RECONSO: A Debris-Detecting Satellite

ECE 4011 Senior Design Project

Project Advisor, Dr. Whit Smith

Team Operation J.A.G.A.N
Neha Nair, nehanair95@gatech.edu
Annu George, ageorge65@gatech.edu
Anjali Shankar, ashankar35@gatech.edu
Joanne Pokrzywa, jpokrzywa3@gatech.edu
Ganapathy Hari Narayan, ganapathy.hari.narayan@gatech.edu

Submitted

4/14/2017

Table of Contents

Executive Summary

RECONSO is working to detect and track small space debris in Low Earth Orbit. RECONSO is a student-run Cubesat initiative, funded by the Air Force Office of Scientific Research, with the objective of detecting and tracking space debris within Low Earth Orbit. RECONSO will track debris ranging from 1-10 cm in size using a Cubesat platform. The Cubesat platform will use a visible light lense and CMOS imager and downlink the information to the ground station [1].

RECONSO is divided into eight different subsystems: Communications (COMM), Command and Data Handling (CDH), Attitude Determination and Control System (ADCS), Electrical Ground Support Equipment (EGSE), Electrical Power System (EPS), Flight Software (FSW), Payload (PAY), Structures (STR), and Thermal (TCS). Each of these subsystems will work congruently to prepare for the launch in 2018 [1].

RECONSO: Space Debris Satellite

1. Introduction

Team Operation J.A.G.A.N will work with RECONSO to support any ECE related tasks specifically in the Communications (COMMS) and Command and Data Handling (CDH) subsystems.

1.1 Objective

The team will design various parts for the CubeSat which will aid in space debris detection in Low Earth Orbit. Space debris will be tracked using a visible light lense and a CMOS imager. Multiple frames will be used to track the space debris by recording the declination, right ascension, and photometric brightness of the debris and downlinking the respective data to the ground [1].

Operation J.A.G.A.N will be split between the COMMS and CDH subsystems. COMMS is the Telecommunications subsystem that is responsible for safe and reliable communication between the GT ground station and the satellite payload. Data will be transferred through the Globalstar network and from the ground station using a UHF packet radio. CDH interfaces all flight hardware with the main flight computer, the Tyvak Intrepid [1].

1.2 Motivation

There are over 500,000 particles that range from 1 to 10 cm in size orbiting Earth [2]. These smaller pieces of debris are significantly more difficult to track than larger debris, which is any piece of debris larger than 10 cm in size [3]. When in Low Earth Orbit, this debris can cause significant damage if it were to collide with any spacecraft. This will be the first CubeSat initiative with the main goal to detect small space debris.

1.3 Background

1.3.1 CubeSat

CubeSats are nano-satellites used specifically for research. They are characterized by the dimensions “Units” or “U” which are 10 cm x 10 cm x 11 cm [4]. CubeSats can measure 1U, 2U, 3U or 6U in size. CubeSats weigh approximately 1.33 kg per U. In addition to their small size, the appeal of these nano-satellites is their significantly lower cost. The cost of a CubeSat launch starts around $100,000 [5]. This is significantly cheaper than launching large geosynchronous orbits (GEO) satellites which can cost between $200-$500 million [6]. CubeSats are cheaper because they do not require a dedicated launch vehicle. Additionally, CubeSats are built with electronic circuit chips like microprocessors and radio frequency transmitters and receivers that are also used in smart-phones and other small electronics. The miniaturization of electronic devices has helped with the creation of nano-satellites.

2. Project Description and Goals

The goals mentioned below are based on the team’s understanding of the work done by each subsystem in RECONSO. These goals are likely to change by the time the team starts working on the project in Fall 2017. This is due to the progress RECONSO will make in Spring 2017 and Summer 2017.

2.1 COMMS

The goals specified by the COMMS subsystem have been listed below[7]:

- Establish UHF radio uplink/downlink to the satellite
- Establish Globalstar uplink/downlink to the satellite
- Transmit and execute satellite commands over RF
- Perform error checking and handling using software algorithms

2.2 CDH

The goals specified by the CDH subsystem have been listed below[8]:

- Interfaces all flight hardware with main flight computer, Tyvak Intrepid
- Integrate and tests CMOS camera, UHF radio, subsystem microcontrollers and sensors with ARM flight processor
- Implement on-board space object multiple hypothesis tracking algorithm in C/C++
- Assemble harnessing for I2C, USB, and SPI communication protocols
- Cross compile C/C++ packages, libraries, and dependencies for ARM processor
- Assembly of printed circuit boards with surface mount and through pin connectors for hardware interfacing

3. Technical Specifications

The technical specifications for COMMS and CDH are based on the goals specified by the subsystems.

