A

Major Project Report

Submitted

in partial fulfillment

for the award of the Degree of

Bachelor of Technology

in Department of Aeronautical Engineering

on

"Missile Guidance Navigation & Control"

Supervisor

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School of Aeronautics (Neemrana)

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AUGUST 2021

CERTIFICATE

This is to certify that LALIT DESHMUKH (1263), ANSHUL DUBEY (1289), RAMAN (1189), CHANDAN KUMAR (1265) and RITUL RAJ (1299) of 8th semester, B.Tech (Aeronautical Engineering) 2020-2021, have presented a project titled "**Guidance Navigation and Control of Missile"** in partial fulfillment for the award of the degree of Bachelor of Technology under Rajasthan Technical University, Kota.

Ms. Bhavna Sharma | **Dr. Luv Verma**
Asst. Professor | **Director**
Date :

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I-04, RIICO Industrial Area, Neemrana, Distt. Alwar, Rajasthan
(Approved by Director General of Civil Aviation, Govt. of India, All India Council for Technical Education, Ministry of HRD, Govt of India & Affiliated to Rajasthan Technical University. Kota, Rajasthan)

APPROVAL

The project entitled "**Guidance Navigation and Control of Missile"** is hereby approved as a creditable engineering project carried out and presented in a satisfactory manner to warrant its acceptance as a prerequisite to B.Tech. for which it has been Submitted.

Ms. Bhavna Sharma
Asst. Professor
(Project Guide)

Dr. Luv Verma
Director

DECLARATION

We hereby declare that the work, which is being presented in the Project entitled "**Guidance Navigation and Control of Missile"** in partial fulfillment for the award of Degree of "Bachelor of Technology" in Department of Aeronautical Engineering with specialization in "Aeronautical Engineering" and submitted to the Department of Aeronautical Engineering, School of Aeronautics (Neemrana) , Affiliated to Rajasthan Technical University is a record of my own investigation carried under the Guidance of Ms. Bhavna Sharma, Department of Aeronautical Engineering, School of Aeronautics (Neemrana).

We have not submitted the matter presented in this report anywhere for the award of any other degree.

Lalit Deshmukh (1263)
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Counter Signed by
Ms. Bhavna Sharma

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our project guide Ms. Bhavna Sharma for her guidance and support for this endeavor. I also want to thank her for her great supervision. She has been a tremendous source for encouragement and immense support throughout our Course.

We want to extend our special thanks to our (Late)Prof. C.C. Ashoka, former Director of School of Aeronautics (Neemrana) for his help & co-operation. This project will be a sincere tribute to him.

Regarding omission if may, we express our sincere apology & undertake all responsibilities.

Lalit Deshmukh (1263)

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ABSTRACT

The goal of our project is to design and build missile guidance navigation & control using MATLAB and FLIGHTGEAR software. And to improve the guidance, navigation and control of missile for hitting target accurately and precisely by increasing the stability with avoiding any obstacle in path. This will be achieved by using a better program and aerodynamics of the movable fins.

The program which will make the missile efficient involved LQR equations and Karman Filters along with the Loop system which will provide feedback for any obstacle in path. These traits of the programming will be successfully tested and we hope this contributes to the aviation field

CHAPTER-1

INTRODUCTION

Guidance, navigation and control GNC systems provide benefits such as alleviating operator work load, smoothing turbulence, fuel savings, etc. In addition, sophisticated applications of GNC enable automatic or remote control.

Guidance refers to the determination of the desired path of travel (the "trajectory") from the vehicle's current location to a designated target, as well as desired changes in velocity, rotation and acceleration for following that path.

Navigation refers to the determination, at a given time, of the vehicle's location and velocity (the "state vector") as well as its attitude.

Control refers to the manipulation of the forces, by way of steering controls, thrusters, etc., needed to execute guidance commands while maintaining vehicle stability.is a branch of engineering dealing with the design of systems to control the movement of vehicles, especially, automobiles, ships, aircraft, and spacecraft

Missile –

In military terminology, a missile, also known as a guided missile or guided rocket, is a guided airborne ranged weapon capable of self-propelled flight usually by a jet engine or rocket motor. Missiles have five system components: targeting, guidance system, flight system, engine and warhead. Missiles come in types adapted for different purposes: surface-to-surface and air-to-surface missiles (ballistic, cruise, anti-ship, anti-tank, etc.), surface-to-air missiles (and anti-ballistic), air-to-air missiles, and anti-satellite weapons.

Developments

Inertial guidance systems were originally developed for rockets. American rocket pioneer Robert Goddard experimented with rudimentary gyroscopic systems. Dr. Goddard's systems were of great interest to contemporary German pioneers including Wernher von Braun. The systems entered more widespread use with the advent of spacecraft, guided missiles, and commercial airliners.

Guidance systems consist of 3 essential parts: navigation which tracks current location, guidance which leverages navigation data and target information to direct flight control "where to go", and control which accepts guidance commands to effect change in aerodynamic and/or engine controls.

The first missiles to be used operationally were a series of missiles developed by Nazi Germany in

World War II. Most famous of these are the V-1 flying bomb and V-2 rocket, both of which used a mechanical autopilot to keep the missile flying along a pre-chosen route.[2] Less well known were a series of Anti-Ship and Anti-aircraft missiles, typically based on a simple radio control (command guidance) system directed by the operator. However, these early systems in World War II were only built in small numbers.

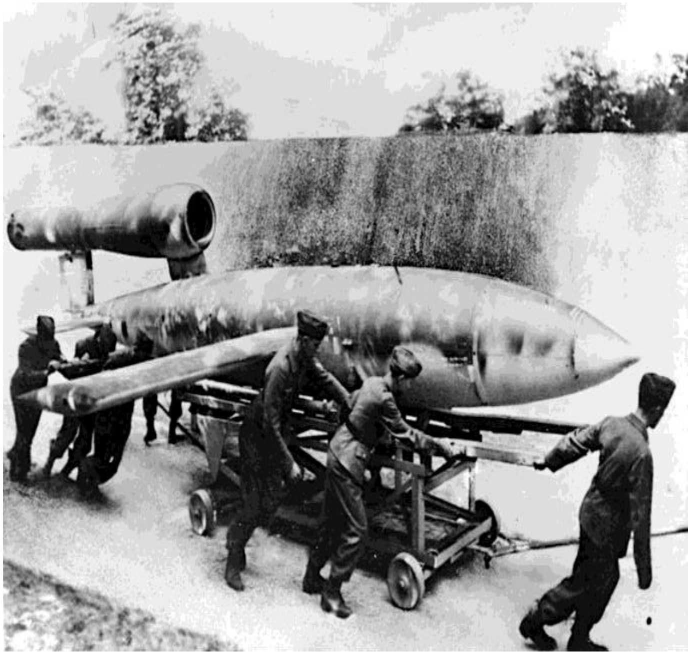


Figure 1 V-1 Missile

US guidance history centers around 2 distinct communities. One driven out of Caltech and NASA Jet Propulsion Laboratory, the other from the German scientists that developed the early V2 rocket guidance and MIT. The GN&C system for V2 provided many innovations and was the most sophisticated military weapon in 1942 using self-contained closed loop guidance. Early V2s leveraged 2 gyroscopes and lateral accelerometer with a simple analog computer to adjust the azimuth for the rocket in flight. Analog computer signals were used to drive 4 external rudders on the tail fins for flight control. Von Braun engineered the surrender of 500 of his top rocket scientists, along with plans and test vehicles, to the Americans. They arrived in Fort Bliss, Texas in 1945 and were subsequently moved to Huntsville, Al in 1950 (aka Redstone arsenal)

The main challenge related to spacecraft FF missions is the design of robust and reliable guidance, navigation, and control (GNC) techniques for onboard systems. Thus, the intent of this paper is to determine the state of the art of the onboard GNC system in terms of hardware/software solutions and achievable performances through a comprehensive survey of past, current, and future FF missions. Many past works focused on the review of the research status of GNC techniques. (2003)
The Canadian Advanced Nanosatellite experiment-4 and -5 (CanX-4&5; see Sec. II.C.4) or the Project

for On-Board Autonomy-3 (PROBA-3) are planned to be launched to test technologies for autonomous proximity operations. In fact, a completely autonomous system guarantees superior performance in terms of control accuracy and higher mission flexibility/adaptability, providing a prompt response to contingencies. Moreover, onboard autonomy allows performing maneuvers far from Earth, overcoming problems due to large communication delays, and reducing the operations costs. (2013)

Onboard autonomy allows performing maneuvers far from Earth, overcoming problems due to large communication delays, and reducing the operations costs. This need for autonomy presents a new set of challenges in the areas of onboard sensing, actuation, and maneuver planning, as well as in mission management and scheduling; monitoring; and fault detection, isolation, and recovery (FDIR)

In 2015 an analysis of the onboard GNC systems, investigating the required/achieved performances, the functional architecture, and the onboard hardware, appears to not be available in the literature except for a specific class of spacecraft, i.e., the small satellites.

The use of small satellites (mass lower than 500 kg), especially Nano and microsatellites , is growing tremendously in the space field, thanks to the development and wide use of the CubeSat standard and all related technology equipment. As an immediate consequence, small satellites have been increasingly proposed to build up distributed space systems for Earth observation and science purposes.

History of Key Technologies

The History of Apollo Onboard Guidance, Navigation, and Control

David G. Hoag
The Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts

Introduction

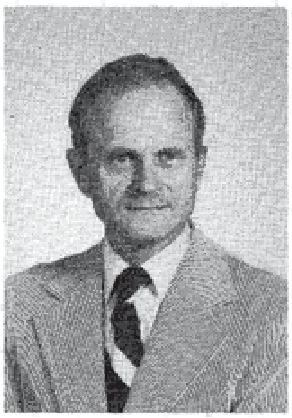
WHEN Apollo astronauts finally walked on the moon, thousands of engineers, scientists, managers, and technicians of many varied disciplines and specialties shared in the glorious accomplishment of an extraordinary national goal. This is the story of an essential part of that endeavor—that of the development and execution of the guidance, navigation, and control systems which, onboard Apollo along with the astronauts, made essential measurements of the spacecraft motions and directed necessary maneuvers for the mission.

The Beginnings

The forerunner of the Apollo guidance, navigation, and control system is found in an unmanned spacecraft and mission study started in 1957 by the Instrumentation Laboratory at MIT under a contract with the Air Force Ballistic Missile Division. The small Instrumentation Laboratory team for this study, led by Milton Trageser and supported by AVCO Corporation, the MIT Lincoln Laboratory, and Thiokol Chemical Corporation, designed a small autonomous spacecraft weighing 150 kg which would take a close-up high-resolution photo of Mars. This Mars probe had several novel features, later incorporated in the Apollo system, including a space sextant to make periodic navigation angle measurements between pairs of celestial objects: the sun, the near planets, and selected stars. The guidance technique utilized original formulations designed by Dr. J. Halcombe Laning and Dr. Richard Battin to operate a small rocket at the appropriate times to put the spacecraft on a corrected trajectory which would utilize the Martian gravity during the close passage such as to send the spacecraft with its Mars picture on a return path back to Earth for physical recovery. Spacecraft attitude control would be accomplished by torquing small momentum wheels using the solar pressure force on adjustable sun vanes to drive the average speed of these wheels toward zero. Overall autonomous operation was managed onboard by a small general purpose digital computer configured by its designer, Dr. Ramon Alonso, for very-low-power drain except at the occasional times needing fast computation speed. A special feature of this computer was the prewired, read-only memory called a core rope, a configuration of particularly high storage density required only one magnetic core per word of memory.

A four-volume report of this work[1] was published in July 1959, and presented to the Air Force sponsors. However, the Air Force was then disengaging from civilian space development, so endeavors were undertaken to interest NASA. Dr. H. Guyford Stever, then a professor at MIT, arranged a presentation for Dr. Hugh Dryden, NASA Deputy Administrator, which took place on September 15, 1959.* On November 10, 1959, NASA sent a letter of intent to contract the Instrumentation Laboratory for a $50,000 study to start immediately. The stated purpose was that this study would contribute to the efforts of NASA's Jet Propulsion Laboratory in conducting unmanned space missions to Mars, Venus, and the Earth's moon scheduled in Vega and Centaur missions in the next few years. A relationship between MIT and JPL did not evolve. JPL's approach to these deep space missions appeared to be primarily ground base control with their large antenna tracking and telemetry systems, considerably different from the onboard self-sufficiency method which the MIT group advocated and could best support.

The Instrumentation Laboratory report on the NASA study appeared in four volumes[2] in April 1960. It described the design of a 35-kg pod comprising a self-contained guidance, navigation, and control system intended for mounting on Centaur vehicles to support a variety of space missions. A space sextant, similar to but improved over the Mars probe



David G. Hoag was graduated in 1946 from the Massachusetts Institute of Technology with an SB degree in electrical communications and received in 1950 an SM degree in instrumentation from the MIT Department of Aeronautics. His early career at the MIT Instrumentation Laboratory involved engineering on Navy fire control systems for guns and missiles. From 1958-1961 he was Technical Director of the Instrumentation Laboratory's development of the guidance system for the Navy's Polaris submarine launched ballistic missile. From 1962 to 1973, he was first Technical Director, and later, Program Manager of MIT's development and operational support of the guidance, navigation, and control systems for the Apollo Command Module and lunar landing spacecrafts. He became Head of the Advanced Systems Department in 1973 when the Instrumentation Laboratory became independent of MIT as The Charles Stark Draper Laboratory, Inc. In that role he now leads activities in precision pointing and tracking for directed energy weapons and space based surveillance systems. He is a corresponding member of the International Academy of Astronautics and serves on the advisory board of its journal, Acta Astronautica. He is a member and Past President of the Institute of Navigation. He was elected Fellow of AIAA in 1974 and is a past Chairman of the New England Section, AIAA. In 1979 he was elected to the National Academy of Engineering. He has received several awards for his work on Apollo including the NASA Public Service Award, the Thurlow Award of the ION, and (with Richard H. Battin) the Louis W. Hill Award of AIAA.

Received Feb. 8, 1982; revision received Oct. 12, 1982.

*Dryden himself did not hear their talks. The MIT Laboratory team was upstaged by the presence of Premier Kruschev that day visiting in Washington.

EDITORS'S NOTE: This manuscript was invited as a History of Key Technologies paper as part of AIAA's 50th Anniversary celebration. It is not meant to be a comprehensive study of the field. It represents solely the author's own recollection of events at the time and is based upon his own experiences.

