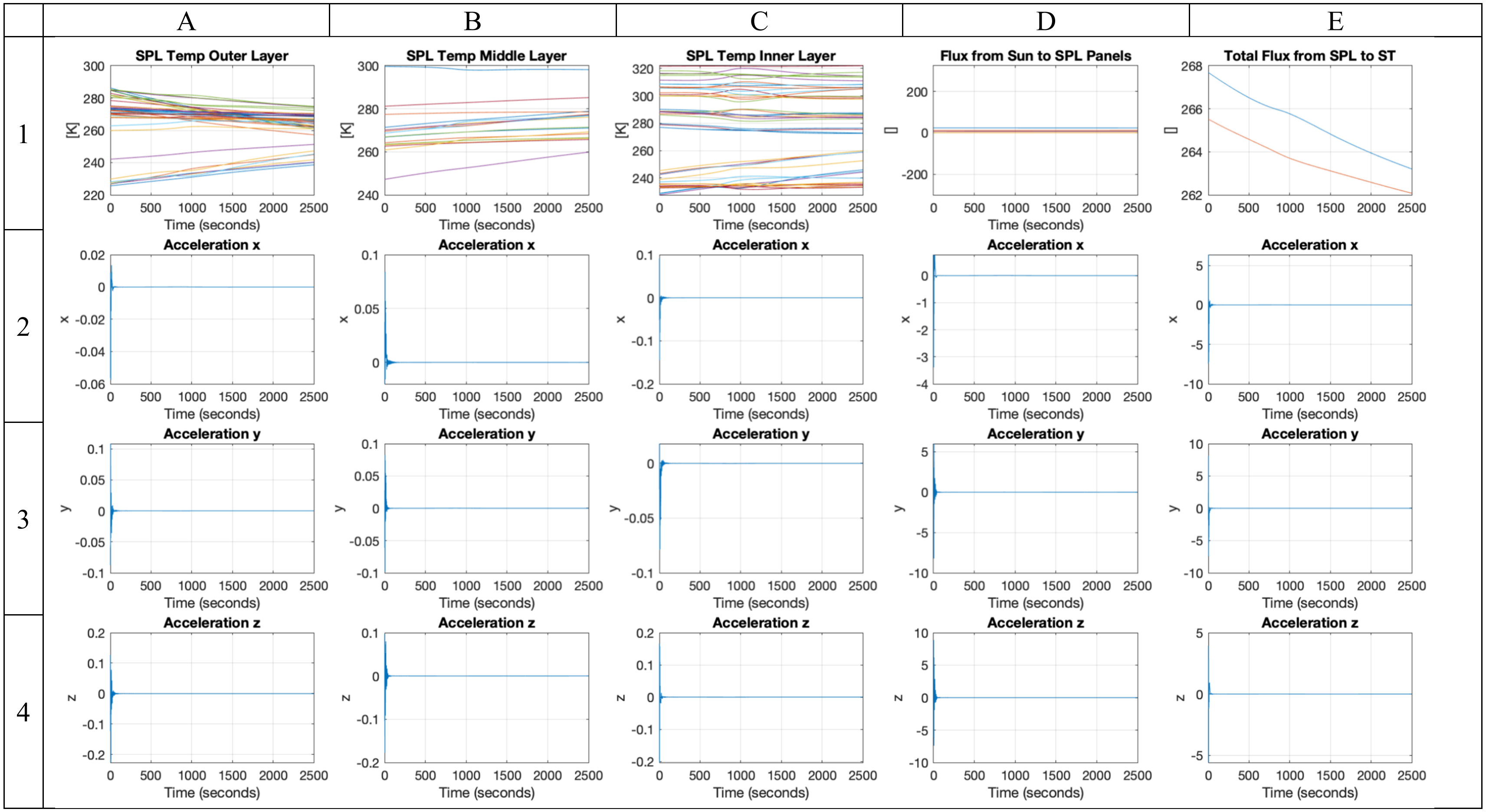



**Figure 21: SPL Signals**

### *Old Example*

MCVT v5 Manual example:
https://docs.google.com/document/d/1J36dAKIitFI5Gj17hXQPpkgAXzvV4GsGWcKNeW2CJF8/edit?usp=sharing

# Appendix

## Overview of Core Systems

### *Subsystem Descriptions*

HabSim v6.3 includes physics-based models with damageable/repairable subsystem properties, including a 3-dimensional world and the associated models, power systems, robotic agents, the pressure, and thermal control aspects of the environmental control life support system (ECLSS), and the fault detection and health management. The simulation also considers both a crewed configuration as well as select aspects of dormant conditions.

HabSim provides the capability to explore techniques and algorithms needed to extract the necessary amount of actionable information for repair and recovery through monitoring and embedded intelligence. To achieve these goals, HabSim was framed in a system-of-systems context, where each component is a constituent system which can operate independently, while their combination establishes the extraterrestrial habitat as an integrated complex system. Doing so delivers both anticipated (and potentially unanticipated) emergent behaviors and allows for the emergence and propagation of performance effects due not only to the disruptions and failures, but also the implemented safety controls.

The subsystems included in the HabSim architecture can be broadly classified into three groups:

1. **Electro-Mechanical Systems (EMS):** those subsystems which directly propagate the physics of the habitat in both its operational condition as well as in its various hazardous states. The systems include a protective regolith layer, a structural system, an environmental control and life support system (ECLSS), and a power generation and distribution system.
2. **Health Management Systems (HMS):** those subsystems which primarily provide system evaluation and decision-making capabilities, but also include a physical aspect. The systems include an internal and interplanetary communication network, a command & control system, and a data repository.
3. **Agent Systems:** a single robotic agent that acts as the interface between the EMS and HMS subsystems, playing a significant role in each as it affects the physical changes in the habitat according to the direction of the HMS.

The HabSim subsystems each have a corresponding number in Simulink, which is used for the output data structure. Table 6 provides the number associated with each subsystem for your reference. The configuration parameters for each subsystem can be found in the SysFiles folder of the integrated v6.3 package. Note that this folder also contains communication, FDD (Fault Detection and Diagnostic) and sensor parameters (the user does not change these parameters).

**Table 6: Core Subsystem and its Corresponding Number in Simulink**

| Subsystem Number | Subsystem |
|---|---|
| 1 | Health Management |
| 2 | Structural |
| 3 | Power |
| 5 | ECLSS (Environmental Control and Life Support System) |
| 6 | Agent |
| 8 | Interior Environment |
| 9 | Disturbances |
| 11 | Structural Protective Layer |

## Simulink Architecture

The Simulink architecture of these core systems is shown in Figure 8 below.

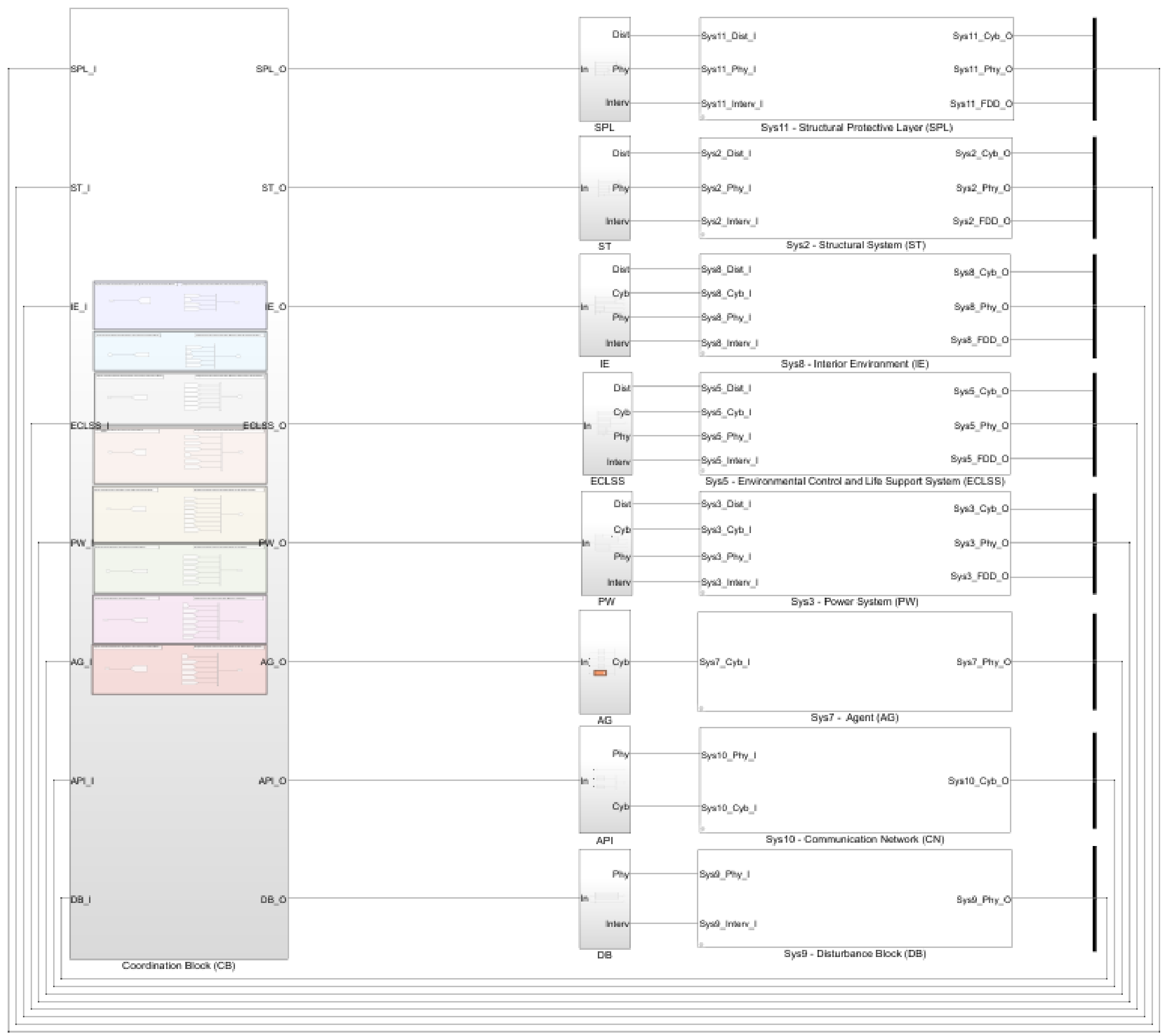
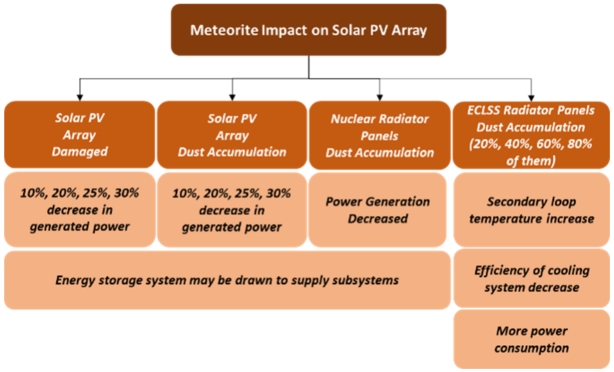



