Summer Fellowship Report

On

Scilab Case Studies

Submitted by

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Acknowledgment

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I express sincere thanks to Indian Institute of Science Education and Research, Bhopal which provided me with the great academic foundation to complement this hands-on experience . Further, I am whole-heartedly grateful to my parents, grand-parents and my uncle, Mr. Mayank Mishra. It would not have been possible without their kind support throughout.

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Chapter 1

Introduction

FOSSEE (Free and Open Source Software in Education) promotes the use of free and open-source tools to improve the quality of education in our country. The aim is to reduce dependency on proprietary software in STEM education. They encourage the use of FOSS (Free and Open Source Software) tools through various activities, develop new FOSS tools and upgrade existing tools to meet requirements in academia and research. Incorporated to FOSSEE program, this summer fellowship looks forward to introduce students to the FOSS.

Scilab is an excellent paradigm of cross-platform numerical computational package, incorporating high-level programming language. It can be used for signal processing, statistical analysis, image enhancement, fluid dynamics simulations, numerical optimization, and modelling, simulation of explicit and implicit dynamical systems and (if the corresponding toolbox is installed) symbolic manipulations.

During my internship, I successfully completed three case studies, each employing a distinctive aspect of Scilab. The first case study is about identification of new elements for the modern periodic table. The second utilized CelestLab and CelestLabX toolboxes for simulating the spacecraft model and analysing the impact of drag on a VLEO (Very Low Earth Orbit) Satellite. VLEO satellites find numerous applications in the areas of earth observation, weather monitoring, and telecommunication. However, in this region of the atmosphere, atmospheric drag is a major concern as it resists the motion of satellites. Hence dealing with the aerodynamic drag can prolong the operational lifespan of the satellite. Finally, the third one is regarding the pitch assesment of airplanes and fighter jets. Pitch is the "up and down" or "nodding" motion of an aircraft. This case study simulated a model of PID Controller on Xcos for the investigation.

Chapter 2

Scilab Case Study

Identification of elements and analysis of their properties using Bohr Model

2.1 Abstract

If an element is synthesised and is likely to find new slot in the modern periodic table, one needs to ensure it is not equivalent to any known member. This case study deals with the methods used to identify such elements, focusing on Scilab. It has several applications in the fields of heavy metal synthesis, material science, chemical engineering (chemical manufacturing), nuclear physics, etc. User needs to input experimental atomic mass of the element and principal quantum number of interest. On entering the tentative atomic number, the program provides standard values of physical quantities such as neutron/proton ratio, most probable separation between nucleus and first electron, various forms of energies possessed by the electron, its velocity, and the period of revolution.

When all the theoretical data approximately matches the experimental properties of the element, then the atomic number guess is correct. Otherwise for the quantities that do not match, the user has to carefully observe dependency of those parameters on n and z, which is examined through graphs and change the guess of z or value of n accordingly. Thus, the study tells exactly where the newly discovered element fits in the periodic table. Additionally, by computing the energy of released/absorbed photon with the help of Scilab, we manifest how Bohr Model aligned with Ritz combination principle. Aim is to find the position of newly found elements by studying their properties along with urging the importance of correct presentation of Bohr Model.

2.2 Problem Statement

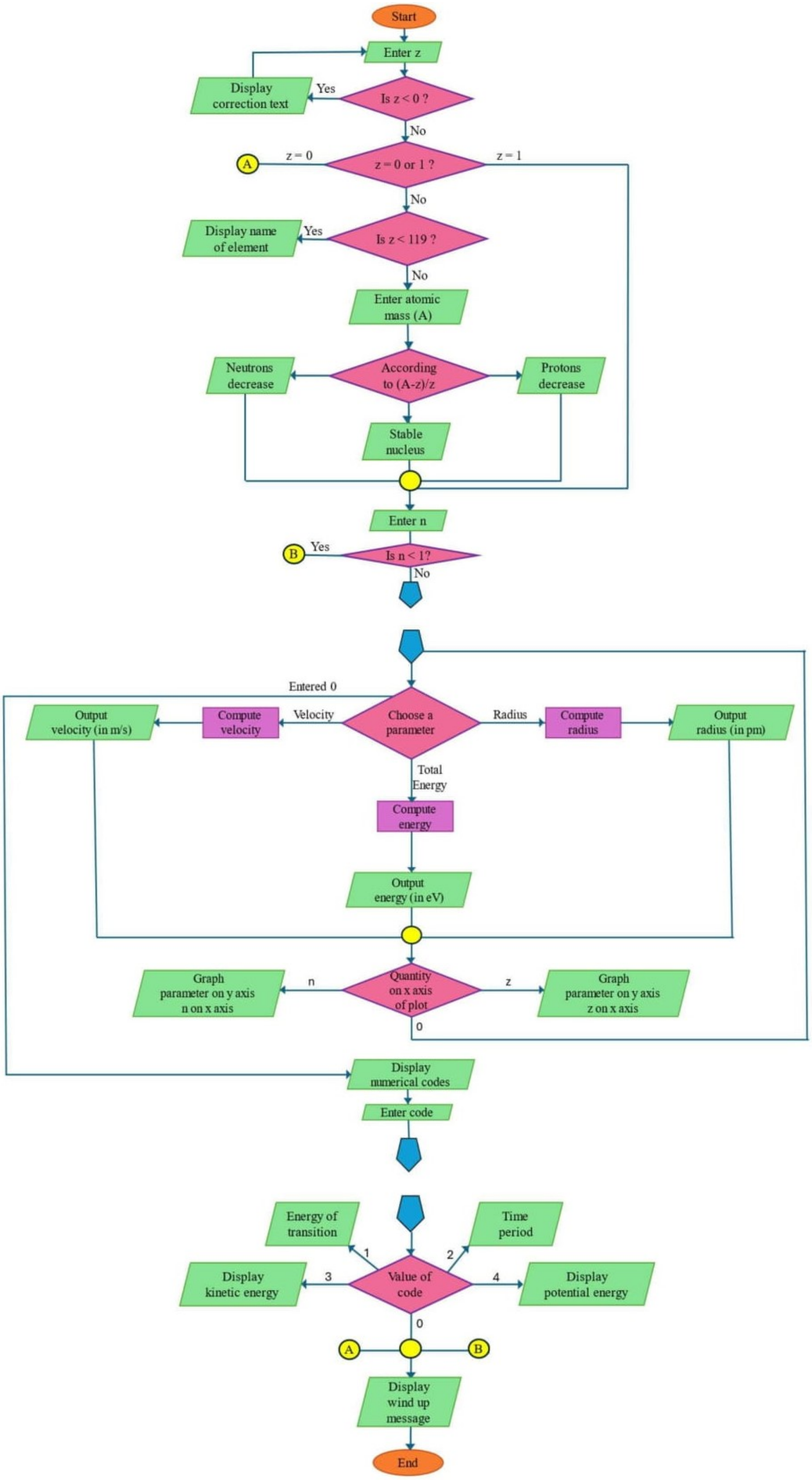
In the era of modern technology, science is developing rapidly but still there are areas in which discoveries are rare- The Periodic Table is one of them. A new element discovered has to get through several qualifications to secure its place in the periodic table. With the help of Scilab, we help the user determine exact position of the element in the periodic table by evaluating standard physical quantities and judging the stability of the nucleus with the help of neutron to proton ratio. As the user exclusively receives standard data analysis for whatever they input, the project is userfriendly.

