Software Requirements Specification for Damped Harmonic Ocsillator: Damped Harmonic Oscillator Illustrated by Online Calculator

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Contents

Revision History

Date	Version	Notes
February 2, 2024	1.0	Initial Document Release

1 Reference Material

This section records information for easy reference.

1.1 Table of Units

Throughout this document SI (Système International d'Unités) is employed as the unit system. In addition to the basic units, several derived units are used as described below. For each unit, the symbol is given followed by a description of the unit and the SI name.

symbol	**unit**	**SI**
m	length	metre
kg	mass	kilogram
s	time	second
N	force	Newton
Hz	frequency	hertz (s^{-1})
v	velocity	metre per second ($m\,s^{-1}$)
a	acceleration	metre per second square ($m\,s^{-2}$)
g	gravity	metre per second square ($m\,s^{-2}$)

1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units. The choice of symbols was made to be consistent with the heat transfer literature and with existing documentation for solar water heating systems. The symbols are listed in alphabetical order.

symbol	**unit**	**description**
k	Newton per metre ($N\,m^{-1}$)	Spring Constant
c	kilogram per second ($kg\,s^{-1}$)	Damping Coefficient
x	metre (m)	Displacement
w	radians per second ($rad\,s^{-1}$)	Angular Frequency

1.3 Abbreviations and Acronyms

symbol	**description**
SRS	Software Requirement Specification
ODE	Ordinary Differential Equation
DE	Differential Equation
DHO	Damped Harmonic Oscillator
SHM	Simple Harmonic Motion

1.4 Mathematical Notation

- **Greek symbols** represent constants and parameters, such as ω for angular frequency.
- **Subscripts** are used to denote specific instances or components, e.g., x_t for the position at time t.
- **Mathematical operations** and functions are denoted as follows: sin and cos for trigonometric functions, e for the exponential function, and d/dt for differentiation with respect to time.

2 Introduction

In physics and engineering, the concept of harmonic oscillators gives us a way to understand how things move back and forth or oscillate. It offering insights into systems' behavior under periodic forces. Understanding system dynamics of a simple pendulum or a mass attached to a spring is crucial for advancements in various scientific and engineering fields. This document introduces a software project aimed at modeling and analyzing harmonic oscillators, providing a tool for educational, research, and industrial applications to observe the effect of damping on oscillating bodies.

This introduction serves as a roadmap to the document, outlining its structure and guiding the reader through the subsequent sections. Following this introduction, the document details the purpose of the SRS, the scope of requirements, characteristics of the intended reader, and the organization of the document itself.

2.1 Purpose of Document

The purpose of this Software Requirement Specification (SRS) document is to outline the functional and non-functional requirements for a software project focused on the simulation and analysis of harmonic oscillators. This document is intended to serve as a comprehensive guide for the development team, ensuring that the software meets the specific needs of its users. Additionally, this SRS aims to facilitate clear communication among stakeholders, provide a basis for estimating costs and timelines, and implementation phases of the project.

2.2 Scope of Requirements

This project is the simulation of harmonic oscillators, a fundamental concept in physics. To manage the complexity in modeling real-world phenomena, the scope of this software will be constrained. Specifically, the project will focus on:

- Modeling in two dimensions to simplify visualizations and computations.
- Ignoring environmental factors such as temperature and pressure variations that might affect the system's properties.

These constraints are chosen to make the problem tractable while still providing valuable insights and educational utility.

2.3 Characteristics of Intended Reader

This document is written for the people who will help build, review, and maintain the software. They should know their way around basic physics and be comfortable with the mathematics, especially the oscillators and how they work. They don't need to be physicists, but they should understand the science behind what I am trying to simulate.

2.4 Organization of Document

The document is organized to facilitate easy navigation and understanding of the software requirements. After this section, the document is structured as follows:

- Section 3: General System Description
- Section 4: Specific System Description
- Section 5: Requirements

Readers are encouraged to refer to Section 3 for general system description, Section 4 for specific system description, and Section 5 for requirements.

3 General System Description

This section outlines the overall framework of the software designed to simulate and analyze harmonic oscillators, both simple and damped. It aims to provide a basic understanding of how the system interacts with its environment, detailing user interaction, external interfaces, and inherent system constraints. The purpose here is to establish a broad context that will make the specific requirements outlined in subsequent sections clearer and more meaningful. By describing the system at a general level, this section remains applicable even as specific functionalities evolve or expand within the project's scope.