**Figure 8: Simulink Architecture of MCVT Subsystems**

# List of Disruption Scenarios



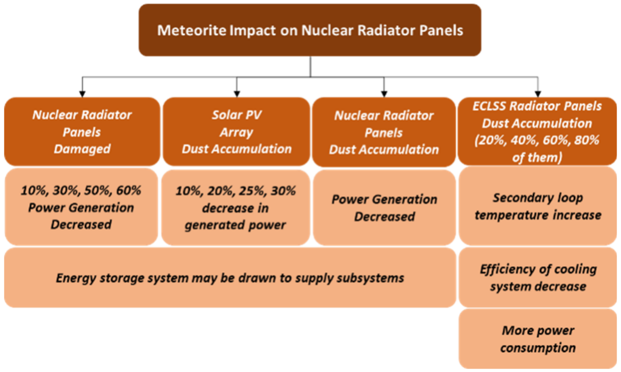




**Figure 9: Meteorite Impact on Solar PV Arrays (IL 2,3,4,5) (left) and Meteorite Impact on Nuclear Radiator Panels (IL 2,3,4,5) (right)**

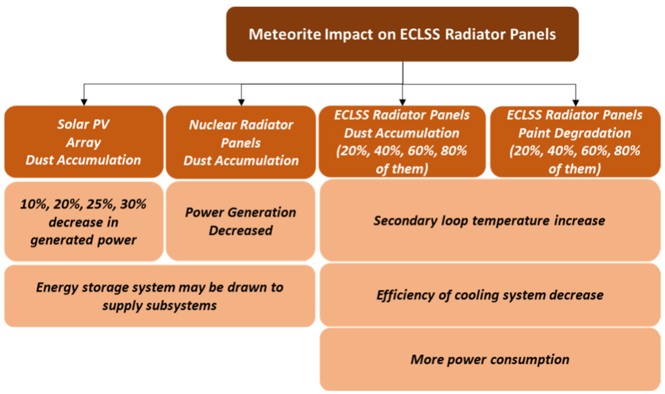



**Figure 10: Meteorite Impact on ECLSS Radiator Panels (IL 2,3,4,5)**

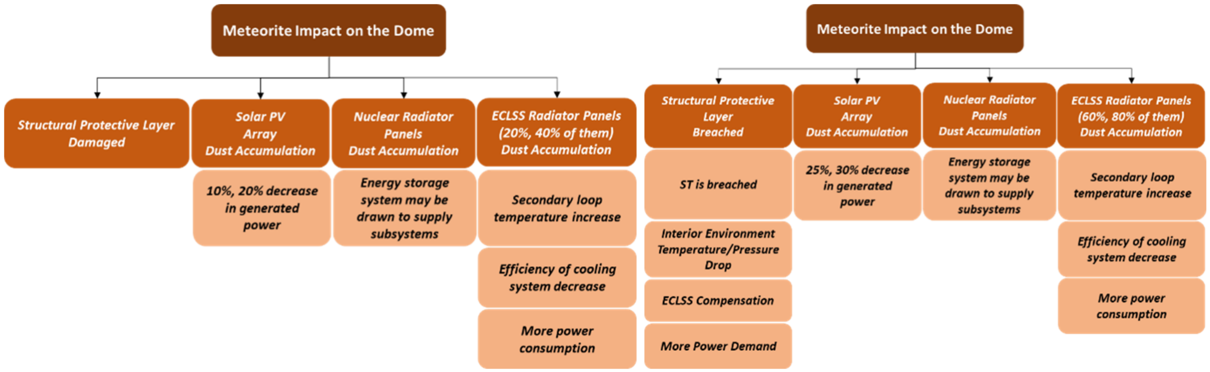



Figure 11: Meteorite Impact on Structure (IL 2,3) (left) and (IL 4,5) (right)

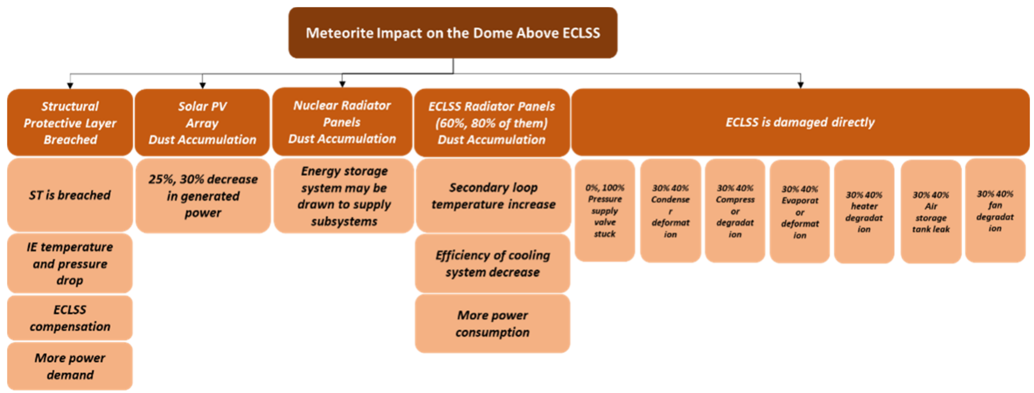



Figure 12: Meteorite Impact on Structure, Above ECLSS (IL 4,5)

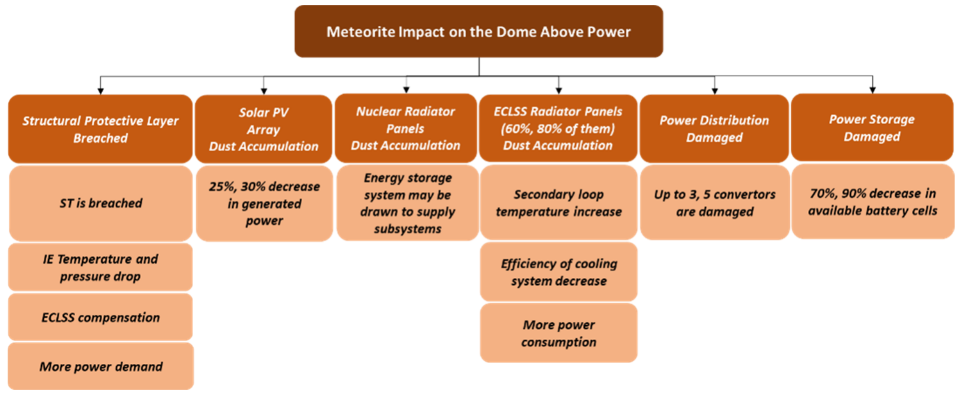
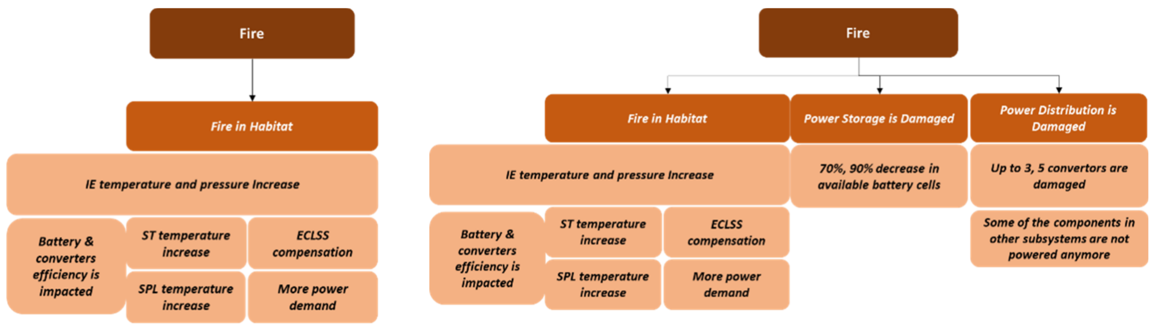



Figure 13: Meteorite Impact on Structure, Above Power (IL 4,5)




**Note:** Damage is due to the heat, nothing is on fire

**Note:** Damage is due to the heat, nothing is on fire

Figure 14: Fire in the Interior Environment in Z1 close to Power (IL 2,3) (left) and (IL 4,5) (right)