It can be used in the field of spectroscopy because the program calculates energy of transition. Since each element has specific energy levels, it must have a distinctive emission spectrum (The same way we have unique fingerprints). We further explain this by taking the example of Balmer series.

In some instances, Bohr's Model is introduced in a more wrong than right way. So, one might wonder why, despite the passage of more than a century, it is still being taught. There even have been proposals that the model should not be taught anymore, as it is too simple to compete the lately accepted atomic structure. However, this is inappropriate as for a tree, the seed must be sown first. With Scilab, the correct picture of Bohr's model can be taught.

One might think that it would scarcely be possible, to bring Bohr's views about the atom into direct relation with the Ritz combination principle. However, a closer investigation through Scilab makes it clear that the relation between the spectra of the elements and the structure of their atoms based on the postulates can be obtained.

2.3 Control Flow



2.4 Simulation and Result

2.4.1 Spectral analysis - Balmer Series

The visible spectrum of light from hydrogen, or Balmer Series displays the wavelengths that correspond to emissions of photons as the electrons in excited states transition to the quantum level with the second principal quantum number.

```
For the simulation of following physical quantities, numerical codes have been designated

Energy released or absorbed by the electron in the
form of photon while undergoing transition       : 1
Period of revolution of electron in nth Bohr orbit: 2
Kinetic energy of the electron                   : 3
Potential energy of the electron                 : 4
To exit                                          : 0

Enter a number: 1

For calculation of the energy of transition
Principal quantum number, from which transition happens [enter a natural number]: 3

Principal quantum number, to which transition happens [enter a natural number]: 2

Positive energy change means that the electron absorbs energy, while negative energy change implies a release of energy
Energy of the photon is: -1.8888889 eV
Enter a number for the quantity of interest (in range [0,4]): 1

For calculation of the energy of transition
Principal quantum number, from which transition happens [enter a natural number]: 4

Principal quantum number, to which transition happens [enter a natural number]: 2

Positive energy change means that the electron absorbs energy, while negative energy change implies a release of energy
Energy of the photon is: -2.55 eV
Enter a number for the quantity of interest (in range [0,4]): 1

For calculation of the energy of transition
Principal quantum number, from which transition happens [enter a natural number]: 5
Principal quantum number, to which transition happens [enter a natural number]: 2

Positive energy change means that the electron absorbs energy, while negative energy change implies a release of energy
Energy of the photon is: -2.856 eV
Enter a number for the quantity of interest (in range [0,4]): 1

For calculation of the energy of transition
Principal quantum number, from which transition happens [enter a natural number]: 6

Principal quantum number, to which transition happens [enter a natural number]: 2

Positive energy change means that the electron absorbs energy, while negative energy change implies a release of energy
Energy of the photon is: -3.0222222 eV
```

Theoretically, the first four wavelengths of this spectrum fall in the visible range of the electromagnetic spectra (Yes! it can be seen).