3.1 System Context

The software operates on a basic design pattern of Inputs → Calculations → Outputs, facilitating user interaction through a structured and intuitive interface. Users input parameters related to the harmonic oscillator system, such as mass, damping coefficients, spring constants, initial conditions, and time frames for simulation. The software processes these inputs to perform complex calculations, simulating the oscillator's behavior over time. The calculated data is then formatted into outputs that are meaningful to the user, such as displacement, velocity, energy over time, and visualizations of the oscillator's motion.

- User Responsibilities:
  - Provide accurate and complete input data relevant to the harmonic oscillator being analyzed, including material properties, system geometry, initial conditions, and any external forces or constraints.
  - Interpret the outputs generated by the software, applying them appropriately in their context of use, whether it be for educational, scientific research, engineering analysis, or exploration purposes.
- Damped Harmonic Ocsillator Responsibilities:

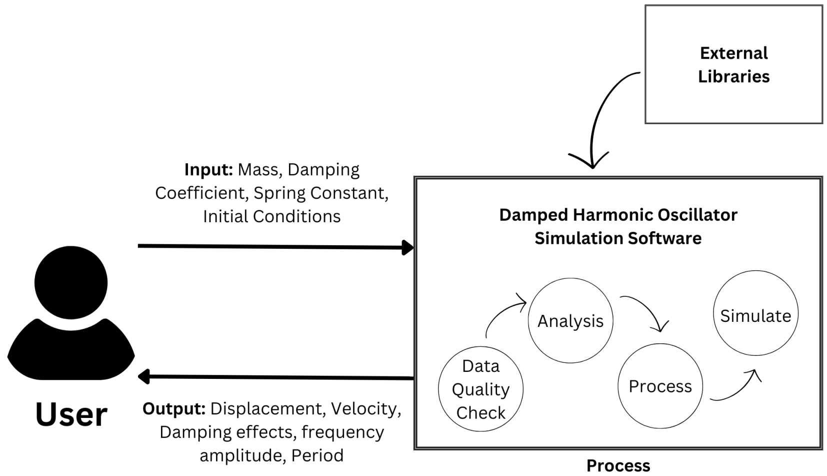

Figure 1: System Context

- Accurately process user inputs to simulate the behavior of harmonic oscillators under specified conditions.
- Detect and handle data type mismatches (e.g., rejecting non-numeric inputs where numbers are expected) and other input errors.
- Generate and present outputs in a clear, understandable format, including graphical visualizations, data tables, and summary reports.
- Ensure the software's calculations and outputs maintain high accuracy and reliability, especially in contexts where precision is critical.

Context of Use:

The software is designed for use in a variety of contexts, including educational environments for teaching physics principles, research settings for exploring the dynamics of new materials or mechanical systems, and engineering projects requiring precise analysis of oscillatory systems. While the software is robust and designed for high accuracy, its application to mission-critical or safety-critical systems should be approached with caution, ensuring that all inputs are verified and that outputs are double-checked against other sources of analysis where possible.

3.2 User Characteristics

Users of the Damped Harmonic Oscillator software are expected to have a basic understanding of calculus and physics at an undergraduate level. Specifically, they should be familiar with the concepts of differential equations as they apply to motion and be able to apply basic physics principles to interpret the simulation results. This foundational knowledge is crucial for effective interaction with the software, enabling users to input realistic parameters and accurately interpret simulation outcomes.

3.3 System Constraints

Several key constraints influence the design and deployment of this software:

- Platform Independence: It should run on common operating systems and web browsers without special hardware requirements.
- Libraries and APIs: Where applicable, the software will rely on standard, open-source libraries for mathematical computations and graphical displays (e.g., NumPy, Matplotlib). The choice of these libraries is constrained by their availability, documentation, and compatibility with the target operating systems.
- User Interface: Aimed at users with a basic understanding of physics and calculus, the software interface will prioritize simplicity to facilitate learning and exploration without overwhelming users with unnecessary complexity.

4 Specific System Description

This section delves into the high-level overview of the problem that the Damped Harmonic Oscillator software aims to solve. Following this, the solution characteristics specification elaborates on the assumptions, theories, definitions, and instance models that explains the solution proposed by this project.