CHAPTER-2

LITERATURE REVIEW

- Inertial guidance systems were originally developed for rockets. American rocket pioneer Robert Goddard experimented with rudimentary gyroscopic systems. Dr. Goddard's systems were of great interest to contemporary German pioneers including Werner von Braun. The systems entered more widespread use with the advent of spacecraft, guided missiles, and commercial airliners.
- The earliest examples of a true guidance system is that used in the German V-1 during World War II. The navigation system consisted of a simple gyroscope, an airspeed sensor, and an altimeter. The guidance instructions were target altitude, target velocity, cruise time, and engine cut off time.
- A guidance system has three major sub-sections: Inputs, Processing, and Outputs. The input section includes sensors, course data, radio and satellite links, and other information sources. The processing section, composed of one or more CPUs, integrates this data and determines what actions, if any, are necessary to maintain or achieve a proper heading. This is then fed to the outputs which can directly affect the system's course. The outputs may control speed by interacting with devices such as turbines, and fuel pumps, or they may more directly alter course by actuating ailerons, rudders, or other devices.
- GNC systems and related technologies and engineering have always been part of our company's core competencies. Currently, GMV's GNC Division is one of the biggest and best in the whole European space industry. The know-how and expertise have been built up over many years of continuous learning and application to a significant number of GNC related technological activities for ESA and to a growing number of ESA missions, such as PROBA-3, IXV, Mars Sample Return, Lunar Lander and others.
- Designing a GNC system requires a very complete and iterative process, that usually comprises a set of different disciplines and requires the involvement of a team made up of people with different background knowledge and education, including: mission design and planning, S/C systems knowledge, trajectory design, control design, sensor technology, navigation strategy and navigation filters design, on-board SW coding, SW verification and system verification (including HW in the loop). This challenge has always been and still is exciting while pushing us towards innovation and self-improvement, which have made GMV a key player in the GNC field in Europe.

CHAPTER-3

CONTRIBUTION, COMPLIANCE AND SCHEDULING

3.1 Contribution to society

- Missile technologies have been used for defense organizations and tech savvy consumers. For defence purpose in order to retaliate when there is attack from other nation.
- Since the project is for improving the accuracy for hitting the target which also considers safety and security of the surrounding area.
- This will help increase in export of the new technologies which will help in growth of economy. This project will also head the nation towards being self reliant encouraging 'Make in India'.
- The innovation and development in the field will open new opportunities and encourage the young minds to explore more.
- Having improved technologies will increase influence on the rival countries.

3.1.1 DEFENCE

Missile have been used over decade by military. From the world wars to present treasure of military weapons with the defence forces, missiles have played a major role. Targeting the desired location has always been the major goal. With increasing technology the defence systems have been more efficient. The organisations like DRDO in India have been continuously striving for perfection in missile technologies.

3.1.2 SAFETY AND SECURITY

The lack of precision and inability of the missiles to hit the target in presence of any obstacle in its path causes destruction to the surrounding area and hence failing the mission. This technology tends to improve the obstacle avoidance and retracing of path to finally hit the target.

3.1.3 SELF RELIANT – MAKE IN INDIA

Importing missiles from the super powers countries have surely increased our defense capabilities. But having the largest manpower we have a treasure of skill, ideas and skills. This project is a small step in the field of missile technology and an encouragement for MAKE IN INDIA vision.

3.1.4 OPPURTUNITIES

This will indeed create interest and opportunities for the youth to explore new fields. Companies like SpaceX and Bellatrix etc. have been the inspiration which have dragged attention of the people towards the field creating self-employment through startups. The government also supports the startups academically and financially which has further encouraged the youth.

3.1.5 INFLUENCE AND STRENGTHENING

The improved defence technology of the country acts as a strength for the rival countries and the can lead to less infiltrations. More efficient the missile more will be the impact on the world. This will also create economic strengths and export rates can also increase, hence increasing the GDP. Not only psychological impact bust also the economic contributor to the world’s wealth.

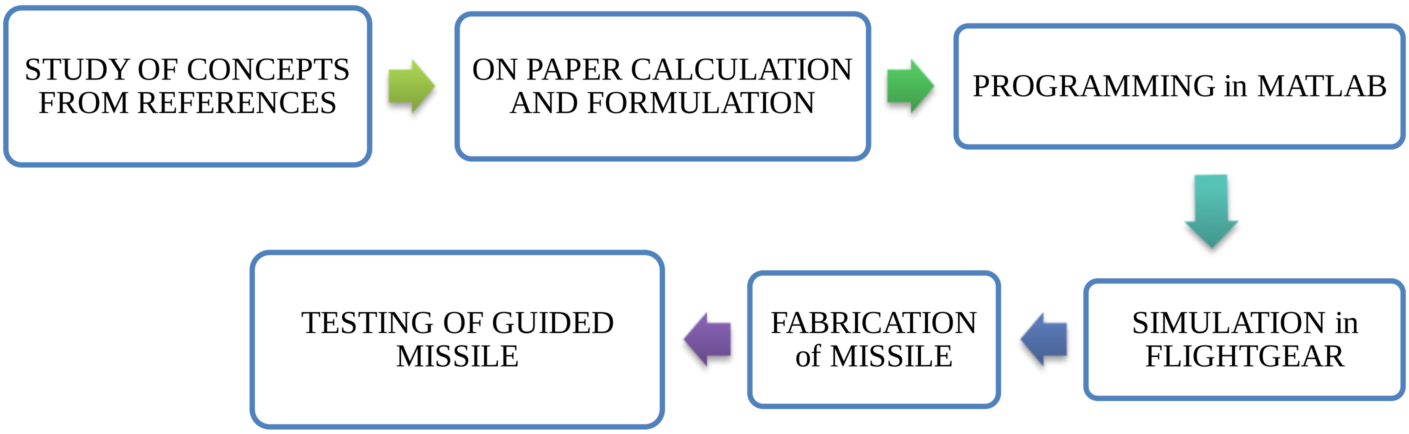
3.2 Compliance to standards

We took standards of AIM-9M missile

- Alternate names : PJ-10
- Originated from : America
- Length : 3.02 m
- Diameter : 127mm
- Launch weight : 85.3 kg
- Warhead mass : 9.4 kg
- Maximum velocity : Mach 2.5-2.8
- Maximum range : 35.4 km
- Basing : Ground-launched, Air-launched, Ship-launched, fixed launchers
- Propulsion : Solid fuel rocket

3.3 Project scheduling and work delegation

The project Guidance Navigation and Control is about the programming the commands for missile, making the prototype of the model in software and hardware, simulation of the missile, synthesizing the propellant and finally collaborating the avionic and aerodynamic equipment with the programming to make it ready for testing.



- Work delegation

Our team consists of a bunch of highly talented students with a wide knowledge base. We have worked with dedication to make this project a success.

Our work delegation shows mantle of every and each team member and ensures the work supports his or her talents to the best.

Below is a table depicting the work done by every member of the team.

S. No.	Student Name	Research Paper Reference	2D design	3D Model (prototype)	Project file	Making propellant	Programming	Misc.
1.	Lalit Deshmukh	✓		✓		✓	✓	✓
2.	Anshul Dubey	✓		✓	✓	✓	✓	✓
3.	Raman			✓		✓		✓
4.	Chandan Kumar			✓		✓		✓
5.	Ritul Raj		✓		✓	✓		✓

CHAPTER-4

DESIGNING OF THE MISSILE

The AIM 9M MISSILE is designed in CATIA V5.

CATIA V5R20: CATIA abbreviates computer aided three--dimensional Interactive Application. As a new user of this softer package, you will be joining hands with thousands of users of this high-end CAD/CAM/CAE tool world-wide. You can upgrade your designing skills with latest release.

CAITA V5, developed by Dassault systems. France is completely re-engineered next generation family of CAD/CAM/CAE software solutions for product life cycle management. CATIA V5 delivers innovative technologies for max Productivity and creativity from concept to the final product. CATIA V5 reduces the learning curve as it allows the flexibility and parametric designs.

Figure 2 AIM-9M Missile

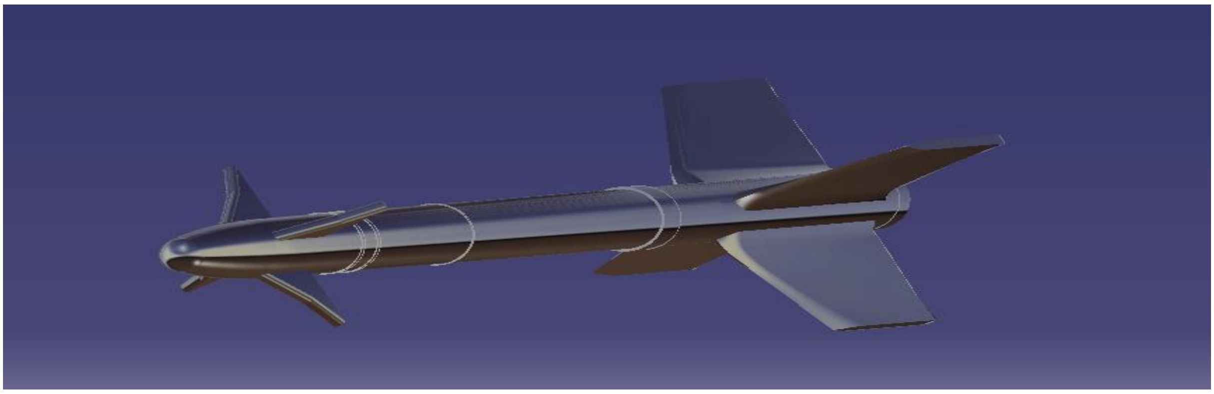


Figure 3 CatiaV5 Model using surfacing and mechanical workbench

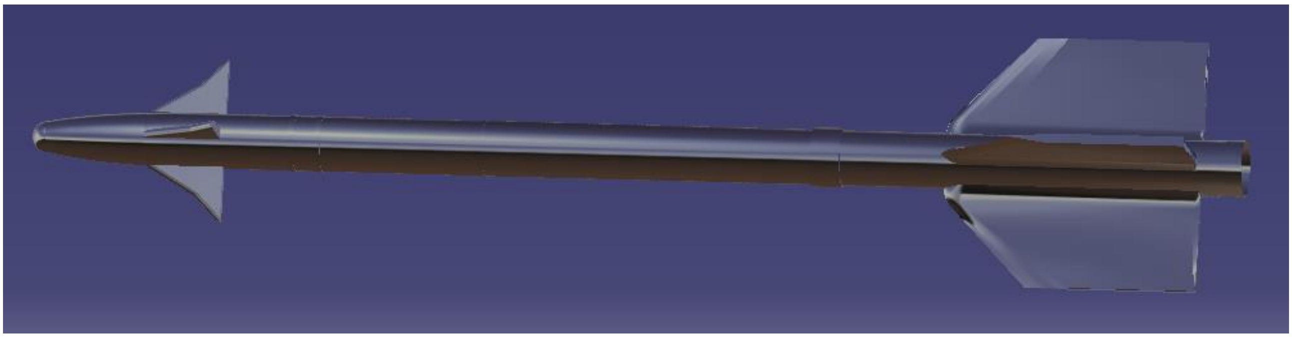


Figure 4 Side view of CATIA Model

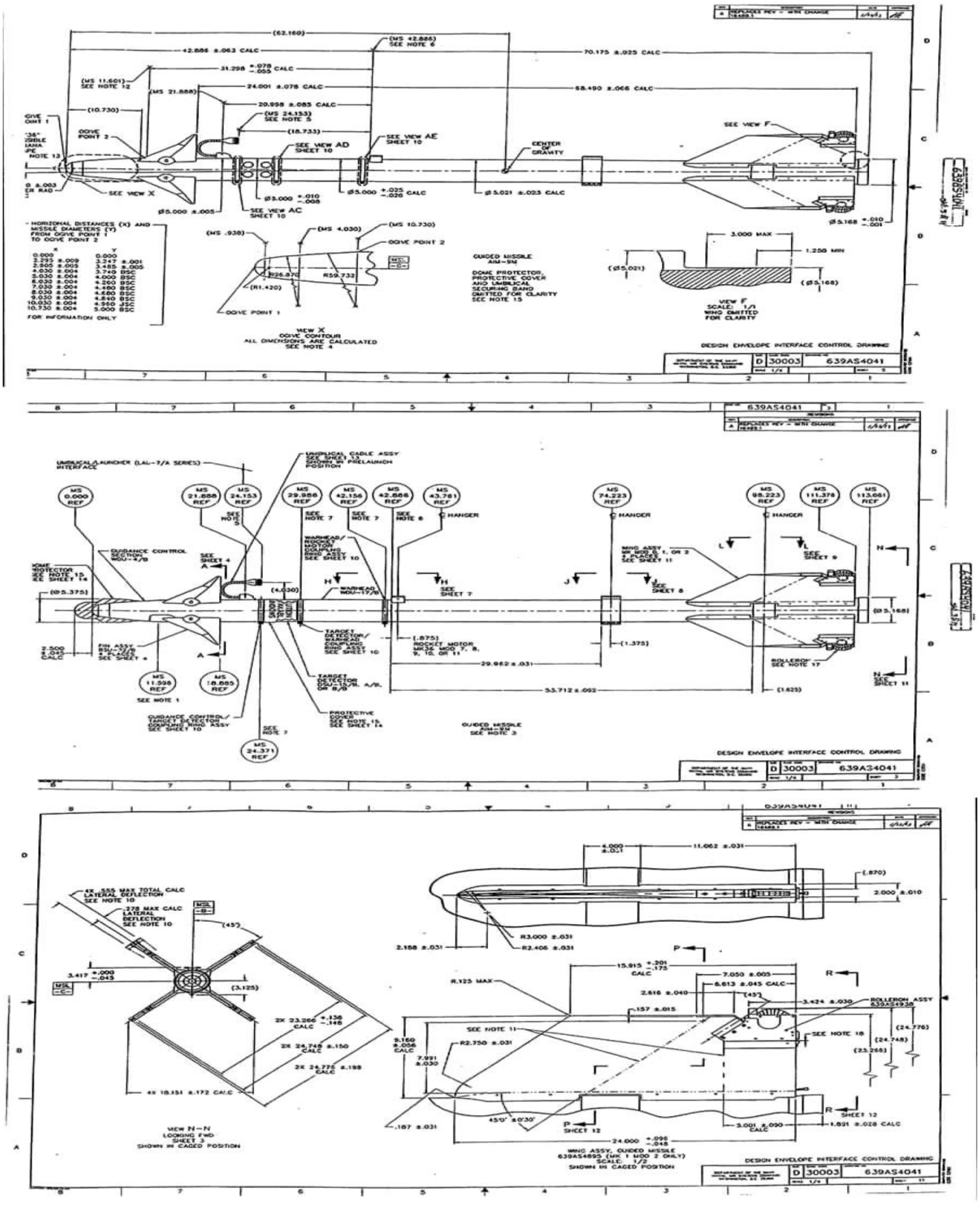


Figure 5 Dimensions of the AIM-9M missile

CHAPTER 5

MATLAB PROGRAMMING

MATLAB is a programming platform designed specifically for engineers and scientists to analyze and design systems and products that transform our world. The heart of MATLAB is the MATLAB language, a matrix-based language allowing the most natural expression of computational mathematics.