3.1 COMMS

Table 1. Team requirements for COMMS subsystem

Item	Specification
UHF uplink/downlink	3 dB margin
Globalstar uplink/downlink	Y/N
RF Communication	Y/N
Error checking and handling	Y/N
Data Transfer Rate	9600 bits/s
Documentation for RECONSO	Y/N

3.2 CDH

Table 2. Team requirements for CDH subsystem

Item	Specification
Interface software with Tyvak Intrepid (main computer)	Y/N
Integrate and tests CMOS camera, UHF radio, subsystem microcontrollers and sensors with ARM flight processor	Y/N
Implement on-board space object multiple hypothesis tracking algorithm in C/C++	Y/N
Assemble harnessing for I2C, USB, and SPI communication protocols	Y/N
Cross compile C/C++ packages, libraries, and dependencies for ARM processor	Y/N
Assembly of printed circuit boards with surface mount and through pin connectors for hardware interfacing	Y/N
Documentation for RECONSO	Y/N

4. Design Approach and Details

4.1 Design Approach

4.1.1 COMMS

A detailed summary of the COMMS subsystem's design approach can be found in the document 'Telecom Interface Control' written by the lead of the COMMS team. This section following extract from the document Telecom Interface Control describes the design approach and the proposal document from the senior design team of Fall 2016:

“Mechanical Interfaces

Both communications modules (the NSL Eyestar module and the Tyvak UHF Radio Flight Unit) will be mounted with flat head and socket cap screws to the internal structure of the satellite towards the –X face for proximity to power systems and to reduce signal loss through cabling. The internal mounting scheme of the Eyestar allows for a 30.48 cm length of SMA coaxial cable to the patch antenna mount, which is the maximum specified in the Eyestar Duplex ICD....

The NSL Patch Antenna will be located on the negative X (−X) face of the spacecraft, which is located opposite of the camera. This is to accommodate the requirement of the camera to face away from the sun and to allow for optimal solar panel placement. To minimize line losses between the duplex module and the antenna, the transceiver units for both systems are placed as close as possible....

The UHF configuration for RECONSO will use a single deployable antenna module consisting of one dipole. The ISIS AntS antenna was selected for the purpose of providing sufficient omnidirectional signal coverage for data uplink. With regards to external placement, the selected configuration is advantageous in that the entire module of antennas is 9 mounted to a single external face. In addition, to minimize interference from the satellite, it is desirable to place these antennas as far as possible from the CubeSat structure. With this in mind, and seeking to optimize the location of the antennas, the camera, and other external components such as the solar panels, the UHF antenna, like the NSL patch antenna, will be

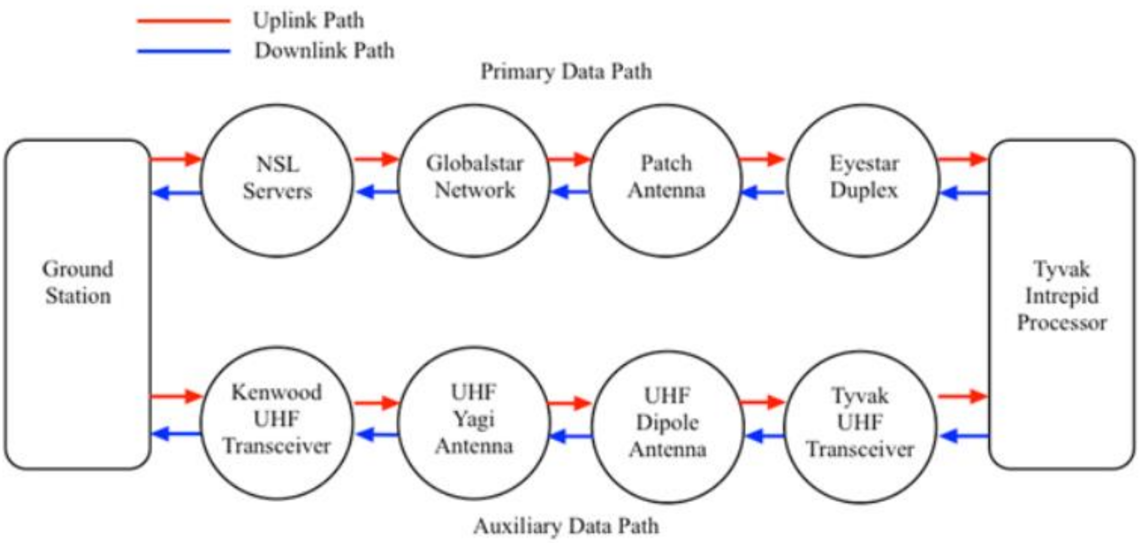
placed on the −X side of the CubeSat....