4.1 Problem Description

Damped Harmonic Ocsillator targets the problem of accurately modeling and simulating the behavior of a damped harmonic oscillator. Such systems are essential in understanding phenomena where an object oscillates and gradually loses energy due to resistance or damping forces. This simulation is vital in fields such as mechanical engineering, where understanding the damping of oscillatory systems can lead to better designs and predictions.

4.1.1 Terminology and Definitions

This subsection provides a list of terms that are used in the subsequent sections and their meaning, with the purpose of reducing ambiguity and making it easier to correctly understand the requirements:

- **Isolated System:** Neglects external forces other than the damping and restoring forces.

- **Harmonic Motion:** Assumes that in the absence of damping, the system would exhibit simple harmonic motion.
- **Linear Damping:** A damping force that is directly proportional to the velocity of the oscillating object.
- **Nonlinear Damping:** A damping force that varies with velocity in a non-proportional manner, often depending on the velocity's magnitude or other factors.

4.1.2 Physical System Description

The system comprises key elements crucial for its analysis and simulation:

- **Mass (m):** Represents the inertia of the oscillating object.
- **Spring Constant (k):** Indicates the force needed to displace the system from its equilibrium position.
- **Damping Coefficient (b):** For linear damping, quantifies the proportionality between the damping force and velocity.
- **Damping Function (f(v)):** For nonlinear damping, represents the relationship between damping force and velocity, which may vary based on the system's specific characteristics.

The system's behavior is significantly influenced by the nature of the damping force. The model must account for both linear and nonlinear damping scenarios, with the interactions between the mass, spring constant, and damping forces defining the system's dynamic response.

4.1.3 Goal Statements

With the inclusion of both linear and nonlinear damping forces, the software aims to:

GS1: Create a simulation model that accurately represents the behaviour of a damped harmonic oscillator in various scenarios.

GS2: Facilitate the understanding of damping effects on oscillatory systems through interactive and visual tools.

GS3: Simulate of mathematical derivation.

GS4: Design tools to allow users to create custom scenarios and do comparative analysis.

GS5: Enhance educational understanding of damped oscillatory systems.

4.2 Solution Characteristics Specification

This section elaborates on the mathematical and physical principles that form the basis of the solution, including assumptions, theoretical models, general definitions, and the derivation of instance models.

4.2.1 Assumptions

This section simplifies the original problem and helps in developing the theoretical model by filling in the missing information for the physical system. The numbers given in the square brackets refer to the theoretical model [TM], general definition [GD], data definition [DD], instance model [IM], or likely change [LC], in which the respective assumption is used.

A1: **Constant Mass [DD2]:** The mass (m) of the oscillator is constant throughout the motion.

A2: **Homogeneous Medium [TM:EOM-LDHO, TM:EOM-NDHO]:** Assumes the oscillator moves through a homogeneous medium, affecting the damping forces uniformly across the system.

A3: **No External Forces [TM:EOM-LDHO,TM:EOM-NDHO]:** External forces, other than damping and restoring forces, are neglected.

A4: **Initial Conditions Known [IM1,IM2]:** The initial position and velocity of the oscillator are known and specified.

4.2.2 Theoretical Models

Theoretical models provide the mathematical foundation necessary for understanding and solving the dynamics of damped harmonic oscillators. These models incorporate physical laws and constitutive equations that describe how the system behaves under various conditions, including both linear and non-linear damping forces. The models are crucial for predicting system behavior and formulating solutions that can be applied in practical scenarios.

RefName: **TM:EOM-LDHO**

Label: Equation of Motion for Linearly Damped Harmonic Oscillators

Equation:

$$m * d^2x/dt^2 + c * dx/dt + kx = 0$$

Description: This equation models the motion of a damped harmonic oscillator, where m is the mass of the oscillator, dx/dt, d^2x/dt^2 represent the velocity and acceleration, respectively, c is the damping coefficient for linear damping, k is the spring constant.

Notes: None.

Source: None

Ref. By: GD1, IM1, A1, A2, A3

Preconditions for TM:EOM-LDHO: Assumes that the oscillator is subject to a restoring force proportional to displacement x from equilibrium and a damping force that is linearly proportional to velocity.

Derivation for TM:EOM-LDHO: Not Applicable

RefName: **TM:EOM-NDHO**

Label: Equation of Motion for Non-Linearly Damped Harmonic Oscillators

Equation:

$$m * d^2x/dt^2 + f(dx/dt) + kx = 0$$

Description: This equation models the motion of a damped harmonic oscillator, where m is the mass of the oscillator, dx/dt, d^2x/dt^2 represent the velocity and acceleration, respectively, $f(dx/dt)$ represents the function describing non-linear damping forces, k is the spring constant.