Functions of MATLAB

- Analyze data
- Develop algorithms
- Create models and applications

MATLAB lets you take your ideas from research to production by deploying to enterprise applications and embedded devices, as well as integrating with Simulink® and Model-Based Design.

5.1 History of MATLAB

The mathematical basis for the first version of MATLAB was a series of research papers by J. H. Wilkinson and 18 of his colleagues, published between 1965 and 1970 and later collected in *Handbook for Automatic Computation*, *Volume II, Linear Algebra*, edited by Wilkinson and C. Reinsch. These papers present algorithms, implemented in Algol 60, for solving matrix linear equation and eigenvalue problems.

EISPACK and LINPACK

In 1970, a group of researchers at Argonne National Laboratory proposed to the U.S. National Science Foundation (NSF) to "explore the methodology, costs, and resources required to produce, test, and disseminate high-quality mathematical software and to test, certify, disseminate, and support packages of mathematical software in certain problem areas." The group developed EISPACK (Matrix Eigensystem Package) by translating the Algol procedures for eigenvalue problems in the handbook into Fortran and working extensively on testing and portability.

Historic MATLAB

In the 1970s and early 1980s, I was teaching Linear Algebra and Numerical Analysis at the University of New Mexico and wanted my students to have easy access to LINPACK and EISPACK without writing Fortran programs. By "easy access," I meant not going through the remote batch processing and the repeated edit-compile-link-load-execute process that was ordinarily required on the campus central mainframe computer.

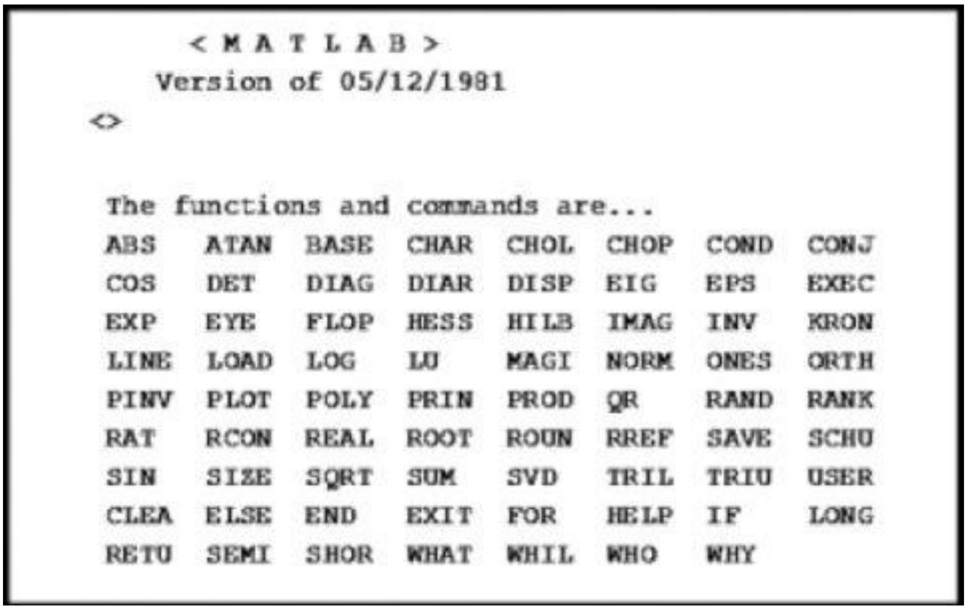


Figure 6 historic MATLAB

Commercial MATLAB

I spent the 1979–80 academic year at Stanford, where I taught the graduate course in Numerical Analysis and introduced the class to this matrix calculator. Some of the students were studying subjects like control theory and signal processing, which I knew nothing about. Matrices were central to the mathematics in these subjects, though, and MATLAB was immediately useful to the students.

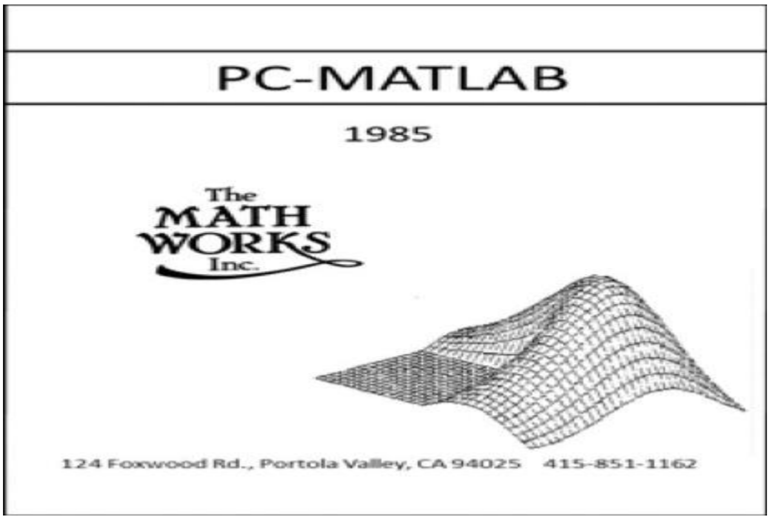


Figure 7 Commercial MATLAB

Modern MATLAB

While preserving its roots in matrix mathematics, MATLAB has continued to evolve to meet the changing needs of engineers and scientists. The key developments are shown in the timeline

```
mu = 5;
vdp = @(t,y) [y(2); mu*(1-y(1)^2)*y(2)-y(1)];
tspan = [0 30];
y0 = [0 0.01]';
[t,y] = ode23s(vdp,tspan,y0);
plot(t,y,'.-')
legend({'y','dy/dt'})
xlabel('t')
```

MATLAB More Accessible: Desktop

The first versions of MATLAB were simple terminal applications. Over time we added separate windows for graphics, editing, and other tools. These gradually made MATLAB easier to use, especially for users without prior programming experience. Two specific features that have had the biggest impact are the desktop and the Live Editor.

Desktop

The MATLAB desktop was introduced in 2000. Here is a screenshot showing how it looks today.

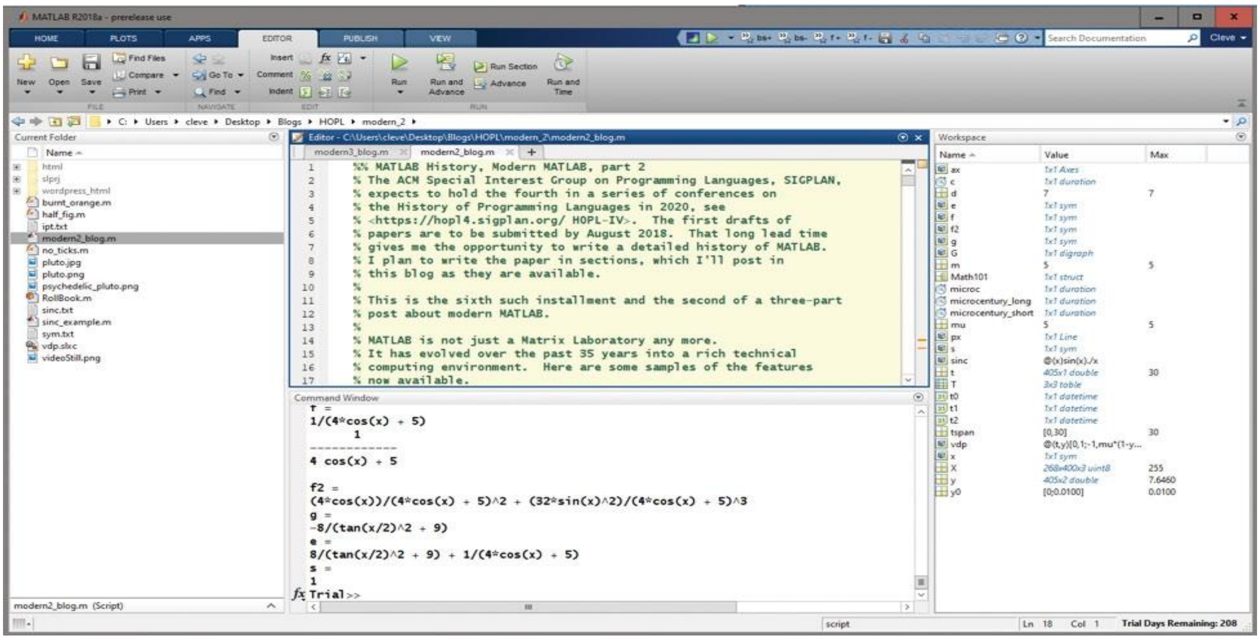


Figure 8 DESKTOP MATLAB

Simulink

Simulink is a MATLAB-based graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in automatic control and digital signal processing for multidomain simulation and model-based design

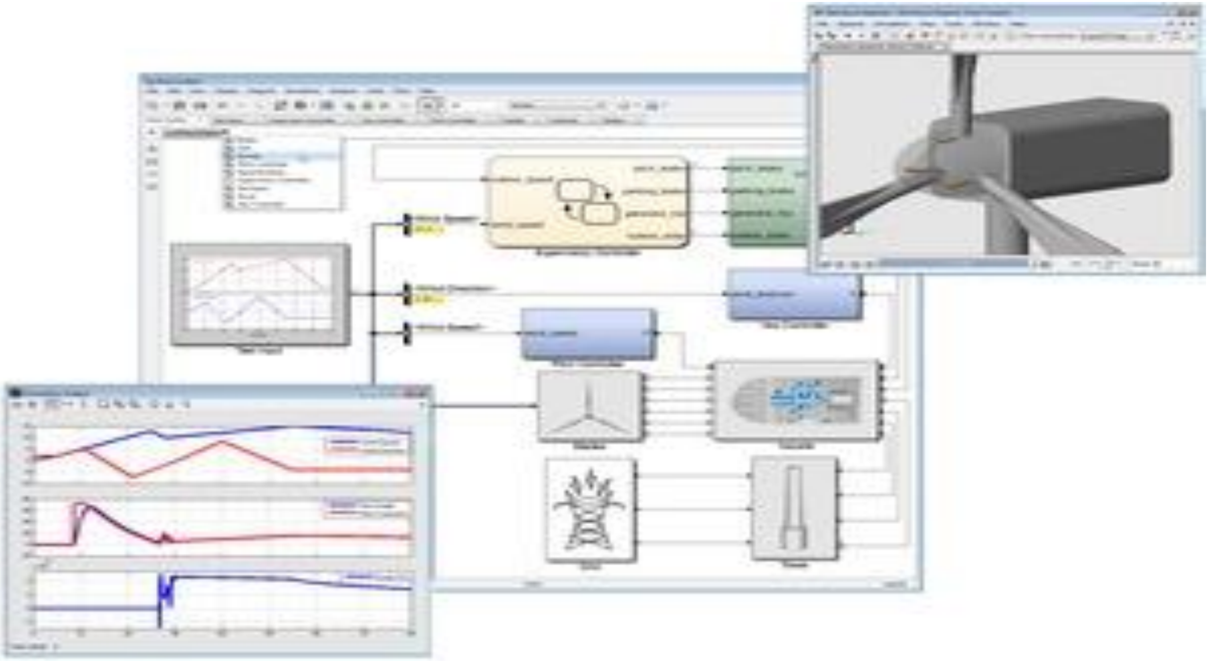


Figure 9 MULTI DOMAIN

Programming in MATLAB

The programming and the following calculation and assumptions are done and taken from the Raytheon aerospace research paper published on Research gate in 2005.

The Concept

Longitudinal autopilots for tactical missiles have been successfully employed for over fifty years. In the past several years, at Raytheon, the "classic" three loop autopilot (often dubbed the "Raytheon autopilot"1) has been the design topology of choice. The design goal of any autopilot is to use sensed quantities to produce a stable response that robustly follows commanded inputs. The classic three loop autopilot has the desired longitudinal acceleration as the command and the sensed acceleration and sensed angular rate as the measured quantities. This paper deals with approaching the autopilot design process by looking at the optimal control problem. It is found that solving the optimal control problem where the cost is a weighted sum of the acceleration error and the fin deflection leads to a two loop controller. The optimal control problem where the cost is the weighted sum of the acceleration error and the fin rates leads to a three loop topology. Next, a "neoclassic" four loop autopilot is presented that has the same commanded and sensed quantities as the three loop designs, but uses four gains instead of three. The adaptation for a Linear Quadratic (LQ) design technique is developed which allows for the direct augmentation of a first order dynamics model (to represent the CAS, IMU, delays, etc.) to the plant. Two five loop topologies are also introduced which allows augmentation of a second order dynamics model to the system. The five loop design requires either more than a single integration of the commanded acceleration or a first order lead. All higher order designs result in either double integration of the acceleration command or the four loop design with more and more complex lead systems. A longitudinal missile example is used throughout the paper to clarify the discussion.

