

Design and Navigation Control of an Advanced Level CANSAT

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ABSTRACT: This paper presents design and navigation control of an advanced level comeback CanSat which is going to be launched to an altitude of about 400 m using an amateur rocket from ground level. The CanSat uses advanced and ultra-light microcontroller, pressure and temperature sensors, 3-axis accelerometer, 3-axis gyro, camera, GPS, IR distance measuring sensor, and RF communication module to communicate with the ground station PC. Three actuators are considered in this work for flight and ground segments control. They are the motor driven propeller, elevator and rudder. For the flight segment, parachute and attitude control are used to control the CanSat descent rate, attitude and heading. For the ground segment control; both the propeller and the rear landing gear of the CanSat is used for heading toward a predefined location on the ground. The rear landing gear is connected to the rudder rotational axis. An indigenous navigation control and electronic circuit design with the test results also are presented in this paper.

KEYWORDS CanSat, Satellite, Rocket, Launch, Navigation Control Algorithm

I. INTRODUCTION:

A CanSat design is considered a fundamental teaching tool for introduction to satellite design and development. Therefore, it is of great importance to understand and experience the whole process of design, test, launch and recovery of CanSat. CanSat consists of many disciplines including electronic circuit design, control, aerodynamics, atmospheric physics, communication, programming, etc. A basic CanSat consists of a Microcontroller, Accelerometer, Pressure and Temperature Sensors, Camera, Structure and Parachute, as shown in Fig.1.

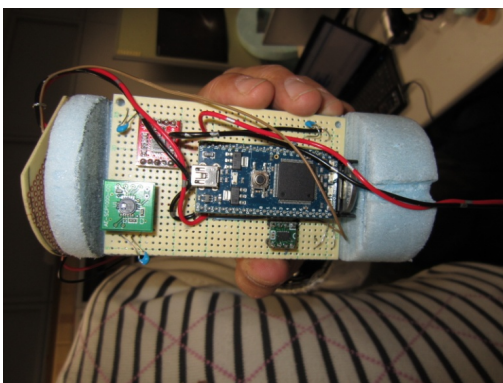


Fig. 1 Basic CanSat hardware

Figure 2 shows the CanSat fitted inside an amateur rocket.



Fig. 2 CanSat packaging inside the rocket just before the launch

In the advanced level CanSat, the mission is to launch and land the CanSat to a predefined target point. Furthermore, CanSat will be sending telemetry data to the ground station. The telemetry data consists of accelerations, angular velocities, GPS data, pressure and temperature as well as the actuators status. In addition to an ultra-light microcontroller, pressure and temperature sensors; 3-axis accelerometer, 3-axis gyro, camera, GPS, IR distance measuring sensor, RF communication module to communicate with the ground station PC and three actuators were used for flight and ground segments

control. These are the motor driven propeller, elevator and rudder servos.

II. ADVANCED LEVEL CANSAT DESIGN

After the rocket is launched to an altitude of 400 m and successful release of the CanSat from the rocket the landing of CanSat, toward a predefined target point on the ground, is started. The landing of the advanced level CanSat includes two segments as shown in Fig. 3. The first segment is the flight segment in which a parachute is deployed. The parachute will generate the lift and required descend rate. A motor driven propeller and servo controlled rudder and elevator are employed to navigate the CanSat during the flight segment. They will be used for both attitude control and heading toward the target. Parachute will be released just before touch-down using the releasing mechanism (servo) at about 300-600 mm above the ground. After parachute releasing and touch-down, the ground segment starts. In this segment both the motor driven propeller and servo controlled rudder will be used to navigate the CanSat toward the target. The rear landing gear is controlled using the same mechanism of the rudder which will enable directional control of the CanSat in the ground segment phase.