Notes: None.

Source: None

Ref. By: GD1, IM1, A1, A2,A3

Preconditions for TM:EOM-NDHO: Assumes that the oscillator is subject to a restoring force proportional to displacement x from equilibrium and a damping force that follows non-linear relationship.

Derivation for TM:EOM-NDHO: Not Applicable

4.2.3 General Definitions

This section collects the laws and equations that will be used in building the instance models.

Number	GD1
Label	**Damping Force**
SI Units	N(Newton)
Equation	$F_{\text{damping}} = -c * dx/dt$ – Linear Damping $F_{\text{damping}} = -f(dx/dt)$ – Non-Linear Damping
Description	This definition differentiates between the damping forces in linear and non-linear systems. For linear systems, the force is proportional to the velocity(dx/dt) with a constant$c$. In contrast, non-linear systems exhibit a damping force represented by $f(dx/dt)$, indicating a dependency on the velocity's magnitude or other factors.
Source	Hadley, Mark. "Damped Harmonic Oscillator" Department of Physics, Graz University of Technology
Ref. By	DD1, DD5

Number	GD2
Label	**Natural Frequency of Oscillation**
SI Units	Hz(Hertz)
Equation	$\omega_0 = \sqrt{k/m}$
Description	This equation provides the natural frequency(w_0) of an undamped harmonic oscillator, derived from the spring constant(k) and mass(m). It signifies the oscillator's inherent vibrational frequency absent damping forces.
Source	Hadley, Mark. "Damped Harmonic Oscillator" Department of Physics, Graz University of Technology
Ref. By	DD2, DD3

Number	GD3
Label	**Energy Dissipation**
SI Units	J(Joules)
Equation	**Total Energy:** $E = 1/2 * kx^2 + 1/2 * mv^2$ **Linear Damping Dissipation Rate:** $dE/dt = -c * dx/dt$ **Non-Linear Damping:** Energy Dissipation rate varies with $f(dx/dt)$
Description	Outlines how the oscillator's total mechanical energy is influenced by damping. In linear damping scenarios, energy dissipation is directly proportional to the square of velocity, while in non-linear scenarios, it is dictated by a function of velocity, $f(dx/dt)$.
Source	Hadley, Mark. "Damped Harmonic Oscillator" Department of Physics, Graz University of Technology
Ref. By	DD1, DD2, DD3, DD5

4.2.4 Data Definitions

This section collects and defines all the data needed to build the instance models. The dimension of each quantity is also given.

Number	DD1
Label	**Damping Coefficient**
Symbol	c (linear damping), $f(dx/dt)$ (non-linear damping)
SI Units	$\mathrm{kg\,s^{-1}}$
Equation	-
Description	For linear damping, c represents the constant proportionality factor between the damping force and the velocity of the oscillator. For non-linear damping, $f(dx/dt)$ represents a function defining the relationship between the damping force and the velocity, which varies with the velocity's magnitude or other system-specific factors.
Sources	"Damped Harmonic Oscillator" – Wikipedia
Ref. By	GD1, IM1, IM2

Number	DD2
Label	**Mass**
Symbol	m
SI Units	kg
Equation	-
Description	Represents the mass of the harmonic oscillator. The mass is a crucial parameter in determining the system's natural frequency and the dynamics of its motion under damping forces.
Sources	"Damped Harmonic Oscillator" – Wikipedia
Ref. By	GD2, IM1, IM2

Number	DD3
Label	**Spring Constant**
Symbol	k
SI Units	$\mathrm{N\,m^{-1}}$
Equation	-
Description	The spring constant k quantifies the stiffness of the spring in the harmonic oscillator. It is a key factor in defining the natural frequency of the oscillator and its response to applied forces.
Sources	"Damped Harmonic Oscillator" – Wikipedia
Ref. By	GD2, IM1, IM2

Number	DD4
Label	**Natural Frequency**
Symbol	ω_0
SI Units	$\mathrm{rad\,s^{-1}}$
Equation	-
Description	The natural frequency ω_0 of an undamped harmonic oscillator is determined by its mass m and spring constant k. This frequency is foundational for analyzing the oscillator's behavior in the absence of damping forces.
Sources	"Damped Harmonic Oscillator" – Wikipedia
Ref. By	GD2

