

# Test Plan for the Companion Cube Calculator ( $C^3$ ) Tool

Geneva Smith

December 19, 2017

# 1 Revision History

Date	Version	Notes
November 13, 2017	1.0.1	Addition of missing test cases
October 25, 2017	1.0	Initial draft completed

## 2 Symbols, Abbreviations and Acronyms

Symbol	Description
$C^3$	Companion Cube Calculator
GUI	Graphical User Interface
IDE	Integrated Development Environment
SRS	Software Requirements Specification
T	Test

# Contents

<b>1</b>	<b>Revision History</b>	<b>i</b>
<b>2</b>	<b>Symbols, Abbreviations and Acronyms</b>	<b>ii</b>
<b>3</b>	<b>General Information</b>	<b>1</b>
3.1	Purpose . . . . .	1
3.2	Scope . . . . .	1
3.3	Overview of Document . . . . .	2
<b>4</b>	<b>Plan</b>	<b>3</b>
4.1	Software Description . . . . .	3
4.2	Test Team . . . . .	3
4.3	Automated Testing Approach . . . . .	3
4.4	Verification Tools . . . . .	4
4.5	Non-Testing Based Verification . . . . .	4
<b>5</b>	<b>System Test Description</b>	<b>6</b>
5.1	Tests for Functional Requirements . . . . .	6
5.1.1	Getting User Inputs . . . . .	6
5.1.2	Conditioning User Inputs . . . . .	13
5.1.3	Correctness of Component Calculations . . . . .	20
5.1.4	Composing Operators . . . . .	31
5.1.5	Presentation of Calculations to the User . . . . .	34
5.2	Tests for Non-Functional Requirements . . . . .	35
5.2.1	Usability . . . . .	35
5.3	Traceability Between Test Cases and Requirements . . . . .	37
<b>6</b>	<b>Unit Testing</b>	<b>39</b>
6.1	Control Flow Unit Tests . . . . .	39
6.2	User Input Unit Tests . . . . .	39
6.3	Interval Data Structure and Interval Conversion Unit Tests . . . . .	43
6.4	Equation Data Structure and Equation Conversion Unit Tests . . . . .	45
6.5	Variable Consolidation Unit Tests . . . . .	51
6.6	Operator Data Structure and Range Solver Unit Tests . . . . .	54
6.7	Output Unit Tests . . . . .	59

<b>7</b>	<b>Appendix: Usability Testing</b>	<b>62</b>
7.1	Tasks . . . . .	62
7.2	Questionnaire . . . . .	62
7.2.1	Test Results (Round values as necessary) . . . . .	62
7.2.2	Software Usability . . . . .	63

## List of Tables

1	Traceability Matrix Showing the Connections Between Requirements and Test Suites . . . . .	37
---	--	----

## List of Figures

1	Traceability Graph Showing the Connections Requirements and Test Suites . . . . .	38
---	---	----

## 3 General Information

This document is a software test plan for the Companion Cube Calculator ( $C^3$ ), a mathematical tool which determines the range of a user-specified function given the domains of the function's variables. The calculations are performed using interval arithmetic.

### 3.1 Purpose

This document describes the software test plan for the  $C^3$  tool and is informed by its SRS documentation (version 2.0) and resulting implementation, including a description of automated testing approach, tools, and test cases. The purpose of documenting this information is to guide the product testing for the initial product release and to provide a basis for regression testing as further developments are made to the  $C^3$  tool.

This document is intended for readers who wish to test the initial version of the product, as well as those who want to refine and expand the tool. As changes are made to the  $C^3$  tool, these test cases will form the foundation of regression testing and will help ensure that any changes made to the product do not affect its original purpose or core functionality.

This test plan is intended to be used for version 1.0 of the  $C^3$  tool, and will only contain test information related to the product description in the product version's SRS documentation (version 2.0). Any functionality defined beyond the scope of the SRS document are not included in this version of the test plan.

All documentation and the associated release of the tool can be found at <https://github.com/GenevaS/CAS741>.

### 3.2 Scope

The  $C^3$  tool relies on interval arithmetic in the domain of real numbers ( $\mathbb{R}$ ), which means that many of its functions can be empirically tested. This plan contains testing for both specific and non-specific implementation aspects of the program. The implementation-specific tests are included to achieve 100% code coverage to ensure that all code paths are reachable and produce expected outcomes. Non-specific implementation testing focuses on the correctness of the program with respect to its original purpose and its adherence to the SRS document.

The purpose of this plan is to modularize testing of the  $C^3$  tool so that it is easy to maintain and improve. It also forms the foundation of the kinds of be-

haviours that the tool should exhibit when it encounters malformed user inputs and unexpected values during its calculations.

### **3.3 Overview of Document**

This document presents a general description of the  $C^3$  tool to establish the context of the test plan and a list of team members responsible for executing it. This background information is followed by a high-level description of the test plan, including the automated testing approach, verification tools, and non-testing based verification methods that will be used. The general plan outline is followed by a description of the system test which is designed to determine if the requirements from the associated SRS document are satisfied. The final section describes implementation-specific tests that were implemented to achieve 100% code coverage.

## 4 Plan

This section describes the test plan for the  $C^3$  tool from a high-level perspective, outlining the methodologies and tools that will be used during the verification process, and the team responsible for executing the plan.

### 4.1 Software Description

The  $C^3$  tool is a stand-alone application for calculating the mathematical range of a user-defined equation given the domains of the equation's component variables. Equation ranges and variable domains are represented by intervals, where intervals are defined as a set of consecutive values bounded by a minimum and maximum value. The minimum and maximum values for any given interval must be defined. To perform its calculations, the  $C^3$  tool uses interval arithmetic.

The purpose of this product is to produce accurate results when they can be found with respect to the host machine's floating-point precision. If a result cannot be found, the tool is expected to communicate the reason back to the user. Exact results are not required, as the tested equations are expected to be implemented in a software environment that has no impact on the external world. These tasks must be completed while presenting all communications to the user in standard function and interval notation.

### 4.2 Test Team

The test team assigned to implement this plan is Geneva Smith.

### 4.3 Automated Testing Approach

The  $C^3$  tool will almost exclusively rely on automated test approaches for its verification process, with the notable exceptions of the non-functional requirements for correctness, verifiability, usability and maintainability described in the SRS document (version 2.0). The verification of correctness cannot be tested by a machine because it relies on mathematical proofs and the remaining non-functional requirements of verifiability, usability, and maintainability are intended for a human audience. These types of verifications are best handled by manual tests and user studies.