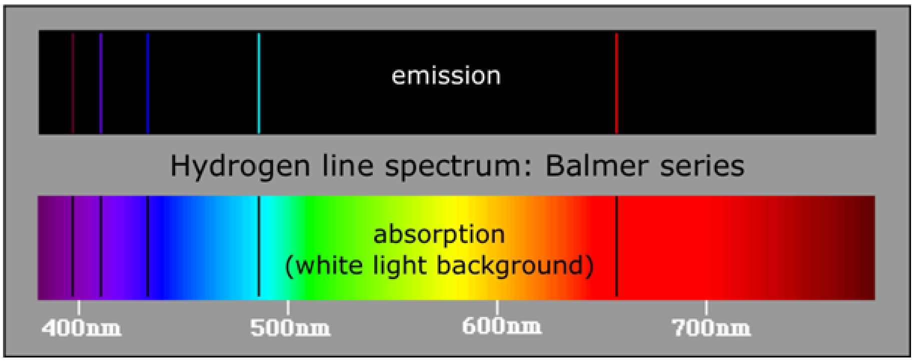


Figure 2.1: The four wavelengths

2.4.2 Classification of elements

```
--> exec('C:\Users\Naini Diwan\OneDrive\FOSSEE_Scilab_Project\Scilab_FOSSEE_Project_Final.sce', -1)

----------Welcome to the Scilab Code----------
Enter the tentative atomic number (0 to quit): 2

The element that already exists with atomic number 2 is: Helium
Enter the tentative atomic number (0 to quit): 11

The element that already exists with atomic number 11 is: Sodium
Enter the tentative atomic number (0 to quit): 31

The element that already exists with atomic number 31 is: Gallium
Enter the tentative atomic number (0 to quit): 39

The element that already exists with atomic number 39 is: Yttrium
Enter the tentative atomic number (0 to quit): 50

The element that already exists with atomic number 50 is: Tin
Enter the tentative atomic number (0 to quit): 83

The element that already exists with atomic number 83 is: Bismuth
Enter the tentative atomic number (0 to quit): 118

The element that already exists with atomic number 118 is: Oganesson
```

Figure 2.2: Scientific names of known elements

2.4.3 Identification of elements

Now, the user thinks he has discovered the 119th element in the modern periodic table. But how would he confirm?

There's a simple cut-and-try approach; guess what the atomic number might be, to begin with. Then compare the experimental value of various parameters with corresponding theoretical data. If the two agree, Kudos!

Let's understand it with an illustration

```
Enter the tentative atomic number (0 to quit): 119

Atomic mass of the element in amu: 204


Heavy metals are radioactive.
Nucleus is expected to undergo electron capture or positron emission.
Principle quantum number of interest [any integer > 0]: 1

Which quantity is to be simulated ?
velocity, radius or total energy [Enter 0 to exit]: velocity

Velocity of electron (in SI Units) is: 2.593D+10 m/s
Enter 0 to exit
Plotting its graph, which quantity is to be kept on x axis, n or z? n


Enter 0 to exit
Plotting on graph, which quantity is to be kept on x axis, n or z? z


Enter 0 to exit
Plotting on graph, which quantity is to be kept on x axis, n or z? 0
```

Figure 2.3: Velocity analysis

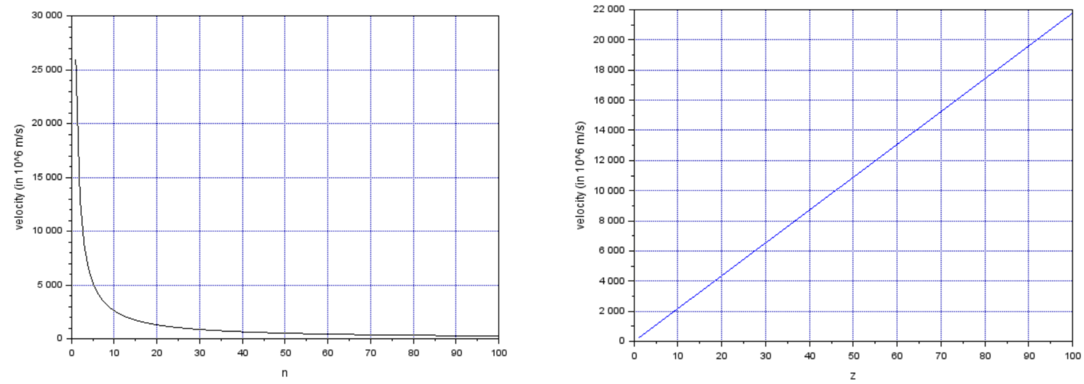


Figure 2.4: Variation of velocity with principle quantum number [left] and atomic number [right]

```
velocity, radius or total energy [Enter 0 to exit]: radius

Radius (in picometres) is: 0.4445378 pm
Enter 0 to exit
Plotting its graph, which quantity is to be kept on x axis, n or z? n


Enter 0 to exit
Plotting on graph, which quantity is to be kept on x axis, n or z? z


Enter 0 to exit
Plotting on graph, which quantity is to be kept on x axis, n or z? 0
```

