Title	A Model-Based Systems Engineering (MBSE) approach to development of attitude determination and control subsystem for first micro-satellite in Vietnam
Sub Title	
Author	Hiep, Cao Xuan(Ioki, Makoto) 五百木, 誠
Publisher	慶應義塾大学大学院システムデザイン・マネジメント研究科
Publication year	2016
Jtitle	
JaLC DOI	
Abstract	
Notes	修士学位論文. 2016年度システムエンジニアリング学 第226号
Genre	Thesis or Dissertation
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40002001-00002016-0011

Master's Dissertation 2016

A Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem for First Micro-Satellite in Vietnam

Cao Xuan HIEP

（Student ID Number：81434661）

Supervisor　Makoto Ioki

September 2016

Graduate School of System Design and Management,

Keio University

Major in System Design and Management

SUMMARY OF MASTER'S DISSERTATION

Student Identification Number	81434661	Name	Cao Xuan HIEP
Title A Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem for First Micro-Satellite in Vietnam			

Abstract

MicroDragon is the Vietnam's first microsatellite, being developed by collaboration of Vietnam and Japan since 2014. The satellite consists of seven subsystems. Among those subsystems, Attitude Determination and Control System (ADCS), which deals with determining the satellite orientation and controlling motion, is one of the most important and complicated subsystems. However, VNSC members, with lack of experience in prior satellite development, find it difficult to assess completeness and consistency in developing ADCS, particularly using a document-based approach.

This research aims at applying a model-based system engineering (MBSE) approach for designing ADCS for MicroDragon satellite. Beginning with analysing context, requirements, stakeholders and their needs, the development process continues with a functional analysis using use cases. Then ADCS architecture is designed. A model of ADCS is developed by using SysML. The verification of design is done by physical checking connections of ADCS components, making satisfy requirements matrix, and analysing traceability of requirements and performance in SysML. The validation of research is done by doing two kinds of interviews: one with VNSC member to assess the potential of MBSE, and the other with MDG members for the effectiveness of the ADCS model.

A model-based system engineering approach can support development of ADCS and provide an opportunity for inexperienced engineers to systematically understand ADCS development process.

Key Word(5 words)

MBSE, SysML, MicroDragon, ADCS, Micro Satellite

Acknowledgements

Foremost, I would like to express my sincere gratitude to my supervisor, Professor IOKI Makoto for the continuous support of my research, for his recommendations to direct the research and for his patience, motivation, enthusiasm and immense knowledge. The research would not have been completed without his support.

My honest thanks go to my second advisor Professor MAENO Takashi, Professor SHIRASAKA Seiko, and Professor NISHIMURA Hidekazu for spending time on helping me and giving me valuable comments and suggestions and for their great support during two years of my master course in SDM.

I would like to thank Mr VU Viet Phuong, Doctor LE Xuan Huy and Doctor TRUONG Xuan Hung for becoming interviewees in my research, for their great advices and comments during the interview.

I am thankful to HIRAMATSU Takashi Sensei, YAMAURA Shusaku Sensei, TOKAJI Ayumu Sensei, who provided me with an excellent atmosphere for doing research an patiently corrected my writing of this thesis.

I would like to thank my colleagues at Vietnam National Satellite Center for giving me great supports all the time I have stayed in Japan. Many thanks to NGUYEN Dinh Quan, DO Anh Tuan, TRINH Hoang Quan, NGUYEN Son Duong, NGUYEN Van Thuc, TRAN Van Ninh, NGO Thanh Cong and the other members of the MicroDragon project.

My sincere thanks go to School of Graduate System Design and Management, Keio University for providing me with all necessary facilities for the research, for compelling lectures and activities that I have had in the last two years.

Finally, my special thanks go to my family for giving me their endless love and encouraging me every moment I have stayed in Japan.

Japan, July 15, 2016

Cao Xuan HIEP

Table of Contents

Acknowledgements III

Table of Contents IV

Table of figures VI

Table of tables IX

List of Abbreviations XI

Chapter 1 Introduction 1

1.1 MircoDragon Project 1

1.2 Problems statement and Challenge 4

1.3 Research Objective and Approach 5

1.3.1 Research Objective 5

1.3.2 Research Approach 6

1.3.3 Originality of the research 6

1.4 Dissertation Outline 7

Chapter 2 Literature Review 8

2.1 Model-Based System Engineering 8

2.1.1 MBSE Overview 8

2.1.2 The Benefits of Applying MBSE Approach to Design Model of Complex System 11

2.1.3 The Tool of MBSE: SysML 13

2.1.4 Vitech MBSE Methodology 15

2.2 Existing Research used MBSE approach on complex system 24

2.2.1 Applying MBSE to a Standard CubeSat 24

2.2.2 Modelling an Attitude and Orbit Control System using SysML 25

Chapter 3 Design of ADCS for MDG by using Model-Based System Engineering Approach 27

3.1 Attitude Determination and Control System 27

3.1.1 Overview 27

3.1.2 Requirement of the Attitude Determination and Control System 30

3.1.3 Components of the Attitude Determination and Control System 32

3.1.4 Mode Operation of Attitude Determination and Control System..................42

3.2 System Design of MDG-ADCS 47

3.2.1 Requirements Analysis 48

3.2.2 Architectural Design 63

3.3 An ADCS model design by using SysML 72

3.3.1 System model organization 72

3.3.2 ADCS requirement diagram 74

3.3.3 ADCS behaviour...76

Chapter 4 Verification and Validation 83

4.1 Verification of ADCS requirements..84

4.1.1 Traceability between requirements and performance 84

4.1.2 Satisfy requirements matrix...86

4.2 Verification of MDG-ADCS connections..88

4.3 Validation by doing the interview..91

4.3.1 Interview with MDG-ADCS project members..91

4.3.2 Interview with manager from Vietnam National Satellite Center 97

Chapter 5 Conclusion 105

5.1 Summary of Research...105

References...106

Index 108

Table of figures

Figure 1.1-1: Roadmap of "Made-in-Vietnam" Satellites by VNSC 1

Figure 1.1-2: Micro Dragon Satellite 3

Figure 1.1-3:Subsystem in MDG satellite 3

Figure 2.1-1: Moving from document-centric to model-centric 8

Figure 2.1-2: The MBSE Integration across Domains 9

Figure 2.1-3: The Life cycle support 10

Figure 2.1-5: SysML diagram taxonomy.. 13

Figure 2.1-6: Vitech MBSE primary SE Domains 16

Figure 2.1-7: Vitech MBSE "Onion Model" 17

Figure 2.1-8: Vitech MBSE activities timeline in Top down Engineering. 20

Figure 2.1-9: Vitech MBSE activities timeline in reverse Engineering. 21

Figure 2.2-1: The research approach to model AOCS of Alessandroand Mauricio and Mauricio 26

Figure 3.1-1: Diagram of a Complete Attitude Determination and Control System 29

Figure 3.1-2: Offset nadir pointing and target pointing of MDG satellite...................... 30

Figure 3.1-3: Impacts of requirements from another subsystem to ADCS 32

Figure 3.1-4: Onboard computer of MDG satellite 33

Figure 3.1-5: Nonspin Solar Aspect Sensor AxelSun-1 34

Figure 3.1-6: Geomagnetic Aspect Sensor 35

Figure 3.1-7: The Axel Star -2 with a reference frame.. 36

Figure 3.1-8: The Fiber Optic Gyroscope TA7584 series 37

Figure 3.1-9: GPS receiver and GPS antenna 39

Figure 3.1-10: Reaction wheels 40

Figure 3.1-11: Magnetorquer used in MDG satellite... 42

Figure 3.1-12: The reliability of satellite form rocket 43

Figure 3.1-13: Coarse Sun pointing mode.. 44

Figure 3.1-14: The Fine Sun pointing mode.. 45

Figure 3.1-15: The Earth Sun pointing mode 45

Figure 3.1-16: The mode sequence working in MDG satellite 46

Figure 3.2-1: The steps in Requirements phase.. 47

Figure 3.2-2: The steps in Architecture Design 48

Figure 3.2-3: The life cycle of MDG satellite 49

Figure 3.2-4: The system of Interest of MDG-ADCS 49

Figure 3.2-5: The stakeholders in MDG-ADCS 50

Figure 3.2-6: Stakeholders and Viewpoints.. 50

Figure 3.2-7: The stakeholder need in MDG 51

Figure 3.2-8: The requirements analysis 52

Figure 3.2-9: Context analysis in deployment phase - Phase C 54

Figure 3.2-10: context analysis in nominal operations – phase D................................. 55

Figure 3.2-11: context analysis on De-orbit and close out – phase E............................ 56

Figure 3.2-12: The use case diagram of ADCS in deployment phase – phase C 57

Figure 3.2-13: Use case diagram of ADCS in nominal operations phase – phase D 59

Figure 3.2-14: Use case diagram of MDG-ADCS in De-Orbit and close out phase...... 61

Figure 3.2-15: the structure of ADCS... 64

Figure 3.2-16: The function flow in deployment phase 65

Figure 3.2-17: The allocations of function and subsystem in deployment phase........... 66

Figure 3.2-18: function follow in nominal operation phase 67

Figure 3.2-19: The allocations function and subsystem in nominal operation phase..... 68

Figure 3.2-20: Function follow in De-orbit and close phase 69

Figure 3.2-21: The allocations of function and subsystem in De-Obit and close phase 70

Figure 3.2-22: the Architectural diagram of ADCS in MDG satellite 71

Figure 3.3-1: System model organization 73

Figure 3.3-2: The requirements in detail 75

Figure 3.3-3: Internal block diagram of ADCS 77

Figure 3.3-4: The activity diagram of "GPS Receiver Processing" 78

Figure 3.3-5: The activity diagram of Sun sensor activity 79

Figure 3.3-6: The activity diagram of Star Tracker processing 80

Figure 3.3-7: The activity diagram of Gyro Sensor Processing 81

Figure 3.3-8: The activity diagram of Magnetometer Sensor Processing 82

Figure 4-1: Vee model for verification and validation of research 83

Figure 4.1-1: The relationships among those point of views 84

Figure 4.1-2: Traceability of requirements 85

Figure 4.1-3: Satisfy matrix of requirements and components 87

Figure 4.2-1: The test layout in Table Sat 88

Figure 4.2-2: ADCS components connection in satellite room 89

Figure 4.2-3: DAS computer on ground station room 89

Figure 4.2-4: Monitoring TLM received in DAS computer 90

Figure 4.3-1: The results of questionnaire with ADCS members 96

Table of tables

Table 1.1-1: The MDG satellite's parameters 4

Table 2.1-1: MBSE Grid.. 10

Table 2.1-2: Comparing between MBSE and Document based base on characteristics .11

Table 2.1-3: Vitech MBSE System Definition Language (SDL) 16

Table 2.1-4: Completion Criteria for Each Layer of the "Onion Model"....................... 18

Table 2.1-5: The learning objectives and sub-activities for Vitech MBSE Top-Level SE activities of source requirements analysis and architecture... 22

Table 2.1-6: System testing methods defined in the Vitech MBSE methodology.......... 23

Table 3.1-1: Steps in Attitude Determination and Control System Design 27

Table 3.1-2: The Specification of OBC in MDG satellite 33

Table 3.1-3: The specification of AxelSun -1 34

Table 3.1-4: The specifications of GAS 35

Table 3.1-5: The specifications of Axel Star - 2 37

Table 3.1-6: The main specifications of FOG TA7584 Series....................................... 38

Table 3.1-7: GPS receiver and GPS antenna Specification 39

Table 3.1-8: The specification of Reaction Wheel 41

Table 3.1-9: The specification of MTQ 42

Table 3.1-10: Activated components and actuators char 45

Table 3.2-1: The high level requirement for ADCS 51

Table 3.2-2: The use case analysis of deployment phase- phase C 58

Table 3.2-3: Use case analysis of MDG-ADCS in nominal operation phase................. 60