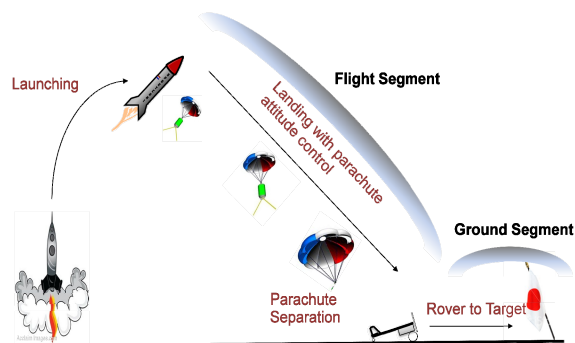


Fig. 3 Landing segments of advanced level CanSat

A. Airframe Design:

Steel can is used as a fuselage. Inside this fuselage, all components are included and/or attached to it. All onboard sensors, electronics and computer are placed inside the can. Batteries and parachute release mechanism are also placed inside the can. Parachute, Motor driven propeller, landing gears, elevator and rudder, GPS, communication module are attached to the can as shown in Fig.4. The geometrical characteristics of the CanSat are presented in Table.1. All CanSat components and its weight are listed in Table.2. The geometric constraint of the CanSat is to fit inside a cylindrical compartment of 400 mm length and 100 mm diameter. The total weight of the CanSat should not exceed 1 kg which is the maximum payload of the rocket.

Elevator and rudder are made of plastic sheet reinforced by flexible thin steel strips. Main landing gears are also made of plastic sheet, flexible thin steel strips and patch tape sandwich. The parachute was

prepared using an umbrella. For stable descend, the upper head of the parachute was cut to create a hole at the top in order to allow air to pass through it.

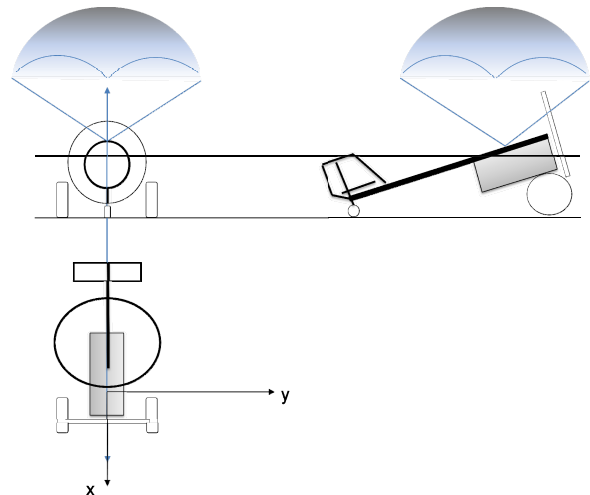


Fig.4. Conceptual design of advanced level CanSat

Table 1 Geometric characteristics

Component/assembly	Length [mm]
Main landing gear diameter	70
Rear landing gear diameter	35
Horizontal tail span	200
Horizontal tail chord	100
Vertical tail chord	100
Vertical tail span	100
Overall length of the CanSat	400

Table 2 Weight estimation

Components	Type	Approximate Weight [g]
Microcontroller	mbed NXP LPC1768	10
2-axis Gyroscope	LPR530AL	1
3-axis Accelerometer	MMA7361L	1
Pressure Sensor	SCP-1000	2
GPS Module	GT-720F	15
Radio Module	Xbee Pro	4
Thermometer	LM35DZ	1
SD Card Module	MSC-MOD10	1
Micro SD Card	DNF-TSD2048	4
2GB Servo Motor	GWSMICRO/2BBMG/J	35
Camera	FS-MD200	13
Motor		45
Motor Drive		10
propeller		10
Landing Gears		60
Frame		150
Li-Po Battery		100
Wiring Board		20
3V battery		5
9V battery		45
Total Weight		532

B. Electronic System Design:

As a microcontroller an Mbed microcontroller was employed. I/O pin layout and interfaces are shown in Fig. 5 [1]. Extensive engineering and testing of all the electronics were done before the final layout, as shown in Fig. 6. Figure 7 shows the final circuit connection diagram and Fig. 8 shows resulting main board connected to GPS, communication module and the Li-Po battery.