Number	DD5
Label	**Displacement**
Symbol	x
SI Units	m
Equation	-
Description	Displacement x from the equilibrium position provides a measure of how far the oscillator moves over time. It is a fundamental quantity for describing the oscillator's motion and is affected by both damping forces and the system's natural dynamics.from the equilibrium position provides a measure of how far the oscillator moves over time. It is a fundamental quantity for describing the oscillator's motion and is affected by both damping forces and the system's natural dynamics.
Sources	"Damped Harmonic Oscillator" – Wikipedia
Ref. By	GD1, IM1, IM2

4.2.5 Instance Models

This section transforms the problem defined in Section 4.1 into one which is expressed in mathematical terms. It uses concrete symbols defined in Section 4.2.4 to replace the abstract symbols in the models identified in Sections 4.2.2 and 4.2.3.

Number	IM1
Label	**Equation of Motion**
Input	Mass of the oscillator m, damping coefficient c or $f(dx/dt)$, spring constant k, initial displacement x_0, initial velocity v_0.
Output	Displacement xt as a function of time t, Velocity $v(t)$ as a function of time t.
Description	This model describes the motion of a damped harmonic oscillator by incorporating linear or non-linear damping forces. The equation of motion for linear damping is given by $m * d^2x/dt^2 + f(dx/dt) + kx = 0$, and for non-linear damping, it is modified to include a non-linear damping term, represented by $f(dx/dt)$, affecting the velocity term.
Sources	Derived from the principles of mechanics as discussed in the provided Wikipedia link and the Graz University of Technology's resource on damped harmonic oscillators.
Ref. By	IM4.2.2, IM4.2.2, DD1, DD2, DD3, DD5, A4, R1, R3, R5

Derivation of Equation of Motion

The equation is derived from Newton's second law of motion, $F = ma$, with force contributions from both the spring $(-kx)$ and the damping force $(-c * dx/dt$ or $-f(dx/dt))$.

Number	IM2
Label	**Energy Dissipation**
Input	Spring constant k, mass m, damping coefficient c or $f(dx/dt)$ initial displacement x_0, initial velocity v_0.
Output	Total energy $E(t)$ of the system as a function of time t.
Description	This model quantifies the energy in the oscillator system and its rate of dissipation due to damping. For linear damping, the rate of energy dissipation is directly proportional to the square of the velocity, whereas, for non-linear damping, the dissipation rate is a function of velocity $f(dx/dt)$.
Sources	Based on energy conservation principles and the work-energy theorem, adapted to include damping forces.
Ref. By	DD1, DD2, DD3, DD4, DD5, A4, R1, R3, R5

Derivation of Energy Dissipation

The total mechanical energy $E(t)$ is given by the sum of kinetic and potential energy. The rate of change of this energy (dE/dt) reflects energy dissipation due to damping.

4.2.6 Input Data Constraints

Table 1 shows the data constraints on the input output variables. The column for physical constraints gives the physical limitations on the range of values that can be taken by the variable. The column for software constraints restricts the range of inputs to reasonable values. The software constraints will be helpful in the design stage for picking suitable algorithms. The constraints are conservative, to give the user of the model the flexibility to experiment with unusual situations. The column of typical values is intended to provide a feel for a common scenario. The uncertainty column provides an estimate of the confidence with which the physical quantities can be measured. This information would be part of the input if one were performing an uncertainty quantification exercise.

The specification parameters in Table 1 are listed in Table 2.

Table 1: Input Variables

Var	**Physical Constraints**	**Software Constraints**	**Typical Value**	**Uncertainty**
m	$m > 0$	$m_{\text{min}} \leq m \leq m_{\text{max}}$	1 kg	5%
k	$k > 0$	$k_{\text{min}} \leq k \leq k_{\text{max}}$	200 N/m	5%
c	$c \geq 0$	$c_{\text{min}} \leq c \leq c_{\text{max}}$	5 N s/m	10%
x_0	$x_0 \geq 0$	$x_{0_{min}} \leq x_0 \leq x_{0_{max}}$	0.1 m	5%
v_0	No constraint	$v_{0_{min}} \leq v_0 \leq v_{0_{max}}$	0 m/s	5%

(*) The software constraints are set to allow a wide range of scenarios, facilitating experimentation with both common and unusual situations. The specified typical values and uncertainties offer a baseline for standard simulations and uncertainty quantification exercises.