Table 3.2-4: Use case analysis of MDG-ADCS in De-Orbit and close out phase 62

Table 3.3-1: High Level Requirements.. 74

Table 4.3-1: Interviewees 92

Table 4.3-2: Questionnaire for ADCS members 93

Table 4.3-3: The questions and answer of interview with manager 1 98

Table 4.3-4: List of questions and answers with manager 2 101

List of Abbreviations

Abbreviation	Explanation
ADCS	Attitude Determination and Control subsystem
AGI	Analytical Graphics, Inc
AOCS	Attitude and Orbit Control System
AOS	Atomic Oxygen Sample
ATOCSC	Antimony Tin Oxide Coating Solar Cell
CMD	Command
COM	Communication Subsystem
DAS	Data Acquisition System
EFFBSs	Enhanced Function Flow Block Diagrams
EPS	Electric Power subsystem
FOG	Fibber Optics Gyroscope
GAS	Geomagnetic Aspect Sensor
GPS	Global Positioning System
INCOSE	International Council on Systems Engineering
INPE/CSE	Instituto Nacional de Pesquisas Espaciasis
LTDN	Local time at Descending Note
MBSE	Model-Based System Engineering
MBSE SDL	MBSE System definition language
MDA	Model-Driven Architecture
MDG	Micro Dragon
MoEs	Measure of Effectiveness
MXL	Michigan Exploration lab
NASA	National Aeronautics and Space Administration
NSAS	Nonspin Solar Aspect Sensor
OMG	Object Management Group
PSM	Platform Specific Model
S&F	Store and Forward
SAP	Solar Array Paddle
SE	System Engineering

SMI	Space-borne Multispectral Imager
STR	Structure subsystem
STT	Star Tracker
SysML	System Modelling Language
TLM	Telemetry
TPI	Triple Polarization Imager
UML	Unified Modelling Language
V&V	Verification and Validation
VNSC	Vietnam Nation Satellite Center

Chapter 1 Introduction

1.1 MircoDragon Project

The first successful satellite made by Vietnamese was launched in 2011 is called PicoDragon. Now Vietnam is starting a big project - "MicroDragon Project" to develop space technology in Viet Nam.

MicroDragon Project is founded by Vietnam National Satellite Center (VNSC) under cooperation in space technology between Vietnam and Japan government in October 2014. Within the framework of the project, 35 researchers of VNSC have been sent to five Japanese universities (The University of Tokyo, Keio University, Tohoku University, Kyushu Institute of Technology, and Hokkaido University). They are taking master courses about satellite technology in order to work for Vietnam Space Center when it is completed. During the time in Japan, they also participate in an educational satellite project. The result of this project will be the first Vietnamese micro satellite called MicroDragon (MDG).

The roadmap of satellite development in Vietnam made by VNSC is illustrated in Figure 1.1-1 [1]

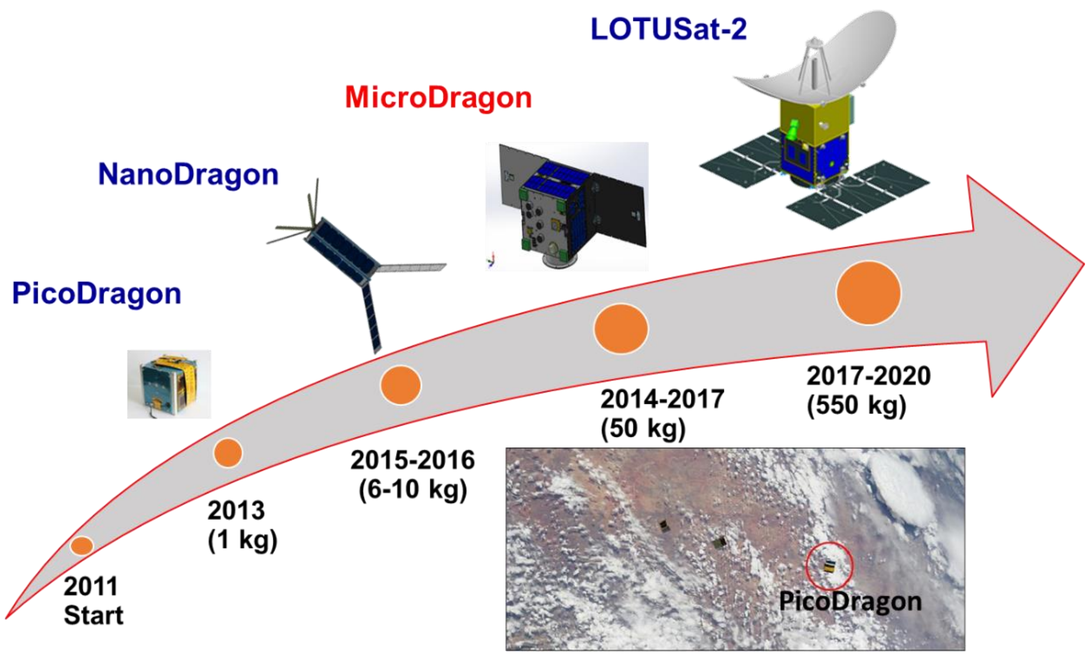

Figure 1.1-1: Roadmap of "Made-in-Vietnam" Satellites by VNSC

MDG satellite is a micro satellite with size 50 cm x 50 cm x 50 cm and mass less than 50 kg. MDG satellite being developed by 35 researchers from VNSC from October 2014 to end of 2018. The satellite is planned to be launched by Epsilon rocket in 2018.

The primary mission of MDG satellite [2]:

- To observe ocean colour in order to assess coastal water quality, locate living resources, and monitor changes of phenomena in coastal water for aquaculture development in Vietnam.
- To detect cover of cloud and characteristics of aerosols for atmospheric corrections.

The secondary missions are [2]:

- *Store and Forward (S&F)*: Use the FluoreProbe sensors to measure information from coastal water and send it to the satellite via UHF frequency when satellite is passing through. This information will be stored in satellite and when the satellite passed over the ground station, the data will be forwarded to ground station.
- *Antimony Tin Oxide Coating Solar Cell (ATOCSC)*: used to verify the charging mitigation capability of Antimony Tin Oxide. By using measuring circuit once every 30 days, current and voltage generated by this solar cell shall be used to assess the reduction in efficiency of coating solar cell.
- *Atomic Oxygen Sample (AOS)*: A satellite moves through the atomic oxygen at a velocity of about 7.5 km/sec at orbital altitudes. Although the density of atomic oxygen is relatively low, the flux of atomic oxygen is high. The large flux of atomic oxygen, which is in a highly reactive state, can produce serious erosion of surfaces through oxidation. Besides, it can alter the conductive or insulating of material. AOS is used to assess these damages on orbit.

Figure 1.1-2 shows a body of MDG satellite without solar cell and overview position of components inside. The cameras are installed in the +Z surface. [2]

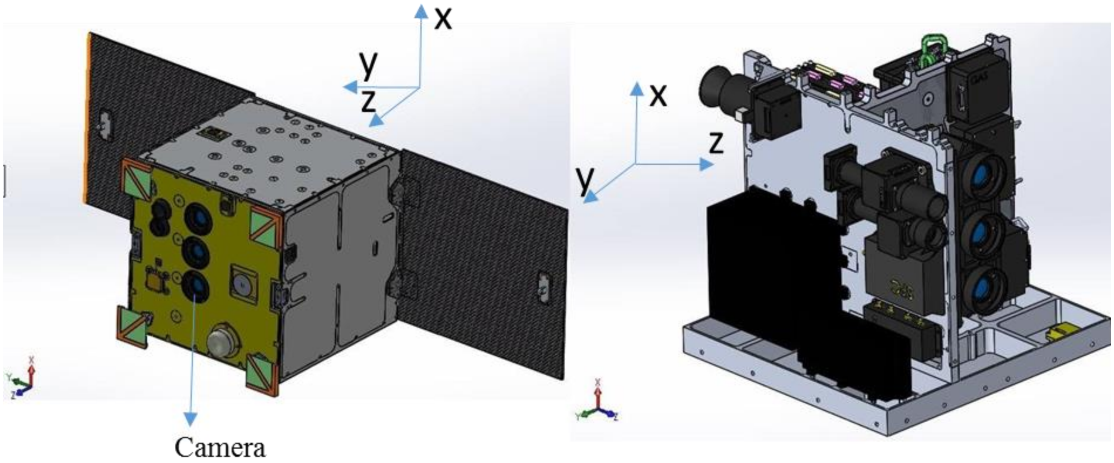

Figure 1.1-2: Micro Dragon Satellite

MDG satellite consists of seven subsystems: (1) Structure subsystem (STR), (2) Electric Power subsystem (EPS), (3) Thermal subsystem, (4) Payload subsystem, (5) Communication subsystem, (6) Command & Data Handling subsystem, (7) Attitude Determination and Control subsystem (ADCS). Figure 1.1-3 shows the seven subsystem in MDG.

Regarding of an interview with managers of VNSC, among seven subsystems, ADCS is one of most important and most complex subsystem. ADCS have function are to determine the orientation of the satellite and re-orient the satellite to the target direction.

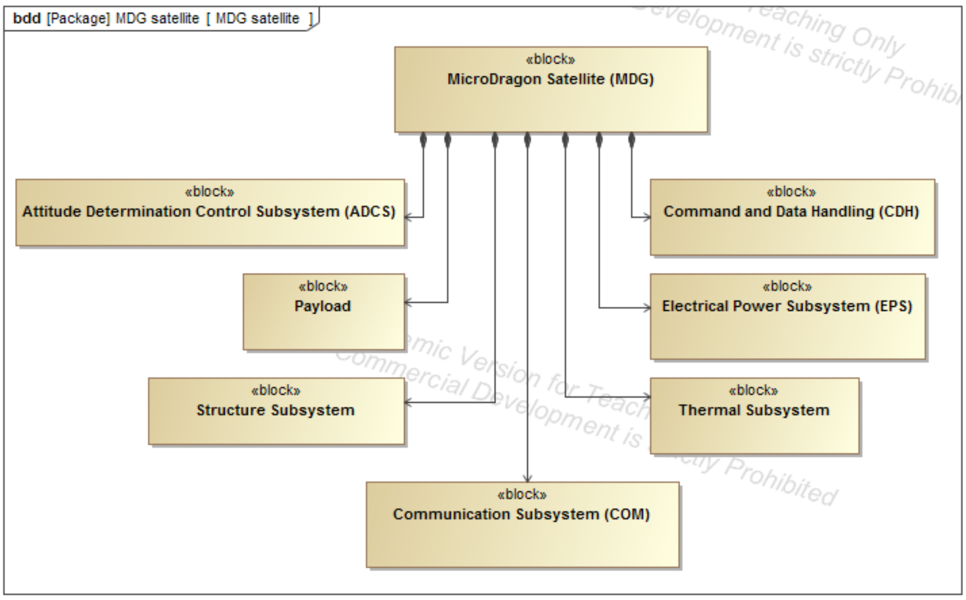

Figure 1.1-3:Subsystem in MDG satellite

The MDG satellite's parameters are illustrated in Table 1.1-1 [3]

Table 1.1-1: The MDG satellite's parameters

Satellite mass, size	50 kg, 50 cm x 50 cm x 50 cm
Orbit	Type: Sun Synchronous Orbit Local time: LTDN 13:00 Altitude: 550 [km] Inclination: 98 [deg]
Main Payload	Space-borne Multispectral Imager (SMI) and Triple Polarization Imager (TPI) cameras
ADCS (Attitude Determination and Control Subsystem)	Nonspin Solar Aspect Sensor (NSAS) (6), Geomagnetic Aspect Sensor (GAS), Star Tracker (STT), Fibber Optics Gyroscope (FOG), GPS Receiver – Magnetic Torques (3), Reaction Wheels (4)
RF Communication (COM)	– S-band: downlink = 64 Kbit/s, uplink = 4 Kbit/s; 2 S-band patch antennas – X-band transmitter: 10 Mbit/s, CCSDS compliant; X-band Iso-flux antenna
Electrical Power Subsystem (EPS)	SAP generation: 140W (max) Li-Ion battery: 22.0-33.6 V, capacity: 5800 mAh

1.2 Problems statement and Challenge

Vietnam has a long way to develop space technology. In the near future, Vietnam wants to develop many satellites: micro satellite will be launched in the 2018, Lotus-1 satellite will be launch in 2020, and Lotus-2 satellite will be launched in 2022 [2]. The purpose of whole MDG satellite project is not only have a MDG satellite. By doing MDG satellite project, VNSC and MDG-ADCS members have a good opportunity to deeply understand the micro satellite development process in general and ADCS development process in particular.