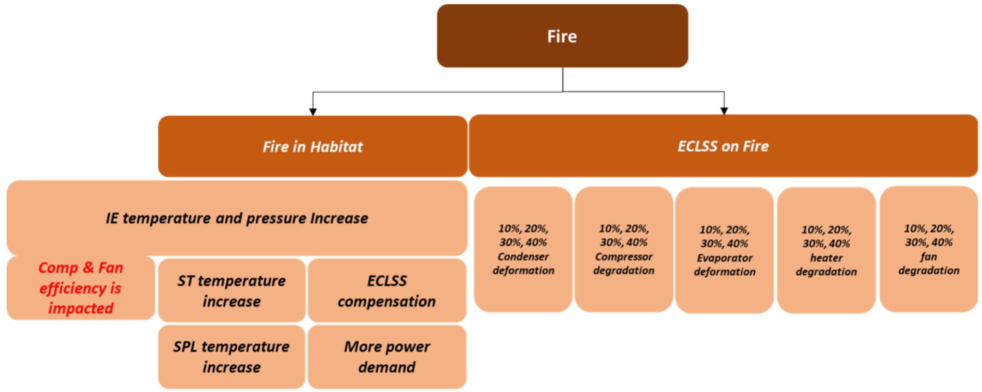



**Figure 15: Fire in the Interior Environment in Z2 close to ECLSS (IL 2,3,4,5)**

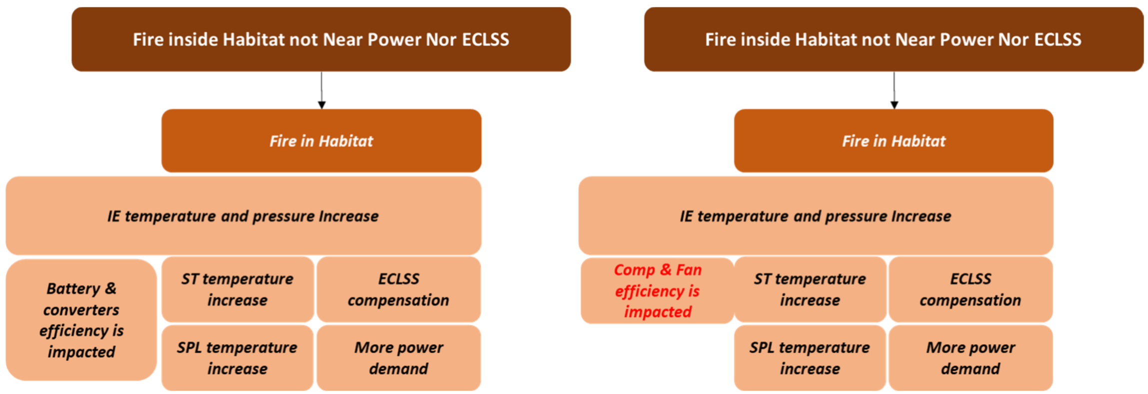



**Figure 16: Fire in the Interior Environment in Z1 (Not near Power) (IL 2,3,4,5) (left) and Fire in the Interior Environment in Z2 (Not near ECLSS) (IL 2,3,4,5) (right)**

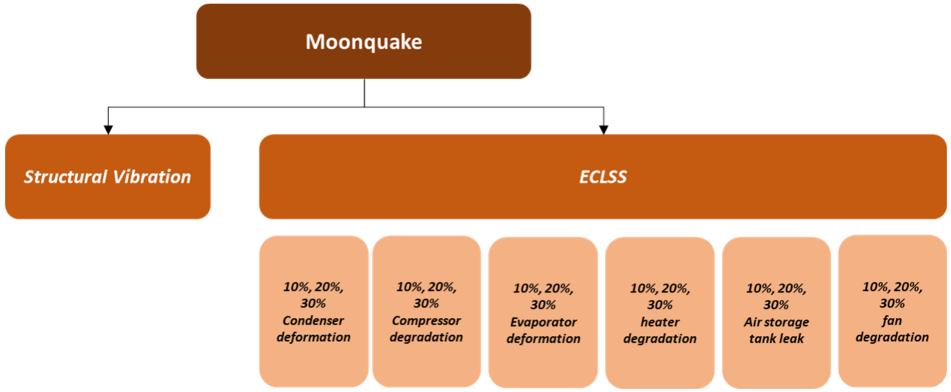



**Figure 17: Moonquake (IL 2,3,4)**

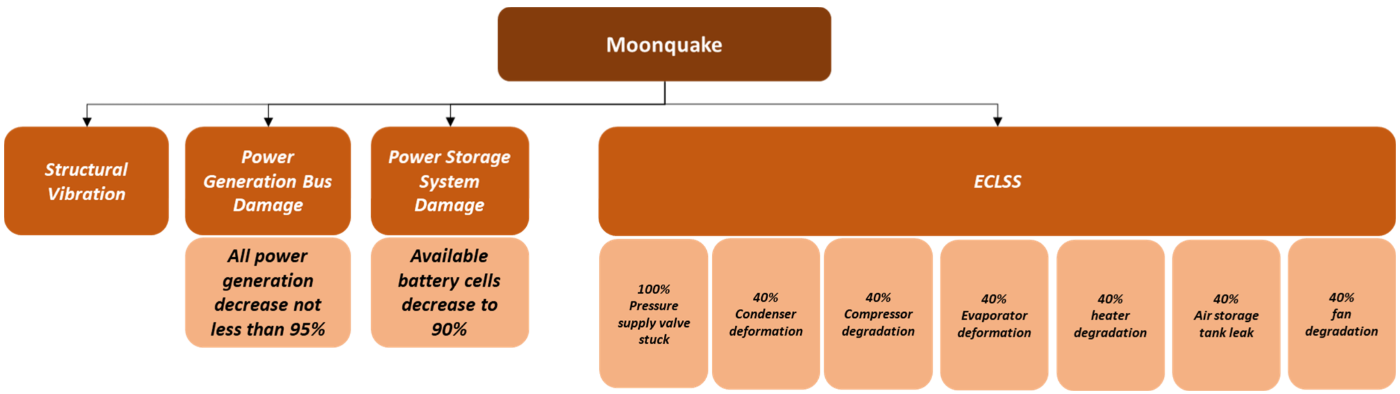



**Figure 18: Moonquake (IL 5)**

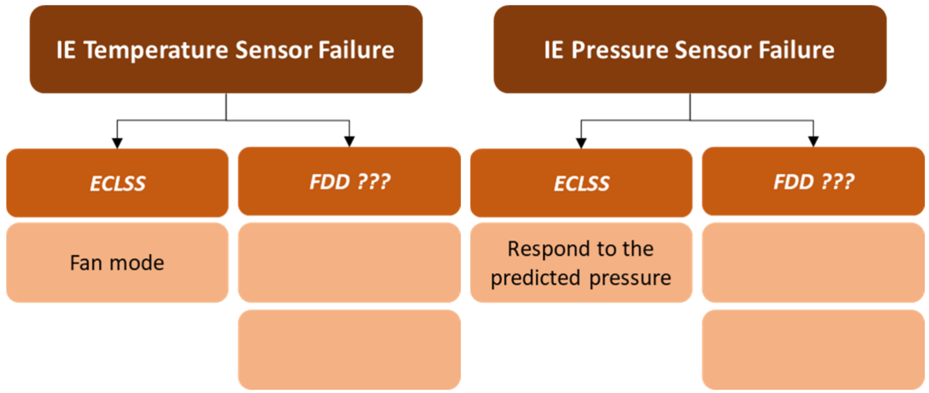



**Figure 19: Sensor Failure**

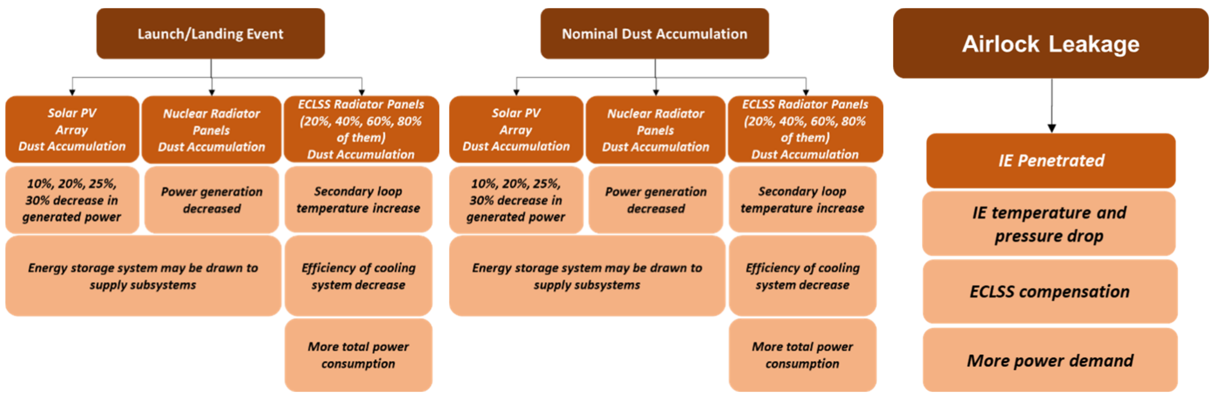



**Figure 20: Launch/Landing Event (left), Nominal Dust Accumulation (middle), and Airlock Leakage (IL 2,3,4,5) (right)**

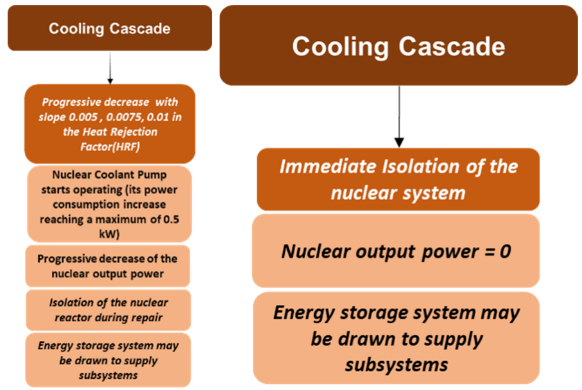



**Figure 21: Cooling System Cascade (IL 2,3,4) (left), Cooling System Cascade (IL 5) (right)**

## Data Output

Table 6 provides all available output data for the user. The variable names can be copied from the table and used when plotting. See any of the *MCVT_Plot_Data_<NAME>.m* files for how to use the model variable names to access the correct data and plot.

