F6 PIVOT
Pleiades Innovative VCDM Optimization Tool

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Innovation You Can Count On™

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PIVOT Overview

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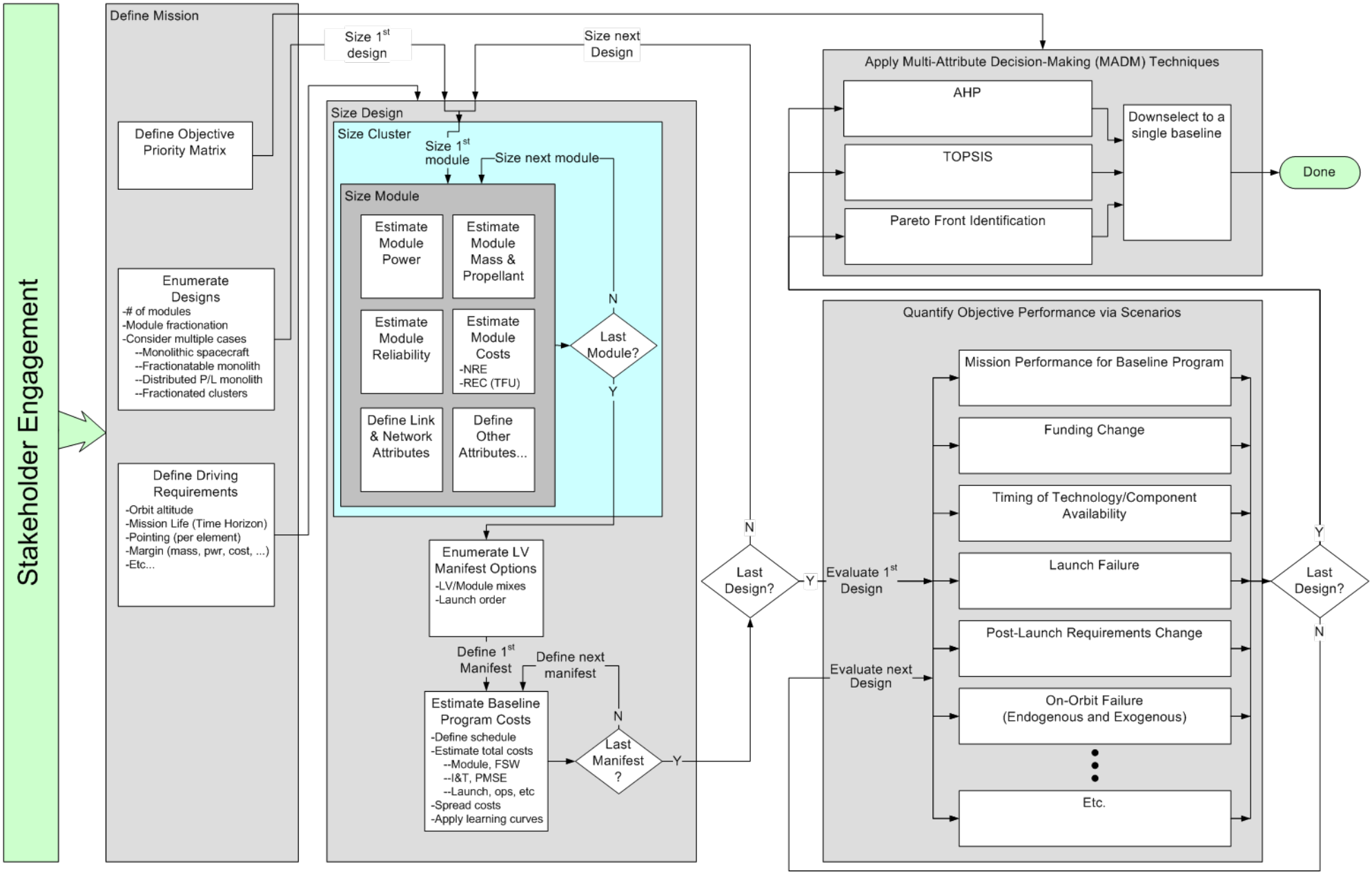
- **Lifecycle Cost, Value, and Risk Assessment Tool**
  - **Monte-Carlo simulation with easy to modify parameter selections/levers**
- **Coded in MATLAB**
  - **Preferred platform for interaction with Georgia Tech.**
  - **Future considerations for integration of other tools (example STK)**
  - **Widespread Use**
    - No additional installation steps (if MATLAB already installed)
    - Simple instructions to execute scripts
- **Incorporates uncertainty models to evaluate design performance**
  - **Launch / On-Orbit Failures, Schedule Slip**
- **Integrated with Design Sizer to rapidly evaluate design tradespace**
  - **Discrete relations**
    - Based on conceptual designs
  - **Parametric relations (rubberized)**
    - From Georgia Tech's GT-FAST design sizer