However, the ADCS in MDG satellite is most complex ADCS they faced so far. MDG-ADCS team is lacked of experience members since most of members in MDG-ADCS team have not developed any ADCS in micro satellite before. For example: During the conceptual development project, many ADCS members asked questions: How do we understand relationship between requirements and current design, where does it come from? How they can make a traceability between requirement and Verification and Validation (V&V) activity? How they can satisfy requirement?

For developing MDG-ADCS, VNSC assigned three batch of students to study master's program in japan to learn space technology. Then when they finish master's program in two years, they will go back to Vietnam. Since each bath students has only two year work in ADCS, therefore they need to transfer knowledge to next new batch students before they go back Vietnam.

Developing a successful ADCS in current situation is challenge for ADCS team members.

Traditionally, large projects have employed a document-based approach to performing the systems engineering activities. This approach produces a variety of textual specifications and design documents in independence. It shows three disadvantages for micro satellite project like MDG satellite project when they use document-based approach [4]:

- MDG-ADCS members are difficult to assess completeness and consistency of information spread across in several documents
- Document-Based approach is Difficult to perform traceability
- MDG-ADCS members is difficult to understand a particular aspect of the system and explicitly explain relationship among design view, V&V view and requirements views.

1.3 Research Objective and Approach

1.3.1 Research Objective

This research has two main objectives

The first objective is to support for inexperienced member in MDG-ADCS team to understand the whole ADCS development process. Inexperienced member in MDG-ADCS will get better understanding of ADCS development process and answer the question how the ADCS of micro satellite can be develop by themself.

The second objective is to design an ADCS model by using an MBSE approach, specifically using System Modelling Language (SysML) for MDG-ADCS. The ADCS model will be designed from many view point: the requirement view, function view, components view, and performance view. The model can be reused and apply to another micro satellite project in VNSC in the future.

1.3.2 Research Approach

By comparing with Document-Based approach in satellite project, the benefit of Model-Based is figured out. The research will use Model-Based approach to design an architecture of MDG-ADCS. Then the MDG-ADCS model is designed by using SysML. By practicing in MDG-ADCS, inexperience members will have strong experiences to develop many micro satellite in near future in Vietnam.

The test in table Sat – the test activities on satellite room at University of Tokyo, is conducted to verify interface between components and functions.

The two interviews with MDG-ADCS members and VNSC managers are conducted to validate the research objectives.

1.3.3 Originality of the research

This research is introduced a model-based systems engineering approach to development of attitude determination and control subsystem for first micro-satellite in Vietnam in a way to support inexperienced members in MDG project and enhance the document reusable.

Using the MBSE to development of ADCS in the research is not new. However, the way of thinking to design ADCS architecture and ADCS model with SysML tool to support inexperience members in MDG project is more effective. It is more helpful for developing country which MBSE or satellite technology have not become popular.

1.4 Dissertation Outline

This dissertation have five chapters and followed by list of references.

Chapter 1 provides an overview of the research. Starting with introduction of MicroDragon satellite project, the problems statement and challenges will be analysed, why is problems come out? Why the research is needed? This part will give a motivation for doing research. Finally, research objectives and approach are discussed

Chapter 2 provides a survey of the literature. In the first part, Model-based system engineering will be discussed: A definition of MBSE in system engineering, the benefits of applying MBSE approach to design complex system why SysML is chosen for doing MBSE? And MBSE method. In the second part, a survey of existing research used MBSE approach on complex system will be provided.

Chapter 3 provides a design ADCS for MDG by using Model-Based System Engineering Approach. The first part of chapter is to analyse an attitude determination and control subsystem in MDG satellite. The requirement, components, mode operation of ADCS is analysed. Then by using MBSE approach, system design of MDG-ADCS is designed. Finally, the model of MDG-ADCS is design by using SysML.

Chapter 4 shows a process of verification and validation. In verification process, MDG-ADCS is verified by doing test performance, by analysing traceability between requirements and performance. In validation process, the research will do questionnaire with MDG project members and interview with experts of satellite.

Chapter 5 summarizes result of research for conclusion.

Chapter 2 Literature Review

2.1 Model-Based System Engineering

2.1.1 MBSE Overview

A mathematical formalism for MBSE was introduced in 1993 by Wayne Wymore [5]. It is becoming more popular and has been standard practice in electrical and mechanical design and other disciplines for many years. With support from technology development like: increasing capability of computer processing, internet high speed and network technology, it is expected that MBSE will become standard practice in system engineering. Figure 2.1-1 [6] shows the moving trend from document-centric to model-centric in SE practices for describing systems.

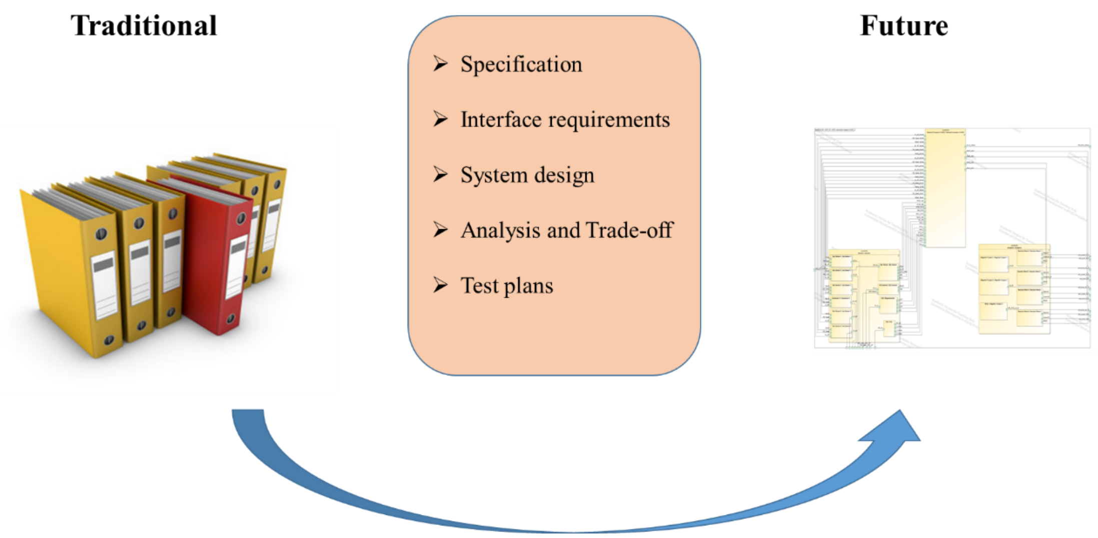

Figure 2.1-1: Moving from document-centric to model-centric

In INCOSE SE vision 2020 (INCOSE-TP-2004-004-02, Sep 2007), the definition of MBSE is:

"Model-based systems engineering (MBSE) is the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases." [7]

In order to support systems engineering activities, MBSE will be support in enhanced specification and design quality, reuses of system specification and design artifact, and communication among the team members in project. The output of the systems engineering activities is a coherent model of the system (i.e., system model). Figure 2.1-2 [8] shows How MBSE interact with other domains in SE process.

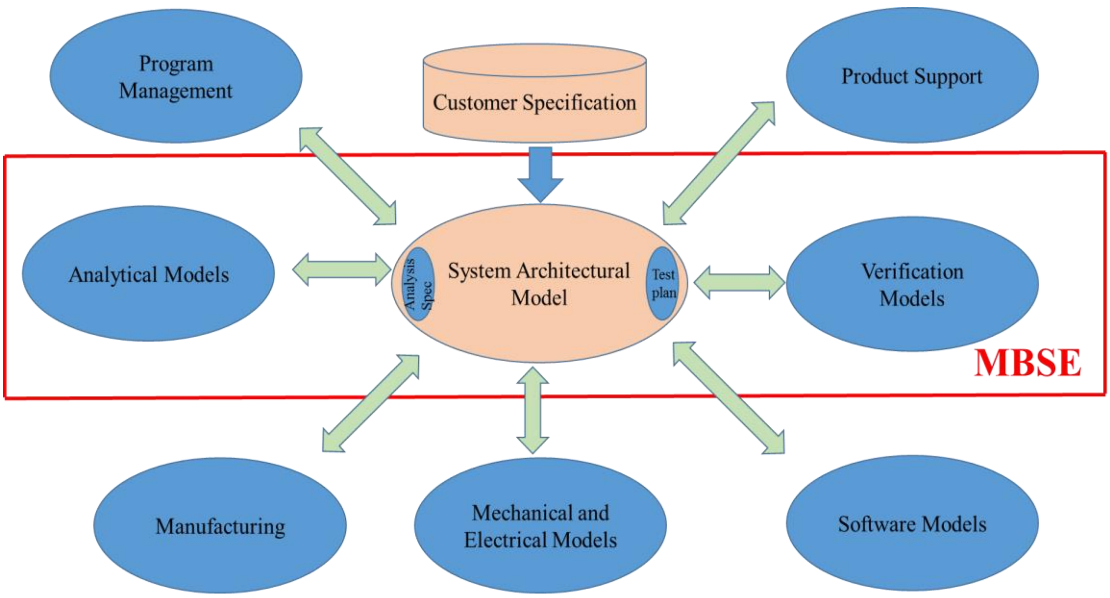

Figure 2.1-2: The MBSE Integration across Domains

In MBSE approach, it have four pillars to represent a system model: Requirement, behaviour, structure and parametric. Layer of abstraction are: concept, problem and solution.

The relationship between Layer of abstraction and pillar in MBSE are shown in the Table 2.1-1. [8]

Table 2.1-1: MBSE Grid

	Pillar				
Layer of Abstraction		**Requirements**	**Behavior**	**Structure**	**Parametrics**
	Concept	User needs	Use cases	System context	Measurements of Effectiveness(MoES)
	Problem	System requirements	Functional Analysis	Subsystems Communication Description	MoES for Subsystems
	Solution	Component Requirements	Component Behavior	Components Assembly	Physical Characteristics

There are three focus of interest in MBSE

- Formalize the practice of systems development through the use of models
- Broad in scope: includes multiple modelling domains across life cycle from concept, operational models, system models to component models
- Result in quality or productivity improvements and reduce risk: Rigor and precision, communication among development team and customer, management of complexity in system.

In general, life cycle support have four phases: Concept, System Development, Production and Operations & Support.

Figure 2.1-3 shows the life cycle support in SE activities:

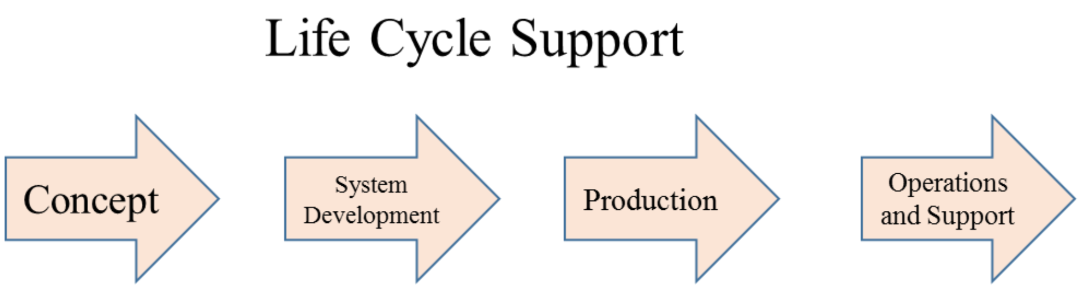

Figure 2.1-3: The Life cycle support

2.1.2 The Benefits of Applying MBSE Approach to Design Model of Complex System

MBSE applies systems modelling as a part of system engineering process to support analysis, specification, design, and verification of the system being developed. A primary aritfact of MBSE is a coherent model of the system being developed. This approach enhances specification and design quality, reuse of system specification and design artifacts, and communications among the development team.