**Table 6. All Subsystem Output Variables**

| **Sys11_out** | **Description** |
|---|---|
| Sys11_out.Temp_Outer_Layer | Temperature of the outer SPL layer |
| Sys11_out.Temp_Middle_Layer | Temperature of the middle SPL layer |
| Sys11_out.Temp_Inner_Layer | Temperature of the inner SPL layer |
| Sys11_out.Total_Flux_to_Z1 | Total Flux to SPL Z1 |
| Sys11_out.Total_Flux_to_Z2 | Total Flux to SPL Z2 |
| Sys11_out.Flux_From_Sun_to_Each_Panel | Flux from Sun to each SPL panel |
| **Sys11_out.Acceleration** | |
| Sys11_out.Acceleration.Coor__0_2_9_0_ | Acceleration node 1 SPL |
| Sys11_out.Acceleration.Coor___2_7_1_1_0_ | Acceleration node 2 SPL |
| Sys11_out.Acceleration.Coor__1_4_1_4__1_4_ | Acceleration node 3 SPL |
| Sys11_out.Acceleration.Coor__0_1_8_1_8_ | Acceleration node 4 SPL |
| Sys11_out.Acceleration.Coor__2_2_0_9_ | Acceleration node 5 SPL |
| **Sys11_out.Health_State** | |
| Sys11_out.Health_State.Radius_of_SPL_hole | Radius of the hole in SPL due to micrometeorite impact |

| **Sys02_out** | **Description** |
|---|---|
| Sys02_out.Temp_Middle_Layer | Temperature of the ST middle layer |
| Sys02_out.Temp_Inner_Layer_To_IE | Temperature of the ST inner layer |
| Sys02_out.Flux_Outer_Layer__From_SPL_ | Heat flux from ST outer layer to SPL inner layer |
| **Sys02_out.Acceleration** | |
| Sys02_out.Acceleration.Coor__0_2_9_0_ | Acceleration node 1 ST |
| Sys02_out.Acceleration.Coor___2_7_1_1_0_ | Acceleration node 2 ST |
| Sys02_out.Acceleration.Coor__1_4_1_4__1_4_ | Acceleration node 3 ST |
| Sys02_out.Acceleration.Coor__0_1_8_1_8_ | Acceleration node 4 ST |

| | |
|---|---|
| Sys02_out.Acceleration.Coor__2_2_0_9_ | Acceleration node 5 ST |
| **Sys02_out.Health_State** | |
| Sys02_out.Health_State.Radius_of_ST_hole | Radius of the hole in ST due to micrometeorite impact |
| Sys02_out.Health_State.Radius_of_SPL_ST_Interface_hole | Radius of the hole in the interface between ST and SPL |

| Sys03_out | Description |
|---|---|
| **Sys03_out.Damages_and_Repairs.** | |
| Sys03_out.Damages_and_Repairs.Solar_PV_Dust | Dust accumulation on solar panels health state |
| Sys03_out.Damages_and_Repairs.Solar_PV_Damaged | Solar panel health state |
| Sys03_out.Damages_and_Repairs.Nuclear_Radiator_Dust | Nuclear radiator dust health state |
| Sys03_out.Damages_and_Repairs.Nuclear_Radiator_Damaged | Nuclear radiator damage health state |
| Sys03_out.Damages_and_Repairs.Remaining_Battry_Cells | Number of remaining battery cells |
| Sys03_out.Damages_and_Repairs.Conventor_1_Damaged | Converter 1 health state |
| Sys03_out.Damages_and_Repairs.Conventor_2_Damaged | Converter 2 health state |
| Sys03_out.Damages_and_Repairs.Conventor_3_Damaged | Converter 3 health state |
| Sys03_out.Damages_and_Repairs.Conventor_4_Damaged | Converter 4 health state |
| Sys03_out.Damages_and_Repairs.Conventor_5_Damaged | Converter 5 health state |
| Sys03_out.Damages_and_Repairs.Conventor_6_Damaged | Converter 6 health state |
| Sys03_out.Damages_and_Repairs.Bus_Damaged | Power bus health state |
| Sys03_out.Damages_and_Repairs.Nuclear_Coolant_Leakage | Coolant leakage indicator/health state |
| **Sys03_out.Power_Demand.** | |
| Sys03_out.Power_Demand.Monitoring_Loads__Sensors__FDDs__Critical_lightings | Power requested by sensors, lightning and FDD loads |
| Sys03_out.Power_Demand.Critical_Loads__ECLSS__Life_Support | Power request from ECLSS |
| Sys03_out.Power_Demand.Other_Loads__Houskeeping___Scientific_instrument | Power requested by housekeeping and scientific instruments loads |
| Sys03_out.Power_Demand.Pump_Power_Consumption | Pump power consumption |
| **Sys03_out.Power_Generations** | |
| Sys03_out.Power_Generations.Nuclear_Power | Generated nuclear power |
| Sys03_out.Power_Generations.Solar_Power | Generated solar power |
| Sys03_out.Power_Generations.Discharging_Power | Discharging power |
| Sys03_out.Power_Generations.Currently_Stored_Energy | Stored energy |

| | |
|---|---|
| Sys03_out.Power_Generations.Maximum_Storage | Generated maximum power |
| Sys03_out.Power_Generations.Generation_Bus_Power | Max power generated delivered through bus |
| Sys03_out.Power_Generations.Dumping_Load_for_Nuclear_Converter | Dumping loads for nuclear power generator |
| **Sys03_out.Step_Up_Converters.** | |
| Sys03_out.Step_Up_Converters.Nuclear | Step up converter output - nuclear power |
| Sys03_out.Step_Up_Converters.Solar | Step up converter output - solar power |
| Sys03_out.Step_Up_Converters.Battry | Step up converter output - energy storage |
| **Sys03_out.Step_Down_Converters.** | |
| Sys03_out.Step_Down_Converters.Critical_Loads__ECLSS__Life_Support | Loads trough converter 4 |
| Sys03_out.Step_Down_Converters.Monitoring_Loads__Sensors__FDDs__Critical_lightings | Loads trough converter 5 |
| Sys03_out.Step_Down_Converters.Other_Loads__Houskeeping___Scientific_instrument | Loads trough converter 6 |
| **Sys03_out.Loads_Supply** | |
| Sys03_out.Loads_Supply.Monitoring_Loads_Supply | Provided power to monitoring loads |
| Sys03_out.Loads_Supply.Other_Loads_Supply | Provided power to accessory loads |
| Sys03_out.Loads_Supply.LifeSupport_Loads_Supply | Provided power to ECLSS |

| **Sys05_out** | |
|---|---|
| **Sys05_out.Health_State.** | |
| Sys05_out.Health_State.Panels_Dust | ECLSS panels health state |
| Sys05_out.Health_State.Panels_Paint | ECLSS panels paint health state |
| Sys05_out.Health_State.Ventalation_Fan | ECLSS ventilation fan health state |
| Sys05_out.Health_State.Air_Tank_Leak | ECLSS air tank health state |
| Sys05_out.Health_State.Pressure_Supply_Valve | ECLSS pressure valve health state |
| Sys05_out.Health_State.Condenser | ECLSS condenser health state |
| Sys05_out.Health_State.Compressor | ECLSS compressor health state |
| Sys05_out.Health_State.Evaporator | ECLSS evaporator health state |
| Sys05_out.Health_State.Heater | ECLSS heater health state |
| Sys05_out.Health_State.Cooling_Fan | ECLSS cooling fan health state |
| **Sys05_out.ATCS** | |
| Sys05_out.ATCS.Evap_Outlet_Temp_C | Evaporator outlet temperature |
| Sys05_out.ATCS.Temp_NH3_C | NH3 temperature |
| Sys05_out.ATCS.Temp_Radi_Surf | ECLSS radiator surface temp |

| | |
|---|---|
| Sys05_out.ATCS.Heat_Gain_kW | ECLSS heat gain |
| **Sys05_out.ATCS.Air_Flow_Rate_m3_s** | |
| Sys05_out.ATCS.Air_Flow_Rate_m3_s.Z1 | Flow rate in Z1 |
| Sys05_out.ATCS.Air_Flow_Rate_m3_s.Z2 | Flow rate in Z2 |
| **Sys05_out.IPCS.Air_Discharge_kg_s** | |
| Sys05_out.IPCS.Air_Discharge_kg_s.Z1 | Discharge flow rate in Z1 |
| Sys05_out.IPCS.Air_Discharge_kg_s.Z2 | Discharge flow rate in Z2 |
| **Sys05_out.IPCS.Air_Supply_kg_s** | |
| Sys05_out.IPCS.Air_Supply_kg_s.Z1 | Supplied air in Z1 |
| Sys05_out.IPCS.Air_Supply_kg_s.Z2 | Supplied air in Z2 |
| **Sys05_out.Power_Request_kW.Heating** | |
| Sys05_out.Power_Request_kW.Heating.PW_req_heater_1_kW | Power requested by heater in Z1 |
| Sys05_out.Power_Request_kW.Heating.PW_req_heater_2_kW | Power requested by heater in Z2 |
| **Sys05_out.Power_Request_kW.Cooling** | |
| Sys05_out.Power_Request_kW.Cooling.PW_req_compressor_kW | Power requested by compressor |
| Sys05_out.Power_Request_kW.Cooling.PW_req_fan_1_kW | Power requested by fan in Z1 |
| Sys05_out.Power_Request_kW.Cooling.PW_req_fan_2_kW | Power requested by fan in Z2 |
| **Sys05_out.Power_Consumption_kW.** | |
| Sys05_out.Power_Consumption_kW.Compressor | Power consumed by compressor |
| Sys05_out.Power_Consumption_kW.Total_kW | Total power consumption |
| Sys05_out.Power_Consumption_kW.Fan | Fan power consumption |
| Sys05_out.Power_Consumption_kW.Heater | Heater power consumption |
| **Sys05_out.Power_Consumption_kW** | |
| Sys05_out.Power_Consumption_kW.Fan.Z1 | Power consumed by fan in Z1 |
| Sys05_out.Power_Consumption_kW.Fan.Z2 | Power consumed by fan in z2 |
| **Sys05_out.Power_Consumption_kW.** | |
| Sys05_out.Power_Consumption_kW.Heater.Z1 | Power consumed by heater in Z1 |
| Sys05_out.Power_Consumption_kW.Heater.Z2 | Power consumed by heater in Z2 |
| **Sys05_out.Thermal_Efficiency** | |
| Sys05_out.Thermal_Efficiency.Compressor | Thermal efficiency of compressor |
| Sys05_out.Thermal_Efficiency.Fan_Z1 | Thermal efficiency of fan in Z1 |
| Sys05_out.Thermal_Efficiency.Fan_Z2 | Thermal efficiency on fan in Z2 |