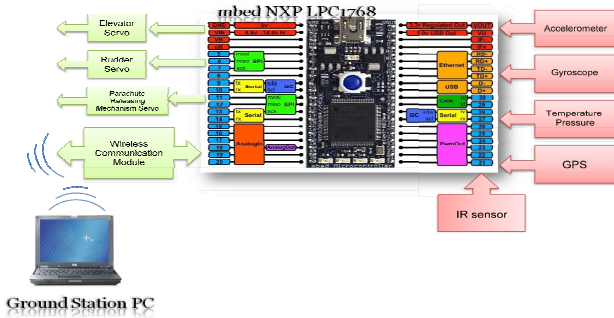


Fig.5 I/O pin layout and interfaces

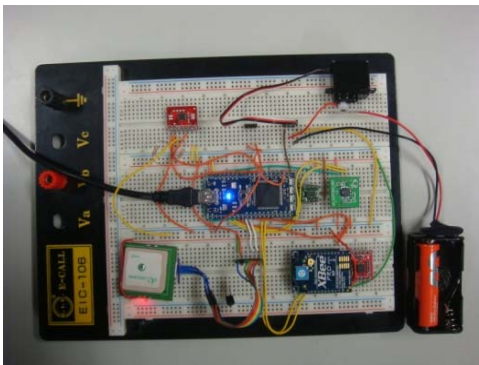


Fig. 6 Development of the onboard electronics

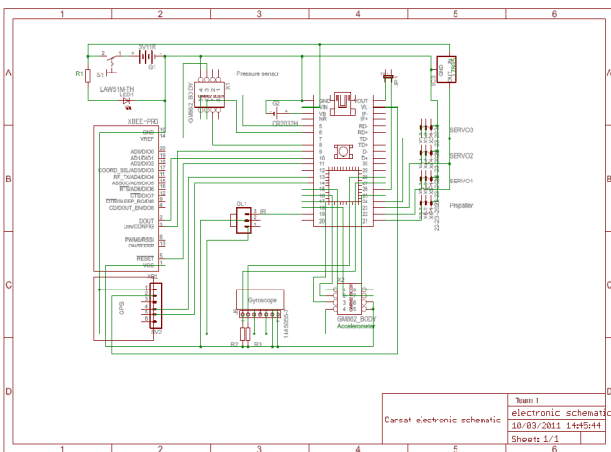


Fig. 7 Schematic of electronic circuit

C. Navigation Control Algorithm:

To ensure stability of the CanSat and its orientation towards the target, two control algorithms have been developed; one for stabilization of the CanSat during flight segment and one for its orientation toward the target during the ground segment. The algorithm of flight control operates as follows:

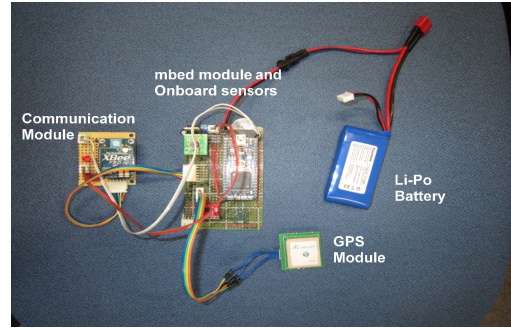


Fig. 8 Onboard electronics

- After separation from the rocket; the CanSat is stabilized by controlling roll and pitch angles and this is realized by actuating both the rudder and elevator with/without the motor driven propeller.
- For the orientation of the CanSat using the rudder, elevator and propeller, detection of the direction of the CanSat is implemented by calculating the angle between the vector position and velocity vector as shown in Fig.9. The calculations of the radius of the circle described by the CanSat around the target allows us to determine the distance between the target and the CanSat, and given by:

$$R = \sqrt{\Delta x^2 + \Delta y^2}$$

Position vector =
 $(a_1 = x(t) - x(0), a_2 = y(t) - y(0))$

Velocity vector =
 $(b_1 = \frac{x(t) - x(t-1)}{\Delta t}, b_2 = \frac{y(t) - y(t-1)}{\Delta t})$