By comparing with document-based approach, The MBSE show some advantage for developing MDG project. MBSE provides multiple aspects of the system for capturing and integrating system requirements, design, analysis, verification and validation information, assessment, and communication of information across the system's life cycle. The information base on characteristics of MBSE and documents based is illustrated in the Table 2.1-2 [8]

Table 2.1-2: Comparing between MBSE and Document based base on characteristics

	Documents based	MBSE based
Information	- Mostly Textual document - Add Hoc Diagrams - Loosely coupled, repeated in multiple documents	- Visual and textual - Constructs defined once and re-used - Shared across domains - Consistent notation in diagrams - Defined relationships
Information View	- By Text document	- Provides viewpoints - Filters by domain, problem space
Measuring change impact	- Spans across multiple documents - Often text req. Are isolated form structure and behaviour	- Relationships define traceability paths. - Natural part of the modelling process

		- Programmatically automated
Measuring integrity-completeness, quality & accuracy.	- By manual inspection	- Programmatically automated - Animation of Specification

Some of the MBSE potential benefits is listed below: [4]

- Enhanced communications
    - Shared understanding of the system across the development team and other stakeholders
    - Ability to integrate views of the system from multiple perspectives
- Improved quality
    - More completed, unambiguous, and verifiable requirements
    - More rigorous traceability between requirements, design, analysis, and testing
    - Enhanced design integrity
- Increased productivity
    - Faster impact analysis of requirements and design changes
    - More effective exploration of trade-space
    - Reuse of existing models to support design evolution
    - Reduced errors and time during integration and resting
    - Automated document generation
- Leveraging the models across life cycle
    - Support operator training on the use of the system
    - Support diagnostics and maintenance of the system
- Enhanced knowledge transfer
    - Capture of existing and legacy designs
    - Efficient access and modification of the information
- Reduced development risk
    - Ongoing requirements validation and design verification
    - More accurate cost estimated to develop the system

2.1.3 The Tool of MBSE: SysML

MBSE is a combination of a modelling language, a methodology and a modelling tool that together provide a productive infrastructure for applying model-driven development in the context of a particular organization.

For a modelling language in research, Object Management Group (OMG) and INCOSE (International Council on Systems Engineering's) have specified OMG Systems Modelling Language (SysML). So, to become more popular and standardize, I chosen SysML is a tool for doing MBSE.

SysML is a general-purpose graphical modelling language that supports the analysis, specification, design, verification, and Validation of complex systems. Many satellite project and space organization like NASA use SysML as a standard modelling language.

SysML is good candidate for modelling an Attitude Determination and Control Subsystem in MDG satellite.

Figure 2.1-4 [4] shows the SysML diagram taxonomy, SysML have nice diagrams: package diagram, behaviour diagram, requirement diagram, parametric diagram, structure diagram.

In behaviour diagram, it includes four diagrams: use case diagram, activity diagram, sequence diagram, state machine diagram.

In structure diagram, it includes two diagrams: block definition diagram and internal block diagram. Each diagram type is summarized in the below, along with its relationship to UML diagrams [4].

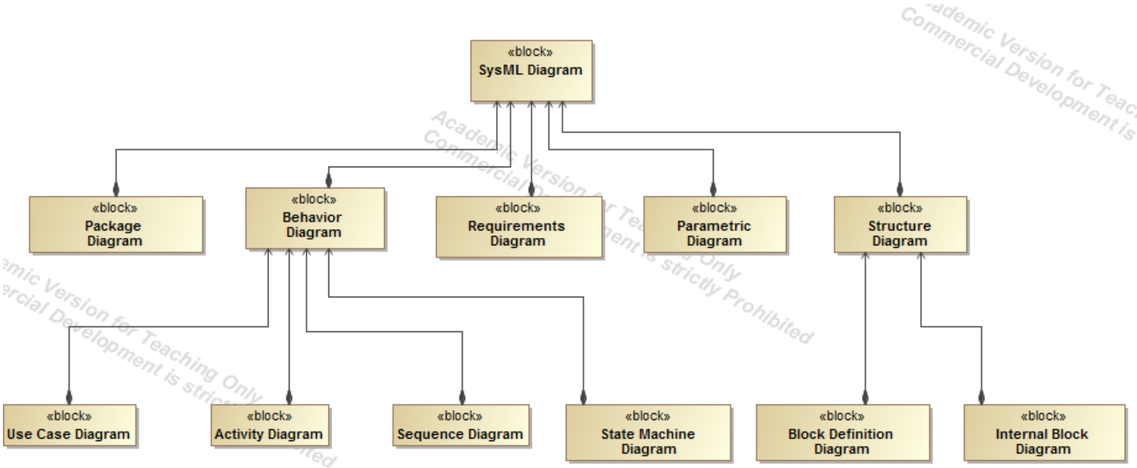

Figure 2.1-4: SysML diagram taxonomy

- *Requirement diagram* represents text-based requirements and their relationship with other requirements, design elements, and test cases to support requirements traceability (not in Unified Modelling Language (UML))
- *Activity diagram* represents behaviour in terms of the order in which actions execute based on the availability of their inputs, outputs, and control, and how the actions transform the inputs to outputs (modification of UML activity diagram)
- *Sequence diagram* represents behaviour in terms of a sequence of messages exchanged between systems, or between parts of systems (same as UML sequence diagram)
- *State machine diagram* represents behaviour of an entity in terms of its transitions between states triggered by events (same as UML state machine diagram)
- *Use case diagram* represents functionality in terms of how a system is used by external entities (i.e., actors) to accomplish a set of goals (same as UML use case diagram)
- *Block definition diagram* represents structural elements called blocks, and their composition and classification (modification of UML class diagram)
- *Internal block diagram* represents interconnection and interfaces between the parts of a block (modification of UML composite structure diagram)
- *Parametric diagram represents* constraints on property values, such as F [m * a, used to support engineering analysis (not in UML)

2.1.4 Vitech MBSE Methodology

The Vitech is providers of the CORE product suite- one of most professional tool for MBSE. Vitech proposed a methodology for MBSE approach called by name Vitech MBSE.

The Vitech MBSE methodology is based on four primary concurrent SE activities. Each of these primary SE activities is linked within the context of associated labelled is "domains". The SE activities are considered elements of a particular kind of domain known as the process domain.

Figure 2.1-5 shows the Vitech MBSE primary SE Domains.

In the Vitech MBSE methodology, MBSE System definition language (MBSE SDL) is needed to manage model artifacts. They defined English equivalent for: Element, Relationship, attribute, attribute of relationship. An example of a Vitech – specified MBSE SDL is illustrated in Table 2.1-3 [9]

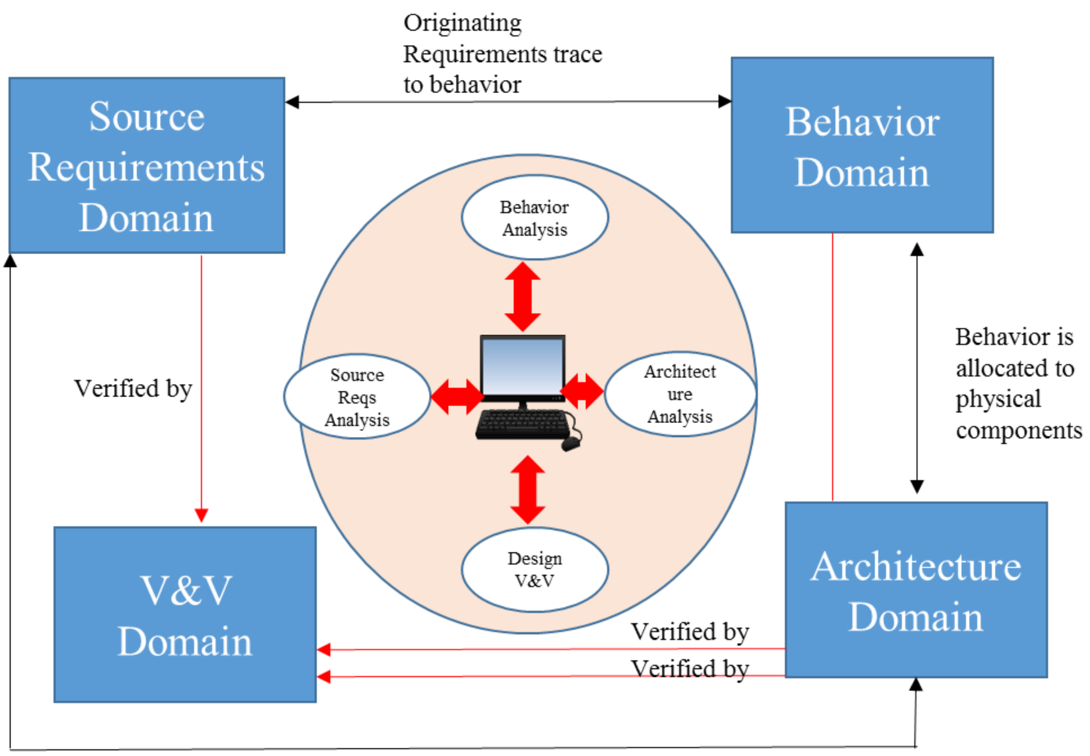

Figure 2.1-5: Vitech MBSE primary SE Domains

There are four core tenets help drive the Vitech MBSE methodology [9]:

1. Model via modelling "language" the problem and the solution space; include semantically-meaningful graphics to stay explicit and consistent. This helps facilitate model traceability, consistent graphics, automatic documentation and artifacts, dynamic validation and simulation, and promotes more precise communication.
2. Utilize a MBSE system design repository.
3. Engineer the system horizontally before vertically, i.e., do it in complete, converging layers.
4. Use tools to do the "perspiration stuff" and your brain to do the "inspiration stuff".

Table 2.1-3: Vitech MBSE System Definition Language (SDL)

SDL Language	English Equivalent	MBSE Example
Element	Noun	• Requirement: Place Orders • Function: Cook Burgers • Component: Cooks
Relationship	Verb	• Requirement basis of Functions • Functions are allocated to Components
Attribute	Adjective	• Creator • Creation Date • Description
Attribute of Relationship	Adverb	• Resource consumed by Function • Amount (of Resource) • Acquire Available (Priority)
Structure	N/A	Viewed as Enhanced Function Flow Block

		Diagram (EFFBD) or FFBD

The Vitech created an "Onion Model" to support tenet number 3 above, which allow complete interim solutions at increasing levels of detail during the system specification process [9]. In Vitech MBSE Onion Model, it have many layer.

Layer 1: from source documents, it will go to originating requirements analysis, behaviour analysis, synthesis/ architecture and final is design V&V. When finish layer 1, it like a draft 1.

Layer 2: From the result of layer 1, Initial requirements for this layer are embodied in the model passed. Next is behaviour analysis, synthesis/ architecture, design V&V. Compare with layer 1, layer 2 is more completed. However, it still is draft 2.

Layer n: It will become a final and completed.

Through do many layer, the engineering activities will be updated which is more completed than previous layer.

The primary concurrent engineering activities at each layer shows more detailed in Figure 2.1-6 [9].