Figure 2.5: Radius analysis

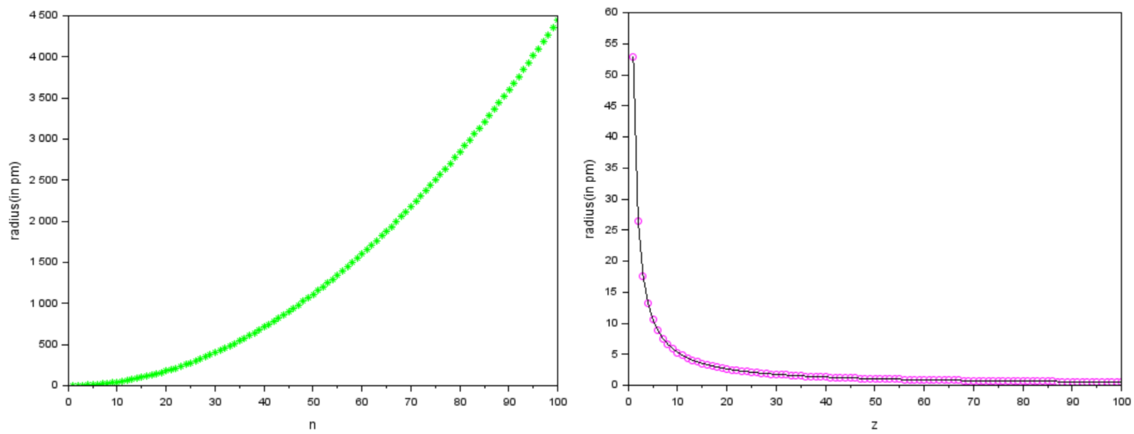


Figure 2.6: Variation of radius with principle quantum number [left] and atomic number [right]

```
Which quantity is to be simulated ?
velocity, radius or total energy [Enter 0 to exit]: total energy

Total energy in electronvolts is: -192589.6 eV
Enter 0 to exit
Plotting its graph, which quantity is to be kept on x axis, n or z? n


Enter 0 to exit
Plotting on graph, which quantity is to be kept on x axis, n or z?: z


Enter 0 to exit
Plotting on graph, which quantity is to be kept on x axis, n or z?: 0

velocity, radius or total energy [Enter 0 to exit]: 0
```

Figure 2.7: Total energy analysis

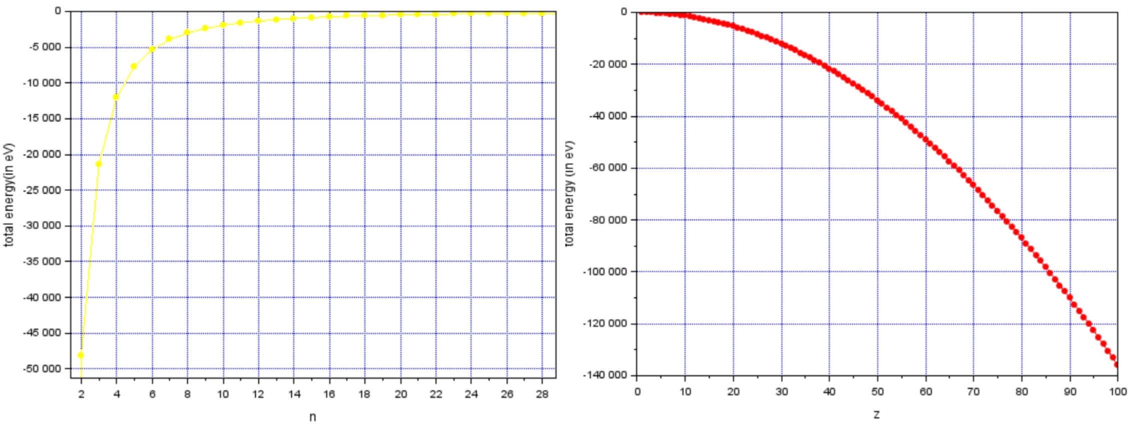


Figure 2.8: Variation of total energy with principle quantum number [left] and atomic number [right]

```
For the simulation of following physical quantities, numerical codes have been designated

Energy released or absorbed by the electron in the
form of photon while undergoing transition        : 1
Period of revolution of electron in nth Bohr orbit: 2
Kinetic energy of the electron                    : 3
Potential energy of the electron                  : 4
To exit                                           : 0

Enter a number: 1

For calculation of the energy of transition
Principal quantum number, from which transition happens [enter a natural number]: 1

Principal quantum number, to which transition happens [enter a natural number]: 2

Positive energy change means that the electron absorbs energy, while negative energy change implies a release of energy
Energy of the photon is: 144442.2 eV
Enter a number for the quantity of interest (in range [0,4]): 2


Time period of the revolution (in picoseconds) is:
1.077D-10 ps
Enter a number for the quantity of interest (in range [0,4]): 3

Kinetic Energy (in electronvolts) is 192589.6 eV
Enter a number for the quantity of interest (in range [0,4]): 4

Potential Energy (in electronvolts) is -385179.2 eV
Enter a number for the quantity of interest (in range [0,4]): 5

Please enter an appropriate number
Enter a number for the quantity of interest (in range [0,4]): 0


  "Winding up...Thank you"

-->
```

Figure 2.9: Some more physical quantities

Chapter 3

CelestLab Toolbox (and its extension) Case Study

Aerodynamic drag analysis on VLEO Satellites

3.1 Abstract

There is a growing interest in research of the operation of satellites in Very Low Earth Orbit (VLEO), due to their ability to provide high-quality Earth observation and communication. In the VLEO region, atmospheric drag is a critical issue which affects the altitude control, satellite orientation and orbit prediction of satellites. This limits the operational life of the spacecraft. The drag arises due to the interaction between atmosphere (primarily the thermosphere layer) and satellite.

For the simulation and drag analysis, this project makes use of CelestLab and its extension CelestLabX, the Scilab toolboxes specialising Space Flight Dynamics. We first employ STELA tool (present in CelestLab) to create the satellite model and define its orbit. Then, we examine drag impacts on the satellite model, in both the scenarios of fixed and rotating solar arrays. Results show that fixed solar panels do not always face the sun, which can reduce their efficiency. However, rotating panels track the sun producing increased energy capture, which makes them more efficient. Furthermore, we investigate the elliptical shape of the satellite's orbit is affected by drag.