The inner product and outer product gives:

$$\text{For } \theta \in \left[-\frac{\pi}{2}, \frac{\pi}{2} \right] : \cos \theta = \frac{a_1 \cdot b_1 + a_2 \cdot b_2}{\sqrt{a_1^2 + a_2^2} \cdot \sqrt{b_1^2 + b_2^2}}$$

$$\text{For } \theta \in \left[\frac{\pi}{2}, -\frac{\pi}{2} \right] : \sin \theta = \frac{a_1 \cdot b_2 - a_2 \cdot b_1}{\sqrt{a_1^2 + a_2^2} \cdot \sqrt{b_1^2 + b_2^2}}$$

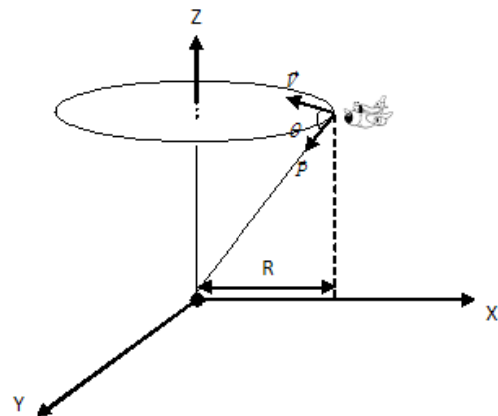


Fig. 9 Orientation of CanSat

Thus the control algorithm for stabilization and orientation of the CanSat are shown in Fig. 10 and Fig 11, respectively.

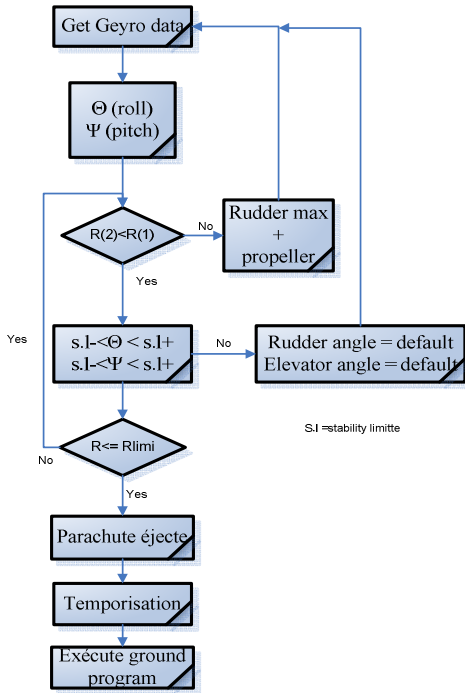


Fig. 10 Control algorithm; stabilization algorithm

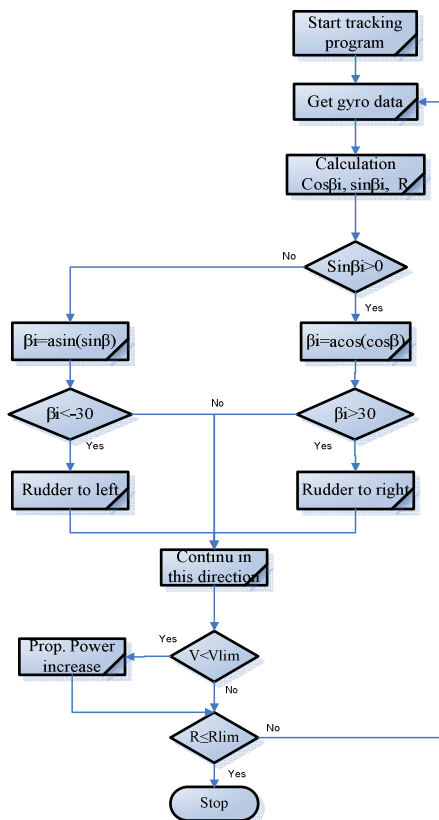


Fig. 11 Control algorithm; orientation algorithm

D. Dynamic Modeling and Simulation:

Figure 12 shows the simulation results of the trajectory of the CanSat during decent using the above mentioned stabilization algorithm.