Electrical Interfaces

The Eyestar Duplex radio is the central electronic component of the subsystem. It connects to the NSL patch antenna with a 12 inch 50 Ω SMA coaxial cable, and sends data to the flight processor via a 9 -pin micro D serial UART connection. Cabling specification for the serial cable is included in appendix A. The Tyvak UHF Transceiver component connects to the ISIS AntS dipole antenna with a 12 -inch 50 Ω coaxial cable that has two female ends connecting the SMA output of the transceiver to the SSMCX input of the ISIS dipole. Additionally, the ISIS dipole system communicates directly with the flight processor via a 9 -pin Omnetics cable carrying two I2C busses for deployment information and system status data.

Data Input/Output Interfaces

Data exchanges between the ground station and the RECONSO flight processor can occur along two separate pathways: the Globalstar system primary pathway and the auxiliary UHF pathway. Figure 1 illustrates the hardware and software path of the data as it moves from



point to point.

Figure 1. Data flow block diagram

The UHF data communications system incorporates the AX.25 amateur radio packet protocol, Internet Protocol (IP) as a network layer, and User Datagram Protocol as a transport layer for network interfacing, but additional data protocols need to be defined. This protocol will be optimized for interfacing with the Core Flight Executive (cFE) software applications suite, which will govern all software exchanges and operations on the satellite. The Globalstar data communications system will function similarly, but all data will contain additional information that Near Space Launch uses to encode data transmissions to multiple satellites in orbit. Additional flight software routines will be required to extract data from the Globalstar packet Format."[7]

4.1.2 CDH

The CDH subsystem will focus on interfacing all the flight hardware with the main flight computer, the Tyvak Intrepid. The board itself is a custom Embedded Linux Build and has a AT91SAM9G20 processor @400Mhz. The board is space ready and mitigates radiation damage to the processor and memory. The following section focuses on the design approach for the main flight computer and CMOS camera being used for space debris detection.

Tyvak Intrepid

The Tyvak Intrepid board is the main flight computer which will be used to guide satellites, and provide processing power to the spacecraft bus and payload. Intrepid is equipped with a AT9I Sam9G20 processor at 400 MHz with 512 MB of flash memory and 32 MB Phase Change memory [9]. Tyvak Intrepid computer systems utilizes a distributed architecture with multiple on-board processors, each specifically tasked with providing mission critical capabilities. Intrepid is responsible for Command and Data Handling (CDH), radio interfaces, complex formation flight, rendezvous and docking algorithms, 'Guidance Navigation and Control', vehicle orientation control, and propulsive operations [10].

CMOS Camera

A Nocturn XL CMOS Camera attached to a Kowa LM60JS5MA lens will be used for capturing images of space objects. The Nocturn XL CMOS Camera, manufactured by PHOTONIS, is used because it has a Lynx CMOS imaging sensor that was designed specifically with night vision. The camera can operate in a temperature range of -40ºC to +60ºC. It has a sensor resolution of 1280x1024 pixels and a pixel pitch of 9.7 µm x 9.7 µm [11]. Once the satellite is deployed in low earth orbit, the camera captures several image datasets. There are multiple visible objects in each dataset. The main objective is to distinguish between stars and resident space objects. An intensity distribution of the image is described by a discrete mapping. The maxima of this mapping indicate the presence of stars or RSOs (resident space objects). Multiple image datasets are analyzed and stars are removed from consideration. This done by making a few assumptions. The object detection sets from the images are transferred to the on-board Raspberry Pi 2B processor which calculates the positions of space objects observed in the images. This information must be downlinked to the ground. The data is converted to an analog signal (470 MHz) [12].

