1. To begin working the ParaPower application, first retrieve the folder containing all necessary files form: (ARL FOLDER DIRECTORY).
2. Unzip the folder to your local Matlab workspace, this is most commonly: C:\Users\YourNAME\Documents\MATLAB. Launch Matlab 2017a or newer.
3. Ensure the folder and all subfolders have been added to your workspace in your workspace browser. If you want to automatically consider this folder part of your workspace follow this tutorial for adding a permanent addition: <https://www.mathworks.com/help/matlab/matlab_env/add-folders-to-matlab-search-path-at-startup.html>
4. Launch the ParaPower.m file. Press F5 or the run button under the ”Editor” tab. The application will now launch on your screen. The GUI is currently formatted to work on all screen resolutions 1280x768 and larger. If your screen has a lower resolution, there could be formatting issues presented.
5. To being a trial look to the “System Parameter” panel.
   1. If you wish to load an existing profile, click the “Load Profile” button and find an existing profile through the file selector. Move onto Step 17.
6. In the “System Parameter” panel there are three editable boxes that need to be filled in prior to continuing. Denoted with their adjacent text, enter the Number of Layers in the geometry, Processing Temperature of the module, and the Initial Node Temperature of the module. Press the Confirm button to publish these values and continue.
   1. Upon filling in the System Parameters panel accurately, (i.e. no negative layers) the Confirm button will now change to read “Update System”. In the event that a change need to be made to any of the System Parameters, the “Update System” button will need to be selected to push any changes into the rest of the GUI. The only visible change would come in the form of adjusting the number of layers. The Module Layers panel will adjust to remove or add to the number of updated layers.
7. The remaining panels and tabs of the ParaPower application will now all be available for editing.
8. The *Base Geometry* panel features a table and a radio button. The base geometry is in reference to any layer that does not have unique geometric definitions, as well as it is used to define the board size of the module. The base layer edge must be equal to or extend past all features defined by the user. A feature cannot overhang the edge of a layer. The radio button toggles between a “User Defined” base geometry definition or a “Program Controlled”.
   1. A user defined input provides maximum flexibility for defining the base layer. Column 1 allows the base layer definition to be centered on every feature to be later defined. If this is selected the X,Y-Coordinates of the base layer will be solved for and just the overall Length (X-Dir) and Width (Y-Dir) of the base layer must be defined. Alternatively leaving this this toggle off will require an input in column 2 of where in the X-Y plane the base layer will be centered.
   2. Toggling the Program Controlled Location radio button will update the table to just require a Boarder Length and Boarder Width input. The base layer will automatically be centered amongst all of the features. The base layer will then extend past the widest feature based on the input distance for the boarder length and width. Commonly setting these values to zero will indefinitely make the base size go to the most extreme edges of the defined features. A program controlled base geometry will also automatically add a constraint for the boarder length and width of the module. If the “Automate Constraints” radio button is toggled on, a constraint of the same values will be published into the constraint tab. In the event a feature extends beyond the original bounds of the base layer in a parametric study, the base layer will grow to maintain the defined boarder size.
9. Moving onto the module environment, the table takes numerical inputs for the convective coefficient and the ambient temperature. These values are defined by each face of the module. Use the heat transfer coefficient to simulate events such as a heat sink applied to the back side of the module.
10. The Layer Parameters panel should now be addressed to define the bulk material for each layer as well as its thickness and layout style. Selecting from the drop down menu in column 1 will define the major material for that layer. The major or bulk material is considered the material that will be present at all extents of the layer. The only exception here is when a layer is defined with features. A layer that also has features, will first be defined with the bulk material and then in the areas that are defined by the alternative feature will take priority. Often times in a device layer, the bulk material is encapsulate, so that the devices are totally surrounded on that plane of the module. The thickness of the layer is defined as a numerical positive real value. Column three allows for the layout to be selected for each layer. Originally only the respective base layout will be provided. However, as layouts are added in the lower tabs they will become available for selection.
11. In order to add a layout as a selectable layer element, first toggle on the “Enable Layout N radio” button. The feature number edit box will now be editable. Input the number of unique features for this layout style. A unique feature is defined as a geometrically consistent element. The only non-unique definition permitted to like features are the coordinates in which they exist. Press the “Confirm Features” button to publish the value into the “Feature Quantity” table. Like features are defined at N.1,N.2,…N.n. Unique features are defined as N.1, N+1,1,N+N.1.