| | |
|---|---|
| **Sys05_out.Set_Points.T_Set_Point_Cooling.** | |
| Sys05_out.Set_Points.T_Set_Point_Cooling.Set_Point_Cooling_Z1 | Cooling setpoint in Z1 |
| Sys05_out.Set_Points.T_Set_Point_Cooling.Set_Point_Cooling_Z2 | Cooling setpoint in Z2 |
| **Sys05_out.Set_Points.T_Set_Point_Heating.** | |
| Sys05_out.Set_Points.T_Set_Point_Heating.Set_Point_Heating_Z1 | Heating setpoint in Z1 |
| Sys05_out.Set_Points.T_Set_Point_Heating.Set_Point_Heating_Z2 | Heating setpoint in Z2 |
| **Sys05_out.Set_Points.P_Set_Point_Discharging.** | |
| Sys05_out.Set_Points.P_Set_Point_Discharging.Set_Point_Discharging_Z1 | Discharging setpoint in Z1 |
| Sys05_out.Set_Points.P_Set_Point_Discharging.Set_Point_Discharging_Z2 | Discharging setpoint in Z2 |
| **Sys05_out.Set_Points.P_Set_Point_Supplying** | |
| Sys05_out.Set_Points.P_Set_Point_Supplying.Set_Point_Supplying_Z1 | Supplying setpoint Z1 |
| Sys05_out.Set_Points.P_Set_Point_Supplying.Set_Point_Supplying_Z2 | Supplying setpoint Z2 |

| **Sys07_out** | **Description** |
|---|---|
| **Sys07_out.Failure_Mode.** | |
| Sys07_out.Failure_Mode.ECLSS_Panels_Dusty | ECLSS dust on panel failure mode |
| Sys07_out.Failure_Mode.ECLSS_Panels_Paint | ECLSS paint failure mode |
| Sys07_out.Failure_Mode.ECLSS_Air_Fan | ECLSS air fan failure mode |
| Sys07_out.Failure_Mode.ECLSS_Tank_Leak | ECLSS air tank failure mode |
| Sys07_out.Failure_Mode.ECLSS_Valve | ECLSS valve failure mode |
| Sys07_out.Failure_Mode.ECLSS_Condenser | ECLSS condenser failure mode |
| Sys07_out.Failure_Mode.ECLSS_Compressor | ECLSS compressor failure mode |
| Sys07_out.Failure_Mode.ECLSS_Evaporator | ECLSS evaporator failure mode |
| Sys07_out.Failure_Mode.ECLSS_Heater | ECLSS heater failure mode |
| Sys07_out.Failure_Mode.ECLSS_Cooling_Fan | ECLSS cooling fan failure mode |
| Sys07_out.Failure_Mode.ST_Penetration | ECLSS micrometeorite impact and penetration on ST failure mode |
| Sys07_out.Failure_Mode.SPL_Penetration | ECLSS micrometeorite impact and penetration on SPL failure mode |
| Sys07_out.Failure_Mode.IE_FireZ1 | Fire in Z1 failure mode |
| Sys07_out.Failure_Mode.IE_FireZ2 | Fire in Z2 failure mode |
| Sys07_out.Failure_Mode.IE_Airlock | Airlock failure mode |
| Sys07_out.Failure_Mode.PW_PV_Arrays_Dusty | Dust on solar array failure mode |
| Sys07_out.Failure_Mode.PW_PV_Arrays_Broken | Broken solar array failure mode |

| | |
|---|---|
| Sys07_out.Failure_Mode.PW_Nuclear_Dusty | Dust on nuclear elements failure mode |
| Sys07_out.Failure_Mode.PW_Nuclear_Broken | broken nuclear element failure mode |
| Sys07_out.Failure_Mode.PW_Battery | Battery failure mode |
| Sys07_out.Failure_Mode.PW_Conv1 | Converter 1 failure mode |
| Sys07_out.Failure_Mode.PW_Conv2 | Converter 2 failure mode |
| Sys07_out.Failure_Mode.PW_Conv3 | Converter 3 failure mode |
| Sys07_out.Failure_Mode.PW_Conv4 | Converter 4 failure mode |
| Sys07_out.Failure_Mode.PW_Conv5 | Converter 5 failure mode |
| Sys07_out.Failure_Mode.PW_Conv6 | Converter 6 failure mode |
| Sys07_out.Failure_Mode.PW_Bus | Power bus failure mode |
| Sys07_out.Failure_Mode.PW_Coolant_Leakage | Coolant leakage failure mode |
| **Sys07_out.Repair_Rate** | |
| Sys07_out.Repair_Rate.ECLSS_Panels_Dusty | ECLSS dust on panel repair rate |
| Sys07_out.Repair_Rate.ECLSS_Panels_Paint | ECLSS paint repair rate |
| Sys07_out.Repair_Rate.ECLSS_Air_Fan | ECLSS air fan repair rate |
| Sys07_out.Repair_Rate.ECLSS_Tank_Leak | ECLSS air tank repair rate |
| Sys07_out.Repair_Rate.ECLSS_Valve | ECLSS valve repair rate |
| Sys07_out.Repair_Rate.ECLSS_Condenser | ECLSS condenser repair rate |
| Sys07_out.Repair_Rate.ECLSS_Compressor | ECLSS compressor repair rate |
| Sys07_out.Repair_Rate.ECLSS_Evaporator | ECLSS evaporator repair rate |
| Sys07_out.Repair_Rate.ECLSS_Heater | ECLSS heater repair rate |
| Sys07_out.Repair_Rate.ECLSS_Cooling_Fan | ECLSS cooling fan repair rate |
| Sys07_out.Repair_Rate.ST_Penetration | ECLSS micrometeorite impact and penetration on ST repair rate |
| Sys07_out.Repair_Rate.SPL_Penetration | ECLSS micrometeorite impact and penetration on SPL repair rate |
| Sys07_out.Repair_Rate.IE_FireZ1 | Fire in Z1 repair rate |
| Sys07_out.Repair_Rate.IE_FireZ2 | Fire in Z2 repair rate |
| Sys07_out.Repair_Rate.IE_Airlock | Airlock repair rate |
| Sys07_out.Repair_Rate.PW_PV_Arrays_Dusty | Dust on solar array repair rate |
| Sys07_out.Repair_Rate.PW_PV_Arrays_Broken | Broken solar array repair rate |
| Sys07_out.Repair_Rate.PW_Nuclear_Dusty | Dust on nuclear elements repair rate |
| Sys07_out.Repair_Rate.PW_Nuclear_Broken | Broken nuclear element repair rate |
| Sys07_out.Repair_Rate.PW_Battery | Battery repair rate |

| | |
|---|---|
| Sys07_out.Repair_Rate.PW_Conv1 | Converter 1 repair rate |
| Sys07_out.Repair_Rate.PW_Conv2 | Converter 2 repair rate |
| Sys07_out.Repair_Rate.PW_Conv3 | Converter 3 repair rate |
| Sys07_out.Repair_Rate.PW_Conv4 | Converter 4 repair rate |
| Sys07_out.Repair_Rate.PW_Conv5 | Converter 5 repair rate |
| Sys07_out.Repair_Rate.PW_Conv6 | Converter 6 repair rate |
| Sys07_out.Repair_Rate.PW_Bus | Power bus repair rate |
| Sys07_out.Repair_Rate.PW_Coolant_Leakage | Coolant leakage repair rate |

| **Sys08_out** | **Description** |
|---|---|
| **Sys08_out.Health_States.** | |
| Sys08_out.Health_States.Radius_Fire_Z1 | Fire radius in Z1 |
| Sys08_out.Health_States.Radius_Fire_Z2 | Fire radius in Z2 |
| Sys08_out.Health_States.Radius_Airlock | Airlock leakage radius |
| **Sys08_out.Press___Temp** | |
| Sys08_out.Press___Temp.Wall_Temperature_K | Wall temperature |
| Sys08_out.Press___Temp.Evap_Outlet_Temp | Evaporator outlet temperature |
| Sys08_out.Press___Temp.ReturnAirTemperature_C | Return line temperature |
| **Sys08_out.Press___Temp.Pressure_Pa.** | |
| Sys08_out.Press___Temp.Pressure_Pa.Z1 | Pressure in Z1 |
| Sys08_out.Press___Temp.Pressure_Pa.Z2 | Pressure in Z2 |
| **Sys08_out.Press___Temp.Air_Temperature_K** | |
| Sys08_out.Press___Temp.Air_Temperature_K.Z1 | Temperature in Z1 |
| Sys08_out.Press___Temp.Air_Temperature_K.Z2 | Temperature in Z2 |
| **Sys08_out.Thermal_Load** | |
| Sys08_out.Thermal_Load.CoolingLoad | Cooling load |
| Sys08_out.Thermal_Load.HeatingLoad_kW | Heating load |
| Sys08_out.Thermal_Load.ThermalLoad | Thermal load |
| **Sys08_out.Flux** | |
| Sys08_out.Flux.HeatGain_W | Heat gain from interior environment |
| Sys08_out.Flux.HeatFlux | Heat flux from interior environment |