4.2 Codes and Standards

The RECONSO CubeSat must follow the codes and standards for a 6U CubeSat. The dimension of the satellite must be 12 cm x 24 cm x 24 cm and weight should not exceed 12 kg [13]. The design specifications have been provided by the Air Force Office of Scientific Research. RECONSO must follow the standards of ITAR (International Traffic in Arms Regulation).

The UHF radio system uses amamteur frequencies and must comply with the regulations of those frequencies. UHF system will use AX.25, IP and UDP as networking protocols for L2, L3 and L4 communications respectively [7].

4.3 Constraints, Alternatives and Tradeoffs

Constraints

The size and weight specifications constrain the design of RECONSO's CubeSat. The satellite design must follow the specifications provided by Air Force Office of Scientific Research (AFOSR). Specific hardware must be used to ensure efficient power consumption. This hardware must also be able to handle the harsh environment in space. Deployer-specific requirements will impose additional constraints such as maximum mass, total envelope, or location of possible access hatches. Another major constraint is that all the different components on-board the satellite cannot be tested in their operating environment. This may lead to unforeseen issues once the satellite is in orbit [14].

Alternatives and Tradeoffs

Data will be transferred using the Globalstar satellite network and UHF packet radio because power consumption is a major constraint. Globalstar module is used because it simplifies data transfer. It allows data uplink and downlink irrespective of the ground station access window [7]. Globalstar is aligned towards US federal standards. It is an IP-based technology which makes it easy to interface and communicate with the network. Its low cost also makes it an ideal candidate. This system is used instead of the S-band system because S-band transmitters are expensive and require more power to operate.

All electronics on-board the satellite must be energy efficient. The increase in energy efficiency increases the operational time but computing performance may get affected. The Tyvak Intrepid processor is used instead of any regular processor that would cost less because it is space-rated. Also, the processor and memory are less sensitive to radiation.

5. Schedule, Tasks and Milestones

Appendix A includes a Gantt chart that shows the project timeline for COMMS and CDH subsystems. Appendix B includes two PERT charts (one for COMMS and one for CDH). The PERT charts show the most-likely, optimistic and pessimistic time for each task. The expected time taken to complete the project has been calculated based on the critical path. Currently, the team does not have access to the updated RECONSO timeline. The Gantt chart and PERT chart are based on their understanding of the tasks involved and their estimation of the time required to complete each task.

6. Project Demonstration

The project must be demonstrated during the Pre-Integration Readiness (PIR) tests mandated by the Air Force Research Lab. The tests are carried out to ensure that the satellite meets all specified requirements and is ready to launch [7].

Within CDH, the projected demonstrations include checking to see if the CMOS camera is functioning correctly based on the commands being sent from the onboard computer (Tyvak Intrepid), checking to see if the ARM processor can cross compile C/C++ packages and libraries, and to ensure if the hardware connected to the board is interfacing with the onboard flight computer.

The COMMS demonstration will have to show to and fro communication of the ground station with the satellite. This includes the establishment of UHF uplink/downlink with the satellite and the establishment of the uplink/downlink of the Globalstar network with the satellite. The communication system will have an efficient image transfer and telemetry over RF. Reboot over RF will also be demonstrated. The satellite to ground link will have error detection and error correction capabilities as well. At this time, the specifications of the communication system and the accuracy of the connection is not known to the team.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

The satellite is being developed by the Georgia Tech School of Aerospace Engineering for a University Nanosatellite Program (UNP-8) competition supported by the Air Force Office of Scientific Research. The satellite is not intended to be marketed. Data collected by the satellite will supplement the existing Space Surveillance Network (SSN) sensors [15]. Thus, marketing analysis has not been included.

7.2 Cost Analysis

The senior design team will join the ongoing project and contribute to the CDH and COMMS subsystems. The cost of materials for the hardware is not included in the cost analysis because the senior design team is not responsible for purchasing materials. The members are part of different subsystems and the required parts have already been ordered and delivered to RECONSO.

