

Nathan Butler

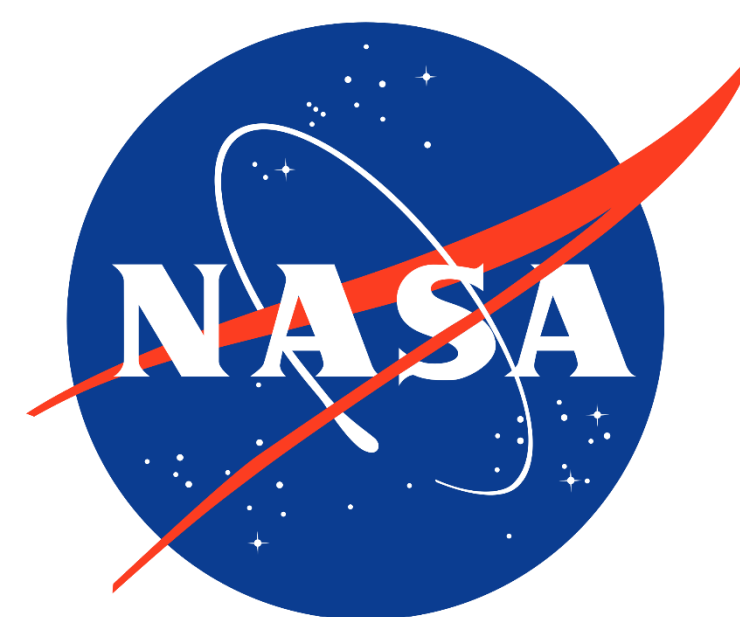
Systems Engineering Toolbox Development for Space Mining Robotics Projects

Introduction

What is Systems Engineering?

“...a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system.”

– NASA Systems Engineering Handbook



NASA Lunabotics Challenge

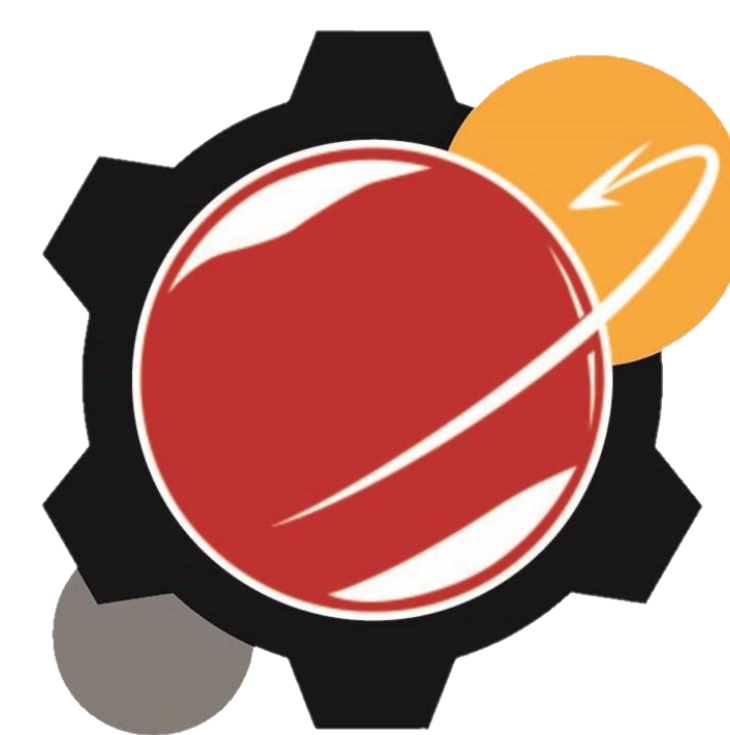
University teams have eight months to design and build a lunar mining robot while using NASA's systems engineering process before competing at the Kennedy Space Center.

Teams are scored not only on robot performance, but on their use of systems engineering.

Cardinal Space Mining Club (CSMC)

Undergraduate student organization that designs, builds, and competes with a mining robot in the annual NASA Lunabotics Challenge.

Uses NASA systems engineering process throughout design phases.



Problem Statement

It is challenging to organize and track the large number of systems engineering activities occurring in a project of this scope. While some software solutions exist for managing this issue, cost and complexity barriers restrict their implementation.