IBM JPL MIT Massachusetts Institute of Technology Georgia Tech

General Flow



Design Sizer – Design Parameters

- **Discrete Evaluations**
  - **Mass Budget**
    - Includes Delta V Budget
  - **Power Budget**
  - **Reliability (FIT values)**
  - **Cost - NRE and RE**

- **Parametric (non-proprietary)**
  - **From Georgia Tech - GTFAST**
  - **Mass**
  - **Power**
  - **Reliability**
    - Uses FIT values of discrete
  - **Cost**
    - SSCM (from GTFAST)
    - SMAD for public releasable version

Value Model Flow

- **Module phase evaluation**
  - **Determines design and launch schedule of each module**
  - **Evaluates current mission phase of each module (Development, Launch, ICO, Ops)**
  - **Applies cost based on applicable phase**
  - **Models**
    - Cost Uncertainty Model
    - TRL Schedule Change Model
    - Launch Failure Model
    - Insurance Model
    - Funding Change Model (stand alone version - to be improved/integrated in Phase 2)
- **Reliability and revenue models**
  - **Failure assessment of active components**
  - **Incorporates link budget analysis to determine preferred DL paths**
  - **Evaluates revenue using pricing models for each mission**
  - **Models**
    - On-Orbit Failure Model
    - Value / pricing models
- **Replenishment decision**
  - **Determines if and when modules will be replenished**
  - **Models / Selections**
    - Replenishment
    - LV Replenishment Strategy
    - Long-Lead Item
- **Value Assessment**
  - **NPV, cumulative cost and revenue computations**

Value Assessment Model Inputs

- **Module Configuration**
  - **Generated from design sizer or point design**
  - **Data Structure of cost and performance parameters**
- **Launch Vehicle Configuration**
  - **Generated from design sizer or point design**
  - **Data Structure of cost and performance parameters**
- **Model Selections**
  - **Simulation parameters (MonteCarlo runs, design horizon)**
  - **Uncertainty Models**
- **Model Parameters**
  - **Cost Uncertainty Parameters**
  - **Value Levers**
- **Default values defined in** pub_Model_Enable_Selection_default.m

Model Parameters

- **Cost Uncertainty Parameters**
  - **Module Cost**
  - **Launch Vehicle Cost**
  - **Operations Cost**

- **Cost / Value Levers**
  - **Discount rate**
  - **Module learning curve rate**
  - **LV learning curve rate**
  - **Insurance cost factor**
  - **Inflation rate**
  - **Operations cost (per module)**
  - **Link cost rates**
  - **Long-lead item time**

- **Default values defined in** pub_Model_Cost_Parameters_default.m

Value Assessment Model Data Structures

- **Module Configuration Input**
  - **'module_config_default' in pub_scenario_main.m**
  - **Generated from design sizer or point design**
  - **Data structure with the following parameters**
    - row # identifies module #
    - Column 1 - Wet Mass
    - Column 2 - NRE
    - Column 3 - RE
    - Column 4 - module_life
    - Column 5 - Design/I&T time
    - Column 6 - ICO time
    - Column 7 - TRL
    - Column 8 - LV assigned
    - Column 9 - F6 Comp array

- **Launch Vehicle Configuration Input**
  - **'lv_config_default' in pub_scenario_main.m**
  - **Generated from design sizer or point design**
  - **Data structure with the following parameters**
    - Row # identifies LV #
    - Column 1 - configuration of which modules on each LV
    - Column 2 - reference for # of modules launched on LV
    - Column 3 - Launch Vehicle Type
    - Column 4 - Launch Vehicle Reliability
    - Column 5 - Launch Vehicle Cost
    - Column 6 - Launch Time (Months)

Value Assessment Model Data Structures

- **Module Summary Table**
  - **Lifecycle summary of all modules**
    - Includes baseline configuration and replenishments
  - **'module_summary' in pub_scenario_main.m**
  - **Data structure with the following parameters**
    - Column 1 - Module counter (for production learning curve)
    - Column 2 - Module ID #
    - Column 3 - Design start time
    - Column 4 - Module Cost
    - Column 5 - LV Cost
    - Column 6 - Module TRL
    - Column 7 - Insurance Cost (if insurance model enabled)
    - Column 8 - Time of Failure
    - Column 9 - On-orbit (operations) time