A missile's longitudinal dynamics can be described using the short period approximation of the longitudinal equations of motion. Written in state space notation the basic missile longitudinal plant is

$\dot{x} = Ax + Bu$ (1)
$y = Cx + Du$

where

$$x = \begin{bmatrix} \alpha \\ q \end{bmatrix} \qquad u = \delta_p \qquad y = \begin{bmatrix} A_{z_m} \\ q_m \end{bmatrix}$$

To be more specific, the short period dynamics are

$$A = \begin{bmatrix} \frac{1}{V_{m_0}}\left[\frac{\bar{Q}SC_{z\alpha_0}}{m} - A_{X_0}\right] & 1 \\ \frac{\bar{Q}SdC_{m\alpha_0}}{I_{YY}} & 0 \end{bmatrix} \qquad B = \begin{bmatrix} \frac{\bar{Q}SC_{z\delta_{p_0}}}{mV_{m_0}} \\ \frac{\bar{Q}SdC_{m\delta_{p_0}}}{I_{YY}} \end{bmatrix}$$

$$C = \begin{bmatrix} \frac{\bar{Q}SC_{z\alpha_0}}{mg} - \frac{\bar{Q}SdC_{m\alpha_0}\bar{x}}{gI_{YY}} & 0 \\ 0 & 1 \end{bmatrix} \qquad D = \begin{bmatrix} \frac{\bar{Q}SC_{z\delta_{p_0}}}{mg} - \frac{\bar{Q}SdC_{m\delta_{p_0}}\bar{x}}{gI_{YY}} \\ 0 \end{bmatrix}$$

The following numerical values will be used in the examples throughout this paper. Note that when $C_{m\alpha_0}$ is positive, the system is statically unstable, and stable when $C_{m\alpha_0}$ is negative.

Variable	Value	Units	Description
V_{m_0}	3350	ft/sec	Total Missile Velocity
m	11.1	slug	Total Missile Mass
I_{YY}	137.8	slug-ft^2	Pitch Moment of Inertia
$\bar{x}$	1.2	ft	Distance from CG to IMU Positive Forward
A_{X_0}	-60	ft/sec^2	Axial Acceleration Positive Forward
$C_{z\alpha_0}$	-5.5313	-	Pitch Force Coefficient due to Angle of Attack
$C_{m\alpha_0}$	±6.6013	-	Pitch Moment Coefficient due to Angle of Attack
$C_{z\delta_{p_0}}$	-1.2713	-	Pitch Force Coefficient due to Fin Deflection
$C_{m\delta_{p_0}}$	-7.5368	-	Pitch Moment Coefficient due to Fin Deflection
$\bar{Q}$	13332	lb/ft^2	Dynamic Pressure
S	0.5454	ft^2	Reference Area
d	0.8333	ft	Reference Length
g	32.174	ft/sec^2	Gravity Constant

For the unstable system this yields

$$A = \begin{bmatrix} -1.064 & 1 \\ 290.26 & 0 \end{bmatrix} \qquad B = \begin{bmatrix} -0.25 \\ -331.40 \end{bmatrix}$$

$$C = \begin{bmatrix} -123.34 & 0 \\ 0 & 1 \end{bmatrix} \qquad D = \begin{bmatrix} -13.51 \\ 0 \end{bmatrix}$$

and the open loop transfer functions are

$$\frac{A_{z_m}}{\delta_p} = \frac{-13.51s^2 + 16.29s + 44800}{s^2 + 1.064s - 290.26} = \frac{-13.51(s + 56.98)(s - 58.18)}{(s + 17.58)(s - 16.51)}$$

and

$$\frac{q_m}{\delta_p} = \frac{-331.4s - 424.7}{s^2 + 1.06s - 290.28} = \frac{-331.4(s + 1.281)}{(s + 17.58)(s - 16.51)}$$

This plant is a relatively fast unstable missile.

For the stable system the state space description is given by

$$A = \begin{bmatrix} -1.064 & 1 \\ -290.26 & 0 \end{bmatrix} \qquad B = \begin{bmatrix} -0.25 \\ -331.39 \end{bmatrix}$$

$$C = \begin{bmatrix} -101.71 & 0 \\ 0 & 1 \end{bmatrix} \qquad D = \begin{bmatrix} -13.51 \\ 0 \end{bmatrix}$$

and the open loop transfer functions are

$$\frac{A_{z_m}}{\delta_p} = \frac{-13.51s^2 + 10.91s + 29780}{s^2 + 1.064s + 290.26} = \frac{-13.51(s + 46.55)(s - 47.35)}{(s + 0.53 \pm 17.03j)}$$

and

$$\frac{q_m}{\delta_p} = \frac{-331.4s - 280.3}{s^2 + 1.064s + 290.26} = \frac{-331.4(s + 0.846)}{(s + 0.53 \pm 17.03j)}$$

This plant is a relatively fast lightly damped stable missile. Both of these models conform to the sign convention that a positive pitch fin deflection produces a negative moment.

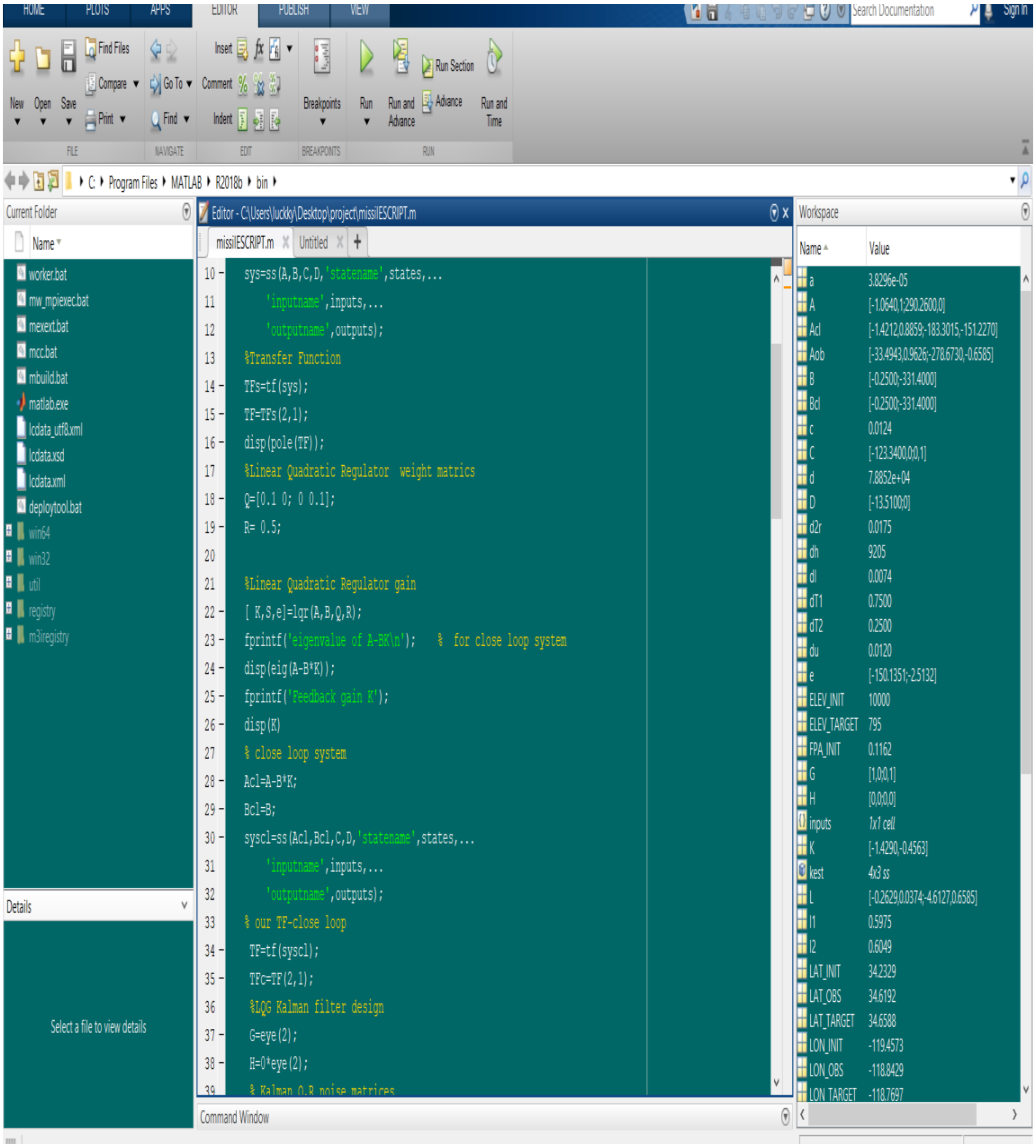


Figure 10 program on MATLAB

Kalman filter is a set of equations that reduces noise to increase the accuracy of the results. LQR (Linear Quadratic Regulator) is the adaptation for a Linear Quadratic (LQ) design technique which allows for the direct augmentation of a first order dynamics model to the plant.