| | |
|---|---|
| Sys08_out.Flux.WallConvection | Wall convection from interior environment |
| **Sys08_out.Flow.** | |
| Sys08_out.Flow.FireHeatFlow | Heat flow due to fire |
| Sys08_out.Flow.AirFlowRate | Air flowrate |
| Sys08_out.Flow.AirCirculation | Air circulation |
| Sys08_out.Flow.AirLeakage | Leaking air towards external environment |
| **Sys08_out.Flow.AirSupply** | |
| Sys08_out.Flow.AirSupply.Z1 | Supplied air by pressure control in Z1 |
| Sys08_out.Flow.AirSupply.Z2 | Supplied air by pressure control in Z2 |
| **Sys08_out.Flow.AirDischarge** | |
| Sys08_out.Flow.AirDischarge.Z1 | Discharged air from Z1 |
| Sys08_out.Flow.AirDischarge.Z2 | Discharged air from Z2 |
| **Sys08_out.Cyber** | |
| Sys08_out.Cyber.Pocket_Door | Pocket door position |
| **Sys08_out.Cyber.Air_Temp** | |
| Sys08_out.Cyber.Air_Temp.Air_Temp_Z1 | Temperature in Z1 |
| Sys08_out.Cyber.Air_Temp.Air_Temp_Z2 | Temperature in Z2 |
| **Sys08_out.Cyber.Air_Pressure** | |
| Sys08_out.Cyber.Air_Pressure.Air_Pressure_Z1 | Pressure in Z1 |
| Sys08_out.Cyber.Air_Pressure.Air_Pressure_Z2 | Pressure in Z2 |
| **Sys08_out.Cyber.Smoke_Detector** | |
| Sys08_out.Cyber.Smoke_Detector.Smoke_Detector_Z1 | Smoke detector state in Z1 |
| Sys08_out.Cyber.Smoke_Detector.Smoke_Detector_Z2 | Smoke detector state in Z2 |

| **Sys09_out.Disturbances_Phy** | **Description** |
|---|---|
| Sys09_out.Disturbances_Phy.GroundTempreture | External ground temperature |
| Sys09_out.Disturbances_Phy.dustAccum | Dust accumulation rate |
| **Sys09_out.Disturbances_Phy.SolarPhy** | |
| Sys09_out.Disturbances_Phy.SolarPhy.Solar_Vector | Solar position vector |
| Sys09_out.Disturbances_Phy.SolarPhy.Solar_Flux_3D | Solar flux |
| Sys09_out.Disturbances_Phy.SolarPhy.Solar_Angle | Solar position angle |

| | |
|---|---|
| Sys09_out.Disturbances_Phy.SolarPhy.Solar_Flux_2D | Solar flux in 2D |
| **Sys09_out.Disturbances_Phy.meteoritePhy** | |
| Sys09_out.Disturbances_Phy.meteoritePhy.meteorite_coord | Meteorite impact coordinates |
| Sys09_out.Disturbances_Phy.meteoritePhy.meteorite_mass | Meteorite mass |
| Sys09_out.Disturbances_Phy.meteoritePhy.meteorite_velocity | Meteorite velocity |
| **Sys09_out.Disturbances_Phy.moonquakePhy** | |
| Sys09_out.Disturbances_Phy.moonquakePhy.moonquakeMag | Moonquake magnitude |
| Sys09_out.Disturbances_Phy.moonquakePhy.accX | Moonquake acceleration in x direction |
| Sys09_out.Disturbances_Phy.moonquakePhy.accY | Moonquake acceleration in y direction |
| **Sys09_out.Disturbances_Phy.Fire_Phys** | |
| Sys09_out.Disturbances_Phy.Fire_Phys.Fire_Temp | Fire temperature |
| Sys09_out.Disturbances_Phy.Fire_Phys.Fire_Coord | Fire origin coordinate |
| Sys09_out.Disturbances_Phy.Fire_Phys.rFire_Z1 | Radius of the fire in Z1 |
| Sys09_out.Disturbances_Phy.Fire_Phys.rFire_Z2 | Radius of the fire in Z2 |
| **Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_PW** | |
| Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_PW.DL_Convertors_DueTo_Temp_Z1 | Damage level to converter due to high temp. |
| Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_PW.DL_ES_Temp_DueTo_Z1 | Damage level to batteries due to high temp. |
| **Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_ECLSS** | |
| Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_ECLSS.DL_Fan_DueTo_Temp_Z1 | Damage level to fan in Z1 due to temp. |
| Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_ECLSS.DL_Fan_DueTo_Temp_Z2 | damage level to fan in Z2 due to temp. |
| Sys09_out.Disturbances_Phy.Sys9_Damage_Level.DL_ECLSS.DL_Compressor_DueTo_Temp_Z2 | Damage level to compressor in Z2 due to temp. |
| **Sys09_out.Disturbances_Phy.IE_HeatGain_kW** | |
| Sys09_out.Disturbances_Phy.IE_HeatGain_kW.IE_PW_Z1_HeatGain_kW | Heat gain to Z1 |
| Sys09_out.Disturbances_Phy.IE_HeatGain_kW.IE_ECLSS_Z2_HeatGain_kW | Heat gain to Z2 |
| **Sys09_out.Meteorite** | |
| Sys09_out.Meteorite.SPL | Meteorite impact intensity level on SPL |
| Sys09_out.Meteorite.ST | Meteorite impact intensity level on ST |
| Sys09_out.Meteorite.IE_Z1 | Meteorite impact intensity level on Z1 |
| Sys09_out.Meteorite.IE_Z2 | Meteorite impact intensity level on Z2 |
| Sys09_out.Meteorite.ECLSS_PR | Meteorite impact intensity level on PR |

| | |
|---|---|
| Sys09_out.Meteorite.ECLSS_TH | Meteorite impact intensity level on TH |
| Sys09_out.Meteorite.ECLSS_EE | Meteorite impact intensity level on EE |
| Sys09_out.Meteorite.PW_PD | Meteorite impact intensity level on PD |
| Sys09_out.Meteorite.PW_ES | Meteorite impact intensity level on ES |
| Sys09_out.Meteorite.PW_S | Meteorite impact intensity level on S |
| Sys09_out.Meteorite.PW_N | Meteorite impact intensity level on N |
| **Sys09_out.Fire** | |
| Sys09_out.Fire.SPL | Fire intensity level on SPL |
| Sys09_out.Fire.ST | Fire intensity level on ST |
| Sys09_out.Fire.IE_Z1 | Fire intensity level on Z1 |
| Sys09_out.Fire.IE_Z2 | Fire intensity level on Z2 |
| Sys09_out.Fire.ECLSS_PR | Fire intensity level on PR |
| Sys09_out.Fire.ECLSS_TH | Fire intensity level on TH |
| Sys09_out.Fire.ECLSS_EE | Fire intensity level on EE |
| Sys09_out.Fire.PW_PD | Fire intensity level on PD |
| Sys09_out.Fire.PW_ES | Fire intensity level on ES |
| Sys09_out.Fire.PW_S | Fire intensity level on S |
| Sys09_out.Fire.PW_N | Fire intensity level on N |
| **Sys09_out.Moonquake** | |
| Sys09_out.Moonquake.SPL | Moonquake intensity level on SPL |
| Sys09_out.Moonquake.ST | Moonquake intensity level on ST |
| Sys09_out.Moonquake.IE_Z1 | Moonquake intensity level on Z1 |
| Sys09_out.Moonquake.IE_Z2 | Moonquake intensity level on Z2 |
| Sys09_out.Moonquake.ECLSS_PR | Moonquake intensity level on PR |
| Sys09_out.Moonquake.ECLSS_TH | Moonquake intensity level on TH |
| Sys09_out.Moonquake.ECLSS_EE | Moonquake intensity level on EE |
| Sys09_out.Moonquake.PW_PD | Moonquake intensity level on PD |
| Sys09_out.Moonquake.PW_ES | Moonquake intensity level on ES |
| Sys09_out.Moonquake.PW_S | Moonquake intensity level on S |
| Sys09_out.Moonquake.PW_N | Moonquake intensity level on N |

# Plot Output

**Table 7: Plot Outputs and Descriptions**

| Health State (HS) | | |
|---|---|---|
| **Subplot** | **Title** | **Description** |
| subplot(4,7,1) | ECLSS Panels Dust Deposition | Dust deposition on ECLSS radiator panels. |
| subplot(4,7,2) | ECLSS Panels Paint | Health state of the ECLSS paint. Health state equal to 1 means unhealthy component |
| subplot(4,7,3) | ECLSS Air Fan | Health state of the ECLSS Zone 1 and 2 fans. Health state equal to 1 means unhealthy component |
| subplot(4,7,4) | ECLSS Tank Leak | Health state of the ECLSS tank. Health state equal to 1 means unhealthy component |
| subplot(4,7,5) | ECLSS Valve | Health state of the ECLSS pressure control valve. Health state equal to 1 means unhealthy component |
| subplot(4,7,6) | ECLSS Condenser | Health state of the ECLSS condenser. Health state equal to 1 means unhealthy component |
| subplot(4,7,7) | ECLSS Compressor | Health state of the ECLSS compressor. Health state equal to 1 means unhealthy component |
| subplot(4,7,8) | ECLSS Evaporator | Health state of the ECLSS evaporator. Health state equal to 1 means unhealthy component |
| subplot(4,7,9) | ECLSS Heater | Health state of the ECLSS heater. Health state equal to 1 means unhealthy component |
| subplot(4,7,10) | ECLSS Cooling Fan | Health state of the ECLSS zone 1 and 2 cooling fan. Health state equal to 1 means unhealthy component |
| subplot(4,7,11) | ST Penetration | Hole radius on structural system |
| subplot(4,7,12) | SPL Penetration | Hole radius on structural protective layer system |
| subplot(4,7,13) | IE Fire Z1 | Fire radius in zone 1 |