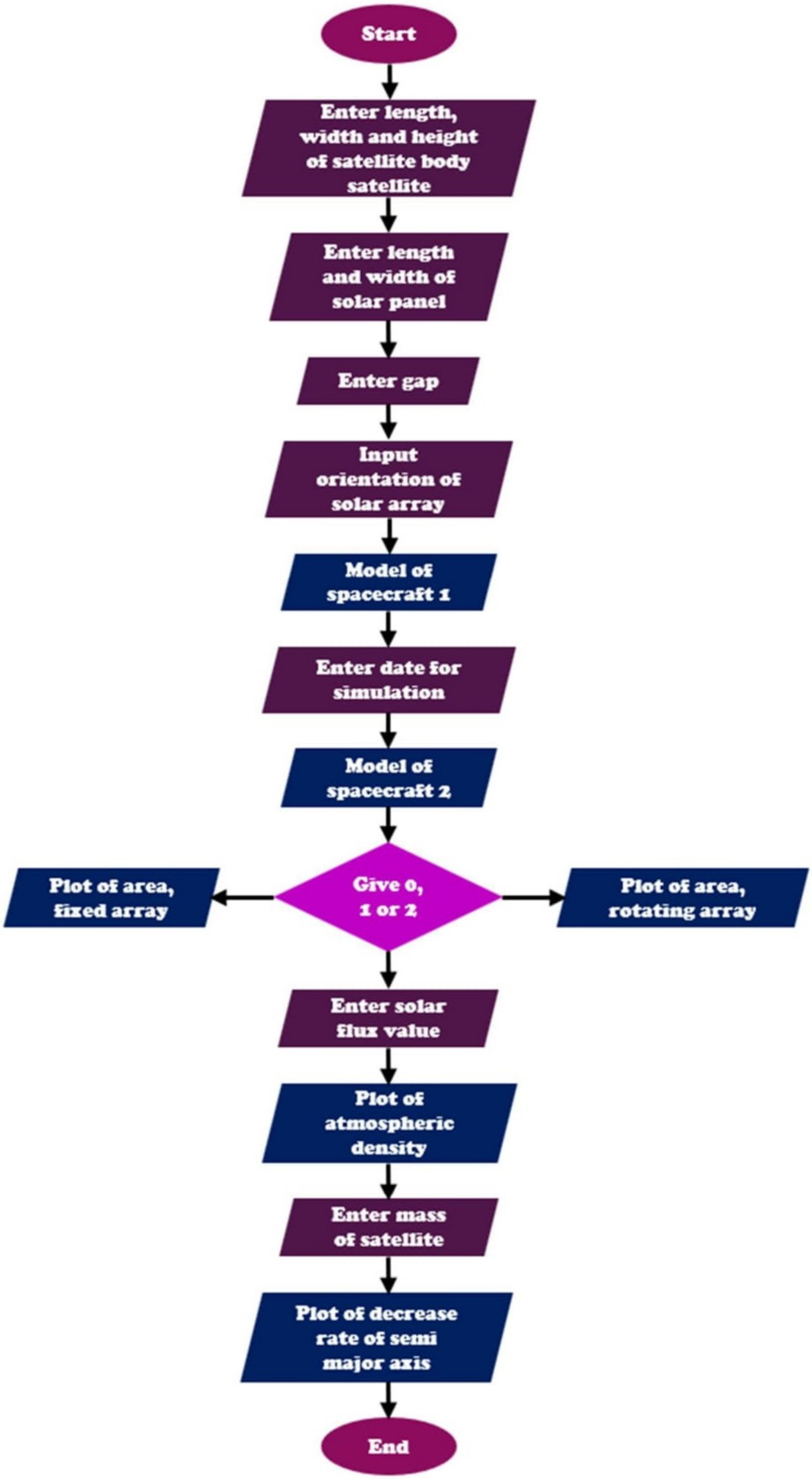
The goal is to simulate such a design of the satellite, which experiences minimum possible drag and captures maximum solar energy. This would help scientists develop drag reduction strategies, thus enhancing the satellite's performance in space missions.

3.2 Problem Statement

In VLEO, atmospheric drag is the main source of the experienced resistance on the satellite. It is triggered by the interchange of molecular momentum between atmosphere and satellite surfaces. This not only intrigues the smooth orbital motion of the satellite but also brings about more fuel consumption. Especially for the gradiometry satellites, it is a must to eliminate disturbances resulted from atmospheric drag to ensure accurate measurements.