Table 2: Specification Parameter Values

Var	Value
$m_{\min}$	0.1 kg
$m_{\max}$	10 kg
$k_{\min}$	50 $\mathrm{N\,m^{-1}}$
$k_{\max}$	500 $\mathrm{N\,m^{-1}}$
$c_{\min}$	0 $\mathrm{N\,s\,m^{-1}}$
$c_{\max}$	50 $\mathrm{N\,s\,m^{-1}}$
$x_{0_{min}}$	0 m
$x_{0_{max}}$	1 m
$v_{0_{min}}$	-10 $\mathrm{m\,s^{-1}}$
$v_{0_{max}}$	10 $\mathrm{m\,s^{-1}}$

4.2.7 Properties of a Correct Solution

A correct solution must exhibit several fundamental physical principles and constraints. These criteria ensure that the model accurately reflects the behavior of real-world systems under both linear and non-linear damping forces. Below is an overview of these essential properties, along with a table summarizing the output variables and their physical constraints.

Essential Properties

- **Conservation of Energy (when applicable):** In the absence of external forces, the total mechanical energy (kinetic plus potential) of the system should be conserved over a complete cycle of motion in an undamped oscillator. For damped oscillators, the solution must show a decrement in total energy over time, corresponding to the energy dissipated due to damping.

- **Harmonic Motion:** The solution should exhibit characteristics of harmonic motion, with periodicity and amplitude consistent with the input parameters for the mass, spring constant, and damping coefficients.

- **Damping Behavior:** For linear damping, the solution must reflect an exponential decay of motion amplitude over time. In the case of non-linear damping, the solution should demonstrate amplitude decay behavior that aligns with the non-linear damping force characteristics.

- **Equilibrium State:** The long-term behavior of the oscillator should converge to a state of equilibrium, where the net force acting on the oscillator is zero, especially under damping conditions.
- **Physical Realism:** The model's outputs must remain within physically plausible ranges, considering the initial conditions and system parameters.

Table 3: Output Variables

Var	Physical Constraints
$x(t)$	Must satisfy boundary conditions
$v(t)$	Consistent with $x(t)$ and damping
$E(t)$	Decreases over time for damped cases

5 Requirements

This section provides the functional requirements, the business tasks that the software is expected to complete, and the nonfunctional requirements, the qualities that the software is expected to exhibit.

5.1 Functional Requirements

R1: The software shall allow users to input parameters for the mass m, spring constant k, damping coefficient c for linear damping or function $f(dx/dt)$ for non-linear damping, initial displacement x_0, and initial velocity v_0. All inputs must adhere to the physical and software constraints specified in Section 4.2.6[IM1, IM2].

R2: Upon receiving the inputs, the software shall display the entered values for user confirmation to ensure accuracy of the inputs.

R3: The software must accurately calculate the displacement $x(t)$, velocity $v(t)$, and total energy $E(t)$ of the harmonic oscillator over time, considering the specified damping effects. Calculations shall be based on the instance models defined in Section 4.2.5, reflecting both linear and non-linear damping scenarios [IM1, IM2].

R4: Implement features to verify the correctness of solutions against known models and benchmarks for damped harmonic oscillators. The software should include error handling to notify users of any calculation discrepancies or input errors.

R5: Outputs including the time-evolution of displacement, velocity, and energy shall be presented in a clear, understandable format, such as graphs or tables[IM1, IM2].

5.2 Nonfunctional Requirements

NFR1: **Accuracy** The software's computational accuracy shall meet the requirements necessary for advanced physics or engineering applications, detailed in the Verification and Validation (V&V) Plan. The expected accuracy level shall be within 0.01% of theoretical values, where applicable.

NFR2: **Usability** The software shall be designed with an intuitive interface suitable for users with a background in physics or engineering, as characterized in the user characteristics section. Usability levels will be assessed as per the guidelines in the V&V Plan.

NFR3: Any likely changes (e.g., updates to models, addition of new damping functions) shall require no more than 25% of the original development effort, ensuring ease of future modifications and updates.

NFR4: The software must be compatible with Windows 10 and above, macOS Catalina and above, and popular Linux distributions (e.g., Ubuntu 20.04 LTS). Portability will be verified through tests outlined in the V&V Plan, ensuring the software runs seamlessly across these operating systems.