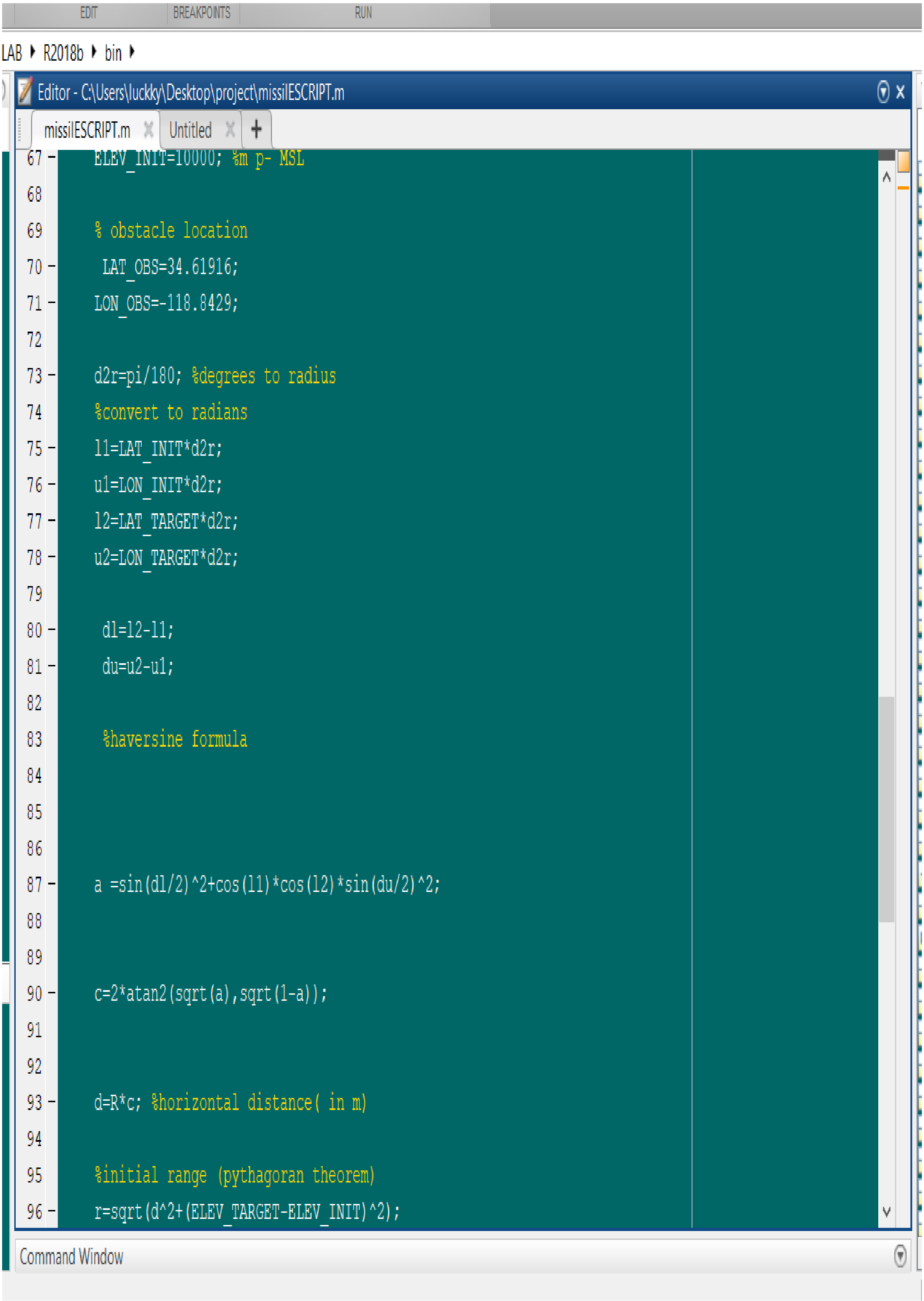


Figure 11program on MATLAB

GUIDANCE PROGRAM

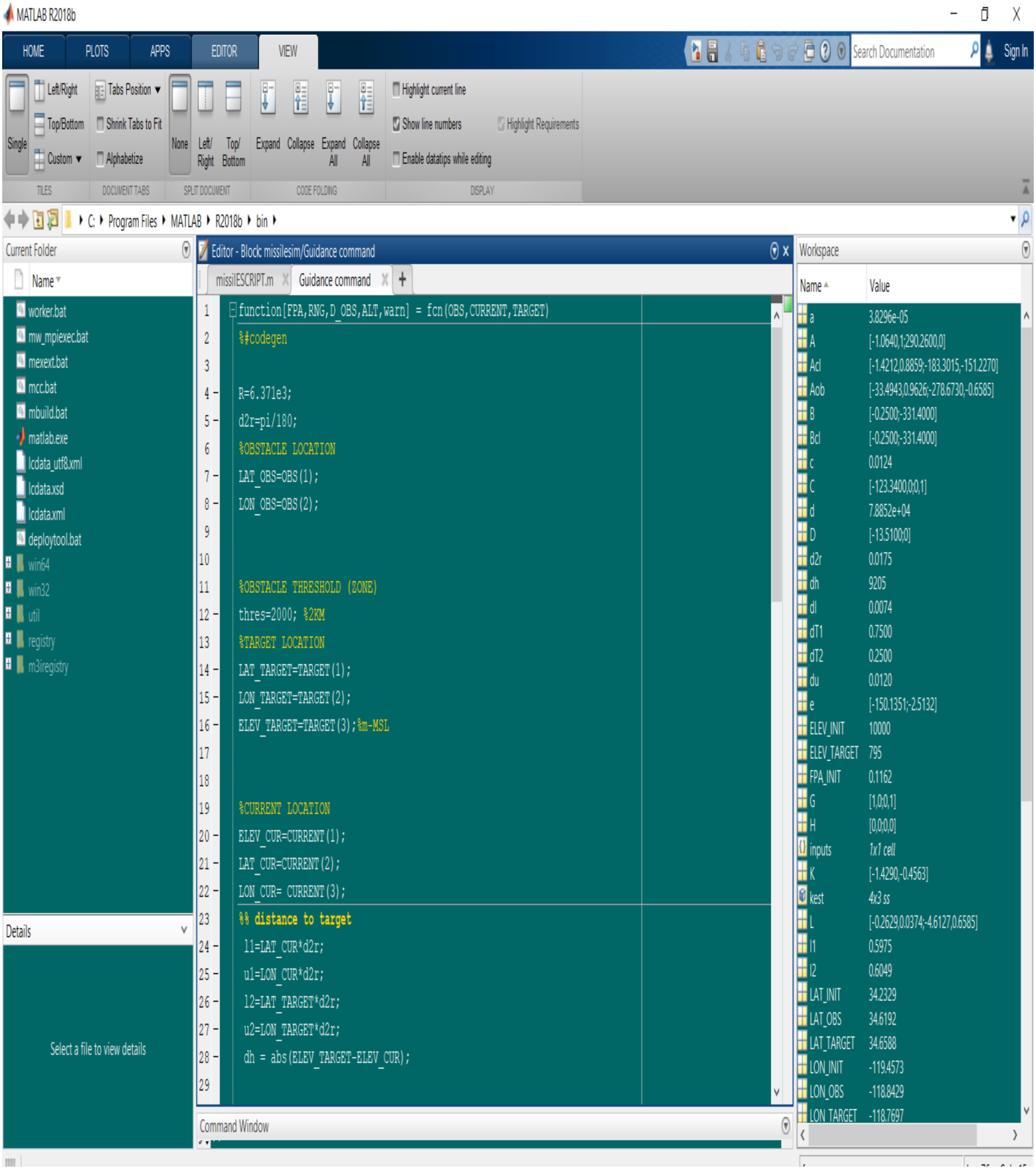
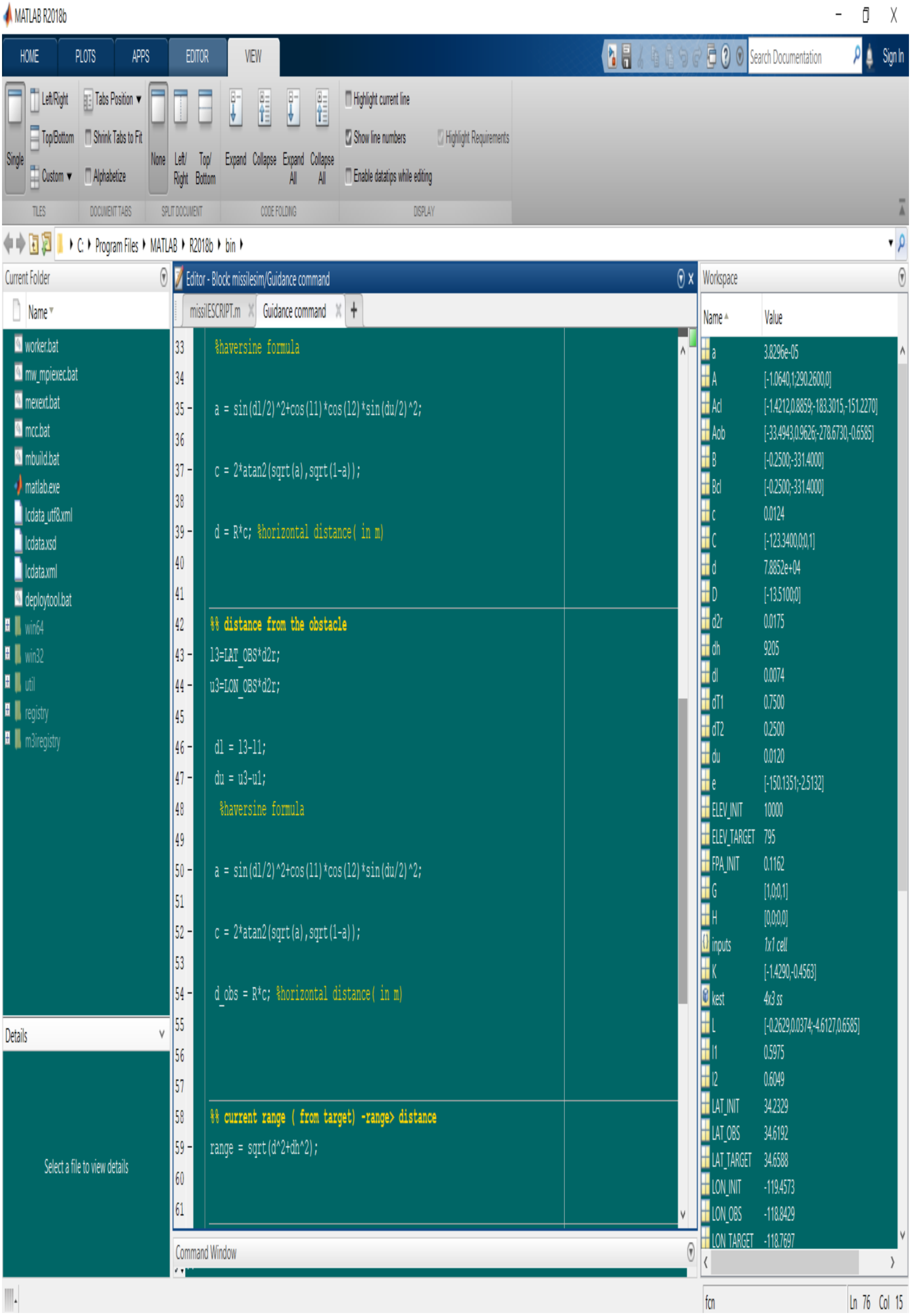


Figure 12guidance program



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Top/ Bottom
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Collapse
Expand All
Collapse All
Highlight current line
Show line numbers
Enable datatips while editing
Highlight Requirements
TILES
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SPLIT DOCUMENT
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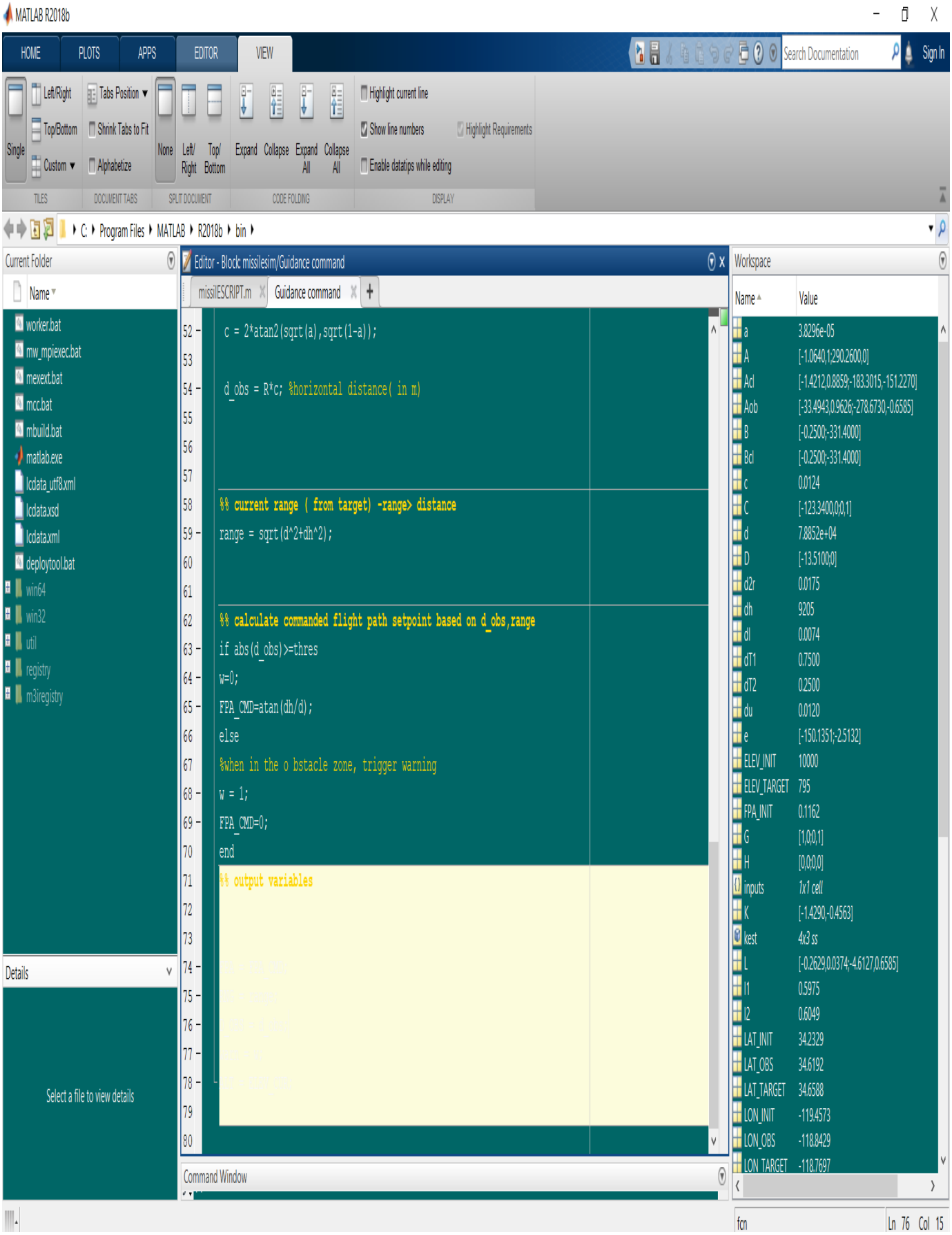
worker.bat
mw_mpiexec.bat
mexext.bat
mcc.bat
mbuild.bat
matlab.exe
lcdata_utf8.xml
lcdata.xsd
lcdata.xml
deploytool.bat
win64
win32
util
registry
m3iregistry
Details
Select a file to view details
Editor - Block: missilesim/Guidance command
missilESCRIPT.m
Guidance command
%haversine formula
a = sin(dl/2)^2+cos(l1)*cos(l2)*sin(du/2)^2;
c = 2*atan2(sqrt(a),sqrt(1-a));
d = R*c; %horizontal distance(in m)
%% distance from the obstacle
l3=LAT_OBS*d2r;
u3=LON_OBS*d2r;
dl = l3-l1;
du = u3-u1;
%haversine formula
a = sin(dl/2)^2+cos(l1)*cos(l2)*sin(du/2)^2;
c = 2*atan2(sqrt(a),sqrt(1-a));
d_obs = R*c; %horizontal distance(in m)
%% current range (from target) -range> distance
range = sqrt(d^2+dh^2);
Command Window
Workspace
Name
Value
a 3.8296e-05
A [-1.0640,1;290.2600,0]
Acl [-1.4212,0.8859;-183.3015,-151.2270]
Aob [-33.4943,0.9626;-278.6730,-0.6585]
B [-0.2500;-331.4000]
Bcl [-0.2500;-331.4000]
c 0.0124
C [-123.3400,0;0,1]
d 7.8852e+04
D [-13.5100;0]
d2r 0.0175
dh 9205
dl 0.0074
dT1 0.7500
dT2 0.2500
du 0.0120
e [-150.1351;-2.5132]
ELEV_INIT 10000
ELEV_TARGET 795
FPA_INIT 0.1162
G [1,0;0,1]
H [0,0;0,0]
inputs 1x1 cell
K [-1.4290,-0.4563]
kest 4x3 ss
L [-0.2629,0.0374;-4.6127,0.6585]
l1 0.5975
l2 0.6049
LAT_INIT 34.2329
LAT_OBS 34.6192
LAT_TARGET 34.6588
LON_INIT -119.4573
LON_OBS -118.8429
LON_TARGET -118.7697
fcn
Ln 76 Col 15


MATLAB R2018b
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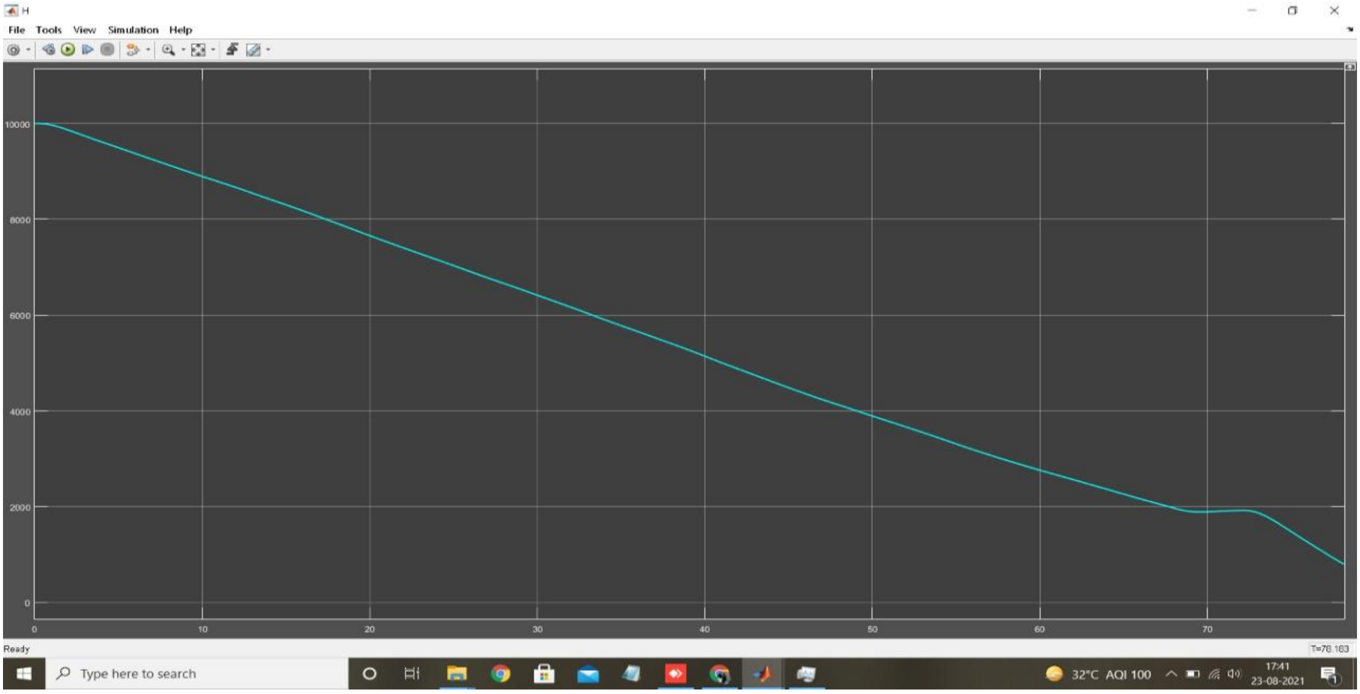
Editor - Block: missilesim/Guidance command
missilESCRIPT.m
Guidance command
c = 2*atan2(sqrt(a),sqrt(1-a));
d_obs = R*c; %horizontal distance(in m)
%% current range (from target) -range> distance
range = sqrt(d^2+dh^2);
%% calculate commanded flight path setpoint based on d_obs,range
if abs(d_obs)>=thres
w=0;
FPA_CMD=atan(dh/d);
else
%when in the o bstacle zone, trigger warning
w = 1;
FPA_CMD=0;
end
%% output variables
Current Folder
Workspace
Command Window
Select a file to view details