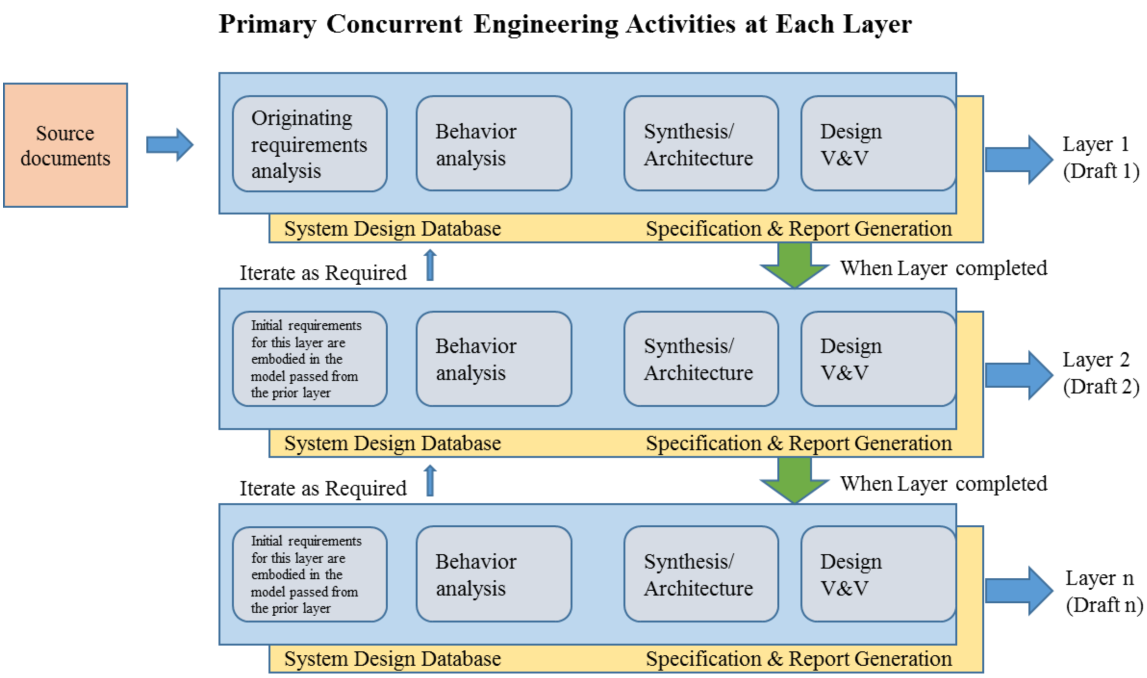

Figure 2.1-6: Vitech MBSE "Onion Model"

According to Childers and Long [9], as the SE team successfully completes one level of

system design, they "Peel off a layer of the onion" and start to explore the next layer. Comparing with waterfall SE approaches, the Onion Model provides a lower risk design approach since complete solutions at increasing levels of detail are available for early review and validation.
The completion criteria for each layer of the Onion Model is illustrated in the Table 2.1-4 [9]:

Table 2.1-4: Completion Criteria for Each Layer of the "Onion Model"

Process Element	Completion Criteria
1. Originating Requirements	1. Agreement on Acceptance Criteria.
2. Behaviour/Functional Architecture	2. Each function is uniquely allocated to at most one component.
3. Physical Architecture Definition	3. Segment/component specs are complete Requirements documents.
4. Qualification	4. V&V requirements have been traced to test system components.

The Onion Model is supported by two set of SE activities timeline that are intend to apply to each layer of the "Onion". One far a top down process and one for reverse engineering. The time is increasing from left to right in these SE activity timelines. Figure 2.1-7 [9] shows the SE activities timelines for a top down process. There are fourteen phases.

0. Define Need & system concept
1. Capture Originating Requirements
2. Define system Boundary
3. Capture Originating Architecture Constraints
4. Derive System Threads
5. Derive Integrated System Behaviour
6. Derive Component Hierarchy
7. Allocate behaviour to Components
8. Define Internal Interfaces
9. Select Design
10. Perform Effectiveness & Feasibility Analyses
11. Define Resources, Error Detection, & Recovery Behaviour
12. Develop Validation Requirements/ Validation Plans
13. Generate Documentation and Specifications

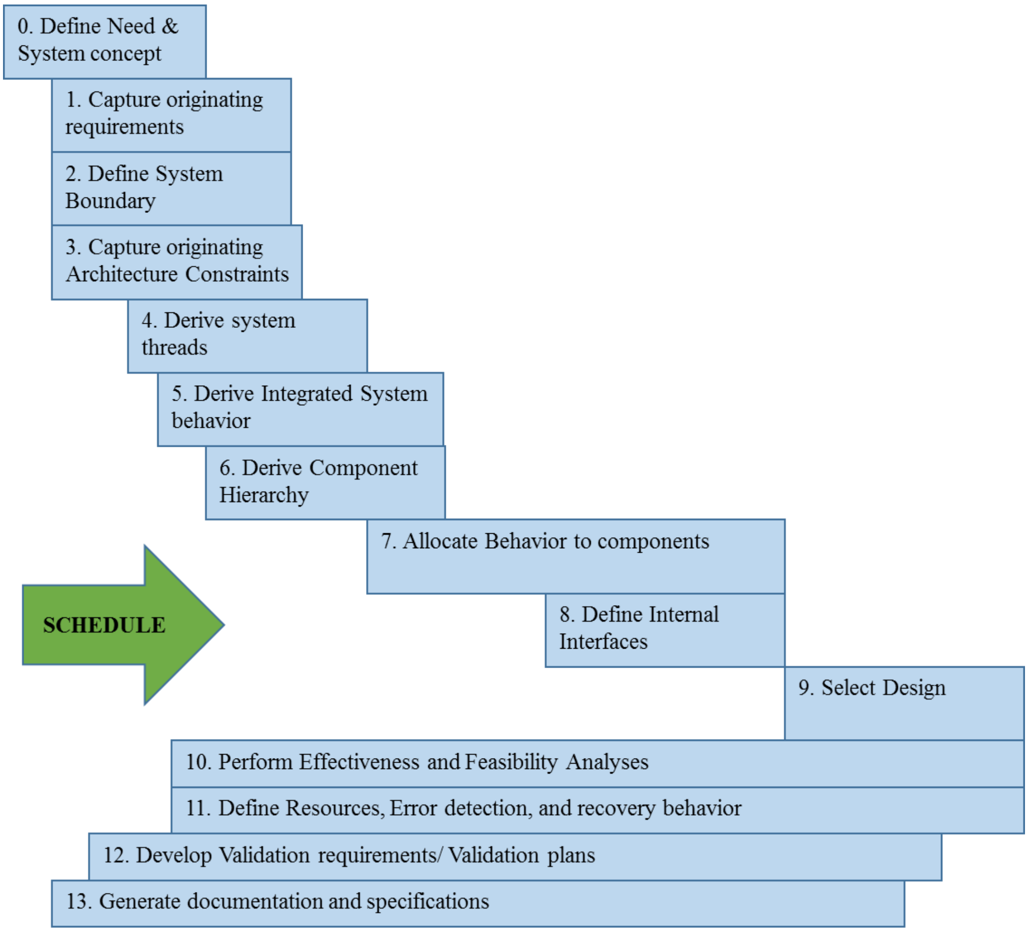

Figure 2.1-7: Vitech MBSE activities timeline in Top down Engineering.

In Figure 2.1-8 [9], it shows schedule of Vitech MBSE activities timeline in reverse engineering. In the first process, from phase one to phase 8, MBSE activities will go to the top. After that, each phase in first process will be modify and update. The purpose of those activities is enhance the quality of design.

This is a list of Vitech MBSE activities in reverse engineering timeline

1. Define System Boundary
2. Capture Interfaces
   => 2a. Define Interface
3. Capture Component Hierarchy
   => 3a. Refine Component Hierarchy
4. Derive As-Built Behaviour of components
   => 4a. Allocate Behaviour to Component
5. Aggregate to As-Built System Behaviour
   => 5a. Modify & Decompose System Behaviour
6. Derive As-Built System Threads
   => 6a. Modify System Threads
7. Derive As-Built System Requirements
   => 7a. Modify Requirements & Architectures. Constraints
8. Update System Boundary
9. Select Design
10. Perform Effectiveness & Feasibility Analyses
11. Capture Error Detection, Resource, & Recovery Behaviour
12. Develop Test Plans
13. Generate Documentation and Specifications

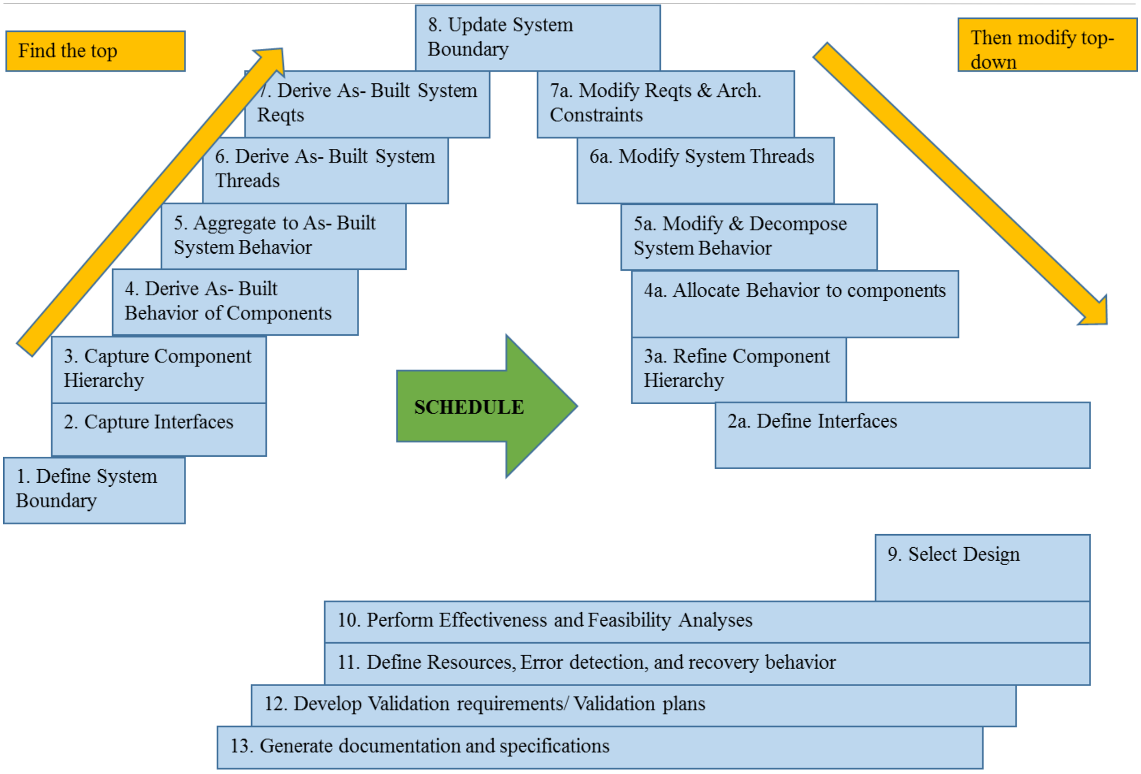

Figure 2.1-8: Vitech MBSE activities timeline in reverse Engineering.

Methods used in the Vitech MBSE methodology to support the Functional/Behaviour analysis top-level activity is based on a set of visual behaviour models and constructs in an graphical language known as Enhanced Function Flow Block Diagrams (EFFBSs) [9].

Table 2.1-5 shows the learning objectives and sub-activities for Vitech MBSE Top-Level SE activities of source requirements analysis and architecture.

Table 2.1-5: The learning objectives and sub-activities for Vitech MBSE Top-Level SE activities of source requirements analysis and architecture

	Source Requirements & Analysis	Architecture/Synthesis

Objective	Identify structure and analyse Requirements from a source.	Expand our understanding of the system.
Activities	1. Identify and extract requirements 2. Organize requirements 3. Analyse requirements 3.1 Discover and identify Issues 3.2 Discover and identify risks 4. Establish requirements relationships 5. View the requirements graphically 6. Generate the requirements and related information in a table	1. Define: 1.1 System boundaries 1.2 Potential interfaces 1.3 Preliminary physical architecture components 1.4 Preliminary functionality 2. Maintain traceability to originating requirements 3. Identify performance factors 4. Identify constraints 5. Continue to mitigate issues and risks

To support the Design Verification and Validation top-level activity include test plan development and test planning with best practices emphasizing that test planning begins during the originating requirements extraction and analysis phase.