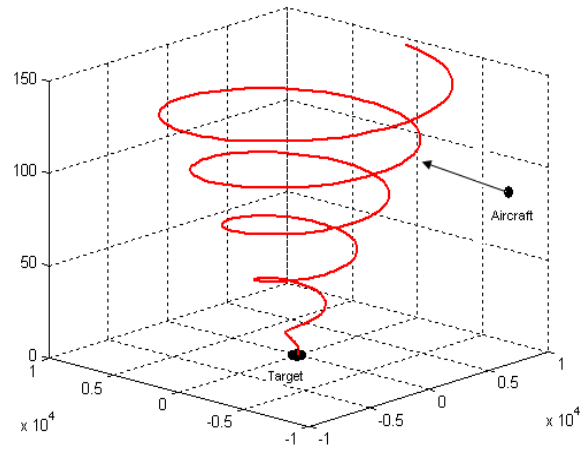


Fig. 12 Simulation of the control algorithm

E. Firmware Development:

The firmware development of the many sensors can be implemented easily by using ready-made codes from mbed cookbook. The present firmware development includes:

- Controlling of propeller Motor
- Controlling of elevators and rudder driving motors
- Accessing GPS data
- Interfacing Gyro, Acceleration, Pressure and Temperature Sensors
- Data Transmission using XBee Modules
- Controlling and navigation

Firmware developed in classes and libraries as shown in Fig. 13.

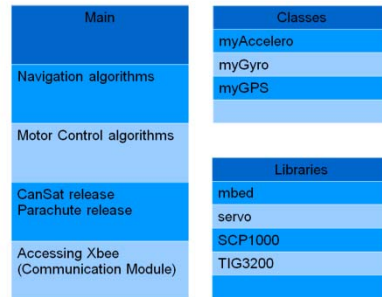


Fig. 13 Software development

Ground station software was developed using Matlab. Real-time data from different sensors and actuators status as well as the trajectory data which is passed on the processed GPS data can be visualized on the ground station interface screen, as shown in the Fig. 14.

F. Fabrication

Fabrication of the CanSat parts and component installations were the most time consuming process. Each modification of the airframe should be tested and should pass both the geometrical and weight contractions. Figure 15 shows the fabricated parachute attachment plate and releasing mechanism. Packaging test inside a compartment similar to that of the rocket is shown in Fig.16. Other fabrications

include tail unit, motor-driven propeller, rear and front landing gears and the servos installation.