Value Assessment Model Data Structures

- **Launch Summary Table**
  - **Lifecycle summary of all launches**
  - **'lv_summary' in pub_scenario_main.m**
  - **Data structure with the following parameters**
    - Row # indicates launch attempt #
    - Column 1 - Configuration of which modules aboard
    - Column 2 - reference for # of modules launched
    - Column 3 - LV cost
    - Column 4 - Time of launch
    - Column 5 – Success (1) or Failure (-1)

Value Assessment Model Data Structures

- **Component State Array**
  - **Tracking summary of component states for all modules**
  - **'Data structure with the following parameters**
    - Row # indicates module #
    - Column 1 - low rate space-ground link
    - Column 2 - high rate space-space link
    - Column 3 - high rate space-ground link
    - Column 4 – low rate 24/7 link
    - Column 5 – Core module
    - Column 6 – SSR (maps to fractionated component 4)
    - Column 7 – MDP (maps to fractionated component 5)
    - Column 8 – Payload 3 (on all modules)
    - Column 9 – Payload 1 (maps to fractionated component 2)
    - Column 10 – Payload 2 (maps to fractionated component 6)


Value Assessment Model Data Structures

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- **Module Statistics Tracking Table**
  - **Tracking summary of modules through phases**
  - **'module_tracking_table' in pub_scenario_main.m**
  - **Data structure with the following parameters**
    - Row # indicates module #
    - Column 1 - Module design start (month)
    - Column 2 - Design phase flag (1 if module in design)
    - Column 3 - Design percent complete counter
    - Column 4 - Scheduled launch time
    - Column 5 - Launch phase flag (1 if module ready to launch)
    - Column 6 - ICO phase flag (1 if module in ICO)
    - Column 7 - ICO percent complete counter
    - Column 8 - Scheduled Ops start time
    - Column 9 - Ops phase flag (1 if module in Ops)
    - Column 10 - Ops percent complete counter
    - Column 11 - Module design delay start time (TRL Schedule slip model)
    - Column 12 - Module design delay length (TRL Schedule slip model)
    - Column 13 - Module decision to replenish flag (set when failure or retired)
    - Column 14 - Module to be replenished flag (set when module will be replenished)
    - Column 15 - Module previous launch (currently spare)
    - Column 16 - Module counter reference

Value Assessment Model Data Structures

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- **Monte-Carlo Summary Table**
  - **Comprehensive Output of value model**
  - **Can be used to recreate specific test run**
  - **'MC_Summary' in pub_scenario_main.m**
  - **Data structure with the following parameters**
    - Row # indicates test Case #
    - Column 1 - Total Program Cost
    - Column 2 - NPV
    - Column 3 - module_tracking_table
    - Column 4 - module_summary
    - Column 5 - launch_summary
    - Column 6 - Module lifecycle cost (module cost per month – each module)
    - Column 7 - Module lifecycle schedule (module phase per month – each module)
    - Column 8 - Module lifecycle revenue (module revenue per month – each module)
    - Column 9 - Cumulative NPV (by month)
    - Column 10 - Cumulative Program Cost (by month)
    - Column 11 - Cumulative Program Revenue (by month)
    - Column 12 - PL2 Cumulative NPV (by month)
    - Column 13 - PL 3 Cumulative NPV (by month)
    - Column 14 - PL1 Cumulative NPV (by month)
    - Column 15 - Total high rate data per month
    - Column 16 - Total low rate data per month
    - Column 17 - Total 24/7 data per month
    - Column 18 - Pipe Capacity summary per month
    - Column 19 - Program Cost per month

Value Assessment Model Data Structures

- **Component State Table**
  - **State of modeled components (1 - active, 0 - not on module or failed)**
  - **Matrix of 'N' modules by 10 components**
    - Next row populated when module reaches orbit
    - Updated every timestep (On-orbit failures or module retirement)
  - **'Data structure with the following parameters**
    - Row # indicates module #
    - Column 1 - low rate DL
    - Column 2 - mission space-space
    - Column 3 - high rate DL
    - Column 4 - 24/7
    - Column 5 - core module
    - Column 6 - solid state data recorder
    - Column 7 - mission data processor
    - Column 8 - payload 1
    - Column 9 - payload 2
    - Column 10 - payload 3