The functional requirements tests (Section 5.1) focus on the behaviour that is expected at each stage of the  $C^3$  tool's work flow. Since these behaviours are inter-



nal to the tool and do not require human guidance, these behaviours can be tested automatically using a series of black box unit tests. Some of the non-functional requirements such as robustness (Section 5.2), can also be tested using automated approaches because they focus on empirically testable data, such as data constraints.

Many of the unit tests are designed to be used as part of integration testing, and the system will be progressively tested starting from the creation of data structures, to conversion processes, to input and output testing. Outputs include messages informing the user of erroneous behaviours or malformed inputs, and the calculated values and resulting equation tree if a no errors are detected.

The remaining unit tests are designed to test the correctness of the tool's calculation. Some of the tests check simple, two variable equations to ensure that the individual calculation types are behaving correctly. The remaining tests will ensure that equations with multiple operators are being decomposed correctly by comparing it to expected results. Once a set of equations has been selected for this task, regression testing becomes available to check further developments to the  $C^3$  tool.

## 4.4 Verification Tools

The C# programming language has been chosen for the development of the  $C^3$  tool because of its GUI building capabilities. The supporting IDE, Visual Studio 2017 (Enterprise Edition), comes with a number of built-in test tools, including:

- **A unit test framework and management system**

This forms the bulk of the automated testing approach and will be used for unit, integration, system, and regression testing. The IDE can be configured so that existing unit tests are run automatically when the program is compiled.

- **Code coverage tools**

The code coverage tools in Visual Studio is connected to the test management system and can help identify code that is not being run by any unit test.

## 4.5 Non-Testing Based Verification

There are a few non-functional requirements that cannot be tested automatically, but are still worth testing to verify their correctness:

- Correctness can be tested using mathematical proofs to verify the correctness of equation decomposition and order of operations.
- Verifiability, usability and maintainability can be verified using user studies tailored for each requirement. This plan specifically contains a user study description for the usability requirements (Appendix 7).

## 5 System Test Description

The system testing of the  $C^3$  tool will focus on inspecting and conditioning user inputs, verifying that the correct values are being produced by program calculations, and ensuring that the  $C^3$  tool is able to produce descriptive outputs for both valid and invalid inputs. These tests are divided into sections based on modules so that integration testing can arise naturally from the gradual addition of components.

### 5.1 Tests for Functional Requirements

The functional requirement tests are broken into four main groups. The “Getting User Inputs” tests (5.1.1) test to make sure that no syntactic errors exist in the user’s inputs that can be reasonably caught by the tool. The “Conditioning User Inputs” tests convert the user’s  $D(v)$ ,  $v \in V$  into internal data structures and parses  $f(V)$  into a semantically correct representation following BEDMAS rules. The “Composing Operators” tests help prove that the composition of individual operators will produce the correct solution  $R(f(V))$ . Finally, the “Presentation of Calculations to the User” tests ensure that the  $C^3$  tool follows the rules for significant figures and precision.

Each test case is associated with specific modules so that developers and maintainers have an idea of where to begin their debugging process should a test fail.

#### 5.1.1 Getting User Inputs

This test suite is designed to determine if the R1 (Accepting  $f(V)$  and  $D(v)$ ,  $v \in V$  as direct input or read from a file) functional requirement and any associated data constraints from R3 are satisfied.

##### User Inputs (As Expected)

1. test-directinput

**Type: Functional, Automatic, Unit**

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Input received from direct input

User Message: -

How test will be performed: Unit Test

Associated Module:

### User Inputs (Function is a Constant Value)

1. test-input\_functionAsConstant

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 42$

Output: [42, 42]

User Message: Warning: The user equation is a constant value and the range will only include this value.

How test will be performed: Unit Test

Associated Module: Equation Conversion

### User Inputs (Extraneous Information)

1. test-input\_variableNotInFunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 3], y = [4, 5], z = [6, 7]$

Output:  $\widehat{x + y}, \{ x = [2, 3], y = [4, 5] \}$

User Message: Warning: Extraneous variables found in interval list (z).

How test will be performed: Unit Test

Associated Module: Variable Consolidation

## User Inputs (Missing Values)

### 1. test-input\_noFunction

**Type: Functional, Automatic, Integration**

Initial State: New Session

Input:  $x = [2, 4], y = [3, 5]$

Output:

User Message: Error: Could not find function  $f(V)$  with variables  $x, y$

How test will be performed: Unit Test

Associated Module:

### 2. test-input\_noDomain

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(X) = x + y, x = [2, 4]$

Output: Success code = -2 (Variable Matching Failed)

User Message: Error: Cannot find intervals for variable name(s):  $y$ .

How test will be performed: Unit Test

Associated Module: Variable Consolidation

### 1. unittest-intervaldatastructuresethighmin

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $x = [3, 4]$

Changes:  $min = 5$

Output:  $x = [4, 5]$

User Message: WARNING: Value provided for minimum bound is greater than the current maximum bound. The values have been exchanged to maintain the interval ordering.

How test will be performed: Unit Testing

Associated Module: IntervalStruct

2. unittest-intervaldatastructuresetlowmax

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $x = [3, 4]$

Changes:  $max = -1$

Output:  $x = [-1, 3]$

User Message: WARNING: Value provided for maximum bound is smaller than the current minimum bound. The values have been exchanged to maintain the interval ordering.

How test will be performed: Unit Testing

Associated Module: IntervalStruct

**User Inputs (Incomplete Values)**

1. test-input\_missingMinDomainValue

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [, 4]$ ,  $y = [3, 5]$

Output:  $+ , \{ x = [4,4], y = [3,5] \}$

$\widehat{x \quad y}$

User Message: -

How test will be performed: Unit Test

Associated Module: Interval Conversion

2. test-input\_missingMaxDomainValue

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $\{f(V) = x + y, x = [2, 4], y = [3, ]\}$

Output:  $\widehat{x + y}, \{x = [2, 4], y = [3, 3]\}$

User Message: -

How test will be performed: Unit Test

Associated Module: Interval Conversion

### User Inputs (Non-Numerical Value in Domains)

#### 1. test-input\_nonNumberInDomain

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 4], y = [a, 5]$

Output:  $\widehat{x + y}, \{ \}$

User Message: Error: The string provided for the minimum bound cannot be converted to a real number.