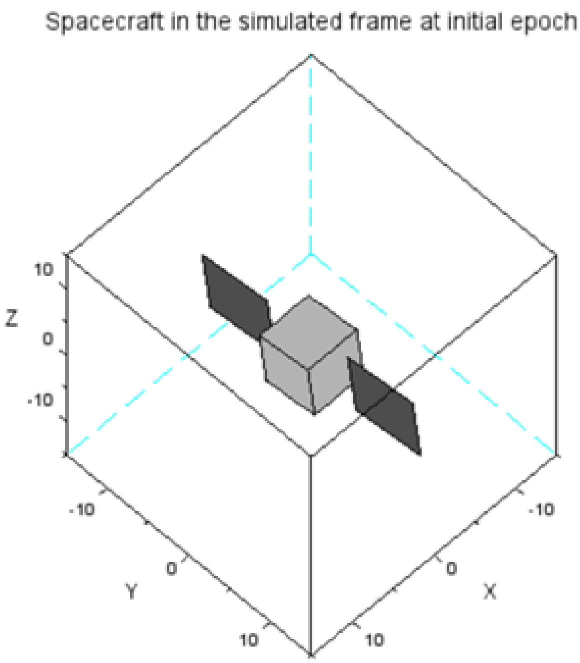
In order to tackle with the problem of aerodynamic drag, this project makes use of two Scilab toolboxes, namely CelestLab and its extension, CelestLabX. This program allows the user to analyse the impacts of the atmospheric drag over the surface of solar array. After executing the simulation for different orientations, the program computes optimal solar activity for the fixed solar flux, which is determined by the distance between the sun and the satellite. Furthermore, the effect of drag on semi major axis is plotted with the help of graphs, in the form of reduction in its elliptical orbit. In this way, the finest models of spacecrafts can be generated that would lead to successful space missions.

3.3 Control Flow



3.4 Simulation and Result

The orientation of the orbiting satellite on the mentioned day would be as follows:



Now, to check whether fixed solar arrays best fit the requirements or rotating solar arrays, we carry out further simulations.

```
Provide a suitable month and year for the satellite's orientation

The month is [range ~ 1 to 12]: 1

The year is: 2025


Enter 0 to exit
For fixed solar panel analysis, enter 1
For rotating solar array, enter 2

Enter a number: 1

Enter a number [0, 1 or 2]: 2

Enter a number [0, 1 or 2]: 0
```