Project Objectives

1. Develop an accessible toolbox for supporting common systems engineering activities performed by the club
2. Utilize toolbox in club operations, refining and expanding functionalities as necessary
3. Generalize toolbox for use in other engineering projects

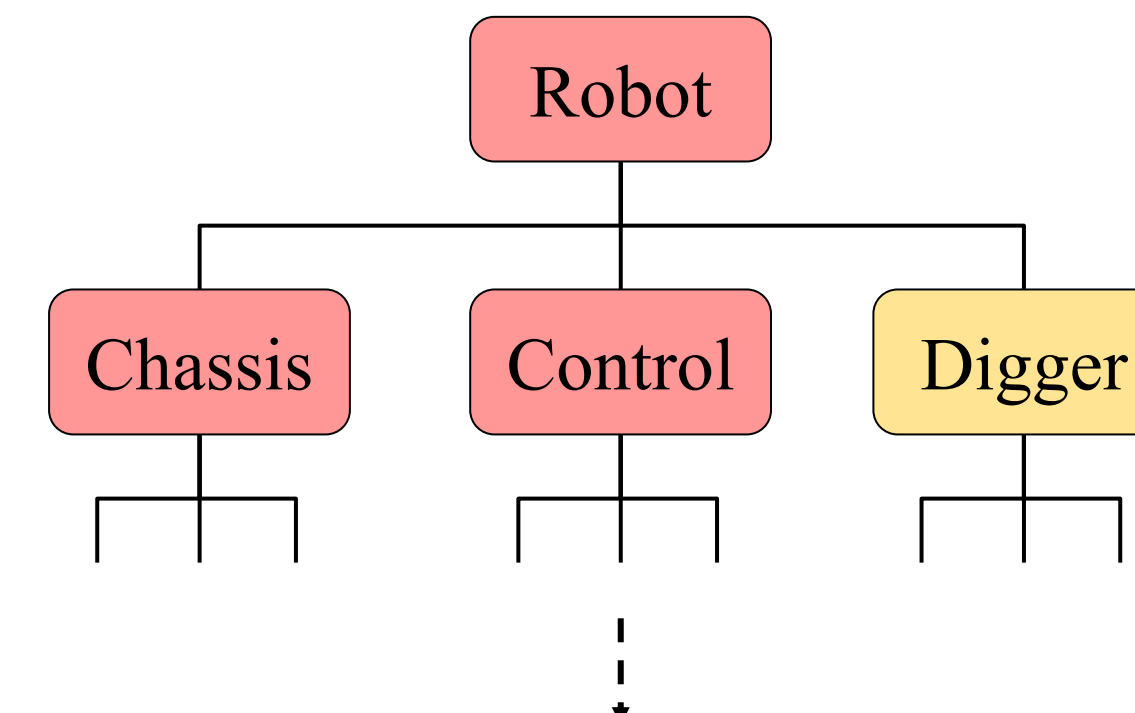
Methods

Microsoft-Based Products

- Two main excel workbooks: System Architecture & Project Management
- Supporting documents hyperlinked in these workbooks as necessary
- Detailed instructions for use included in with each tool

Workbook Tools

System Architecture



Workflow

1. Identify primary function(s) of block
2. Fill out additional requirements for subsystem defined by block
3. Conceptualize features capable of meeting all requirements
4. Perform trade-off study to select best solution
5. Identify functions necessary to support selected feature & repeat process

Block Contents

Name: Digger Primary Function: Mine material

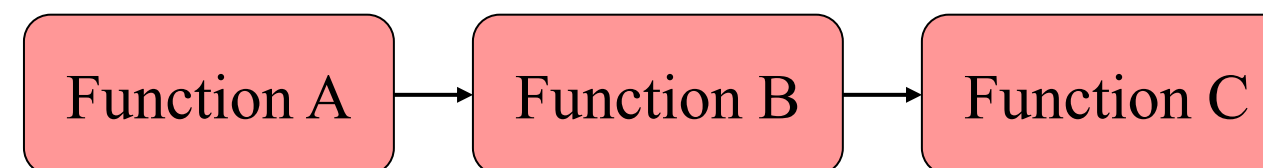
Requirements & Verification Plans

ID	Requirement	Verification Plan
01	The digger shall mine at rate...	Demonstrate Rate
02	The digger shall weigh...	Inspect Weight
03	The digger shall have a volume...	Inspect Volume

Trade-Off Study for Feature Selection

Criteria	Weight	Concept A	Concept B	Concept C
Mining Rate	0.45	X	X	X
Mass	0.25	X	X	X
Power Use	0.30	X	X	X
Totals:		X	X	X

Further Decomposition



Risk Assessment

Design Failure Mode & Effects Analysis

- List failures, impacts, root causes, and detection methods
- Assign each a ranking according to predefined metrics