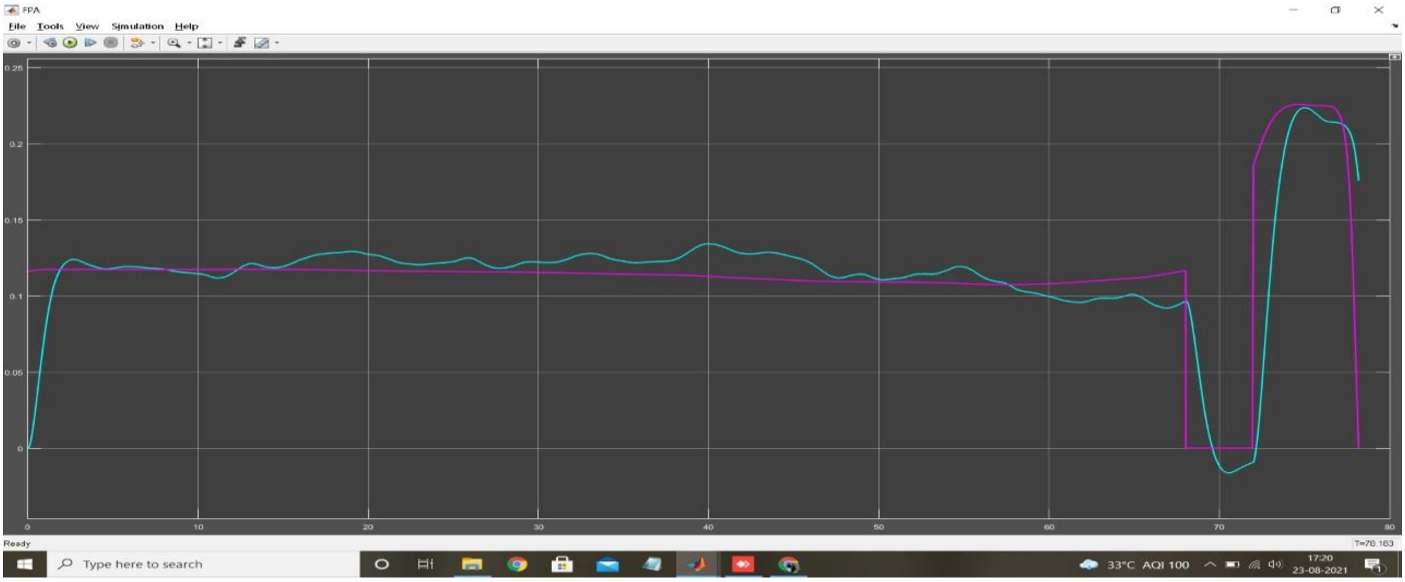
Graphs in MATLAB for different variations

The following is the graph of the how the missile height is changing in accordance with the time as we can clearly see that the missile is clearly avoiding the obstacle which is coming in its path without missing the target.



(Graph 1)

- ➢ The below graph shows that how the flightpath angle is changing with respect to time and the disturbance at T=70.183 clearly shows that there is change in flightpath angle when an obstacle comes in between and how the missile changes its flightpath in accordance with that.

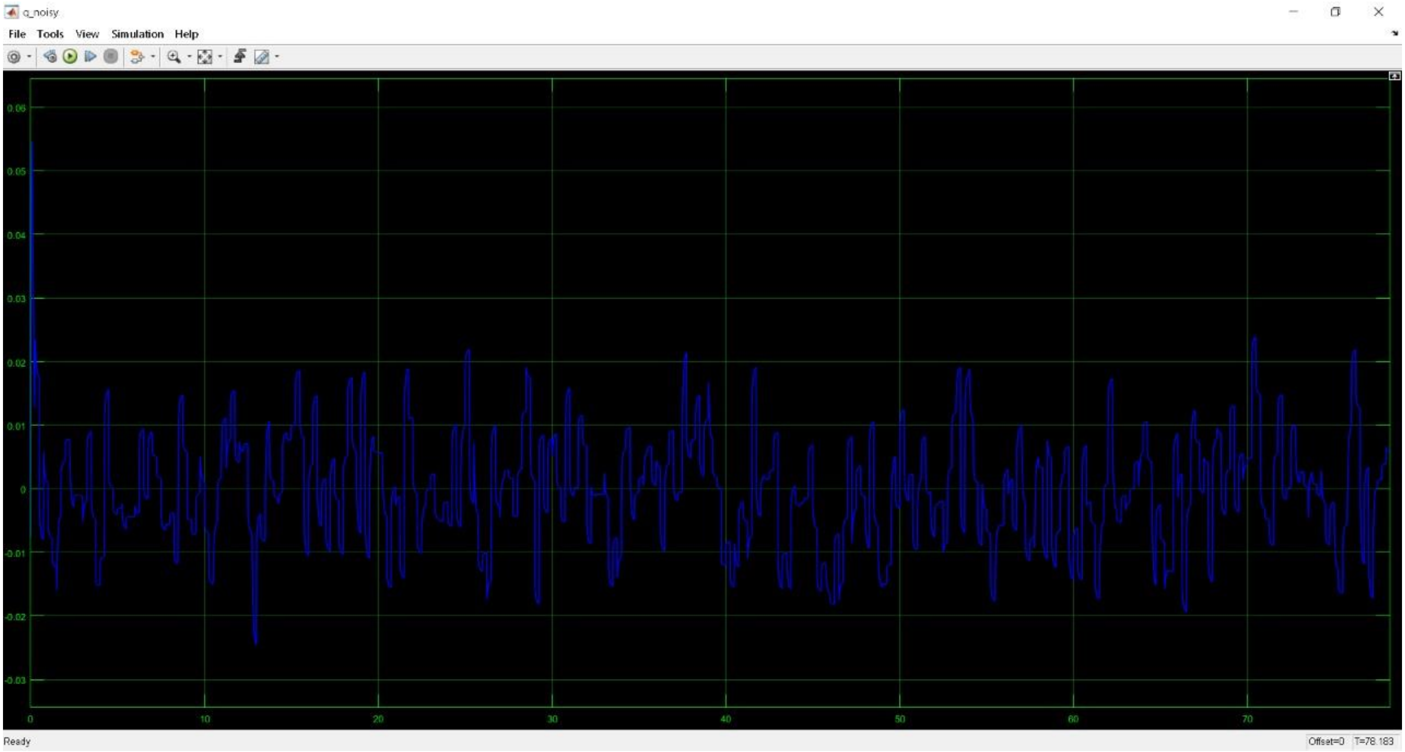


(Graph 2)

The next graph shows the pitch rate so that should not exceed one and we can clearly seeing it on the graph that it is below one so our missile is running well.

(Graph 3)

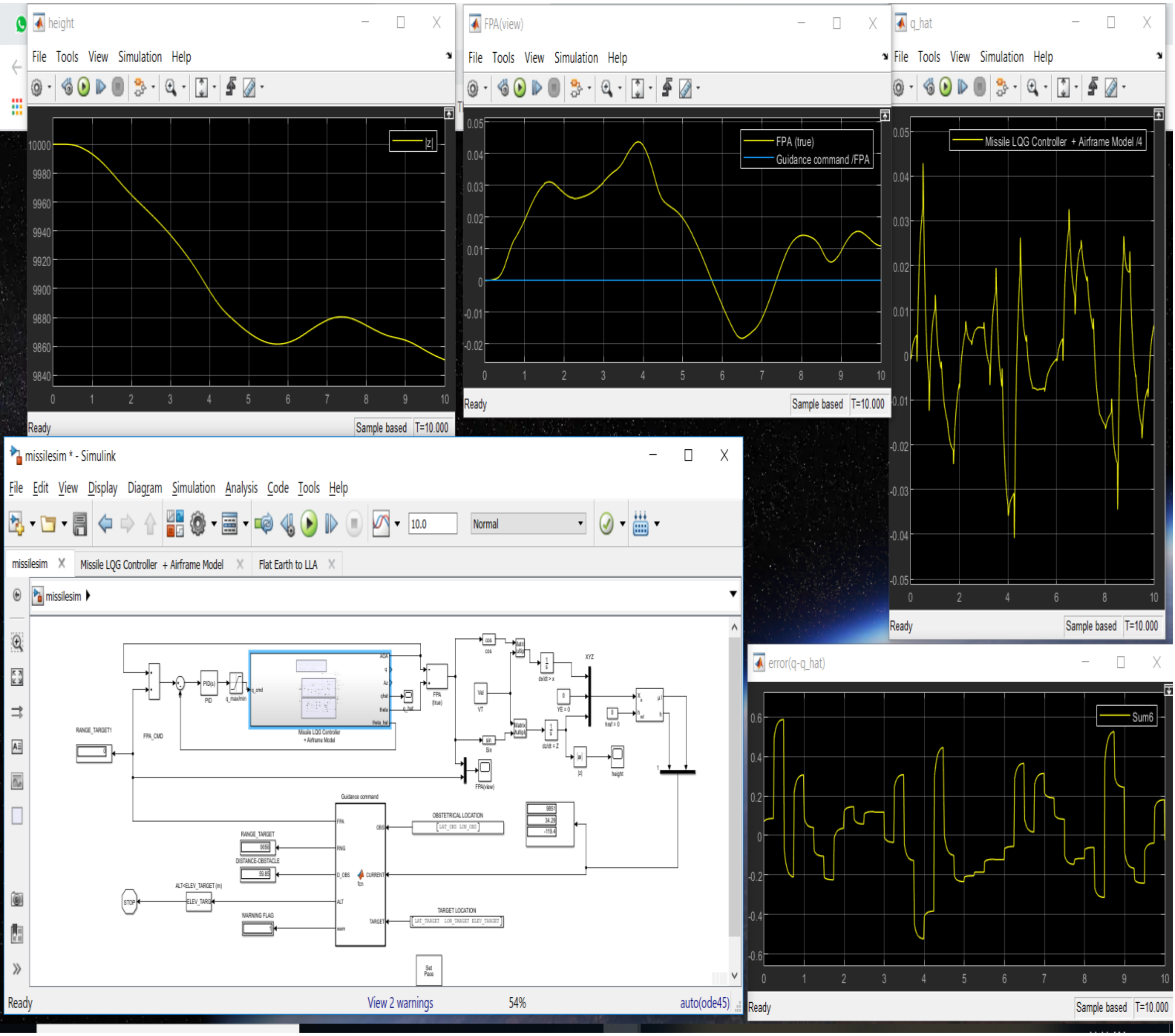
The next graph shows the noise in the system as one knows that any working model contains noise in its system.



(Graph 4)

IMPROVEMENT

This below demonstration show how the previous system works which is not based on loop system and doesn't avoid obstacle in between the target. And this comparison clear sly shows our improvement done in our project.



(Figure showing the previous missile guidance and navigation system)

CIRCUIT FOR SIMULINK

The overall circuit:-

The overall circuit containing FPA, Matrices, Missile LQG controller and Airframe model as this whole circuit is the optimal control problem where the cost is the weighted sum of the acceleration error and the fin rates leads to a three loop topology. Next, a "neoclassic" four loop autopilot is presented that has the same commanded and sensed quantities as the three loop designs, but uses four gains instead of three. The adaptation for a Linear Quadratic (LQ) design technique is developed which allows for the direct augmentation of a first order dynamics model (to represent the CAS, IMU, delays, etc.) to the plant. Two five loop topologies are also introduced which allows augmentation of a second order dynamics model to the system. The five loop design requires either more than a single integration of the commanded acceleration or a first order lead. All higher order designs result in either double integration of the acceleration command or the four loop design with more and more complex lead systems.