| | | |
|---|---|---|
| subplot(4,7,14) | IE Fire Z2 | Fire radius in zone 2 |
| subplot(4,7,15) | IE Airlock Leakage | Airlock leakage radius |
| subplot(4,7,16) | PW PV Arrays Dust Deposition | Dust deposition on solar panel arrays |
| subplot(4,7,17) | PW PV Arrays Broken | Health state of solar panels. Health state equal to 1 means unhealthy component |
| subplot(4,7,18) | PW Nuclear Panels Dust Deposition | Dust deposition on PW nuclear radiators panels |
| subplot(4,7,19) | PW Nuclear Panels Broken | Health state of the PW nuclear radiators. Health state equal to 1 means unhealthy component |
| subplot(4,7,20) | Battery | Remaining battery cells |
| subplot(4,7,22) | PW Converter 1 | Health state of PW converter 1. Health state equal to 1 means unhealthy component |
| subplot(4,7,23) | PW Converter 2 | Health state of PW converter 2. Health state equal to 1 means unhealthy component |
| subplot(4,7,24) | PW Converter 3 | Health state of PW converter 3. Health state equal to 1 means unhealthy component |
| subplot(4,7,25) | PW Converter 4 | Health state of PW converter 4. Health state equal to 1 means unhealthy component |
| subplot(4,7,26) | PW Converter 5 | Health state of PW converter 5. Health state equal to 1 means unhealthy component |
| subplot(4,7,27) | PW Converter 6 | Health state of PW converter 6. Health state equal to 1 means unhealthy component |
| subplot(4,7,28) | PW Bus | Health state of the PW routing bus . Health state equal to 1 means unhealthy component |
| subplot(4,7,21) | PW Coolant Leakage | Health state of the PW nuclear cooling system. Health state equal to 1 means unhealthy component |
| **Agent (AG)** | | |
| **Subplot** | **Title** | **Description** |
| subplot(4,7,1) | ECLSS Panels Dusty | Dust repair on ECLSS radiator panels. |

| | | |
|---|---|---|
| subplot(4,7,2) | ECLSS Panels Paint | Repair action of the ECLSS paint. |
| subplot(4,7,3) | ECLSS Air Fan | Repair action of the ECLSS Zone 1 and 2 fans. |
| subplot(4,7,4) | ECLSS Tank Leak | Repair action of the ECLSS tank. |
| subplot(4,7,5) | ECLSS Valve | Repair action of the ECLSS pressure control valve. |
| subplot(4,7,6) | ECLSS Condenser | Repair action of the ECLSS condenser. |
| subplot(4,7,7) | ECLSS Compressor | Repair action of the ECLSS compressor. |
| subplot(4,7,8) | ECLSS Evaporator | Repair action of the ECLSS evaporator. |
| subplot(4,7,9) | ECLSS Heater | Repair action of the ECLSS heater. |
| subplot(4,7,10) | ECLSS Cooling Fan | Repair action of the ECLSS zone 1 and 2 cooling fan. |
| subplot(4,7,11) | ST Penetration | Hole radius on structural system |
| subplot(4,7,12) | SPL Penetration | Hole radius on structural protective layer system |
| subplot(4,7,13) | IE FireZ1 | Fire suppression in zone 1 |
| subplot(4,7,14) | IE FireZ2 | Fire suppression in zone 2 |
| subplot(4,7,15) | IE Airlock | Airlock repair activity |
| subplot(4,7,16) | PW PV Arrays Dusty | Dust removal on solar panel arrays |
| subplot(4,7,17) | PW PV Arrays Broken | Repair action of solar panels. |
| subplot(4,7,18) | PW Nuclear Dusty | Dust removal on PW nuclear radiators panels |
| subplot(4,7,19) | PW Nuclear Broken | Repair action of the PW nuclear radiators. |
| subplot(4,7,20) | PW Battery | Battery cells repair |
| subplot(4,7,22) | PW Conv1 | Repair action of PW converter 1. |
| subplot(4,7,23) | PW Conv2 | Repair action of PW converter 2. |
| subplot(4,7,24) | PW Conv3 | Repair action of PW converter 3. |
| subplot(4,7,25) | PW Conv4 | Repair action of PW converter 4. |
| subplot(4,7,26) | PW Conv5 | Repair action of PW converter 5. |
| subplot(4,7,27) | PW Conv6 | Repair action of PW converter 6. |
| subplot(4,7,28) | PW Bus | Repair action of the PW routing bus . |
| subplot(4,7,21) | PW Coolant Leakage | Repair action of the PW nuclear cooling system. |
| **Power (PW)** | | |
| **Subplot** | **Title** | **Description** |
| subplot(3,6,1) | ECLSS Load | ECLSS power demand |

| | | |
|---|---|---|
| subplot(3,6,2) | Monitoring Loads | Monitoring power demand |
| subplot(3,6,3) | Other Housekeeping Instruments | Other power demand |
| subplot(3,6,4) | Pump Power Consumption | Pump power demand |
| subplot(3,6,5) | Nuclear Power | Nuclear power generation |
| subplot(3,6,6) | Solar Power | Solar power generation |
| subplot(3,6,7) | Discharge Power | Discharge power |
| subplot(3,6,8) | Currently Stored Energy | Currently stored energy |
| subplot(3,6,9) | Dumping Load | Dumping power |
| subplot(3,6,10) | Generation Bus Power | Generation power produced |
| subplot(3,6,13) | Output of Step Up Conv1 Nuclear | Output nuclear power sent |
| subplot(3,6,14) | Output of Step Up Conv2 Solar | Output solar power sent |
| subplot(3,6,15) | Output of Step Up Conv3 Battery | Output energy storage power |
| subplot(3,6,16) | Output of Step Down Conv4 | ECLSS power sent |
| subplot(3,6,17) | Output of Step Down Conv5 | Housekeeping loads power sent |
| subplot(3,6,18) | Output of Step Down Conv6 | Monitoring loads power sent |
| **ECLSS (ECLSS)** | | |
| **Subplot** | **Title** | **Description** |
| subplot(2,3,1) | PW Request Heater 1 | Power requested from heater in zone 1 |
| subplot(2,3,2) | PW Consumption Heater Z1 | Power consumed from heater in zone 1 |
| subplot(2,3,3) | PW Request Heater 2 | Power requested from heater in zone 2 |
| subplot(2,3,4) | PW Consumption Heater Z2 | Power consumed from heater in zone 2 |
| subplot(2,3,5) | PW Consumption Compressor | Power consumed by ECLSS compressor |
| subplot(2,3,6) | Total PW Consumption | Total power consumption |
| **Interior Environment (IE)** | | |
| **Subplot** | **Title** | **Description** |
| subplot(2,5,1) | Pressure Zone 1 | Pressure in zone 1. |
| subplot(2,5,2) | Pressure Zone 2 | Pressure in zone 2 |
| subplot(2,5,3) | Temperature Zone 1 | Temperature in zone 1 |
| subplot(2,5,4) | Temperature Zone 2 | Temperature in zone 2 |
| subplot(2,5,5) | Pocket Door | Pocket in |

| | | |
|---|---|---|
| subplot(2,5,6) | Fans Air Flow Rate | Zone 1 and 2 fan flow rates |
| subplot(2,5,7) | Air Flow Z1-Z2 | Air in flow z1 z2 |
| subplot(2,5,8) | Air Leakage | Air in |
| subplot(2,5,9) | Air Supply | Air in |
| subplot(2,5,10) | Air Discharge | Air in |
| **Structural (ST)** | | |
| **Subplot** | **Title** | **Description** |
| subplot(3,5,1) | Acceleration x | Habitat structure acceleration in x direction. Location 1 |
| subplot(3,5,6) | Acceleration y | Habitat structure acceleration in y direction. Location 1 |
| subplot(3,5,11) | Acceleration z | Habitat structure acceleration in z direction. Location 1 |
| subplot(3,5,2) | Acceleration x | Habitat structure acceleration in x direction. Location 2 |
| subplot(3,5,7) | Acceleration y | Habitat structure acceleration in y direction. Location 2 |
| subplot(3,5,12) | Acceleration z | Habitat structure acceleration in z direction. Location 2 |
| subplot(3,5,3) | Acceleration x | Habitat structure acceleration in x direction. Location 3 |
| subplot(3,5,8) | Acceleration y | Habitat structure acceleration in y direction. Location 3 |
| subplot(3,5,13) | Acceleration z | Habitat structure acceleration in z direction. Location 3 |
| subplot(3,5,4) | Acceleration x | Habitat structure acceleration in x direction. Location 4 |
| subplot(3,5,9) | Acceleration y | Habitat structure acceleration in y direction. Location 4 |
| subplot(3,5,14) | Acceleration z | Habitat structure acceleration in z direction. Location 4 |
| subplot(3,5,5) | Acceleration x | Habitat structure acceleration in x direction. Location 5 |
| subplot(3,5,10) | Acceleration y | Habitat structure acceleration in y direction. Location 5 |
| subplot(3,5,15) | Acceleration z | Habitat structure acceleration in z direction. Location 5 |
| **Structural Protective Layer (SPL)** | | |
| **Subplot** | **Title** | **Description** |
| subplot(3,5,1) | Acceleration x | Habitat structural protective layer acceleration in x direction. Location 1 |
| subplot(3,5,6) | Acceleration y | Habitat structural protective layer acceleration in y direction. Location 1 |
| subplot(3,5,11) | Acceleration z | Habitat structural protective layer acceleration in z direction. Location 1 |
| subplot(3,5,2) | Acceleration x | Habitat structural protective layer acceleration in x direction. Location 2 |