12. Now in the “Feature Quantity” input the total number of each feature that is required for this layout. Press the “Confirm Quantities” button when complete.
13. The geometry table will now be populated with the required features as defined. Select a material from the drop down menu that the feature should be made of, followed by defining the center coordinates. An edit is made to any of the non-unique inputs, all other features of that type will update to reflect this change.
14. Repeat the process to adding a new layout as needed.
15. Clear any layout by selecting the clear layout button in the Layout Parameters panel.
16. Toggle off any layout by unselecting the radio button for the respective layout. Entries will be maintained but must be confirmed upon a re-enable of the layout. When a layout is no longer enabled, it will also be removed from a valid selectable layout for the layer panel.
17. Upon completing these steps, the “Run” button can be selected to process the steady state condition of the defined geometry. The results are available in the “Results” tab, and can be published to excel using the “Save Results” button.
18. If a parametric sweep is to be included Constraints, Boundary Conditions, and Parameters must also be set.
19. Beginning with defining the varying parameter, enable the “Parameters” tab by clicking the “Enable Parametric Study” radio button.
20. There are three subsections of available parameter types. First are “Feature Parameters” this group contains the ability to adjust any feature’s physical attributes, including position, size, and heat generation. Appendix A contains a complete description for how each parameter type works and what it will adjust. Select the type of parameter that is desired.
21. Then select the feature geometry that is to be adjusted. The list will contain a layer definition such as Layer 4 as L4, followed by the layout type as .N and then the sub feature N.N. Layer 4, with Layout 1 adjusting Feature 1.1 would be defined as L4.1 F1.1.
22. Similarly, if this feature is to be adjusted with respect to another feature, an “Associated” feature can be paired with this parameter. An example of this would be the length of one feature should start as the same size as the associated feature and then grow by 0.1 mm. The “Associated” feature can be thought as defining the feature to be changed with respect to an existing feature.
23. Finally, define the minimum (starting value), step (increment value), and max (final value) that the parameter will be adjusted by. The feature will maintain its originally defined geometry/ position and then step through the changes as defined here. If the position of a feature is at 0,0 and the x-position is to be changed up to 0,1 the MSM input would be (0,5,1). The process will solve a solution starting at 0,0, and then in solve five increments up to shifting the x-position to 1.
24. The same process is valid for the System Parameters and Material Properties. Parameter descriptions for both of these can also be found in Appendix A.
25. Moving onto Boundary Conditions, a condition can be set to ensure the simulation does not solve a trial if a condition is broken. Enable the Boundary Condition radio button and then select between a “Feature” or “System” Condition. Similar to the parameters, a condition can be selected and then the respective feature that it applies to.
26. In the event that a parameter exceeds for example the maximum module volume, any trial beyond that limit will be excluded from being solved. An internal error log is available if a trial is quarantined from being solved. It will also contain the relevant condition that was broken.
27. A constraint can be set in the same manner. Constraints are intended to be used to fix a geometry in any physical way. Constraints are also helpful if a feature has been a parametrized and its relation to another feature must be maintained. Rather than making two parameters to shift two features in the same direction a constraint on their x-coordinates can be set, so that when the one feature is moved the other will be forced to follow in that same solution. This is effective if an array of features needs to all be adjusted in an identical manner.
28. When a parametric sweep is conducted there will be many solutions produced in the results tab. Nodal information is available for each solution upon exporting, but the plots and visuals are representative of the maximum values produced in each trial.
29. Depending on the type of parametric sweep conducted, the data plotted in the results figure could need to be adjusted. By selecting the “Plot Results” pop up menu, different pre-loaded data display types can be shown.
30. From the drop-down solutions menu, a trial can be selected to “View Individually”. This will publish both the layer and 3d model of the current solution. The layer can be adjusted in the Layer Slice Panel.
31. By selecting “View All Results”, data for each trial will be published into the graph. If “Enable Looping” is also selected, it will show each solution temporarily, before moving onto the next.
32. The “Highlight Solution” radio button will display the selected solution in the graph with a larger icon. This can be used to better visualize where the trial falls in the overall parametric sweep.
33. The “Remove Encapsulant Layers” radio button will turn any layers that are visually shown to have encapsulant to be invisible. This generally allows a better visual of devices that may otherwise be totally enclosed in the 3d visual.
34. If the trial was successful and the profile that was entered should be saved for using in the future, simply select the “Save Profile” button from the top left panel. This will prompt a traditional file save protocol, where all the entered information can be stored.