How test will be performed: Unit Test

Associated Module: Interval Conversion

### Variable Names

#### 1. test-input\_simpleVariableName

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$

Output:  $\{x, y\}$

User Message: -

How test will be performed: Unit Test  
Associated Module: Equation Conversion

2. test-input\_multiCharacterVariableName1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_1 + y$

Output: {  $x_1$ ,  $y$  }

User Message: -

How test will be performed: Unit Test

Associated Module: Equation Conversion

3. test-input\_multiCharacterVariableName2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_- + y$

Output: {  $x_-$ ,  $y$  }

User Message: -

How test will be performed: Unit Test

Associated Module: Equation Conversion

4. test-input\_multiCharacterVariableName3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x_{-1} + y$

Output: {  $x_{-1}$ ,  $y$  }

User Message: -

How test will be performed: Unit Test



Associated Module: Equation Conversion

5. test-input\_multiCharacterVariableName4

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x.i + y$

Output: { x.i, y }

User Message: -

How test will be performed: Unit Test

Associated Module: Equation Conversion

6. test-input\_multiCharacterVariableName5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x'' + y$

Output: { x'', y }

User Message: -

How test will be performed: Unit Test

Associated Module: Equation Conversion

7. test-input\_multiCharacterVariableName6

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = xy + y$

Output: { xy, y }

User Message: -

How test will be performed: Unit Test

Associated Module: Equation Conversion

### 5.1.2 Conditioning User Inputs

This test suite is designed to determine if the R2 (Converting each  $D(v)$  into DD1) and R4 (Decomposing  $f(V)$  into two-operand equations following BEDMAS rules) functional requirements and the associated data constraints from R3 are satisfied.

#### Unexpected Domain Ordering

1. test-parse\_domainOrder

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = [2, 4], y = [3, -5]$

Output:  $\{ x = [2, 4], y = [-5, 3] \}$

User Message: WARNING: Value provided for intervals are not in increasing order. The values have been exchanged to maintain the interval ordering.

How test will be performed: Unit Testing

Associated Module: Interval Data Structure

#### Creating Equation Trees

1. test-parse\_addition

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$

Output:  $+ , \{ x, y \}$

$$\begin{array}{c} \wedge \\ x \quad y \end{array}$$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

2. test-parse\_subtraction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x - y$

Output:  $-$ , { x, y }

$\widehat{x \quad y}$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

3. test-parse\_multiplication

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$

Output:  $*$ , { x, y }

$\widehat{x \quad y}$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

4. test-parse\_division

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$

Output:  $/$ , { x, y }

$\widehat{x \quad y}$

User Message: -

How test will be performed: Unit Testing

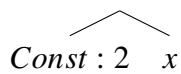
Associated Module: Equation Conversion

5. test-parse\_intervalexponents

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 2^x$

Output:  $\wedge, \{x\}$   


User Message: -

How test will be performed: Unit Testing


Associated Module: Equation Conversion

6. test-parse\_intervalbase

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$

Output:  $\wedge, \{x\}$   


User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

## Constant Values

1. test-parse\_constantValue1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 4 + x$

Output:  $\quad + \quad , \{ x \}$

$\quad \swarrow \quad \searrow$   
 $Const : 4 \quad x$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

## 2. test-parse\_constantValue2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = -4 + x$

Output:  $\quad + \quad , \{ x \}$

$\quad \swarrow \quad \searrow$   
 $Const : -4 \quad x$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

## 3. test-parse\_constantValue3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x / -4$

Output:  $\quad / \quad , \{ x \}$

$\quad \swarrow \quad \searrow$   
 $x \quad Const : -4$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

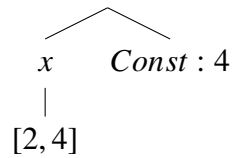
4. test-parse\_constantValue4

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + 4$

Output:  $\quad + \quad , \{ x \}$



User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

5. test-parse\_constantValue5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + -4$

Output:  $\quad + \quad , \{ x \}$



User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

6. test-parse\_constantValue6

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + 42$

Output:  $\quad + \quad , \{ x \}$



User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

#### 7. test-parse\_implicitMultiplication

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 4x$

Output:  $\quad \quad \quad * \quad \quad , \{ x \}$

$\quad \quad \quad \swarrow \quad \searrow$   
 $Const : 4 \quad x$

User Message: Warning: Encountered an implicit multiplication of a constant value and a variable. Expanding with explicit operator.

How test will be performed: Unit Testing

Associated Module: Equation Conversion

### Precedence of Brackets

#### 1. test-parse\_brackets1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + (y - z)$

Output:  $\quad \quad \quad +$

$\quad \quad \quad \swarrow \quad \searrow$   
 $x \quad ()$   
 $\quad \quad \quad |$   
 $\quad \quad \quad -$   
 $\quad \quad \quad \swarrow \quad \searrow$   
 $\quad \quad \quad y \quad z$

User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

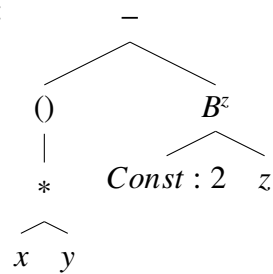
2. test-parse\_brackets2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = (x * y) - 2^z$

Output:



User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

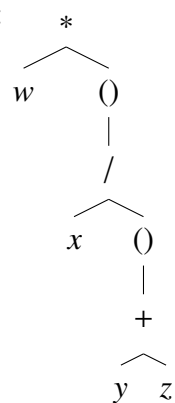
3. test-parse\_brackets3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = w * (x / (y + z))$

Output:





User Message: -

How test will be performed: Unit Testing

Associated Module: Equation Conversion

### Open Brackets

1. test-parse\_openLeftBracket

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y - z$

Output: NULL

User Message: Error: Unrecognized sequence encountered during Atomic Equation parsing. Remaining equation = )

How test will be performed: Unit Testing

Associated Module: Equation Conversion

2. test-parse\_openRightBracket

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + (y - z$

Output: NULL

User Message: Error: Could not find the end of the equation.

How test will be performed: Unit Testing

Associated Module: Equation Conversion

### 5.1.3 Correctness of Component Calculations

This test suite is designed to determine if the R5 (Solving each component equation in  $f(V)$ ) and R7 (Ensuring that the calculated result is represented in closed, interval form) functional requirements, and the associated data constraints from R8 are satisfied.