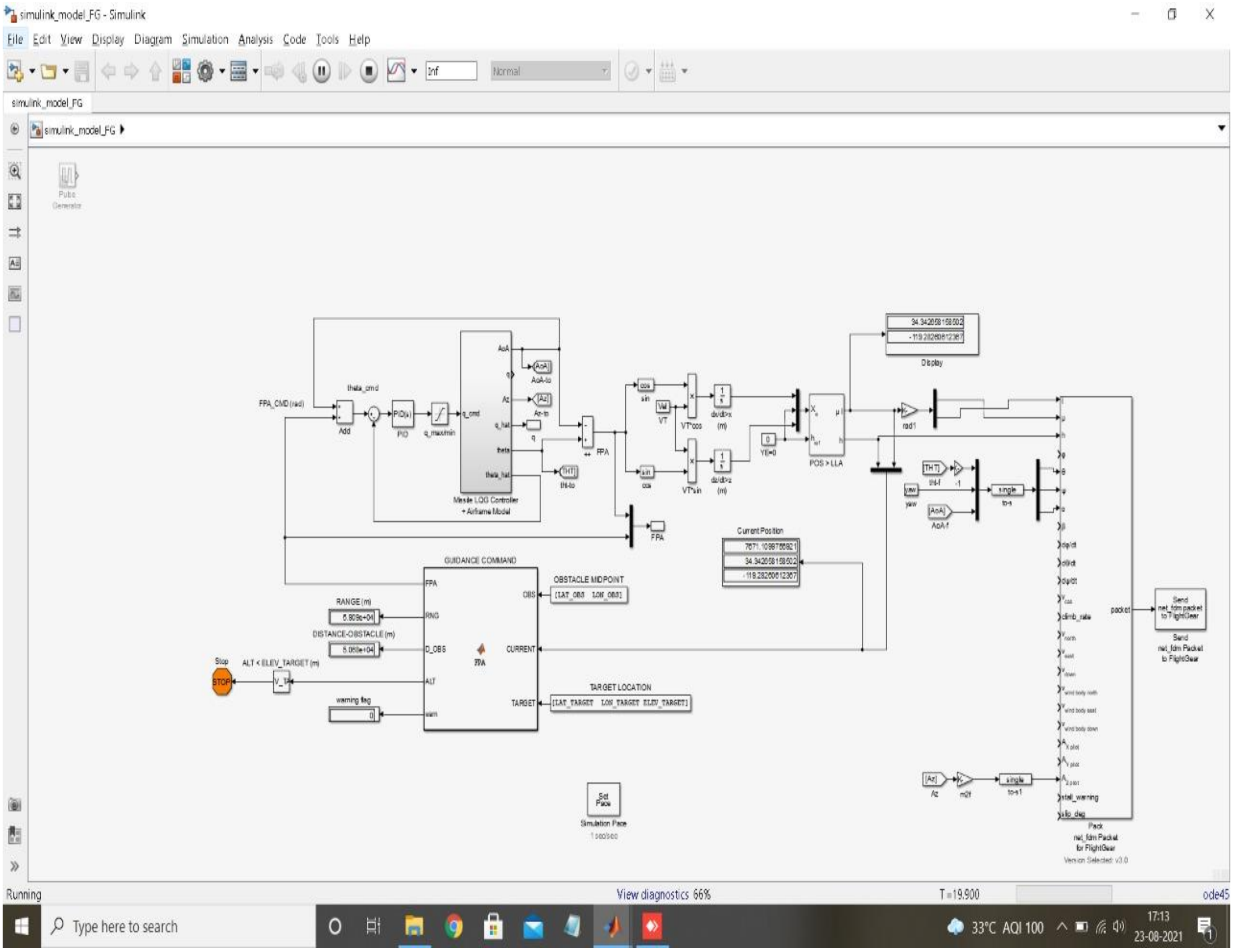


Figure 13 CIRCUIT IN SIMULINK

MISSILE LQG CONTROLLER + AIRFRAME MODEL IN SIMULINK

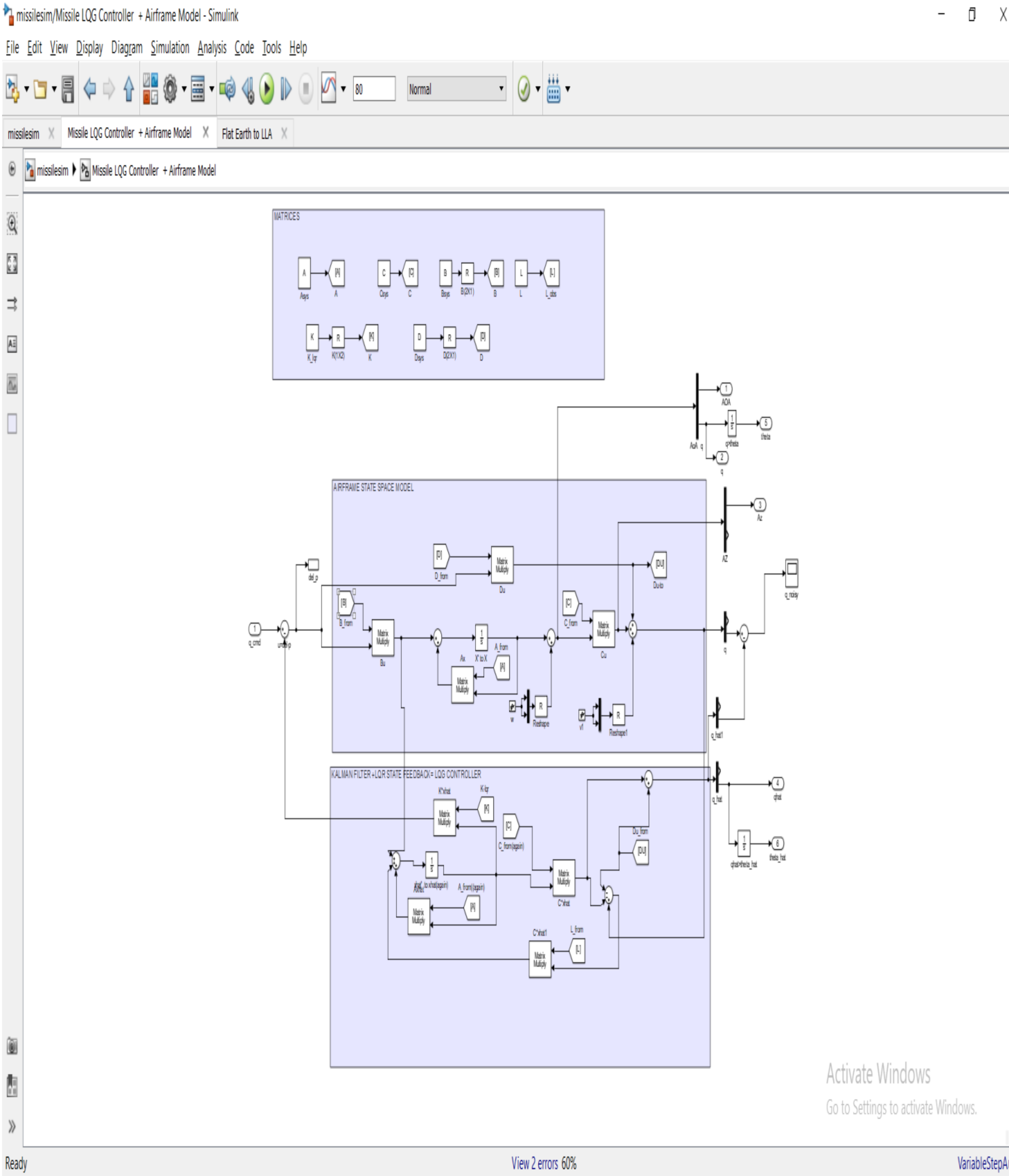


Figure 14MISSILE LQG CONTROLLER + AIRFRAME MODEL IN SIMULINK

RUNNING THE PROGRAM FOR SIMULATION ON MATLAB

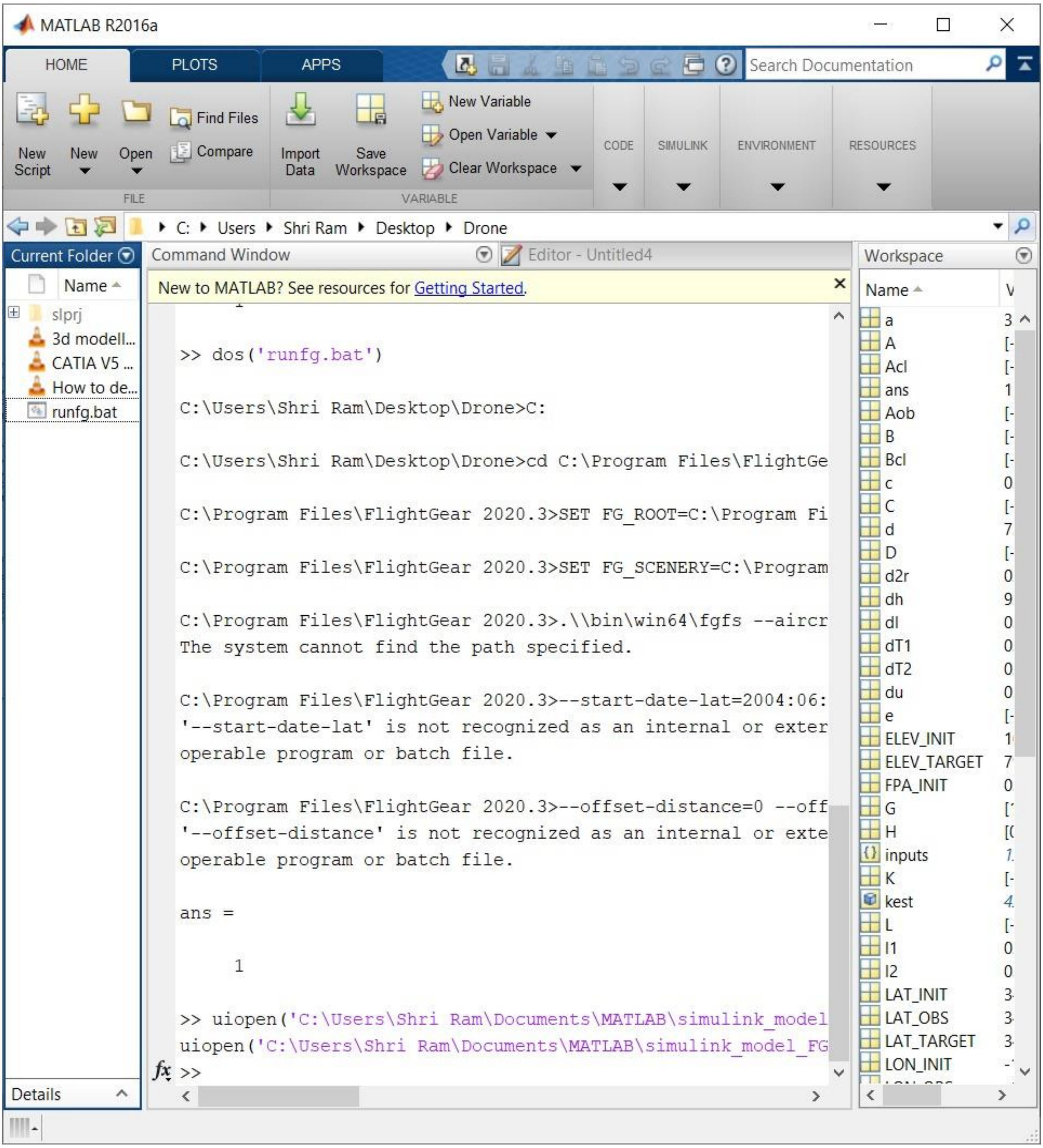


Figure 15 RUNNING THE PROGRAM FOR SIMULATION ON MATLAB

FLIGHTGEAR AND MATLAB SYSTEM INTEGRATION

The following figure shows the integration of the MATLAB and FLIGHTGEAR software as after the successfully programming and the circuit simulation on the MATLAB the simulation is shown/done on the FLIGHTGEAR software and below we can see that on running the program and circuit in MATLAB the Simulation starts on the FLIGHTGEAR

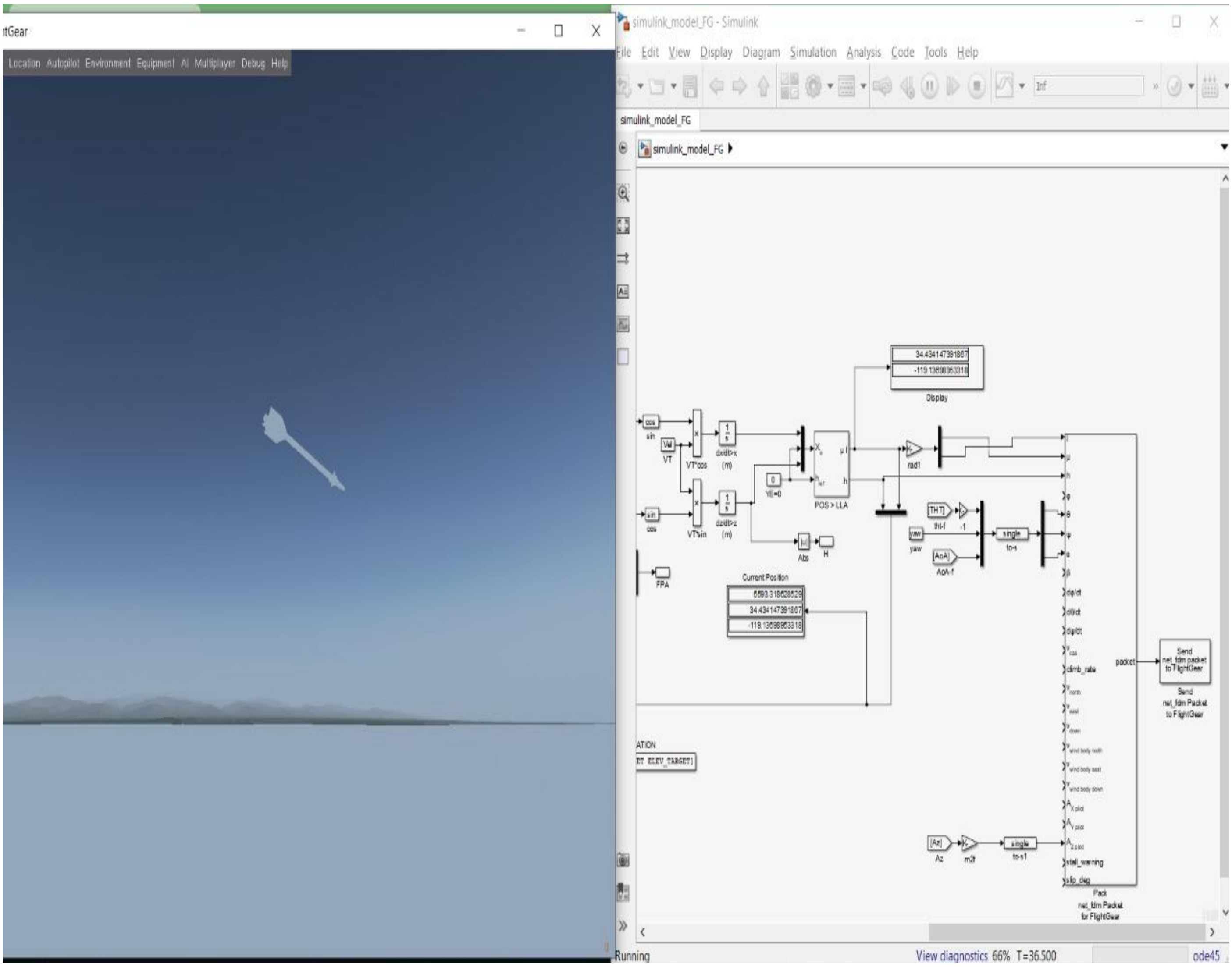


Figure 16 MATLAB and FLIGHTGEAR integration

CHAPTER-8

METHODOLOGY

The components of model are: -

- Arduino
- Servomotor
- Digital gyroscope sensor
- Battery
- Launch pad
- Jumper wire
- Fins (3D Printed)
- Solid rocket motor

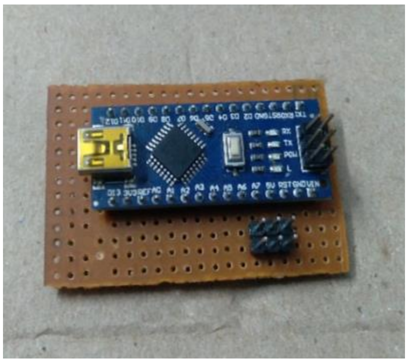


Figure 17 flight computer cum preprogrammed Arduino.