**How to add a new material into library:**

1. Open matlibfun.m file in MATLAB
2. Find the location in the existing alphabetically organized list where the new entry should reside.
3. Being by stating the new material name with how it is to be displayed in the application. For example, Aluminum was shortened to be Al (the remaining instructions will use aluminum to demonstrate the required skills)
4. The variable name should be followed with an equal sign and a pair of brackets, ***Al = []***
5. The material properties can now be entered in the following order Al = [Conductivity (w/mL), Coeff. Of Thermal Expansion, Modulus of Elasticity, Poison’s Ratio, Density(kg/m3), Specific Heat(J/C)]
6. The new material now needs to be added into the material properties matrix (matprops), do this by adding the variable name followed by a semicolon in the same order as it appears originally. matprops=[***Al;***Cu;AlN;SiC;EN;Chip;Alumina;AIR]
7. Repeat a similar process for the matlist variable but add the entry as a string by surrounding it with and two apostrophes followed by a semicolon. matlist={***'Al';***'Cu';'AlN';'SiC';'EN';'Chip';'Alumina';'AIR'};
8. The next time the ParaPower application is opened it will access the updated material list. Be sure that all values publish correctly into the layer table.

**Excel Profile Variable Definitions:**

**Number of Layers:** Total number of layers in the system stack up

**Temp Process.:**  Processing temperature of solder layers

**Initial Node Temp.:** Defines the initial temperature of each node in network at the start of the experiment.

**Materials by Layer:** Defines the material of each layers (1,2,3….). This material is the bulk material for each layer any area defined by a feature will supersede in the specified locations.

**Layer Type:** Defines if the layer has a layout within it or if it is a standardized base layer only containing one material.

**Layer Type Code:** References a 0 if the Base Geometry is Program Controlled, 99 if the Base geometry is User Defined and any number represents the associated layout number that exists on that layer. This variable is used to properly handle and create the material network based on what each layer is defined as.

**Base Geo:** Column B defines the length of the Base geometry definition. An entry of 2 Represents P.C. and 5 represents U.D. The proceeding columns are representative of the columns found in the base geometry table.

**Quantity:** Defines quantities of [Layouts, Constraints, Boundary Cond., Parameters, Groupings] these values will be used for indexing to ensure the right rows are captured. A quantity can never be less than 1, i.e. if there are no defined Boundary Conditions the quantity should be defined as 1.

**Tab Status:** Represents the radio button status on all of the tabs within the GUI.

**Layout N:** [Number of Features, Total Quantity of Features, Quantity of Feature 1, …Quantity of feature N]

**Layout N Feat. Data:** Defines the geometry conditions for all of the features in each layout. [Feature Number, Material, Center X-coor, Center Y-coor, Length, Width, Heat (W)]

**Constraint:** Defines feature and system constraints [Constraint, Feature, Linked Feature, Min]. Row order of each constraint is not critical.

**Boundary Conditions:** Defines any relevant boundary conditions in the following format [B.C., Feature, Linked Feature, Min, Max] Row order of each B.C. is not critical.

**Parameters:** Defines parameters in the following format [Parameters, Geometry, Associated, Min, Steps, Max] Row order of each Parameter is not critical.

**Groupings:**

**Results:** Stores any result information generated by a completed trial.

**MATAB Variable Descriptions:**

Tables:

All tables are pre-defined as an empty cell array with one row and as many columns as the table requires. For example the constraint tables only require four columns so their empty cell matrix is defined as cell(1,4).

Table headings and row names are predefined in the *tables* function.