Labor costs are calculated by using a median starting salary of $73,000 per year for computer engineers [16]. Thus, each engineer earns approximately $40 per hour.There are 5 engineers working on the project for a time span of 16 weeks. The team's weekly meetings will last 3 hours. The members will have weekly meetings with their advisor which will last 1 hour. The team has also has to attend the weekly hour long RECONSO meeting. Each member of the team will spend 10 hours every week working on the project

Table 3. Overall labor costs for project

Project Component	**Labour hours**	**Labor Costs**	**Total Cost**
Design	160	$32000	$32000
Team Meetings	48	$9600	$41600
Advisor Meeting	16	$3200	$44800
RECONSO Meeting	16	$3200	$48000
Test demonstration	9	$1800	$49800
Projected Total	-	-	**$49800**

8. Current Status

Currently, the different subsystems are running command execution tests to make sure the various components of the satellite work correctly. They are preparing to demonstrate their work for the Pre-Integration Readiness tests as required by the Air Force Research Lab. Every subsystem maintains documentation to provide sufficient information to the new incoming teams. Team Operation J.A.G.A.N is currently working on understanding the details of RECONSO so that the members are prepared when they start working on the project in Fall 2017.

9. Leadership Roles

Every member of the team will lead different aspects of the project in ECE 4012. The table below mentions the leadership role taken up by each member.

Table 4. Team members and their leadership roles

Name	**Leadership Role**
Neha Nair	Team Leader
Ganapathy Hari Narayan	Web Master
Annu George	Documentation
Anjali Shankar	Expo Coordinator
Joanne Pokrzywa	RECONSO Contact

References

[1] M. Garcia, "Space Debris and Human Spacecraft," NASA, 2013. [Online]. Available: https://www.nasa.gov/mission_pages/station/news/orbital_debris.html. Accessed: Nov. 21, 2016.

[2] "Scanning & Observing," European Space Agency, 2013. [Online]. Available: http://www.esa.int/Our_Activities/Operations/Space_Debris/Scanning_observing. Accessed: Nov. 21, 2016.

[3] L. Z. 2016, "RECONSO," 2016. [Online]. Available: http://reconso.gatech.edu/. Accessed: Nov. 21, 2016.

[4]European Space Agency. (2013, April 20). ESA Heads Towards Removing Space Debris, [Online]. Available: http://www.esa.int/Our_Activities/Space_Engineering_Technology/Clean_Space/ESA_heading_towards_removing_space_debris.

[5] Dean, James (16 May 2015). "NASA seeks launchers for smallest satellites". *Florida Today*. 2015-05-16.

[6] R. Zelnio. "*The effects of export control on the space industry."* The Space Review, vol. 35, pp. 22-27, Jan. 2013.

[7] Montana Bowman, Brennan Bukovics, Luis Fernando Lopes, Keary Mobley, Changjun Ahn and Michael Reymond, "RECONSO: A Earth Orbit Object Detecting Nanosatellite," Georgia Inst. of Tech., Georgia, GA, April 2016.

[8] [Online]. Available: https://www.linkedin.com/in/lubna-zubair. [Accessed: April.9,2017].

[9] L. Zubair, J. Lee, S. Virani, T. Murphy, and M. Holzinger, "Hardware-In-The-Loop Comparison of space object detection and tracking methodologies," 2016. [Online]. Available: http://www.ssdl.gatech.edu/sites/default/files/papers/conferencePapers/AAS-16-266.pdf. [Accessed:Mar. 4, 2017].

[10] T. Inc, "Custom projects," 2016. [Online]. Available: http://www.tyvak.com/capabilities/. [Accessed: Mar. 5, 2017].

[11] "Photonis Nocturnal XL Technical Specifications," in http://www.nocturncamera.com/, 2014. [Online]. Available: http://www.nocturncamera.com/pdf/Nocturn_XL.pdf. Accessed: Mar. 5, 2017.