## Correctness of Addition, Subtraction, and Multiplication

### 1. test-calculate\_addition

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:  $[5, 9]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

### 2. test-calculate\_additionconstant

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + 4$ ,  $x = [2, 4]$

Output:  $[6, 8]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

### 3. test-calculate\_subtraction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x - y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:  $[-1, -1]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

4. test-calculate\_multiplication1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:  $[6, 20]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

5. test-calculate\_multiplication2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$ ,  $x = [-1, 3]$ ,  $y = [-3, 5]$

Output:  $[-9, 15]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

6. test-calculate\_multiplication3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y$ ,  $x = [-3, -1]$ ,  $y = [-5, -2]$

Output:  $[2, 15]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

## Correctness of Division

1. test-calculate\_divisionPositiveDivisor1  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$   
Output:  $[0.4, 1.3333333333333333]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver
  
2. test-calculate\_divisionPositiveDivisor2  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [0, 4]$ ,  $y = [3, 5]$   
Output:  $[0, 1.3333333333333333]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver
  
3. test-calculate\_divisionPositiveDivisor3  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-1, 4]$ ,  $y = [3, 5]$   
Output:  $[-0.3333333333333333, 0.8]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver

4. test-calculate\_divisionPositiveDivisor4  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-2, 0]$ ,  $y = [3, 5]$   
Output:  $[-0.6666666666666666, 0]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver
  
5. test-calculate\_divisionPositiveDivisor5  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-2, -1]$ ,  $y = [3, 5]$   
Output:  $[-0.6666666666666666, -0.2]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver
  
6. test-calculate\_divisionNegativeDivisor1  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, -5]$   
Output:  $[-0.8, -0.6666666666666666]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver

7. test-calculate\_divisionNegativeDivisor2  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [0, 4]$ ,  $y = [-3, -5]$   
Output:  $[-0.8, 0]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver
8. test-calculate\_divisionNegativeDivisor3  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-1, 4]$ ,  $y = [-3, -5]$   
Output:  $[-0.8, 0.2]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver
9. test-calculate\_divisionNegativeDivisor4  
Type: Functional, Automatic, Integration  
Initial State: New Session  
Input:  $f(V) = x/y$ ,  $x = [-2, 0]$ ,  $y = [-3, -5]$   
Output:  $[0, 0.4]$   
User Message: -  
How test will be performed: Unit Testing  
Associated Module: Range Solver

10. test-calculate\_divisionNegativeDivisor5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [-2, -1]$ ,  $y = [-3, -5]$

Output: [0.333333333333, 0.4]

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

11. test-calculate\_divisionbyzero

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/0$ ,  $x = [2, 4]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

Associated Module: Range Solver

12. test-calculate\_divisionMixedIntervalDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, 5]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

Associated Module: Range Solver

13. test-calculate\_divisionMixedIntervalDivisorZero1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, 0]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

Associated Module: Range Solver

14. test-calculate\_divisionMixedIntervalDivisorZero2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [0, 3]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

Associated Module: Range Solver

15. test-calculate\_mixedDivisorComponent

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/(y * z)$ ,  $x = [-2, -1]$ ,  $y = [3, 5]$ ,  $z = [-1, 1]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

Associated Module: Range Solver



**Note:** Ideally, the error message should also output the results calculated up until the division operation (e.g.  $[-2, -1]/[-3, 5]$ ).

### **Correctness of Intervals as Exponents**

1. test-calculate\_intervalAsExponents

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 2^x$ ,  $x = [2, 4]$

Output:  $[4, 16]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

2. test-calculate\_intervalAsExponentsInvalidBase

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 1^x$ ,  $x = [2, 4]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Exponent base  $\leq 1$ ).

How test will be performed: Unit Testing

Associated Module: Range Solver

### **Correctness of Intervals as Base Numbers**

1. test-calculate\_intervalWithExponent1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^3$ ,  $x = [2, 4]$

Output: [8, 64]

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

2. test-calculate\_intervalWithExponent2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [2, 4]$

Output: [4, 16]

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

3. test-calculate\_intervalWithExponent3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [0, 4]$

Output: [0, 16]

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

4. test-calculate\_intervalWithExponent4

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [-2, 4]$

Output: [0, 16]

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

5. test-calculate\_intervalWithExponent5

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [-4, -2]$

Output:  $[4, 16]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Range Solver

6. test-calculate\_intervalWithInvalidExponent1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^{2.1}$ ,  $x = [2, 4]$

Output:  $[4, 16]$

User Message: Warning: The value provided for the exponent 2.1 is not a natural number. It has been rounded to 2.

How test will be performed: Unit Testing

Associated Module: Range Solver

7. test-calculate\_intervalWithInvalidExponent2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^{-1}$ ,  $x = [2, 4]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Exponent < 0).

How test will be performed: Unit Testing

Associated Module: Range Solver

### Intervals-Only Exponentiation

#### 1. test-calculate\_intervalsOnlyExponentiation

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: NULL

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Exponents).

How test will be performed: Unit Testing

Associated Module: Range Solver

### 5.1.4 Composing Operators

This test suite is designed to determine if the R6 (Recomposing the results from the component equations of  $f(V)$ ) and R7 (Ensuring that the calculated result is represented in closed, interval form) functional requirements, and the associated data constraints from R8 are satisfied.

The tests that follow these assume that the user input tests (5.1.1), input conditioning tests (5.1.2), and component equation calculation tests (5.1.3) have passed.

### Operational Precedence Tests

#### 1. test-parse\_commutativityOfAdditionSubtraction

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y - z == f(V) = (x + y) - z$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output: True

User Message: -

How test will be performed: Unit Testing

Associated Module:

2. test-parse\_commutativityOfMultiplicationDivision

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x * y / z == f(V) = (x * y) / z, x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

User Message: -

How test will be performed: Unit Testing

Associated Module:

3. test-parse\_precedenceOfOperators1

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y * z == x + (y * z), x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

User Message: -

How test will be performed: Unit Testing

Associated Module:

4. test-parse\_precedenceOfOperators2

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = 2^x * y == (2^x) * y, x = [2, 4], y = [3, 5]$

Output: True

User Message: -

How test will be performed: Unit Testing

Associated Module:

5. test-parse\_precedenceOfOperators3

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x^2 * y == (x^2) * y, x = [2, 4], y = [3, 5]$

Output: True

User Message: -

How test will be performed: Unit Testing

Associated Module:

6. test-parse\_precedenceOfOperators4

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x * (y + z), x = [2, 4], y = [3, 5], z = [2, 2]$

Output: [10, 28]

User Message: -

How test will be performed: Unit Testing

Associated Module:

7. test-control\_precedenceOfOperators5

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = 2(x + y)^2 / 3^z, x = [1, 2], y = [3, 4], z = [5, 6]$

Output: [0.0438957475994513, 0.296296296296296]

User Message: -

How test will be performed: Unit Testing

Associated Module:

### 5.1.5 Presentation of Calculations to the User

This test suite is designed to test that the final functional requirement, R9 (Showing the results to the user or an error if a result cannot be found), is satisfied. It is assumed that any inputs that do not produce a viable result have been caught previously and an appropriate error or warning message was presented to the user.