Sample Cases General Format

- **Run File – sample_test_case.m**
- **1) Set global parameters**
  - **Set orbit parameters, module lifetime**
  - **Set design global parameters**
    - pub_globals_bus_types.m
      - Defines globals related to the core spacecraft bus (mass, power, cost, FIT, TRL)
      - Allows parameters to be modified
      - Future work ➔ to be driven by GUI
    - pub_globals_f6_elements.m
      - Defines fractionation elements (mass, power, cost, FIT, TRL) & invalid combinations
      - Future work ➔ to be driven by GUIs
  - **Load value global parameters**
    - pub_value_globals.m
- **2a) Define scenario / perturbation model states**
  - **Simulation settings and state of uncertainty models**
    - pub_Model_Cost_Parameters_default.m
- **2b) Define scenario / perturbation model parameters**
  - **Cost and value Levers**
    - pub_Model_Enable_Selection_default.m
- **3) Select Configuration**
  - **Module and LV design**
    - pub_baseline_config.m
- **4) Run Model**
  - pub_scenario_main.m
- **5) Save / Plot Data**
  - plot_cost_revenue_pv.m

Sample Cases Design Tradespace Evaluation

- **Run file – pub_F6_VCDM_Input_Script.m**
- **1) Set global parameters**
  - **Set orbit parameters, module lifetime**
  - **Set design global parameters**
    - pub_globals_bus_types.m
    - pub_globals_f6_elements.m
- **2) Set model parameters and load designs**
  - **Load all fractionation design concepts (load files for up to 10 modules provided)**
    - Based on total number of fractionatable elements (set by pub_globals_f6_elements.m)
  - **Eliminate Invalid designs (component placement constraints)**
    - pub_component_placement_constraints_new.m
  - **Load Value global parameters**
    - pub_value_globals.m
  - **Define Scenario / Perturbation model inputs**
    - pub_Model_Cost_Parameters_default.m
    - pub_Model_Enable_Selection_default.m

Sample Cases
Design Tradespace Evaluation

- **Continued from – pub_F6_VCDM_Input_Script.m**
- **3) Select Configuration**
  - **Design Sizer**
    - Discrete
      - Uses global parameter inputs
    - Parametric
      - Based on Georgia Tech's GTFAST
      - Cost models provided based on SSCM and SMAD (SSCM not for public release)
      - gtfast_calc_cost_pub_SMAD.m
  - **Run additional constraints based on sized designs**
  - **LV manifest**
    - Sets Launch combinations to be considered for each launch vehicle
    - Launch vehicle tradespace set in pub_lv_input.m
    - Several manifest strategies to use – based on desired number of combinations to consider
      - pub_lv_manifest.m
      - pub_lv_manifest_limited.m (preferred configurations)
- **4) Run Model**
  - **Each Design runs through model**
    - **pub_scenario_main.m**
- **5) Save / Plot Data**
  - plot_all_combos.m

Sample Cases
LV Trade Study – Single and Dual Launches

- **Run File – pub_test_lv_trade_revenue.m**
- **1) Set global parameters**
  - **Set orbit parameters, module lifetime**
  - **Set design global parameters**
    - pub_globals_bus_types.m
    - pub_globals_f6_elements.m
  - **Load value global parameters**
    - pub_value_globals.m
- **2a) Define scenario / perturbation model states**
  - **Simulation settings and state of uncertainty models**
    - pub_Model_Cost_Parameters_default.m
- **2b) Define scenario / perturbation model parameters**
  - **Cost and value Levers**
    - pub_Model_Enable_Selection_default.m
- **3) Select Configuration**
  - **Module design**
    - Load baseline design pub_baseline_config.m
    - Overwrite necessary parameters for single launches
  - **LV design**
    - Currently Hard-Coded for Single and Dual Launch trades
    - Launch vehicle tradespace set in pub_lv_input.m
- **4) Run Model**
  - pub_scenario_main.m
- **5) Save / Plot Data**
  - Each Simulation added to same figure
    - **For separate single and dual launch plots, remove % from figure()**
  - lv_trade_ellipse_plot_revenue_pv.m