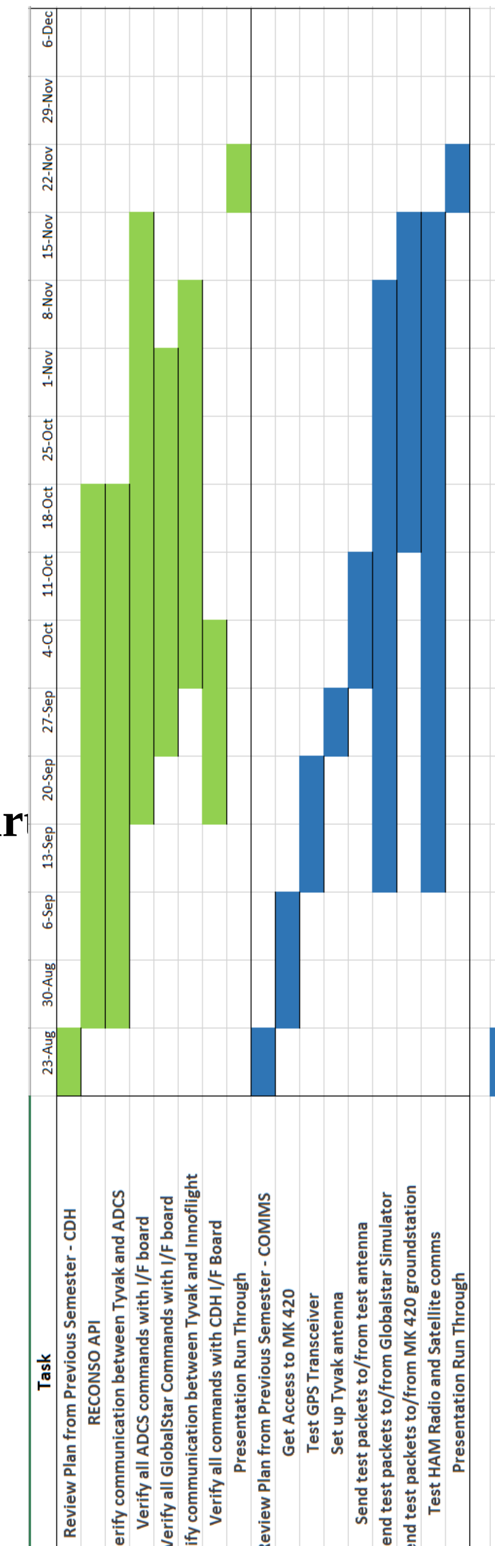
[12] Jefferson, Andy, and Agrawal, Varsha. Satellite Technology: Principles and Applications (3rd Edition). Somerset, NJ, USA: Wiley, 2014. [Online] Available: ProQuest ebrary
[13] "6U CubeSat Design Specification Rev. PROVISIONAL", 2015. [Online]. Available: https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/573fa2fee321400346075f01/1463788288448/6U_CDS_2016-05-19_Provisional.pdf. [Accessed: April 14, 2017]

[14] Erik Lomas, Yoontae Sim, Nam Son Phan, Jonathan Stai, Adam Stebbing, Tam Ton, "Space Debris Satellite (RECONSO)," Georgia Inst. of Tech., Georgia, GA, Nov 2016.

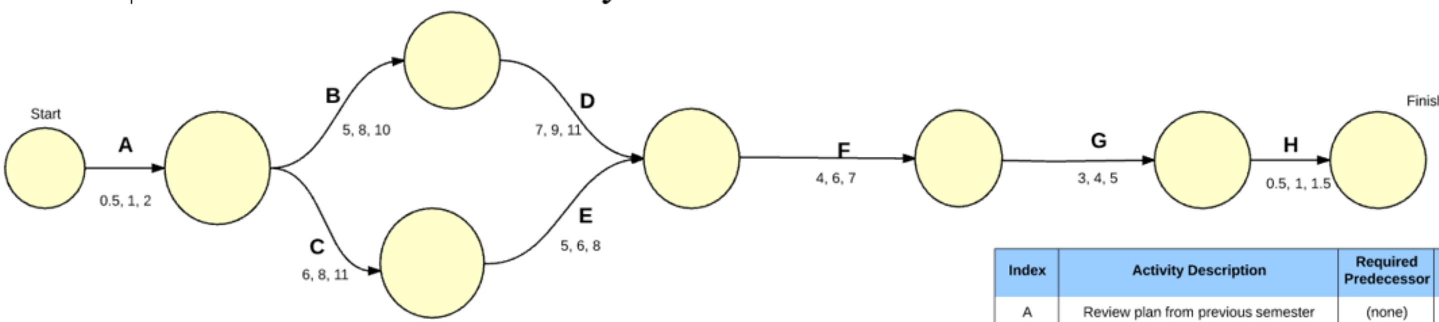
[15] [Online]. Available: http://www.ssdl.gatech.edu/research. Accessed: April 14, 2017

[16] Career and Salary Survey (2006-2016) [Online]. Available: https://webapps.gatech.edu/cfcampus/adors/commencement/salary_report_result.cfm?termcode=201608&college=3&level=1&surveyid=105&Submit=Submit. Accessed: April 12, 2017.