The primary system testing methods described by the MBSE methodology are summarized in Table 2.1-6. [9]

Table 2.1-6: System testing methods defined in the Vitech MBSE methodology

Functional Testing	Test conditions are set up to ensure that the correct outputs are Produced, based upon the inputs of the test conditions. Focus is on whether the outputs are correct given the inputs (also called "black box" Testing).
Structural Testing	Examines the structure of the system and its proper functioning. Includes such elements as performance, recovery, stress, security, safety, Availability. Some of the less obvious elements are described below.
Performance	Examination of the system performance under a range of nominal Conditions, ensures system is operational as well.
Recovery	Various failure modes are created and the system's ability to return to an Operational mode is determined.
Interface	Examination of all interface conditions associated with the system's Reception of inputs and sending of outputs.
Stress Testing	Above-normal loads are placed on the system to ensure that the system can handle them; these above-normal loads are increased to determine the system's breaking point; these tests proceed for a long period of time in an environment as close to real as possible.

2.2 Existing Research used MBSE approach on complex system

2.2.1 Applying MBSE to a Standard CubeSat

CubeSate is a small satellite, low-cost, standardized satellite which are typically launched as secondary payload. An MBSE challenge project was established to model a hypothetical Fire Sat satellite system to evaluate the suitability of SysML for describing space systems. To demonstrate in this challenge, researcher from Michigan Exploration lab (MXL) and SRI international developed a standard CubeSat by applying MBSE and using SysML is modelling language.

CubeSat case study objective in this research. [10]

- To codify the experience of Subject Matter Experts into a CubeSat Modeling Framework complete with domain specific extensions to SysML.
- To utilize the framework as an educational tool.
- To research the integration of analytical models for orbital determination, structural design, executing schedules for operations, and other parametric analyses. Through our commercial participants, AGI and InterCAX, a provider of MBSE software and services, we plan to explore the integration of analytical models, thereby enabling the transfer of information between various modeling systems.

The model of cube sat in this project include: [10]

- The entire satellite mission, including orbital determination and interfaces to external entities such as ground stations and targets of interest.
- Key satellite hardware, including systems, subsystems and components and their interfaces, dependencies, and associations.
- Key satellite behaviors and interfaces to the various hardware entities.
- Key satellite constraints and measures-of-effectiveness.

In the "Applying MBSE to a standard CubeSat" research, SysML models provide a comprehensive description of the mission such that it can interface with a diversity of analysis tools. It also support solving a problem or analyze a relevant part of the system and integrate the solution from mission specification.

For my research, I can have a reference from ADCS development mission viewpoint. How the satellite mission will be effected from ADCS development. How requirement come from mission team or pay load team. It is have a strong relationship between mission of satellite and requirement for ADCS development team.

2.2.2 Modelling an Attitude and Orbit Control System using SysML

By using SysML, Alessandroand Mauricio and Mauricio from Instituto Nacional de Pesquisas Espaciasis (INPE/CSE) Brazil, they a model to support for development Attitude and Orbit Control System (AOCS) process. They started in analyzing context diagram, stakeholder and their need. From that, AOCS will be derived system requirements and measure of effectiveness (MoEs). After that they did functional Analysis by using use case. Constraints and parametric diagram are described. Physical aspects are modeled and considered to model behavior using sequence diagrams. Finally, AOCS model is refined to become a Platform Specific Model (PSM) model from software viewpoint, allowing code generation.

According Model-Driven Architecture (MDA) A SysML model can be considered a PSM. And in the simplest form of MDA (OMG, 2003), it can be refined generating a PSM from software viewpoint.

The graphically followed approach in Alessandroand Mauricio and Mauricio is showed in Figure 2.2-1: [11]

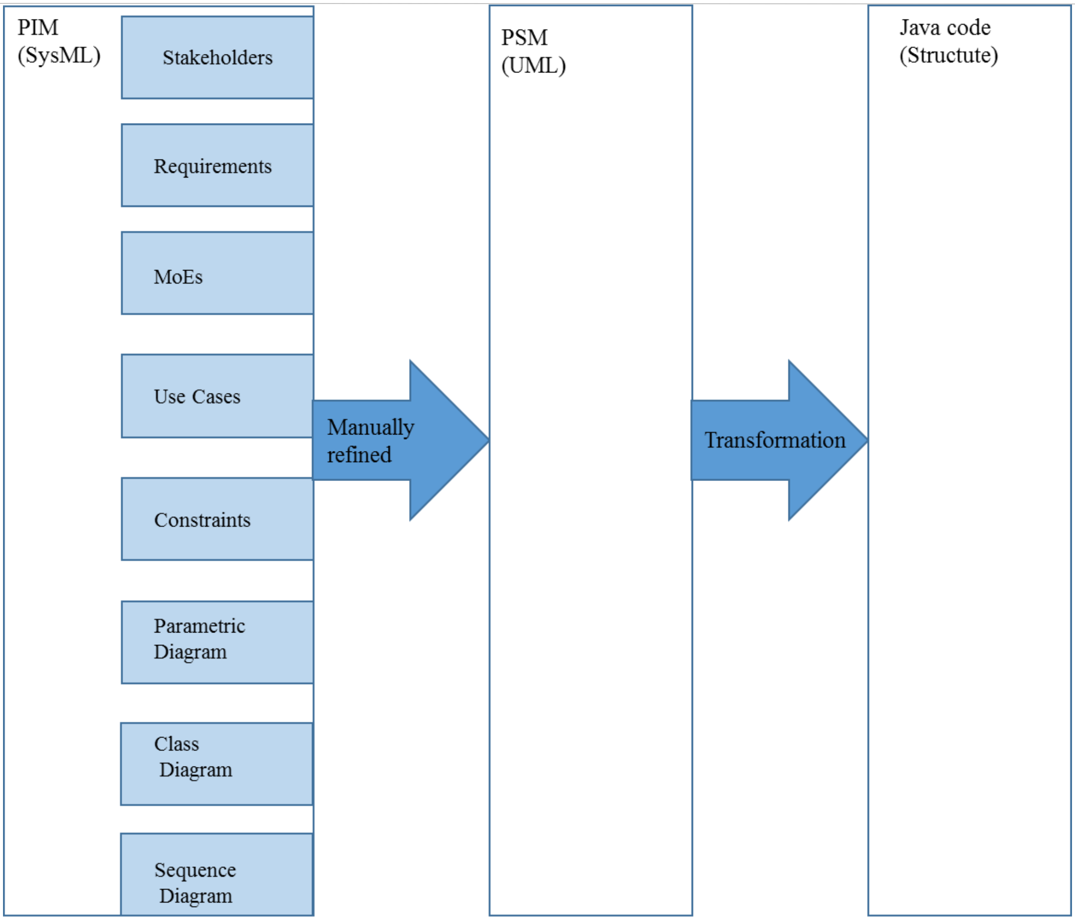

Figure 2.2-1: The research approach to model AOCS of Alessandroand Mauricio and Mauricio

In the "Modelling an Attitude and Orbit Control System using SysML" research, SysML is a good candidate to become a de facto standard for system engineering aiding designers on modeling and understanding system behavior and its effects on other system aspects [11]. However, the research of authors has not completed, the research of authors use MBSE approach focus on AOCS software development process. An approach to starting from context diagram and finish on software code. Important feature and benefit of SysML are allocations: allocate among tables, test cases, viewpoints formalization, activity diagrams and flow ports [11].

For my research, I would like to use MBSE approach to design ADCS in: requirements analysis, context analysis, Use case analysis, components performance. And also, my research will create an architectural design of MDG satellite, making a traceability between requirement and V&V activities.

Chapter 3 Design of ADCS for MDG by using Model-Based System Engineering Approach

3.1 Attitude Determination and Control System

3.1.1 Overview

Attitude is the three-dimensional orientation of a vehicle with respect to a specified reference frame. Attitude systems include the sensors, actuators, avionics, algorithms, software, and ground support equipment used to determine and control the attitude of a vehicle. Attitude systems can have a variety of names, such as attitude determination and control system (ADCS), attitude ground system (AGS), attitude and orbit control system (AOCS), guidance, navigation and control (GNC). [12]

Attitude determination is the process of combining available sensor inputs with knowledge of the spacecraft dynamics to provide an accurate an unique solution for the attitude state as a function of time, either onboard for immediate use, or after the fact. [12]

Attitude control is the combination of the prediction of and reaction to a vehicle's rotational dynamic. [12]

[12] Defines six general steps in ADCS system design. Each step has inputs and outputs with are described in Table 3.1-1.

Table 3.1-1: Steps in Attitude Determination and Control System Design

Step	Inputs	Outputs
1. • Define Control Modes • Define or Derive System–Level Requirements by Control Mode.	• Mission requirements, mission profile, type of insertion for launch vehicle	• List of different control modes during mission. Requirements and constraints.

2. • Quantify Disturbance Environment	• Spacecraft geometry, orbit, solar/magnetic models, mission profile.	• Values for torques form external and internal sources
3. Select Type of Spacecraft Control by Control Mode	• Payload, thermal & Power needs orbit, pointing direction Disturbance environment accuracy requirements	• Method for stabilization & control: 3-axis, spinning, gravity gradient, etc.
4. Select and Size ADCS Hardware	• Spacecraft geometry and mass properties, required accuracy, orbit geometry, mission lifetime, space environment, pointing direction, slew rates. Failure detection and redundancy.	• Sensor suite: Earth, Sun, Star, FOG • Control actuators: reaction wheels, thrusters, magnetic torques, etc. • Data processing avionics, if any, or processing requirements for other subsystem or ground computer.
5. Define Determination and Control Algorithms	• Performance consideration, attitude knowledge & control accuracy, slew rate, balanced against system-levels limitations.	• Algorithms and parameters for each determination and control mode, and logic for changing from one mode to another.

6. Iterate and Document	• All of document outputs.	• Refined mission and subsystem requirements. More detailed ADCS design. Subsystem and component specifications.

Figure 3.1-1 shows the diagram of complete attitude determination and control system. How the ADCS parts interact each other inside ADCS

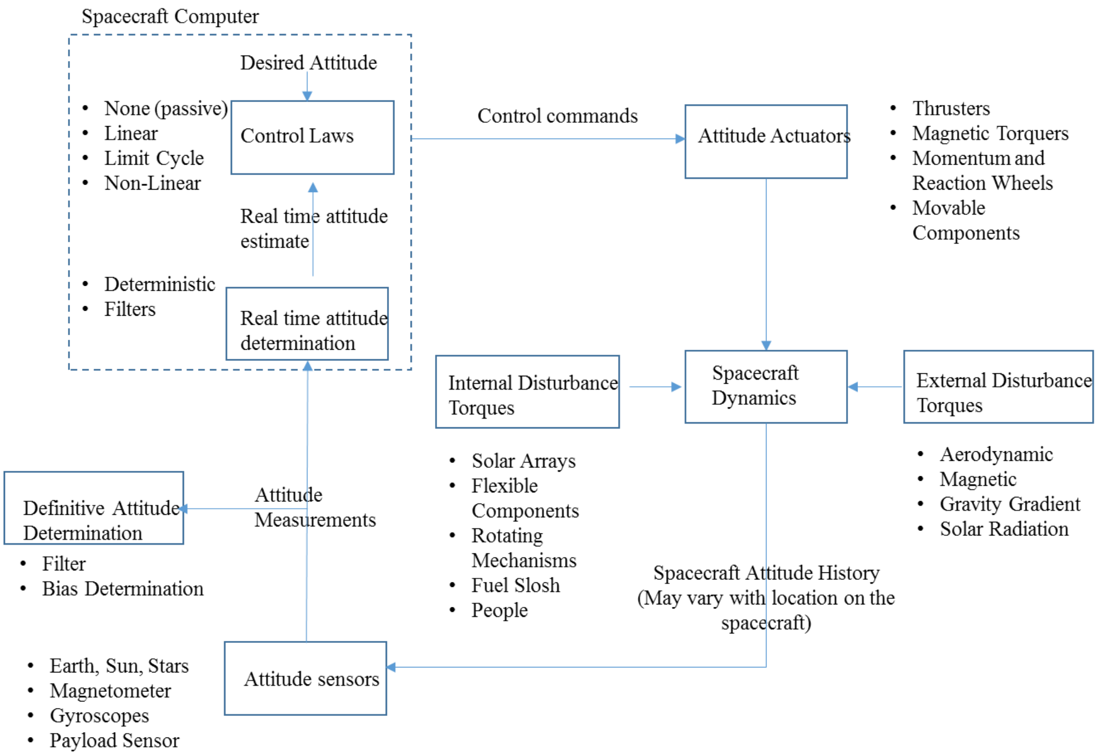

Figure 3.1-1: Diagram of a Complete Attitude Determination and Control System

For doing my research, I made a research plan for designing system design of ADCS follow the steps:

Phase 1: Requirement Analysis of MDG satellite

1) Define system life cycle of MDG satellite

- ***Context Analysis***

2) Context diagram

3) Clarify system boundary

- ***Use Case Analysis***

2) Use case diagram

3) Use case description

4) Set of functional requirements

Phase 2: Architectural Design of MDG satellite

- ***Functional Design***

7) Function Flow Block Diagram (FFBD)

- ***Physical Design of MDG satellite***

7) Subsystem structure (Tree Diagram)

8) Function to subsystem allocation

9) Architectural Diagram

3.1.2 Requirement of the Attitude Determination and Control System

The main mission of MDG satellite is to observe Vietnam coastal sea to access quality of water and finding potential sources of fish in East Sea. This specific mission requires MDG satellite to have ability point mission camera to nadir direction in certain area of interest with high stability accuracy. Figure 3.1-2 shows the offset nadir pointing and target pointing of MDG satellite in mission.