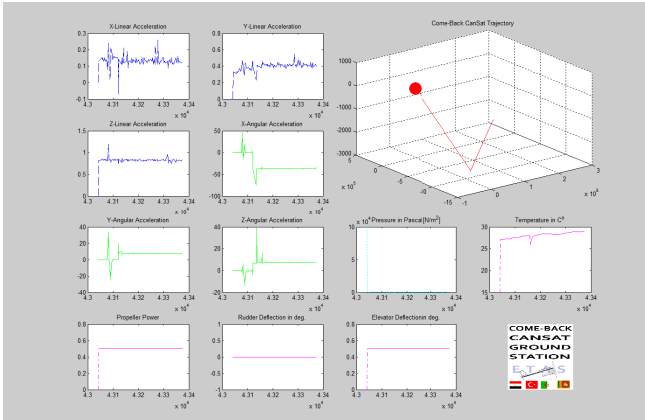


Fig. 14 Ground station software interface

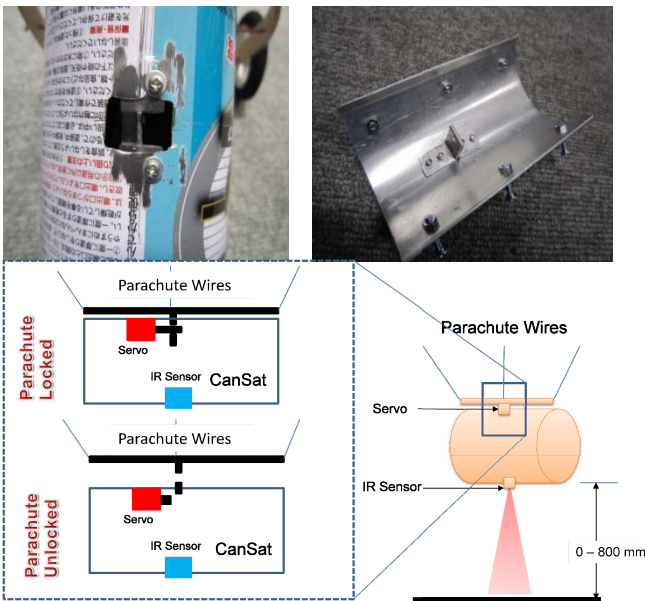


Fig. 15 Parachute releasing mechanism

G. Testing

Testing is the most crucial element of CanSat engineering each component is extensively tested during the firmware development and before final design review. Figures 17 and 18 show the testing results of the pressure and GPS sensors, respectively.

Other tests which have been performed as follows:

- Parachute Tests were performed to decide parachute diameter, stabilization hole diameter and rope length for stable descend and proper descend rate.
- Rover Tests were performed to decide proper angular velocity for turning in order avoid falling over
- Parachute Separation Mechanism tests were performed to ensure sustainable and reliable separation.
- Balloon Tests were performed to test whole process as shown in Fig. 19.