All drop down menus are also predefined in the *tables* function but often times are automatically updated while using the GUI to represent just the required options. An example of this after a user has generated feature definitions and assigned them to layers, the will be added into constraint and parameter feature table selections. Layer 5 used Layout 1, Features 1-4, this would convert to the list [L5.1 F1.1; L5.1 F1.2… L5.1 F1.3]. In the event that there are multiple features within a layout they follow their numbering scheme accordingly, Feature 2.1 and Feature 2.2 would be represented with F2.1 and F2.2.

Layout:

[x y z master]layout: Holds geometry and physical data of each layer of each trial. In the event that there is a parametric study the layout matrix holds all singles solution variations of experiment consecutively. There is always a consistent length to the total number of rows in each trial allowing the masterlayout to be indexed by the length of a single trial. This index is also used to quarantine trials by selecting the range of a trail and moving it to the quarantine matrix. The columns of the layout matrix posess the following scheme: [Xdim1 Xdim2 Xdim3 Xdim4 Q Layer Material# Layout# Feature# Ydim1 Ydim2 Ydim3 Ydim4 LayerThickness Layer Height]

Master:

Variables denoted with “Master” are the highest use case of that respective information. These variables such as resultsmaster contain the final set of data that can be published or saved. \

**Appendix A:**

**Parameters:**

**Feature:**

* Position X: Adjusts the center coordinate in the X-Direction of the associated feature.
* Position Y: Adjusts the center coordinate in the Y-Direction of the associated feature.
* Length: Adjusts the length (X-Direction) of a defined feature.
* Width: Adjusts the length (Y-Direction) of a defined feature.
* Scale: Uniformly: Adjusts the Length and Width of a feature.
* Heat Generation: Adjusts the defined feature’s heat generation value.

**System:**

* Transient: Determines a system wide transient analysis between two-time intervals
* Layer Thickness: Adjusts the thickness of a selected layer.
* Convection Coefficient (h): Adjusts a side’s convection coefficient value.
* Ambient Temperature (Ta): Adjusts a side’s Ambient temperature.

**Material:**

* Generates a system wide update to the material properties. This does not permanently change the material library, but rather just for the associated profile.

**Boundary Conditions:**

**Feature:**

* Distance Range X: Allowable X-Coordinate range of selected feature.
* Distance Range Y: Allowable Y-Coordinate range of selected feature.
* Heat Generation Range: Allowable heat generation range of selected feature.

**System:**

* Layer Thickness Range: Allowable Layer thickness range of selected layer.
* Sub straight Thickness Ratio: Allowable ratio of thinnest layer to sub straight layer thickness for accurate stress analysis.
* Convection Coefficient Range: Allowable convection coefficient range of selected side.
* Ambient Temperature Range: Allowable ambient temperature range of selected side.
* Base Length Range: Allowable base length range of selected all base layers.
* Base Width Range: Allowable base width range of selected all base layers.
* Module Volume: Allowable module volume range.

**Constraints:**

**Feature:**

* Distance Fixed X: Affixes the distance between two features or a feature and the origin
* Distance Fixed Y: Affixes the distance between two features or a feature and the origin
* Heat Generation Fixed: Affixes the heat generation of a feature to a specific value or with respect to another feature.
* Base Length: Affixes the base length to one value.
* Base Width: Affixes the base width to one value.
* Base Boarder Length: Affixes the base boarder length size to one value.
* Base Boarder Width: Affixes the base boarder width size to one value.

**System:**

* Layer Thickness Fixed: Affixes the thickness of a layer to one value, or with respect to another layer’s thickness.
* Convection Coefficient Fixed: Affixes the convection coefficient of a module side to one value, or with respect to another module side
* Ambient Temperature Fixed: Affixes the ambient temperature of a module side to one value, or with respect to another module side

**Tables:**

All tables are pre-defined as an empty cell array with one row and as many columns as the table requires. For example the constraint tables only require four columns so their empty cell matrix is defined as cell(1,4).

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**Additional GUI Features:**

GUI Menu/Toolbar:

A GUI toolbar area would allow for additional features to be added for general functionality as well as specific axes interactions. These include rotating in 3d space or having an interactive curser to the plot. These features can be added through the GUIDE interface following this tutorial: <https://www.mathworks.com/videos/adding-a-toolbar-to-a-gui-97318.html>