Failure	Severity	Occurrence	Detection
Chain Breaks	Cannot Mine	Connector Shear	Undetectable
Low Power	Stalls	Low Charge	Power Monitor
Belt Slips	Temporary Stop	High Torque	Motor Current

Additional Tools

- Project Cost Budget
- Project Technical Budget
- Project Scheduling Gantt Chart
- Design Optimization Analysis
- Bill of Materials

Interface Tracking

N-Squared Diagram

- Place subsystems along diagonal
- Inputs into top and bottom of subsystem, outputs leave left and right
- Define mechanical, electrical, software, environmental, user, and more interfaces

Subsystem A	A to B Interface	A to C Interface
B to A Interface	Subsystem B	Blank (no Interface)
Blank (no Interface)	C to B Interface	Subsystem C

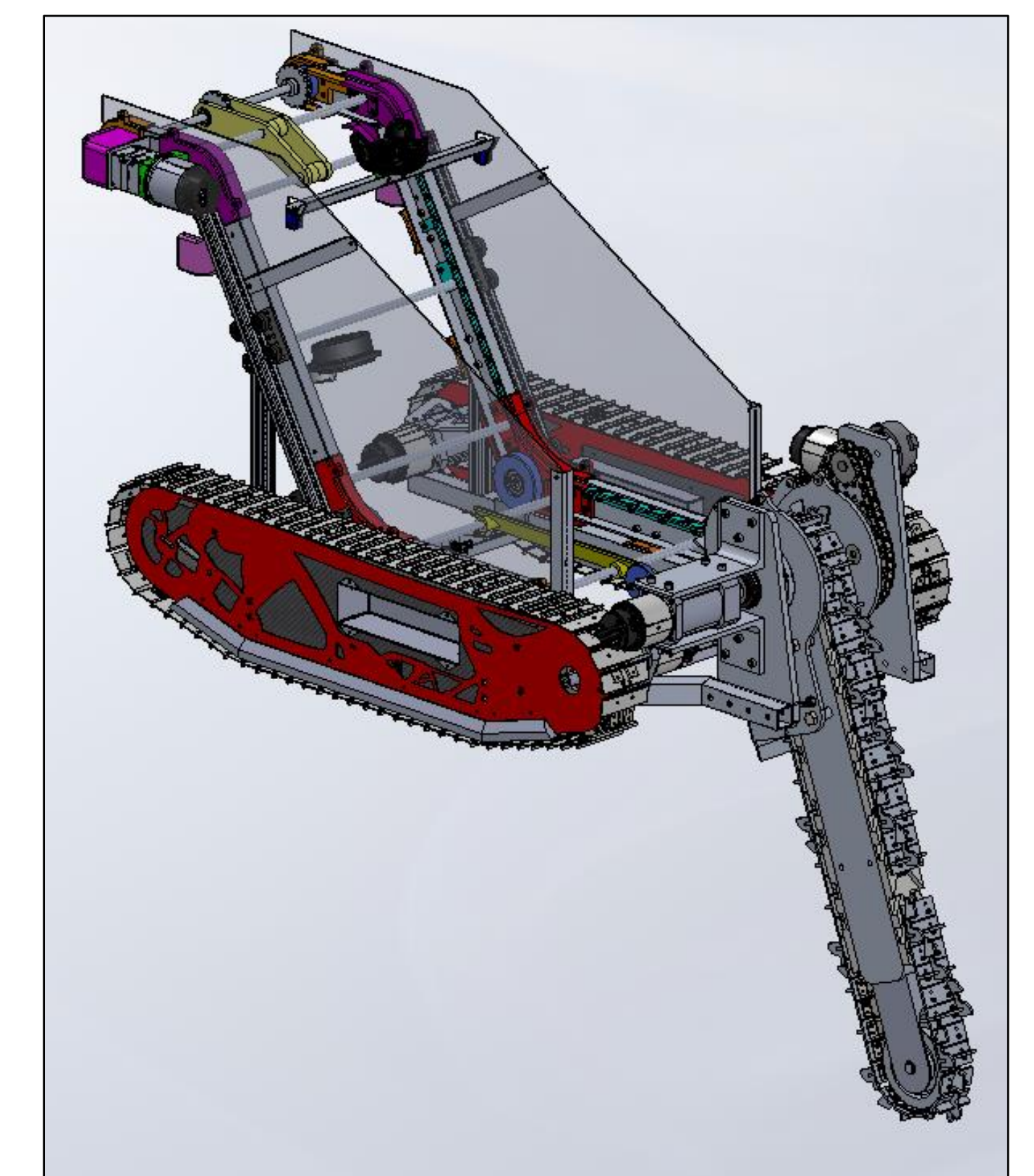
Application & Results

Application to CSMC Robot Development

With the release of competition rules in September 2022, CSMC began utilizing workbook tools in robot development processes. Throughout the fall semester, refinements were identified and implemented in several aspects of the toolbox, including trade study calculations, decomposition strategy, budget management, and more.