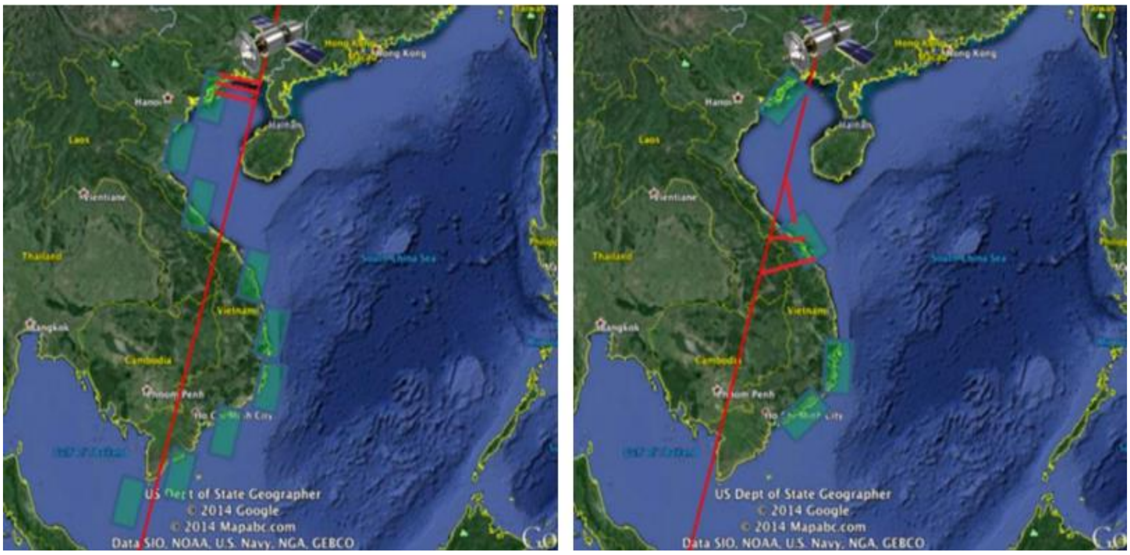

Figure 3.1-2: Offset nadir pointing and target pointing of MDG satellite

The most important requirements of ADCS come from payload subsystem. It required MDG satellite must operate in the target pointing mode which have the +Z axis is always pointed to a fixed target in the Earth surface during the time camera is taking picture of target. A picture is taken from MDG satellite has a size is 33 km x 44 km (when taken along the nadir direction) with the 33 km side is perpendicular to the coastal line of Vietnam. This 33 km side is required to have at least 3 km of the land and 25 km of the sea. From those information, payload subsystem required to ADCS satisfy an accuracy of 0.1 deg and a stability of 0.019 deg/s within a period of 0.3s. [2].

Another requirements of ADCS come another subsystems in MDG satellite such as: Structure subsystem, Electric subsystem, Communication subsystem. EPS give two requirements for ADCS: to secure direction of solar cell direct to the sun to generate power and total power consumption of all ADCS for each mode operation is less than power generation for ADCS. From Structure give to ADCS three main requirements: all components of ADCS need to fit in MDG satellite body, sensors mounting location and make a minimum of distance between centre of mass and centre of gravity as possible. From Communication subsystem give to ADCS a requirement: to secure direction of antenna point to the ground station.

Figure 3.1-3 shows the impact of requirements from another subsystem to the ADCS. The red arrow from ADCS to Structure subsystem is requirement from ADCS to Structure subsystem.

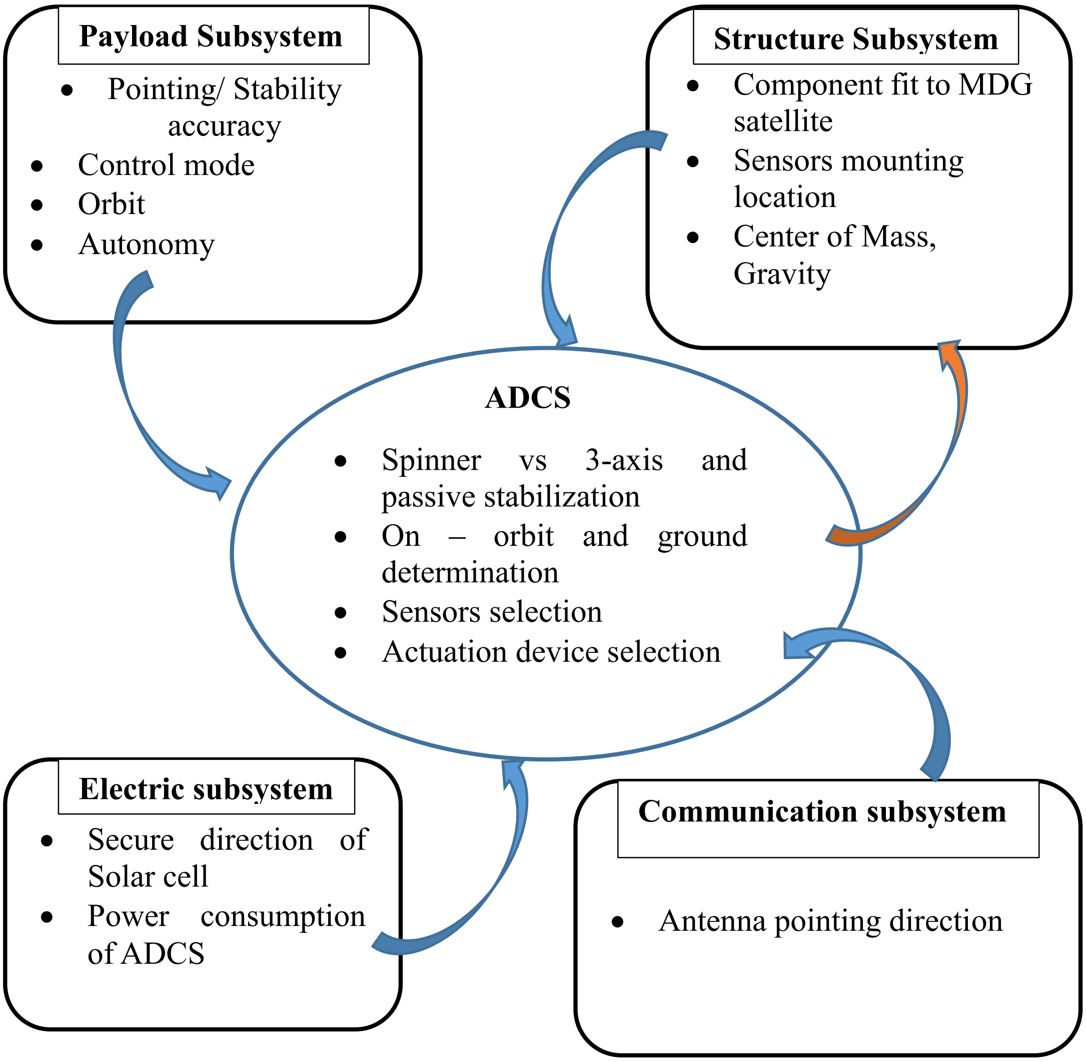

Figure 3.1-3: Impacts of requirements from another subsystem to ADCS

3.1.3 Components of the Attitude Determination and Control System

3.1.3.1 Onboard Computer

In the ADCS of MDG satellite, Onboard Computer have two function:

1. To control every other subsystem of the satellite
2. To process data an do the function of ADCS

Figure 3.1-4 shows the look of onboard computer of MDG satellite

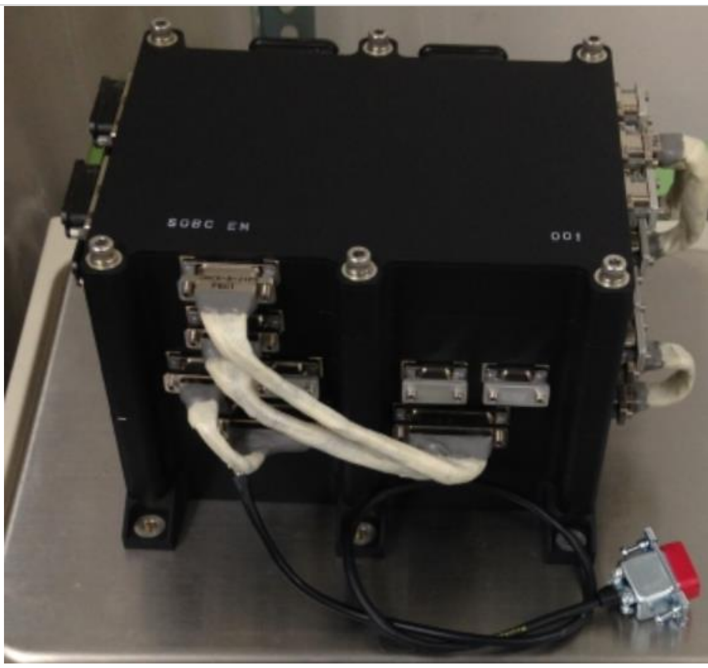

Figure 3.1-4: Onboard computer of MDG satellite

Table 3.1-2 shows the main specification of OBC in MDG satellite:

Table 3.1-2: The Specification of OBC in MDG satellite

Clock	System: 20 MHz CPU: 60 MHz
Performance	CPU 48 MIPS
Memory	- Flash: 4MByte (for program) - SRAM: 2MByte (for program and work area) - SDRAM: 64MByte (for work area and storage) - Flash: 512 MB (for storage)
Communication Interface	- RS422-UART: 16-24ch - Space Wire: 1ch - DC(LVTTL) IN: 16ch - DC(LVTTL) OUT: 16ch - Active Analog (AA): 8ch - Passive Analog (PA): 16ch - Reset Signal IN: 1ch

3.1.3.2 Nonspin Solar Aspect Sensor

MDG satellite uses 6 Nonspin Solar Aspect Sensor (NSAS), in each face of MDG body is assembled on NSAS. The function of NSAS is detect the sun, its output is a vector form the satellite's position toward to the sun – called Sun vector.