#### Printing Intervals

1. test-output\_printvariableintervalWithName

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $x = [2, 4]$

Output:  $x = [2, 4]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Output

2. test-output\_printvariableintervalNoName

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $x = [2, 4]$

Output:  $[2, 4]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Output

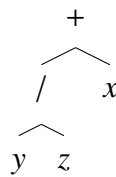
## Printing Equation Trees

1. test-output\_printequationtree

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:



Output:

```
+ - {+}
| +- {/}
| | +- {VAR} y
| | +- {VAR} z
| +- {VAR} x
```

User Message: -

How test will be performed: Unit Testing

Associated Module: Output

## 5.2 Tests for Non-Functional Requirements

Some of the non-functional requirements can be tested using the same tests as their associated functional requirements. This includes correctness and verifiability (5.1.4), and robustness (applicable at every process stage). This leaves the non-functional requirements of usability and maintainability to test separately.

Due to the intended audience for the initial version of the  $C^3$  tool and the size of the test team, maintainability testing will not be included in this test plan.

### 5.2.1 Usability

The tests for usability focus on the notation used to represent  $f(V)$  and  $D(v)$ ,  $v \in V$  and the user's ability to use the tool intuitively without external guidance or instruction. This testing will be completed via a user study (Appendix 7).



## Use of Standard Mathematical Notation

### 1. test-enteringFV

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user is given a  $f(V)$  to enter into the tool; the  $f(V)$  chosen will be taken from the functional requirement tests (Operational Precedence Test, ID: 7)

Result: The user should be able to enter in the  $f(V)$  with no guidance

How test will be performed: User study (7)

### 2. test-enteringDv

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user is given a series of  $D(v)$  to enter into the tool; the  $D(v)$  chosen will be taken from the same functional requirement tests (5.1) as the  $f(V)$  usability test (Test ID: test-enteringFV)

Result: The user should be able to enter in the  $D(v)$  with no guidance

How test will be performed: User study (7)

### 3. test-presentationOutputs

Type: Non-Functional, Manual, System

Initial State: End Session

Condition: The user will be shown the results that the tool produces after it completes its calculations

Result: The user should be able to find and understand the system's outputs from the GUI with no guidance

How test will be performed: User study (7)

### 5.3 Traceability Between Test Cases and Requirements

The purpose of the traceability matrix (Table 1) and graph (Figure 1) is to provide easy references between the test suite and the requirements from the SRS (version 2.0). In the table, the test suites that verify a requirement are marked with an “X” in the requirement’s column. In the graph, tests appear at the tail of an arrow and requirements appear at the head.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	NF: Usability
5.1.1	X		X							
5.1.2		X	X	X						
5.1.3					X		X	X		
5.1.4						X	X	X		
5.1.5									X	
5.2.1										X

Table 1: Traceability Matrix Showing the Connections Between Requirements and Test Suites

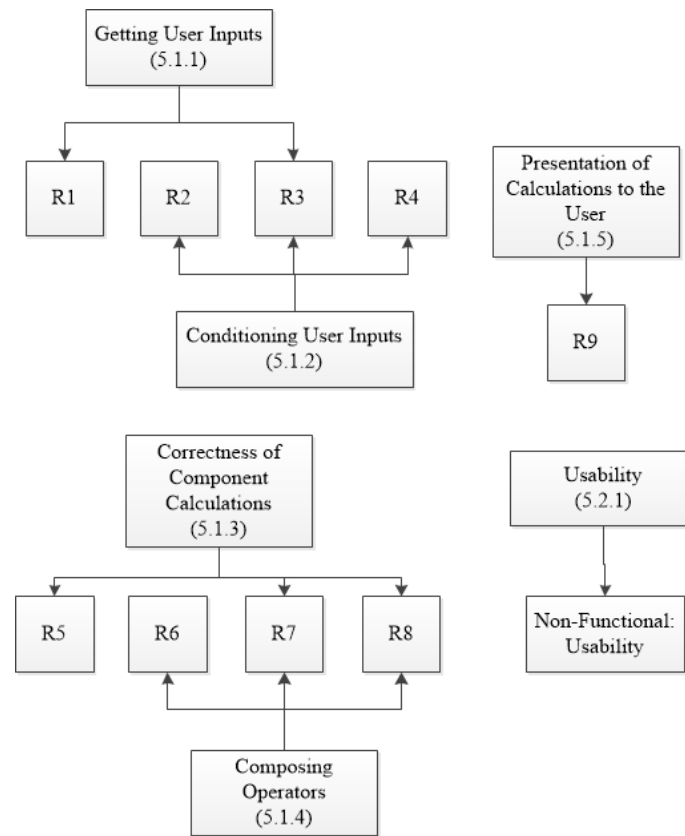


Figure 1: Traceability Graph Showing the Connections Requirements and Test Suites

## 6 Unit Testing

As shown by the system test description (Section 4), the system and integration testing of the  $C^3$  tool can be divided into several unique steps. However, these tests do not cover all possible code paths such that 100% code coverage can be achieved. The unit tests were created in addition to the functional requirements tests to realize this goal. Unit testing is divided by modules.

### 6.1 Control Flow Unit Tests

#### 1. unittest-intervaldatastructure

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $x = [2, 4]$

Output:  $[2, 4]$

User Message: -

How test will be performed: Unit Testing

Associated Module: Output

### 6.2 User Input Unit Tests

These tests are designed to exercise all code paths in the `Input.cs` file in the `CompanionCubeCalculator.csproj` project file. They are implemented in the `InputTests.cs` file in the `UnitTests_CompanionCubeCalculator.csproj` project file. These projects are collected in the `CompanionCubeCalculator.sln` solution file.

#### File I/O

#### 1. unittest-fileinput

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File containing:

x + y  
x , 2 , 4  
y , 3 , 5

Output: {"x+y", "x,2,4\ny,3,5"}

User Message: -

How test will be performed: Unit Test

## 2. unittest-fileinputwithequals

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File containing:

f (V) = x + y  
x , 2 , 4  
y , 3 , 5

Output: {"x+y", "x,2,4\ny,3,5"}

User Message: -

How test will be performed: Unit Test

## 3. unittest-emptyfile

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File containing no information

Output: NULL

User Message: Error: The file is empty.