Schedule & Design Results

- Shortest development time from rules release to Critical Design Review in over 5 years
- Requirements-driven designing reduced quantity of costly late-season redesigns



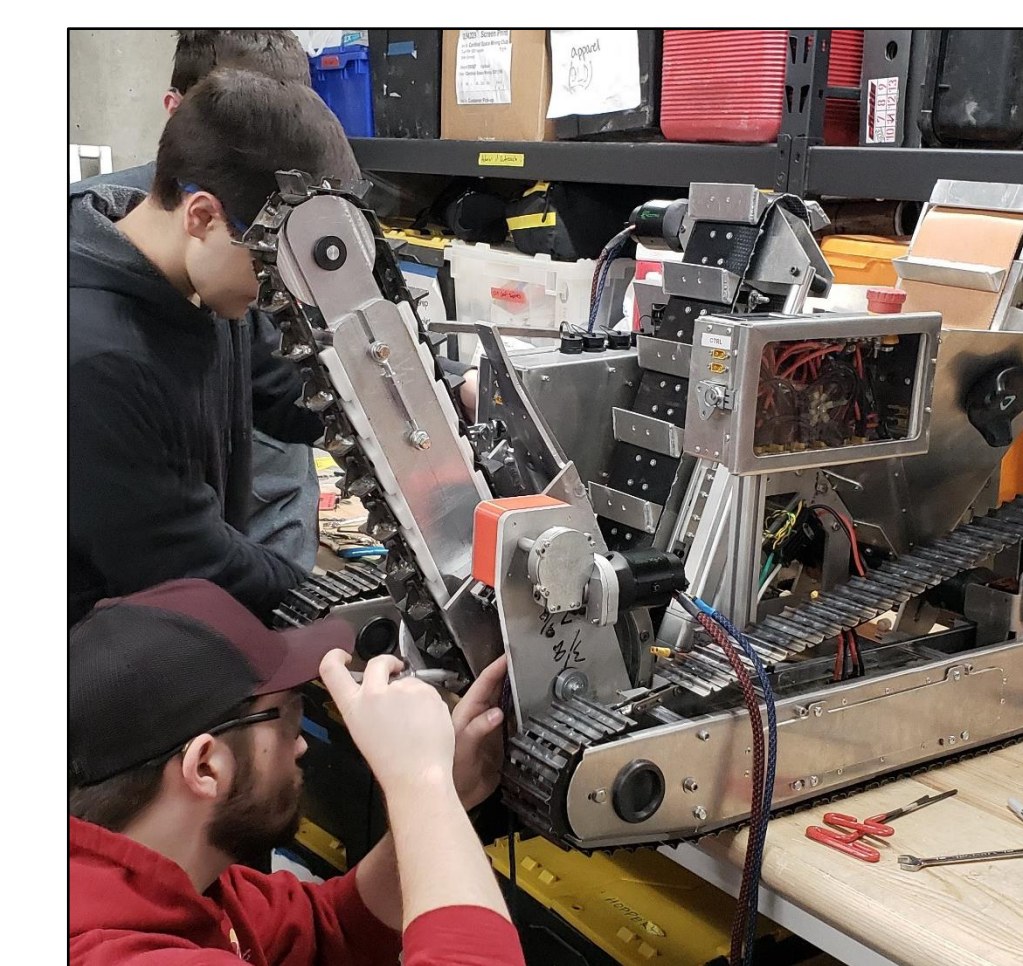
Toolbox Template Progress

- Each item in the toolbox has been cleared of content to form a blank template
- Stored as a file folder containing all workbooks.

Going Forward

Continued Development & Refinement in Spring 2023

- Addition of functionalities for guiding project manufacturing and integration stages
- Close-out project loop by creating verification test plan templates for confirming constructed robot meets project goals
- Robot operations plan details



Toolbox Refinements and Packaging

- Expand on detail of all process descriptions to make toolbox as accessible to new users as possible
- Develop high-level project guidance document to instruct users on when different processes should be used throughout the project lifecycle
- Continue poll of club members to identify helpful ease-of-use changes