Appendix A: Gantt Chart



PERT Chart for CDH Subsystem



Index	Activity Description	Required Predecessor	Duration (weeks)
A	Review plan from previous semester	(none)	1
B	RECONSO API	A	8
C	Verify communication between Tyvak & ADCS	A	8
D	Verify all ADCS commands with I/F board	B	9
E	Verify all Globalstar commands with I/F board	C	6
F	Verify all communication between Tyvak & Innoflight Tyvak	D, E	6
G	Verify all commands with CDH I/F board	F	4
H	Run through for presentation	G	1

Appendix B: PERT Chart

Critical Path: A → C → E → F → G → H

Expected time: $t_e = (t_o + 4t_m + t_p)/6$

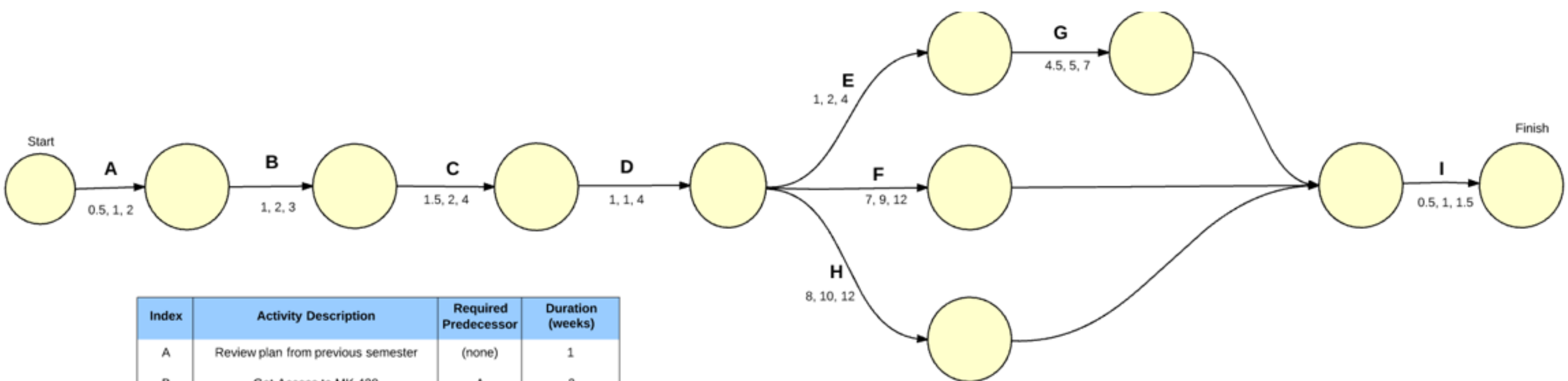
Activity	Expected Time (weeks)
A	1.083
B	7.833
C	8.167
D	9
E	6.167

F	5.833
G	4
H	1

Total expected time is expected time critical path.

Expected time for COMMS = 26.25 weeks

PERT Chart for COMMS Subsystem



Index	Activity Description	Required Predecessor	Duration (weeks)
A	Review plan from previous semester	(none)	1
B	Get Access to MK 420	A	2
C	Test GPS transceiver	B	2
D	Set up Tyvak antenna	C	1
E	Send test packets to/from test antenna	D	2
F	Send test packets to/from Globalstar simulator	D	9
G	Send test packets to/from MK 420 ground station	E	5
H	Test HAM radio and satellite comms	D	10
I	Presentation run through		1

Critical Path: A → B → C → D → E → G → I

Expected time: $t_e = (t_o + 4t_m + t_p)/6$

Activity	Expected Time (weeks)
A	1.083
B	2
C	2.25
D	1.5
E	2.167
F	9.167
G	5.25
H	10
I	1

Total expected time is expected time critical path.

Expected time for COMMS = 15.25 weeks