Sample Cases
Additional High Rate DL Module

- **Run File – trade_study_add_HRDL.m**
  - **can be modified for any additional module configuration**
- **1) Set global parameters**
  - **Set orbit parameters, module lifetime**
  - **Set design global parameters**
    - pub_globals_bus_types.m
    - pub_globals_f6_elements.m
  - **Load value global parameters**
    - pub_value_globals.m
- **2a) Define scenario / perturbation model states**
  - **Simulation settings and state of uncertainty models**
    - pub_Model_Cost_Parameters_default.m
- **2b) Define scenario / perturbation model parameters**
  - **Cost and value Levers**
    - pub_Model_Enable_Selection_default.m
- **3) Select Configuration**
  - **Module and LV design**
    - pub_baseline_config.m
- **4a) Run Model / save baseline results**
  - pub_scenario_main.m
- **4b) Load new design for additional High Rate DL module and run model**
  - **Add new module to module configuration**
  - **Add single launch to launch configuration**
  - **Run model save results**
- **5) Plot Data**
  - plot_additional_HRDL.m

Sample Cases
F6 (5yr) vs. Monolith (10yr)

- **Run File – pub_f6_monolith_comparison.m**
  - **can be modified for any additional module configuration**
- **1) Set global parameters**
  - **Set orbit parameters, module lifetime**
  - **Set design global parameters**
    - pub_globals_bus_types.m
    - pub_globals_f6_elements.m
  - **Load value global parameters**
    - pub_value_globals.m
- **2a) Define scenario / perturbation model states**
  - **Simulation settings and state of uncertainty models**
    - pub_Model_Cost_Parameters_default.m
- **2b) Define scenario / perturbation model parameters**
  - **Cost and value Levers**
    - pub_Model_Enable_Selection_default.m
- **3) Select Configuration**
  - **Module and LV design**
    - pub_baseline_5yr_config.m
- **4a) Run Model – (TLife Override version)**
  - pub_scenario_main_TLife_override.m
- **4b) Load new design for monolith and repeat**
  - **Requires setting design horizon**
  - **Run model**
- **5) Save / Plot Data**
  - Plot_f6_monolith_comparison.m

Sample Cases Altitude Trade

- **Run File – trade_study_altitude.m**
  - **can be modified for any additional module configuration**
- **1) Set global parameters**
  - **Set orbit parameters, module lifetime**
  - **Set design global parameters**
    - pub_globals_bus_types.m
    - pub_globals_f6_elements.m
  - **Load value global parameters**
    - pub_value_globals.m
- **2a) Define scenario / perturbation model states**
  - **Simulation settings and state of uncertainty models**
    - pub_Model_Cost_Parameters_default.m
- **2b) Define scenario / perturbation model parameters**
  - **Cost and value Levers**
    - pub_Model_Enable_Selection_default.m
- **3) Select Configuration**
  - **Module and LV design**
    - pub_baseline_config.m
- **4a) Run Model**
  - pub_scenario_main.m
- **4b) Load new altitude (550) and repeat**
  - **Requires setting design horizon**
  - **Run model**
- **4c) Load new altitude (600) and repeat**
  - **Requires setting design horizon**
  - **Run model**
- **5) Save / Plot Data**
  - **plot_altitude_trade.m**

PIVOT: Notes Regarding Initial Release

- **Initial release of PIVOT used as a Programmer's toolkit for the modeled reference mission.**

- **Current Tool Limitations**
  - **Designs must currently adhere to a set structure of a single bus type**
  - **Tool accommodates maximum of six fractionated elements**
  - **Parameter modifications must be done manually**
    - Following slides identify host files for design and model parameters
  - **Value model only applicable to design reference mission**

- **Future work**
  - **GUI interface**
  - **plug-and-play capability**
    - Design Characteristics
      - Additional Bus types
      - Additional F6 elements
    - Value Model

Design / Parameter Modifications

- **Design Modifications (Discrete Relations)**
  - **Core module characteristics (pub_globals_bus_types.m)**
    - Subsystem mass and power budgets
    - Reliability (FIT values)
    - TRL Level (Cost-weighted average)
    - Schedule parameters
      - Design time, long-lead items
    - Module design constraints
      - Mass, power, propellant
  - **Fractionated components (pub_globals_f6_elements.m)**
    - Mass, power, reliability (FIT values), cost, and TRL for each element
    - Component placement constraints – eliminate known invalid configurations
      - Used for volume, interface, power, or mass constraints
      - array of invalid configurations of F6 element combinations – column indicates element #
      - Ex. [0 1 0 0 0 1] indicates element 2 cannot be paired with element 6
  - **Launch Vehicle Selections (pub_lv_input.m)**
    - LV performance, cost, and reliability
- **Perturbation / scenario parameter selection**
  - **Model selection (pub_Model_Enable_Selection_default.m)**
  - **Model parameters (pub_Model_Cost_Parameters_default.m)**