How test will be performed: Unit Test

## 4. unittest-invalidfiletype

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File with an unsupported extension

Output: NULL

User Message: Error: Cannot read files of this type.

How test will be performed: Unit Test

5. unittest-input\_noFunctionFile

Type: Functional, Automatic, Unit

Initial State: New Session

Input: A file containing:

x , 2 , 4

y , 3 , 5

Output: NULL

User Message: Error: The first line of the file is not an equation or the equation contains ','.

How test will be performed: Unit Test

6. unittest-noFile

Type: Functional, Automatic, Unit

Initial State: New Session

Input: A file that does not exist

Output: NULL

User Message: Error: The specified file does not exist.

How test will be performed: Unit Test

7. unittest-badFileInput

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File that cannot be read

Output: NULL

User Message: Error: Cannot read files of this type.

How test will be performed: Unit Test

## Getters

### 1. unittest-testgetlinedelimiter

Type: Functional, Automatic, Unit

Initial State: New Session

Input: -

Output: \r\n

User Message: -

How test will be performed: Unit Testing

### 2. unittest-testgetfielddelimiter

Type: Functional, Automatic, Unit

Initial State: New Session

Input: -

Output: ,

User Message: -

How test will be performed: Unit Testing

### 3. unittest-testgetfiletypes

Type: Functional, Automatic, Unit

Initial State: New Session

Input: -

Output: \*.txt

User Message: -

How test will be performed: Unit Testing

## 6.3 Interval Data Structure and Interval Conversion Unit Tests

These tests are designed to exercise all code paths in the `IntervalStruct.cs` and `IntervalConversion.cs` files in the `CompanionCubeCalculator.csproj` project file. They are implemented in the `IntervalTests.cs` file in the `UnitTests.CompanionCubeCalculator.csproj` project file. These projects are collected in the `CompanionCubeCalculator.sln` solution file.

### Interval Data Structure

#### 1. unittest-intervaldatastructuresetters

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $x = [3, 4]$

Changes:  $min = 2, max = 5, leftBoundClosed = TRUE, rightBoundClosed = TRUE$

Output:  $x = (2, 5)$

User Message: -

How test will be performed: Unit Testing

#### 2. unittest-intervaldatastructuresetvarname

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $x = [3, 4]$

Changes:  $varName = y$

Output:  $y = [-1, 3]$

User Message: -

How test will be performed: Unit Testing



## Interval Conversion

### 1. unittest-intervalconversionmissingbounds

Type: Functional, Automatic, Unit

Initial State: New Session

Input: **x**

Output: {}

User Message: Error: No fields found for variable (Line n). Skipping line.

How test will be performed: Unit Testing

### 2. unittest-intervalconversionemptybounds

Type: Functional, Automatic, Unit

Initial State: New Session

Input: **x, ,**

Output: {}

User Message: Error: No values provided for either interval bound.

How test will be performed: Unit Testing

### 3. unittest-intervalconversionmissingvarname

Type: Functional, Automatic, Unit

Initial State: New Session

Input: **3.0,4.0**

Output: {}

User Message: Error: Intervals must have an associated variable name.

How test will be performed: Unit Testing

### 4. unittest-intervalconversionemptyvarname

Type: Functional, Automatic, Unit

Initial State: New Session

Input: , 3.0, 4.0

Output: {}

User Message: Error: Intervals must have an associated variable name.

How test will be performed: Unit Testing

5. unittest-intervalconversiontoomanyfields

Type: Functional, Automatic, Unit

Initial State: New Session

Input: x, 3, 4, 5

Output: {}

User Message: Error: Encountered a variable with more than three fields (Line n). Skipping line.

How test will be performed: Unit Testing

## 6.4 Equation Data Structure and Equation Conversion Unit Tests

These tests are designed to exercise all code paths in the `EquationStruct.cs` and `EquationConversion.cs` files in the `CompanionCubeCalculator.csproj` project file. They are implemented in the `EquationTests.cs` file in the `UnitTests_CompanionCubeCalculator.csproj` project file. These projects are collected in the `CompanionCubeCalculator.sln` solution file.

### Equation Data Structure

#### Constructors

1. unittest-equationdatastructurenoop

Type: Functional, Automatic, Unit

Initial State: New Session

Input: "", "", *null*, *null*

Output: Exception

User Message: Error: Equation structures must be assigned an operator during initialization.

How test will be performed: Unit Testing

2. unittest-equationdatastructureconstructnulls

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", "x", null, null

Output: 
$$\begin{array}{c} + : x \\ \wedge \\ null \quad null \end{array}$$

User Message: -

How test will be performed: Unit Testing

3. unittest-equationdatastructureconstruct

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", "x", VAR : y , VAR : z

$$\begin{array}{c} \wedge \quad \wedge \\ null \quad null \quad null \quad null \end{array}$$

Output: 
$$\begin{array}{c} + : x \\ \wedge \\ \begin{array}{cc} VAR : y & VAR : z \\ \wedge \quad \wedge \\ null \quad null & null \quad null \end{array} \end{array}$$

User Message: -

How test will be performed: Unit Testing

## Getters

### 1. unittest-equationdatastructuresetvarname

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", "x", *null*, *null*, y

Output:     + : y  
           $\wedge$   
        *null*   *null*

User Message: -

How test will be performed: Unit Testing

### 2. unittest-equationdatastructuresetlefttop

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", "x", *null*, *null*, [.VAR : y [.*null* ] [.*null* ] ]

Output:             + : x  
           $\wedge$   
        VAR : y   *null*  
       $\wedge$   
    *null*   *null*

User Message: -

How test will be performed: Unit Testing

### 3. unittest-equationdatastructuresetrighttop

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", "x", *null*, *null*, [.VAR : z [.*null* ] [.*null* ] ]

Output:             + : x  
           $\wedge$   
        *null*   VAR : z  
               $\wedge$   
            *null*   *null*

User Message: -

How test will be performed: Unit Testing

## Equation Conversion

### 1. unittest-equationconversionconfignoops

Type: Functional, Automatic, Unit

Initial State: New Session

Input: new OperatorStruct[] , Solver.GetValidTerminators()

Output: FALSE

User Message: Error: No operators were passed to the parser.