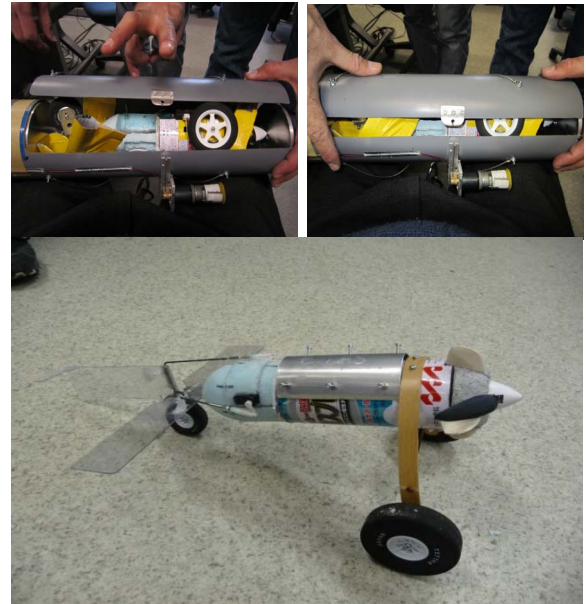


Fig. 16 Packaging of the CanSat

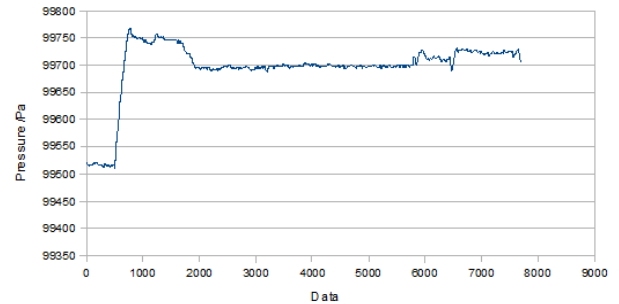


Fig. 17 Testing of pressure sensor

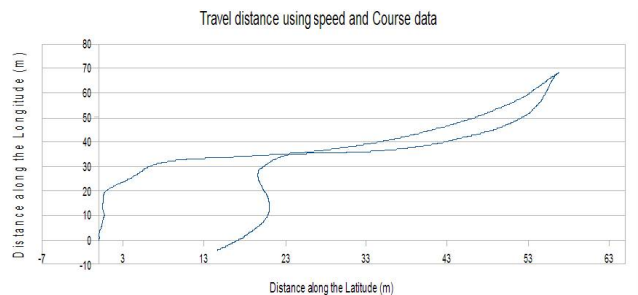
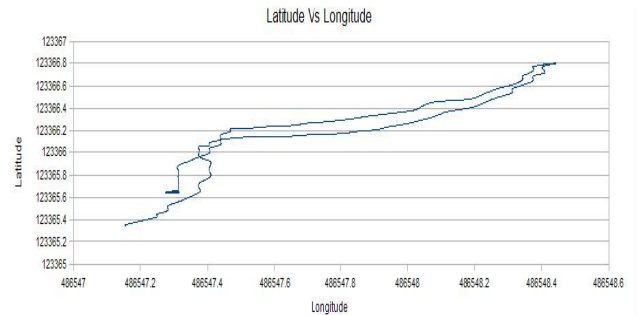


Fig. 18 GPS Testing

H. Risk Analysis

Risk analysis was performed to identify the most critical element and/or path for the whole mission.

The following issues are considered during the analysis.



Fig. 19 Balloon test

1. Loading Phase:
 - a. No smooth fitting inside the rocket.
2. Launch Phase:
 - a. Break in the hardware,
 - b. Motor's sudden start in the rocket due to vibration,
 - c. No start for the recording.
3. CanSat Deployment Phase:
 - a. No opening of the parachute
 - b. Motor's sudden start before parachute stability
 - c. No recording.
4. Navigation Phase:
 - a. Navigation control algorithm bugs,
 - b. No connection to satellites for GPS,
 - c. No connection with ground stations,
 - d. Improper control of the control surfaces and motor.
5. Landing Phase:
 - a. Parachute not release before touch down,
 - b. No landing on landing gears.
6. Rower Back Phase:
 - a. Non control of control surfaces and motor,
 - b. Bad GPS communications,
 - c. During rovering fold down of CanSat due to obstacles,
 - d. Bugs in the navigation algorithm.

I. Systems Engineering Process

System engineering planning is the first step in the System Engineering Process. Initial brain storming phase was done to develop an initial plan of how to best organize and manage people, resources, and materials needed for the project. Tasks, sequence of tasks, and estimated time required to complete tasks were identified to construct a Work Breakdown Structure (WBS) diagram. The following major task and milestones are identified: Preliminary Design Review (PDR), Engineering Model (EM), Quality Assurance (QA), Critical Design Review (CDR), Flight Model, and the launch date. The milestones are illustrated in the process plan for the construction of the CanSat as shown in Fig.20.



Fig. 20. Process plan for the construction of the CanSat

III. RESULTS, CONCLUSION AND LESSONS LEARNED

The first basic CanSat was launched from KADA launch site to 350m altitude in Wakayama, Japan using an amateur rocket. The wind was strong but the launch was proceeded as planned. Pre-launching procedure was executed successfully. Both the launching and parachute deployment was very successful. However due strong wind both the rocket and CanSat was drifted away. CanSat drifted until it became invisible by naked eye.

- Strong wind cause unsuccessful recovery and this warrant to perform simple aerodynamics calculation to ensure minimum drift.
- Telemetry sensor data and GPS should implemented
- Put your name and address on your CanSat

Due to earthquake that hit Japan on 11th March 2011 and the resulting tsunami and nuclear leakage the advanced level CanSat launch was cancelled.

The following key factors are highlighted during the development process of the CanSat project.

- Project Management
- System Engineering
- Team Work
- Communication
- Reliability

IV. REFERENCES

- [1] mbed programming workshop for CanSat, senio networks, inc. 2011,