| | | |
|---|---|---|
| subplot(3,5,7) | Acceleration y | Habitat structural protective layer acceleration in y direction. Location 2 |
| subplot(3,5,12) | Acceleration z | Habitat structural protective layer acceleration in z direction. Location 2 |
| subplot(3,5,3) | Acceleration x | Habitat structural protective layer acceleration in x direction. Location 3 |
| subplot(3,5,8) | Acceleration y | Habitat structural protective layer acceleration in y direction. Location 3 |
| subplot(3,5,13) | Acceleration z | Habitat structural protective layer acceleration in z direction. Location 3 |
| subplot(3,5,4) | Acceleration x | Habitat structural protective layer acceleration in x direction. Location 4 |
| subplot(3,5,9) | Acceleration y | Habitat structural protective layer acceleration in y direction. Location 4 |
| subplot(3,5,14) | Acceleration z | Habitat structural protective layer acceleration in z direction. Location 4 |
| subplot(3,5,5) | Acceleration x | Habitat structural protective layer acceleration in x direction. Location 5 |
| subplot(3,5,10) | Acceleration y | Habitat structural protective layer acceleration in y direction. Location 5 |
| subplot(3,5,15) | Acceleration z | Habitat structural protective layer acceleration in z direction. Location 5 |
| | **Disturbance Block (DB)** | |
| **Subplot** | **Title** | **Description** |
| subplot(3,9,1) | Meteorite SPL | Meteorite impact on SPL intensity level |
| subplot(3,9,2) | Meteorite ST | Meteorite impact on ST intensity level |
| subplot(3,9,3) | Meteorite ECLSS PR | Meteorite impact on ECLSS pressure controller intensity level |
| subplot(3,9,4) | Meteorite ECLSS TH | Meteorite impact on ECLSS thermal controller intensity level |
| subplot(3,9,5) | Meteorite ECLSS EE | Meteorite impact on ECLSS external components intensity level |
| subplot(3,9,6) | Meteorite PW PD | Meteorite impact on PW power distribution intensity level |
| subplot(3,9,7) | Meteorite PW ES | Meteorite impact on PW energy storage intensity level |
| subplot(3,9,8) | Meteorite PW S | Meteorite impact on PW solar system intensity level |
| subplot(3,9,9) | Meteorite PW N | Meteorite impact on PW nuclear system intensity level |
| subplot(3,9,10) | Fire IE Z1 | Fire in zone 1 intensity level |
| subplot(3,9,11) | Fire IE Z2 | Fire in zone 2 intensity level |

| | | |
|---|---|---|
| subplot(3,9,12) | Fire ECLSS PR | Fire on ECLSS pressure controller intensity level |
| subplot(3,9,13) | Fire ECLSS TH | Fire on ECLSS thermal controller intensity level |
| subplot(3,9,14) | Fire PW PD | Fire on PW power distribution intensity level |
| subplot(3,9,15) | Fire PW ES | Fire on PW energy storage intensity level |
| subplot(3,9,19) | Moonquake SPL | Moonquake on structural protective layer intensity level |
| subplot(3,9,20) | Moonquake ST | Moonquake on habitat structure intensity level |
| subplot(3,9,21) | Moonquake ECLSS PR | Moonquake on ECLSS pressure controller intensity level |
| subplot(3,9,22) | Moonquake ECLSS TH | Moonquake on ECLSS thermal controller intensity level |
| subplot(3,9,23) | Moonquake ECLSS EE | Moonquake on ECLSS exterior components intensity level |
| subplot(3,9,24) | Moonquake PW PD | Moonquake on power distribution intensity level |
| subplot(3,9,25) | Moonquake PW ES | Moonquake on PW energy storage intensity level |
| subplot(3,9,26) | Moonquake PW S | Moonquake on PW solar intensity level |
| subplot(3,9,27) | Moonquake PW N | Moonquake on PW nuclear intensity level |

## Transitions

In this version of HabSim, the user can control the available power and thermal and pressure setpoints by setting variables from the input file.

### Available Power Setting (Power Generation Units Control)

In HabSim, the standard simulation settings are full availability of solar, nuclear and energy storage power. The PWset variable has a standard value of 100100100. This indicates: 100% nuclear power availability, 100% solar power availability and 100% energy storage availability. This variable can be changed, for example to PW = 087023045, which means. 87% nuclear power availability, 23% solar power availability and 45% energy storage availability. This gives the results shown in Figure 22.

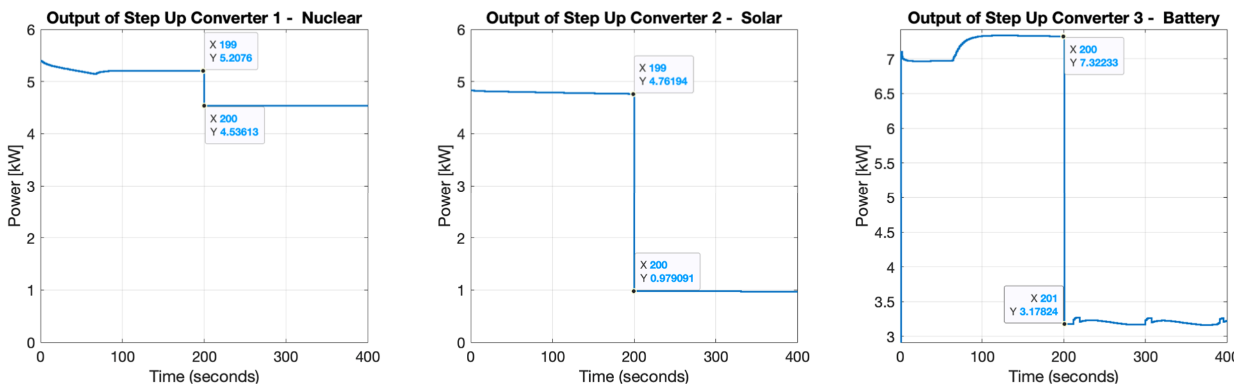



**Figure 22: Change of Nuclear, Solar and Energy Storage Availability**

### ECLSS Thermal Control Setpoints ECLSS (Temp Control)

For the ECLSS thermal control, the standard value of the variable ECLSS_TH is **012931530315**. This variable is better explained in Table 8. The heating zone number refer to the zone to be heated by ECLSS thermal control. The user can decide to heat one zone or both zones. About the mode, the user can turn thermal control off, setting it to automatically heating and cooling, or selecting to use only the heating, only the cooling or only the fan air recirculation system. The heating setpoint is the temperature at which the heating will be activated, and the cooling setpoint is the temperature at which the cooling system will be activated.

**Table 8: Explanation of ECLSS_TH Variable**

| Heating setting | Zone # | Mode | M | Heating set point (K) | Cooling set point (K) |
|---|---|---|---|---|---|
| Both Zones | 0 | OFF | 0 | 293.15 | 303.15 |
| Zone 1 | 1 | Auto (Cooling & Heating) | 1 | | |
| Zone 2 | 2 | Heating | 2 | | |
| | | Cooling | 3 | | |
| | | Fan | 4 | | |

An example of setpoint temperature change is shown in Figure 23. The simulation shows the thermal setting to prepare the habitat for dormant state. In this case, at 200 seconds, the variable IE_TEMP is set to 012831528615. This changes the cooling setpoint of both zone one and zone two to 286.15K, and the heating setpoint will be set to 283.15K. Both cooling and heating will be activated.

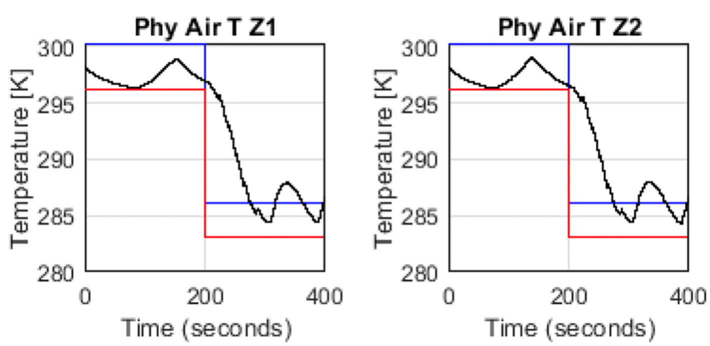



**Figure 23: Change of Temperature Setpoint**

### ECLSS Pressure Control Setpoints ECLSS (Press Control)

The standard values for the ECLSS pressure control boundaries are set by using the variable ECLSS_PR, which standard values is **012931530315.** This variable is better explained in Table 9. The control setting number refer to the zone to be controlled by ECLSS pressure control. The user can decide to control the pressure in one zone or both zones. About the mode, the user can turn pressure control off, setting it to automatically supplying and discharge air, or selecting to use only the air supplying, only the air discharge.

The supply setpoint is the temperature at which the pressure supply will be activated, injecting air into the system. The discharge setpoint is the pressure at which the air discharging system will be activated to vent out air to the exterior environment.

**Table 9: Explanation of ECLSS_PR Variable**

| Control settings | Zone # | Mode | M | Supply set point (Pa) | Discharge set point (Pa) |
|---|---|---|---|---|---|
| Both Zones | 0 | OFF | 0 | 10032500 | 10232500 |
| Zone 1 | 1 | Auto (Supply & Discharge) | 1 | | |
| Zone 2 | 2 | Supply | 2 | | |
| | | Discharge | 3 | | |

An example of pressure setpoint change is shown in Figure 24. The simulation shows the pressure setting to prepare the habitat for dormant state. In this example, the pressure setpoint is changed at 200 seconds by setting the value of IE_PRESS to 010603250006532500. This pressure will accommodate the habitat dormant conditions.

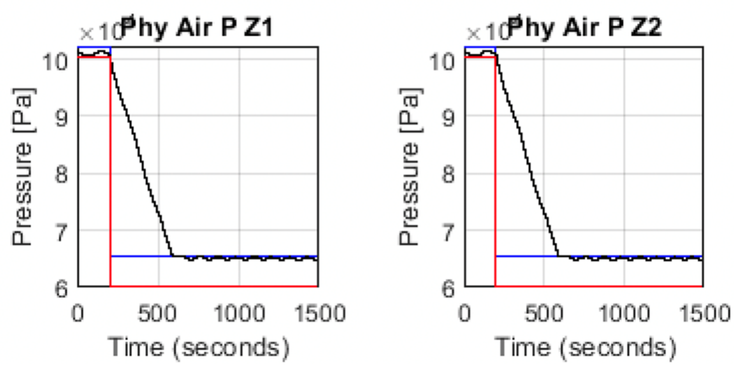



Figure 24: Change of Pressure Setpoints