How test will be performed: Unit Testing

### 2. unittest-equationconversionconfigunary

Type: Functional, Automatic, Unit

Initial State: New Session

Input: new OperatorStruct[] new OperatorStruct("-", 5, true, false, false, false) , Solver.GetValidTerminators()

Output: TRUE

User Message: -

How test will be performed: Unit Testing

### 3. unittest-equationconversionconfigbinary

Type: Functional, Automatic, Unit

Initial State: New Session

Input: new OperatorStruct[] new OperatorStruct("-", 5, false, true, false, false) , Solver.GetValidTerminators()

Output: TRUE

User Message: -

How test will be performed: Unit Testing

4. unittest-equationconversionconfigternary

Type: Functional, Automatic, Unit

Initial State: New Session

Input: `new OperatorStruct[] new OperatorStruct("&", 5, false, false, true, false) , Solver.GetValidTerminators()`

Output: FALSE

User Message: Error: The parser cannot process the & operator.

How test will be performed: Unit Testing

5. unittest-equationconversionconfigunbalancedleftterm

Type: Functional, Automatic, Unit

Initial State: New Session

Input: `Solver.GetValidOperators(), new string[] "(" , ""`

Output: FALSE

User Message: Error: An unbalanced left terminator token was encountered ().

How test will be performed: Unit Testing

6. unittest-equationconversionconfigunbalancedrightterm

Type: Functional, Automatic, Unit

Initial State: New Session

Input: `Solver.GetValidOperators(), new string[] "" , ")"`

Output: FALSE

User Message: Error: An unbalanced right terminator token was encountered ()).

How test will be performed: Unit Testing

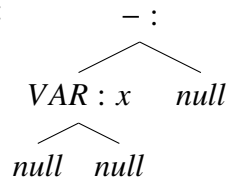
7. unittest-equationconversionparseunary

Type: Functional, Automatic, Unit

Initial State: New Session

Input: "-x", new OperatorStruct("-", 5, true, false, false, false)

Output:



User Message: -

How test will be performed: Unit Testing

8. unittest-equationconversion\_missingFunctionValue1

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $f(V) = x+$

Output: NULL

User Message: Error: Could not find the end of the equation.

How test will be performed: Unit Test

9. unittest-equationconversion\_missingFunctionValue2

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $f(V) = *x$

Output: NULL

User Message: Error: Unrecognized sequence encountered during Atomic Equation parsing. Remaining equation =  $*x$ .

How test will be performed: Unit Test

10. unittest-equationconversion\_missingFunctionValue3

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $f(V) = x + *y$

Output: NULL

User Message: Error: Unrecognized sequence encountered during Atomic Equation parsing. Remaining equation =  $*y$ .

How test will be performed: Unit Test

## 6.5 Variable Consolidation Unit Tests

These tests are designed to exercise all code paths in the `Consolidate.cs` file in the `CompanionCubeCalculator.csproj` project file. They are implemented in the `VariableConsolidationTests.cs` file in the `UnitTests_CompanionCubeCalculator.csproj` project file. These projects are collected in the `CompanionCubeCalculator.sln` solution file.

1. unittest-consolidatetestinit

Type: Functional, Automatic, Integration

Initial State: New Session

Input: -

Output: *TRUE*

User Message: -

How test will be performed: Unit Testing

2. unittest-consolidatetestinit

Type: Functional, Automatic, Integration

Initial State: New Session

Input: -

Output: *TRUE*

User Message: -



How test will be performed: Unit Testing

3. unittest-consolidatenoops

Type: Functional, Automatic, Integration

Initial State: New Session

Input: `ConvertAndCheckInputs(x+y, x, 2, 3 \ny, 4, 5, { }, Solver.GetValidTerminators())`

Output: *successCode* = -1

User Message: Error: No operators were passed to the parser.

How test will be performed: Unit Testing

4. unittest-consolidatenorightterm

Type: Functional, Automatic, Integration

Initial State: New Session

Input: `ConvertAndCheckInputs(x+y, x, 2, 3 \ny, 4, 5, Solver.GetValidOperators, { { "(" } })`

Output: *successCode* = -1

User Message: Error: An unbalanced left terminator token was encountered ("  
")

How test will be performed: Unit Testing

5. unittest-consolidatenoleftterm

Type: Functional, Automatic, Integration

Initial State: New Session

Input: `ConvertAndCheckInputs(x+y, x, 2, 3 \ny, 4, 5, Solver.GetValidOperators, { { ")" } })`

Output: *successCode* = -1

User Message: Error: An unbalanced right terminator token was encountered ("  
")

How test will be performed: Unit Testing

6. unittest-consolidatesimpleinputs

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$

Output:  $\widehat{x + y}, \{ x = [2, 3], y = [4, 5] \}$

User Message: -

How test will be performed: Unit Testing

7. unittest-consolidateextractvariables

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$

Output:  $\{ x = [2, 3], y = [4, 5] \}$

User Message: -

How test will be performed: Unit Testing

8. unittest-consolidateincompleteequation

Type: Functional, Automatic, Integration

Initial State: New Session

Input: "", "x,2,3\n"

Output: *successCode* = -1

User Message: Error: Unrecognized sequence encountered during Atomic Equation parsing. Remaining equation =

How test will be performed: Unit Testing

## 6.6 Operator Data Structure and Range Solver Unit Tests

These tests are designed to exercise all code paths in the `OperatorStruct.cs` and `Solver.cs` files in the `CompanionCubeCalculator.csproj` project file. They are implemented in the `SolverTests.cs` file in the `UnitTests_CompanionCubeCalculator.csproj` project file. These projects are collected in the `CompanionCubeCalculator.sln` solution file.

### Operator Data Structure

1. `unittest-operatordatastructureconstructor`

Type: Functional, Automatic, Unit

Initial State: New Session

Input: `" + ", 1, false, true, false, true`

Output: `OperatorStruct(+, 1, false, true, false, true)`

User Message: -

How test will be performed: Unit Testing

2. `unittest-operatordatastructuremissingsym`

Type: Functional, Automatic, Unit

Initial State: New Session

Input: `"" , 1, false, true, false, true`

Output: `Exception`

User Message: Error: Cannot have an operator with no representative symbol.

How test will be performed: Unit Testing

3. `unittest-operatordatastructurelowprecedence`

Type: Functional, Automatic, Unit

Initial State: New Session

Input: `" + ", 0, false, true, false, true`

Output: `Exception`

User Message: Error: Precedence values must be greater than 0.