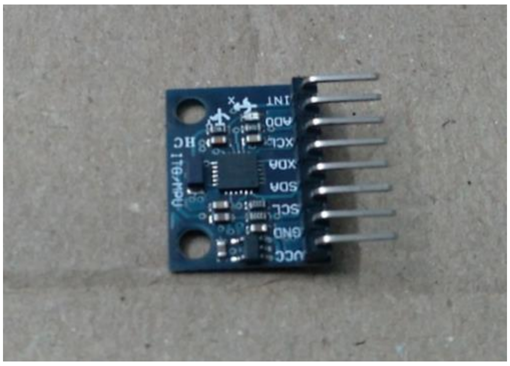


Figure 18 Gyro

Figure 19 servo attached with fin

MAKING OF MISSILE PROTOTYPE

STEP 1: for body of missile take a cylindrically shaped hard cardboard.

STEP 2: using a hard card board sheet make a cone for the nose of missile.

STEP 3: make provision for motor by sectioning the body.

STEP 4: make holes for fixing the fins to the body.

STEP 5: electrical connection made between battery, ESC, servo & receiver.

STEP 6: insert the programmed gyro and flight computer cum preprogrammed Arduino.

STEP 7: attach the fins with servo motors.

STEP 8: fix the nose on top of the body.

STEP 9: insert and fix the propellant motor

STEP 10: make the launch pad ready with the igniter connection.

Calculation for Thrust measurements and the required balanced CG on OPEN ROCKET software

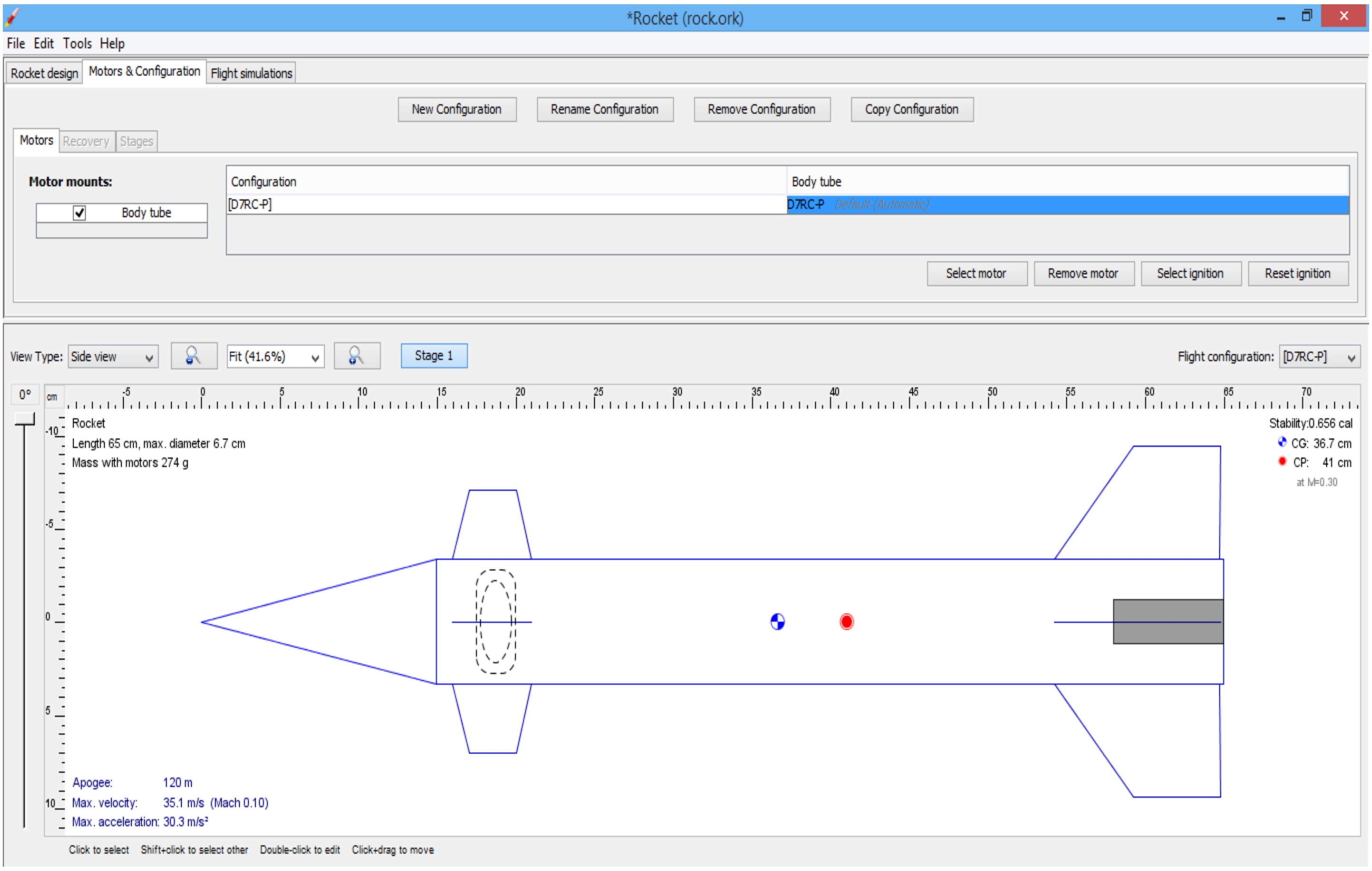


Figure 20 OPEN ROCKET software

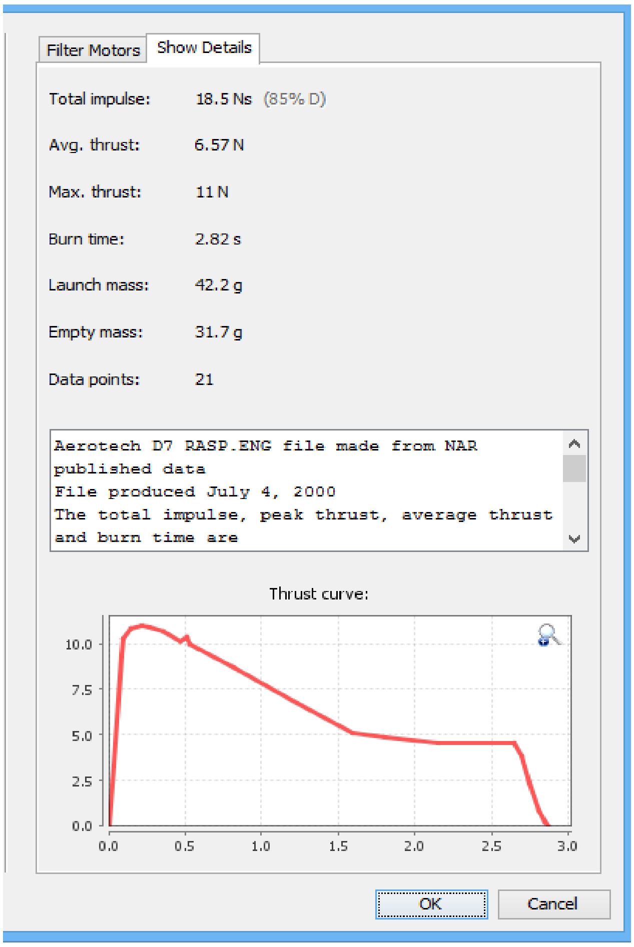


Figure 21 THRUST CALCULATOR

MAKING OF BLACK POWDER AS SOLID ROCKET PROPELLANT

Chemicals Required:

- Charcoal
- Sulphur
- Potassium Nitrate
- Ethyl Alcohol/ Acetone

Apparatus Required

- Pistil And Mortar
- Heating Equipment
- Measuring Apparatus
- Cloth
- Aluminium Foil

Figure 22 Preparing black powder

STEPS INVOLVED:

1. Measuring the chemicals ratio
2. Heating the mixture
3. Mix well
4. Squeeze extra water
5. Let it dry.
6. Fill it in the motor of the required size.

Figure 23 Black powder

CHAPTER-7

RESULTS

SIMULATION ON FLIGHTGEAR

Showing the avoidance of obstacle and retracing its path.

Figure 24 SIMULATION ON FLIGHTGEAR

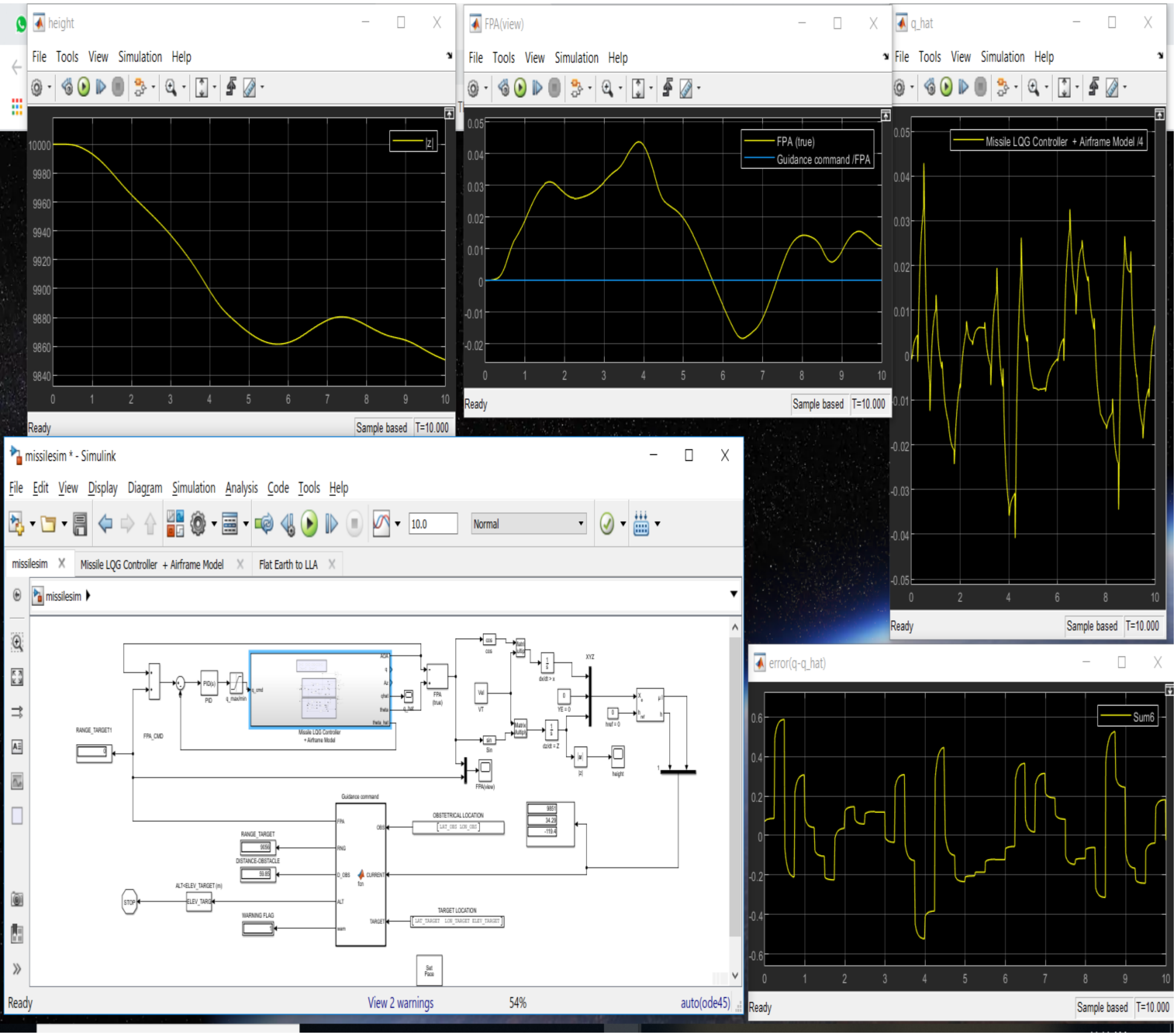
PROTOTYPE OF MISSILE

Figure 25 PROTOTYPE

Figure 26 MODEL SHOWING AVIONIC SYSTEM

Improvement

This below demonstration show how the previous system works which is not based on loop system and doesn't avoid obstacle in between the target. And this comparison clear sly shows our improvement done in our project.



(Figure showing the previous missile guidance and navigation system)

CHAPTER-8

CONCLUSION

The missile technology is developing and requires better results. Missiles sometimes fail to hit the desired target due to obstacles. This project worked for improving the guidance, navigation and control of missile for hitting target accurately and precisely by increasing the stability with avoiding any obstacle in path. This was achieved by using a better program and aerodynamic of the movable fins.

The program which made the missile efficient involved LQR equations and Karman Filters along with the Loop system which provides feedback for any obstacle in path. These traits of the programming was successfully tested at a minor level and we hope this contributes to the aviation field.

- *Grewal, Mohinder S.; Weill, Lawrence R.; Andrews, Angus P. (2007). Global Positioning Systems, Inertial Navigation, and Integration (2nd ed.). Hoboken, New Jersey, USA: Wiley-Interscience, John Wiley & Sons, Inc. p. 21. ISBN 978-0-470-04190-1.*

- *Farrell, Jay A. (2008). Aided Navigation: GPS with High Rate Sensors. USA: The McGraw-Hill Companies. pp. 5 et seq. ISBN 0-07-164266-8.*

- *Draper, C. S.; Wrigley, W.; Hoag, G.; Battin, R. H.; Miller, E.; Koso, A.; Hopkins, A. L.; Vander Velde, W. E. (June 1965). Apollo Guidance and Navigation (PDF) (Report). Massachusetts: Massachusetts Institute of Technology, Instrumentation Laboratory. pp. I-3 et seqq.*

- *Curtis P. Mracek; D. Brett Ridgely. Raytheon Missile Systemsq "Missile Longitudinal Autopilots: Connections Between Optimal Control and Classical Topologies"*

E-links

- **https://www.researchgate.net/publication/321539579_Survey_on_Guidance_Navigation_and_Control_Requirements_for_Spacecraft_Formation-Flying_Missions**

- **https://archive.org/details/globalpositionin00grew_526**

- **https://www.nasa.gov/sites/default/files/atoms/files/gnc.pdf**

- **https://youtu.be/vxzR3W2BcRk**

- **https://youtu.be/0AJ6E48Aj9U**

- **https://youtu.be/wrr-QZxX4Og (MAKING BLACK POWDER)**