5.3 Rationale

The decisions made in this SRS document, including the scope, modeling choices, assumptions, and specified typical values, are rooted in the aim to create a comprehensive, accurate, and user-friendly simulation tool for damped harmonic oscillators. The functional requirements are designed to ensure that the software can perform a wide range of simulations relevant to both educational and research purposes in physics and engineering. The nonfunctional requirements underscore the software's reliability, ease of use, maintainability, and broad accessibility, reflecting the project's commitment to quality and user satisfaction.

6 Likely Changes

LC1: Future versions of the software may incorporate external forces acting on the harmonic oscillator, beyond the current scope of damping and restoring forces alone[A3].

LC2: The software could be adapted to simulate oscillators with variable mass, a feature not currently supported[A1].

LC3: Considering the effect of temperature on damping forces could be a significant enhancement, acknowledging that damping coefficients can vary with temperature[A2].

LC4: Enhancements could include more complex initial conditions, such as pre-set oscillation patterns or initial conditions defined by functions rather than simple numeric values[A4].

7 Unlikely Changes

LC5: The underlying physics principles that govern harmonic motion and damping are not expected to change, as these are based on well-established theories.

LC6: The basic architecture of the software, particularly its modular design allowing for the separation of the user interface from the calculation engine, is not expected to undergo major revisions.

LC7: Basic methods of input (via UI) and output (display on screen) are foundational and expected to remain stable over time.

8 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an "X" may have to be modified as well. Table 4 shows the dependencies of theoretical models, general definitions, data definitions, and instance models with each other. Table 5 shows the dependencies of instance models, requirements, and data constraints on each other. Table 6 shows the dependencies of theoretical models, general definitions, data definitions, instance models, and likely changes on the assumptions.

The purpose of the traceability graphs is also to provide easy references on what has to be additionally modified if a certain component is changed. The arrows in the graphs represent dependencies. The component at the tail of an arrow is depended on by the component at the head of that arrow. Therefore, if a component is changed, the components that it points to should also be changed. Figure **??** shows the dependencies of theoretical models, general definitions, data definitions, instance models, likely changes, and assumptions on each other. Figure **??** shows the dependencies of instance models, requirements, and data constraints on each other.

	TM4.2.2	TM4.2.2	GD1	GD2	GD3	DD1	DD2	DD3	DD4	DD5	IM1	IM2
TM4.2.2			X	X							X	
TM4.2.2			X	X							X	
GD1	X	X				X				X	X	
GD2	X	X					X	X			X	
GD3					X	X	X	X		X		X
DD1			X		X						X	X
DD2				X	X						X	X
DD3				X							X	X
DD4												
DD5			X		X						X	X
IM1	X	X	X	X		X	X	X		X		
IM2					X	X	X	X		X		

Table 4: Traceability Matrix Showing the Connections Between Items of Different Sections

	IM1	IM2	R1	R2	R3	R4	R5
IM1			X		X		X
IM2			X		X		X
R1	X	X					
R2							
R3	X	X					
R4							
R5	X	X					

Table 5: Traceability Matrix Showing the Connections Between Requirements and Instance Models

	A1	A2	A3	A4
TM4.2.2	X	X	X	
TM4.2.2	X	X	X	
GD1		X		
GD2		X		
GD3				
DD1	X			
DD2	X			
DD3				
DD4				
DD5				
IM1	X	X	X	X
IM2	X			X
LC1			X	
LC2	X			
LC3		X		
LC4				

Table 6: Traceability Matrix Showing the Connections Between Assumptions and Other Items

9 Values of Auxiliary Constants

This section enumerates the values assigned to symbolic constants introduced throughout this SRS document. These constants are used to define parameters, thresholds, and specific metrics critical to the software's functionality and performance criteria.

- **Natural Frequency Constant:** Represents the natural frequency of an undamped harmonic oscillator. Value calculated as $\omega_0 = \sqrt{k/m}$.
- **Critical Damping Coefficient:** The value of the damping coefficient that results in critical damping. Value calculated as $c_{crit} = 2\sqrt{mk}$.
- **Maximum Simulation Time(T_{max}):** The maximum duration for which the simulation runs. Value calculated as $\omega_0 = \sqrt{k/m}$.
- **Natural Frequency Constant:** Represents the natural frequency of an undamped harmonic oscillator. Value is User-defined, with a suggested default of 10 seconds to observe transient and steady-state behaviors.