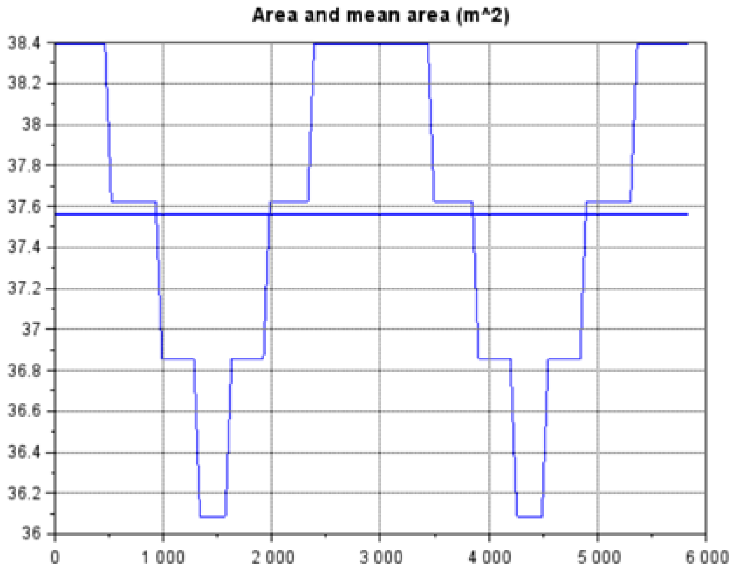


Figure 3.1: Fixed solar panels

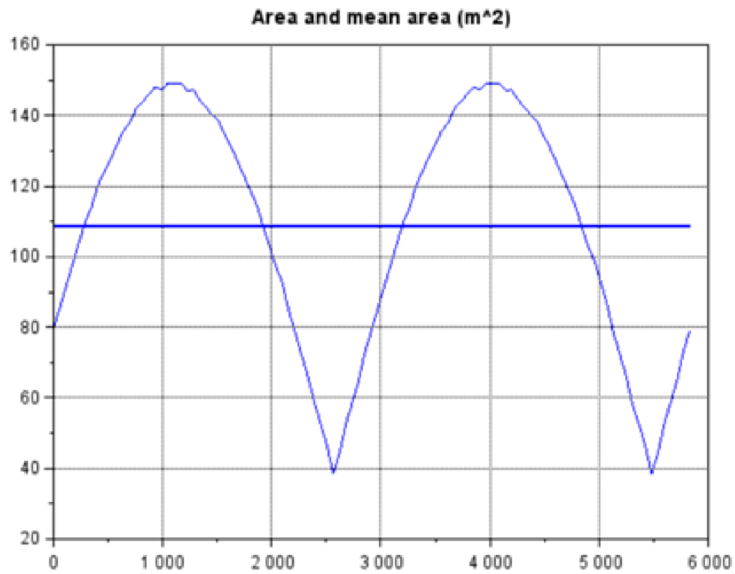


Figure 3.2: Rotating solar panels

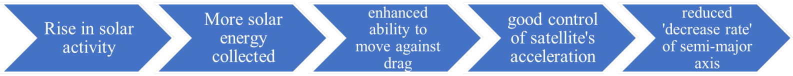
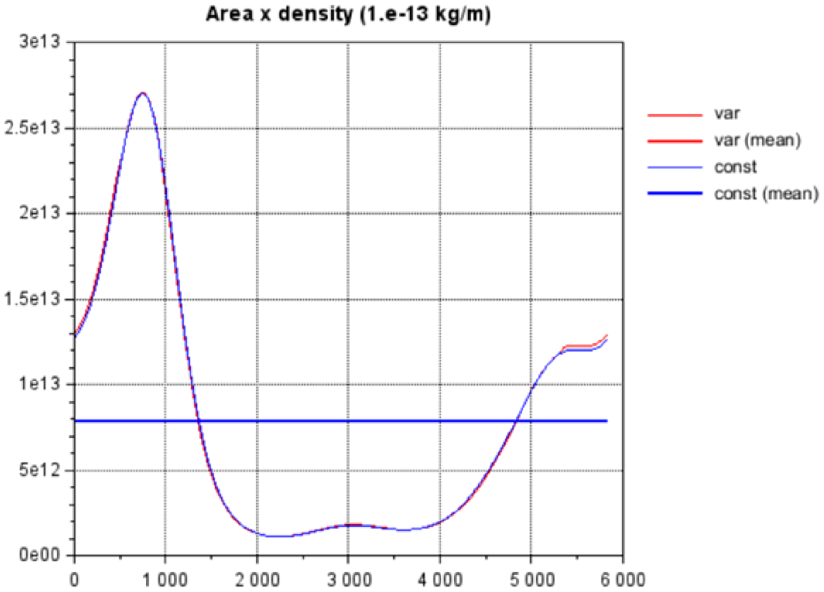
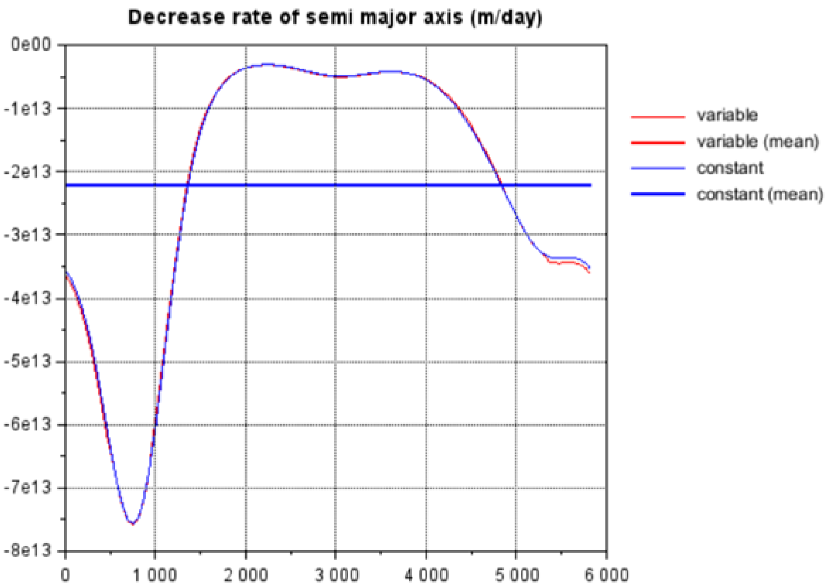


Figure 3.3: The effect of solar activity

```
Solar flux intensity throughout the solar system (it decreases on receding the sun):
Location                  Average solar flux (W/m2)
Mercury                   8,750
Venus                     2,857
Earth                     1,400
Mars                      622
Jupiter                   52
Saturn                    15
Uranus                    4
Neptune                   2
Pluto                     1

Solar flux [Greater than or equal to 1]: 1500

Enter mass of the spacecraft in kilograms: 900

Winding up. . .
Thank you
```

Figure 3.4: Solar flux in the region of the satellite





Chapter 4

Xcos Case Study

Pitch simulation of an aircraft

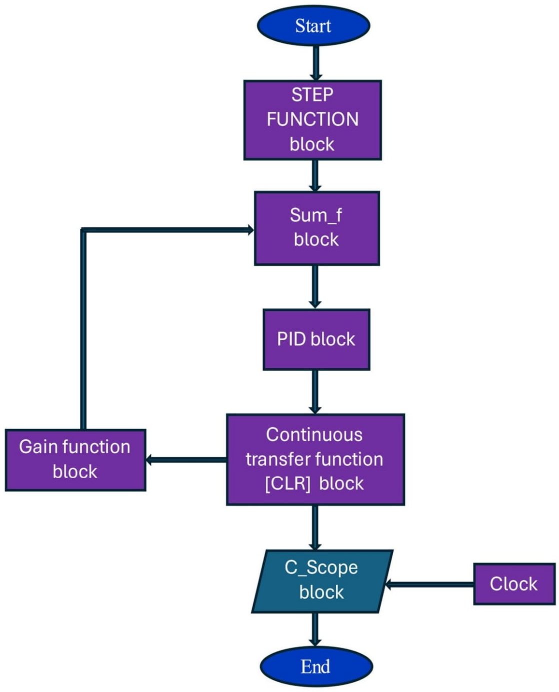
4.1 Abstract

Air vehicle orientation and movement control is a not a linear process. It involves three critical parameters (the angles of rotation in three dimensions about the vehicle's centre of gravity), called pitch, roll and yaw. In this project, simulation of the pitch of an aeroplane is carried out. It is determined by the axis perpendicular to the longitudinal plane of symmetry. The study is accomplished using a PID (Proportional – Integral – Derivative) controller system on Xcos. Xcos is an open-source application of Scilab that supports modelling and simulating dynamic systems. Pitch is controlled by adjustment of the elevator, present at the rear side of the plane. These are Flight Control Surfaces (FCS) which redirect the air flow and the action of pressure on the wings. Further, longitudinal dynamic stability is also a crucial feature. It denotes the damping of stabilizing moments, which prevents persistent or rising oscillations in pitch. A decent pitch control ensures safe descend and ascend of the aircraft.