How test will be performed: Unit Testing

4. unittest-operatordatastructureoverloadedtype1

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", 1, *true, true, false, true*

Output: **Exception**

User Message: Error: An operator cannot be overloaded to be unary, binary, and ternary.

How test will be performed: Unit Testing

5. unittest-operatordatastructureoverloadedtype2

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", 1, *false, true, true, true*

Output: **Exception**

User Message: Error: An operator cannot be overloaded to be unary, binary, and ternary.

How test will be performed: Unit Testing

6. unittest-operatordatastructureoverloadedtype3

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", 1, *true, false, true, true*

Output: **Exception**

User Message: Error: An operator cannot be overloaded to be unary, binary, and ternary.

How test will be performed: Unit Testing

7. unittest-operatordatastructurenotype

Type: Functional, Automatic, Unit

Initial State: New Session

Input: " + ", 1, *false*, *false*, *false*, *true*

Output: **Exception**

User Message: Error: Operators must be assigned a number of operands type.

How test will be performed: Unit Testing

## **Range Solver**

1. unittest-solvernoequation

Type: Functional, Automatic, Integration

Initial State: New Session

Input: *null*,  $x = [1, 2]$

Output: **Exception**

User Message: Error: No information was provided for the equation.

How test will be performed: Unit Testing

2. unittest-solverunknownop

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x * * x$ ,  $x = [2, 3]$

Output: *NULL*

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Unknown operator).

How test will be performed: Unit Testing

3. unittest-solvermissingintervals

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x, \{\}$

Output: *NULL*

User Message: Error: Could not find an associated interval for variable  $x$ .

How test will be performed: Unit Testing

4. unittest-solverconstantfunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input: 42,  $\{\}$

Output: [42, 42]

User Message: -

How test will be performed: Unit Testing

5. unittest-solvervariablefunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x, \{x = [2, 3]\}$

Output: [2, 3]

User Message: -

How test will be performed: Unit Testing

6. unittest-solveradditionleftsidenull

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $(y/z) + x, \{x = [2, 4], y = [-3, 5], z = [-1, 1]\}$

Output: *NULL*

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

7. unittest-solversubtractionleftsidenull

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $(y/z) - x, \{x = [2, 4], y = [-3, 5], z = [-1, 1]\}$

Output: *NULL*

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

8. unittest-solvermultiplicationleftsidenull

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $(y/z) * x, \{x = [2, 4], y = [-3, 5], z = [-1, 1]\}$

Output: *NULL*

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

9. unittest-solverdivisionleftsidenull

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $(y/z)/x, \{x = [2, 4], y = [-3, 5], z = [-1, 1]\}$

Output: *NULL*

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

10. unittest-solverexponentleftsidenull

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $(y/z) \wedge 4, \{y = [-3, 5], z = [-1, 1]\}$

Output: *NULL*

User Message: Error: An unsupported operation was encountered while solving for the range of the equation (Mixed interval division).

How test will be performed: Unit Testing

## 6.7 Output Unit Tests

These tests are designed to exercise all code paths in the `Output.cs` file in the `CompanionCubeCalculator.csproj` project file. They are implemented in the `OutputTests.cs` file in the `UnitTests_CompanionCubeCalculator.csproj` project file. These projects are collected in the `CompanionCubeCalculator.sln` solution file.

1. unittest-outputopenstructure

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = (2, 4), true$

Output:  $x = (2, 4)$

User Message: -

How test will be performed: Unit Testing

2. unittest-outputclosedleftstructure

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = [2, 4), true$



Output:  $x = [2, 4)$

User Message: -

How test will be performed: Unit Testing

3. unittest-outputclosedrightstructure

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = (2, 4], true$

Output:  $x = (2, 4]$

User Message: -

How test will be performed: Unit Testing

4. unittest-outputconstwithname

Type: Functional, Automatic, Integration

Initial State: New Session

Input: *CONST* : 3, *true*

Output: *CONST*: 3

User Message: -

How test will be performed: Unit Testing

5. unittest-outputconstnoname

Type: Functional, Automatic, Integration

Initial State: New Session

Input: *CONST* : 3, *false*

Output: *CONST*: 3

User Message: -

How test will be performed: Unit Testing

6. unittest-outputlongresult

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = [0.333333333333, 0.6666666666666666], false$

Output: [0.333333333333, \n 0.6666666666666666]

User Message: -

How test will be performed: Unit Testing

## 7 Appendix: Usability Testing

An informal user study was conducted as part of the Companion Cube Calculator test suite, where participants were recruited from the examiner’s lab. Participants were sent a compressed file containing the program, user manual, and instructions and asked to complete it on their own time. The instructions file contained a URL to the associated study questionnaire.

The instructions that were sent to participants can be found at:

<https://github.com/GenevaS/CAS741/tree/master/Doc/TestReport/UserStudy>

### 7.1 Tasks

User study participants were asked to complete two tasks given the information:

$$\frac{2(x+y)^2}{3^z}$$

where

$$x = [1, 2], y = [3, 4], z = [5, 6]$$

The first task was to input the information directly into the GUI and the second task was to load the information into the program via a file.

Participants were free to access the program user guide as they saw fit.

### 7.2 Questionnaire

This survey were designed to accompany the user study. The questionnaire was distributed as a Google Form. All Likert scale questions were from 1 to 5, where 1 is “Strongly Disagree” and 5 is “Strongly Agree”.

#### 7.2.1 Test Results (Round values as necessary)

1. (Long Answer) What range value did you calculate in Task 1?
2. (Long Answer) What was the resulting equation tree from Task 1?
3. (Long Answer) What range value did you calculate in Task 2?
4. (Long Answer) What was the resulting equation tree from Task 2?

### **7.2.2 Software Usability**

#### **Task 1: Entering values directly into the GUI**

1. (Likert Scale) I found it easy to find the input mechanism for entering the equation into the GUI.
2. (Likert Scale) I found it easy to use the function input mechanism.
3. (Likert Scale) I found it easy to find the input mechanism for entering variable domains into the GUI.
4. (Likert Scale) I found it easy to use the variable domain input mechanism.

#### **Task 2: Loading values into the program from a file**

1. (Likert Scale) I found it easy to find the option to load from a file.

#### **Understanding the Results**

1. (Likert Scale) I found it easy to find the calculated range in the GUI.
2. (Likert Scale) I found it easy to understand the calculated range.
3. (Likert Scale) I found it easy to understand the sequence of steps required to use the software.
4. (Long answer) Describe any interactions with the program that confused you during the tasks.
5. (Long answer) Do you have any suggestions for improving the process flow of the tool?