4.2 Problem Statement

To achieve the desired control over pitch of an aircraft, a well-defined mathematical model is essential. For this purpose, system identification is a favourable numerical process. It is required that the output of the controller varies smoothly in reaction to the error or rate of change of error. When the system is a combination of different continuous controller modes this aim can be easily accomplished. Therefore, this project utilises the PID controller, simulated over Xcos.

4.3 Control Flow



4.4 Simulation and Result

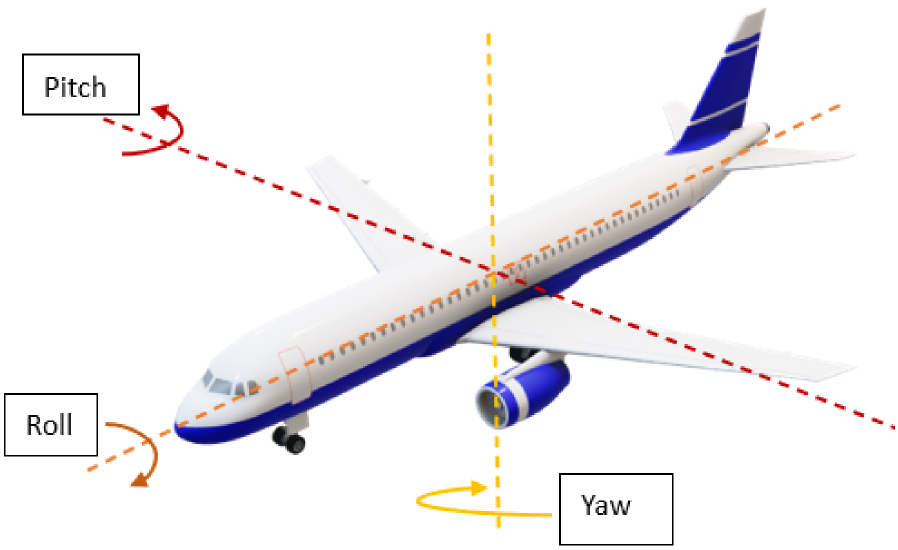


Figure 4.1: Aircraft principal axes

PID controller is used to generate a control action for the error signal. An error signal is the deviation between the controlled output and an applied set point. That signal is fed to the controller in order to reduce it. This routine is continued till the controller output becomes equal to that of an applied set point.

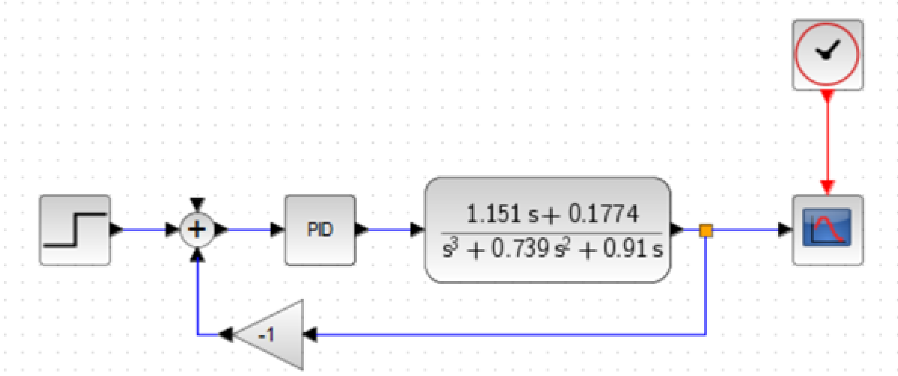


Figure 4.2: Xcos block diagram

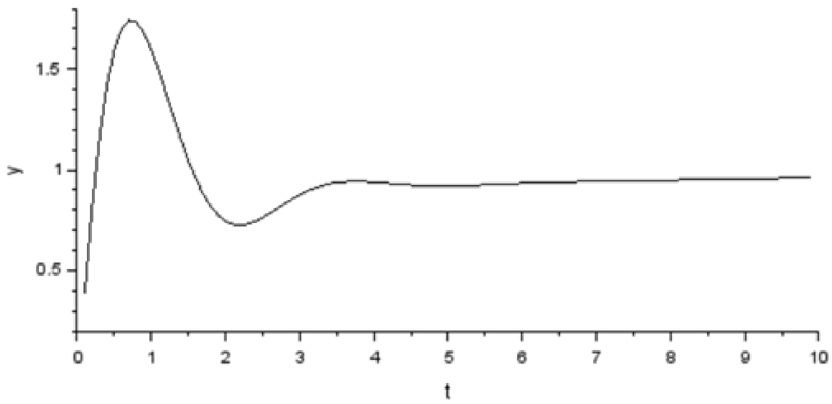


Figure 4.3: Plot generated [Using Firefly Algorithm]

Chapter 5

Conclusion

FOSSEE Summer Fellowship has been an immensely rewarding experience, marked by a range of learning opportunities and notable accomplishments. I explored numerous topics ranging from element discovery to aerodynamics. Along with that, I honed the practical skills by working on Scilab and its toolboxes, Xcos and LaTeX. Overcoming challenges in LaTeX documentation and collaborating on interdisciplinary projects expanded my perspective, underscoring the importance of adaptive problem-solving and debugging.

To conclude, not only my knowledge of computational tools and control systems has enhanced, but has also equipped me for future pursuits in research and academia. I am grateful for the opportunities, mentorship, and insights gained, all of which have significantly advanced my professional development. I am excited to apply these skills and insights.

References

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- CelestLabX Toolbox
- FOSSEE - IIT Bombay
- scilab.in
- Scilab Case Studies