Figure 3.1-5 shows the view of AxelSun -1:

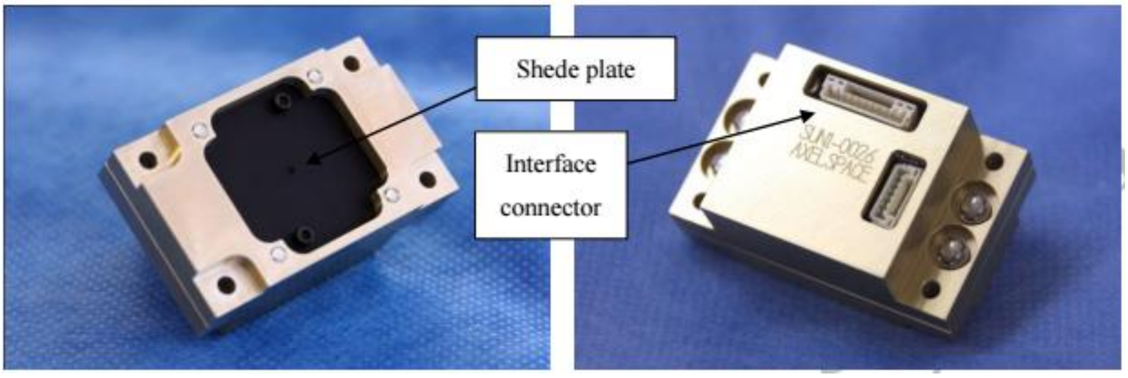

Figure 3.1-5: Nonspin Solar Aspect Sensor AxelSun-1

Those NSAS is developed by Axelspace Company, it is AxelSun -1, a very small and light weight. The field of view of AxelSun -1 is 100 x 100 [deg], so it can only detect the Sun if the angle between the sun vector and its Z-axis is less or equal 50 degree.

The Table 3.1-3 shows the specification of AxelSun -1

Table 3.1-3: The specification of AxelSun -1

Size	30.5 x 49.7 x 21.0 [mm]
Weight	46 [g]
Power	165 [mW]
Temperature range	-20 to 50 [degree Celsius]
Performance	Field of view: 100 deg x 100 deg Angular resolution: 1 deg

3.1.3.3 Geomagnetic Aspect Sensor

MDG satellite uses one Geomagnetic Aspect Sensor (GAS). The function of GAS is measure the magnetic field of the Earth. GAS can control satellite orientation with

minimized power consumption. However, the accurate of GAS is not so high. GAS will be used on detumbling mode and keep satellite spin around one axis.
Figure 3.1-6 shows the view of GAS:

Figure 3.1-6: Geomagnetic Aspect Sensor

This GAS is developed by NESTRA. The Table 3.1-4 shows the main specification of GAS

Table 3.1-4: The specifications of GAS

Size	95 x 95 x 45 [mm]
Weight	0.3 [kg]
Power	0.2 [W]
Temperature	-10 to 50 [degree Celsius]
Performance	Range: -100,000 to 100,000 [nT] Noise: ± 10 nTp-p Output voltage: 0 to 5 [V]

3.1.3.4 Star Tracker

MDG satellite uses one Star Tracker. The function of Star Tracker is measures the

positions of the stars. By comparing the measurements results with the star map data. The MDG's attitude can be derived.
Figure 3.1-7 shown the view of Star -2 with a reference frame

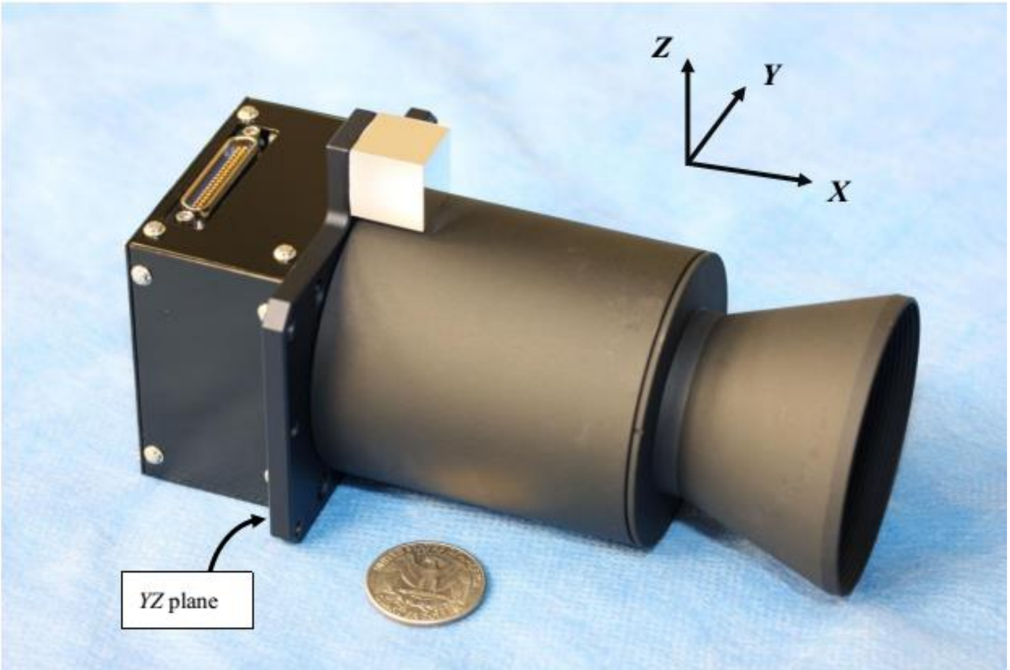

Figure 3.1-7: The Axel Star -2 with a reference frame

Axel Star – 2 is installed in MDG to provide high accurate attitude determination. Input data from Axel Star – 2 will be updated every one second. One problem that may need considering is the possibility that the star tracker be pointed directly toward the Sun and could be damaged.
By considering that, the +X axis of Axel Star -2 will be aligned in MDG's –Z axis and SMI should be required to operate at the local time avoid 12 pm.
This Axel Star – 2 is developed by Axelspace Corporation. Table 3.1-5 shows the specification of Axel Star - 2:

Table 3.1-5: The specifications of Axel Star - 2

Size	147 x 80 x 77 [mm]
Weight	0.51 [kg]
Power	2.5 [W]
Temperature	-20 to 50 [degree Celsius]
Performance	Field of View: 8 deg x 8 deg Number of Pixels: 1024 x 1024 Accuracy of star direction determination: < 5 arcsec (1σ, when 4 stars are visible) Accuracy of attitude determination: - Around Y and Z axes: < 7 arcsec (3σ) - Around X axis: < 77 arcsec (3σ)

3.1.3.5 Fiber Optic Gyroscope

MDG satellite uses one Fiber Optic Gyroscope (FOG). The function of FOG is measure of satellite's angular velocity based on the interference of light which has passed through a coil of optical fiber. FOG is used in all high accurate pointing modes to increase precision of ADCS. Input data will be update each 20 Hz.

Figure 3.1-8 shows a view of FOG TA7584 series:

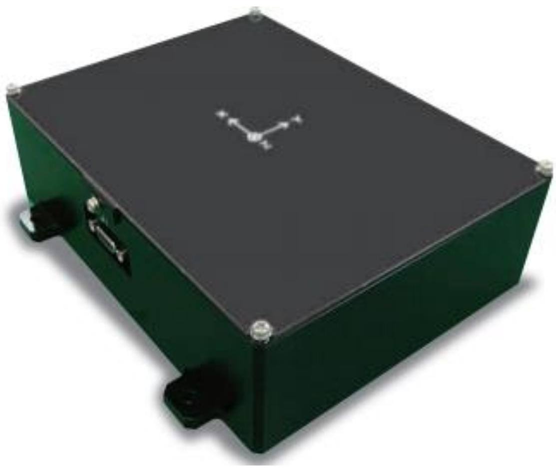

Figure 3.1-8: The Fiber Optic Gyroscope TA7584 series

This Fiber optic Gyroscope TA 7584 series is developed by NESTRA Corporation. Table 3.1-6 show the specification of FOG TA series

Table 3.1-6: The main specifications of FOG TA7584 Series

Item	**Value**	**Remarks**
Dimension	135×150×45mm	Including mounting areas
Mass	1.0kg less	
Standard power supply voltage	28 or 15V	
Power consumption	3.5W less	When the standard power supply voltage
Detection range	±5°/s less	
Bias	±10°/h less	ON/OFF : 5°/h less In-RUN : 5°/h less
Bias stability	1.73°/h（1σ） less	Allan variance: 1 sec
Linearity error	0.1%FS less	
Vibration	6G 5～100Hz sine wave 11Grms 200～2000Hzrandom	
Temperature range	-10～＋50°C	
Date update	20Hz	

3.1.3.6 GPS

The altitude of MDG in orbit is 540 km. MDG satellite can use GPS signal from GPS satellite to detect the position and velocity and as well as current time information. MDG satellite is installed one GPS receiver and two antenna

Figure 3.1-9 shows the view of Axel – 1 GPS receiver and GPS antenna.

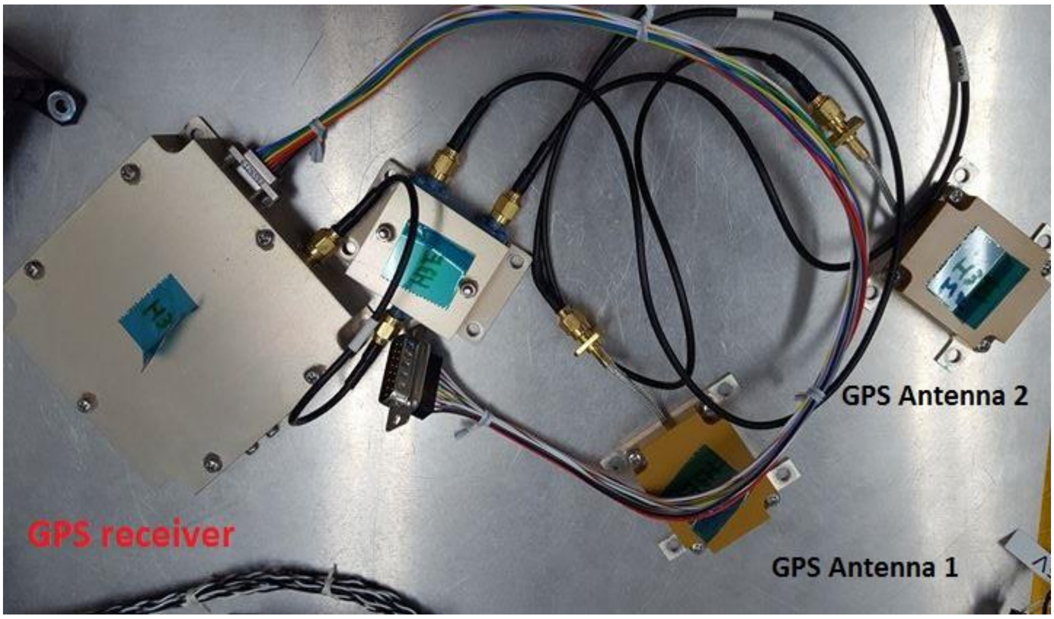

Figure 3.1-9: GPS receiver and GPS antenna

The AxelNav -1 GPS receiver and GPS antenna are developed by AxelSpace. The positioning accuracy is 3.24 m in highest accurate. And speed accuracy is 1 m/s.

Table 3.1-7 shows the specifications of GPS receiver and GSP antenna are installed in MDG satellite:

Table 3.1-7: GPS receiver and GPS antenna Specification

Size	95 x 95 x 19.5 [mm] (receiver) 58 x 46 x 14 [mm] (antenna)
Weight	164g (receiver) 53g (antenna)

Power	0.8 W (receiver) 0.3 W (antenna)
Temperature	-20 to 70 [degree Celsius]
Performance	Position Accuracy: 11.4 [m] Velocity Accuracy: 1.0 [m/s] Direction Accuracy: 0.4 [deg]

3.1.3.7 Reaction Wheel

Reaction wheels are actuators that can control the satellite's attitude rapidly with high accuracy and high torque. MDG satellite are installed four reaction wheels as the main actuator in the highest accuracy pointing. Three reaction wheel are needed for three-axis stabilization.

The reaction wheel number four is installed for redundancy.

Figure 3.1-10 shows the view of reaction wheels.

Those reaction wheels are developed by NESTRA for 50 kg to 100 kg spacecraft. In reaction wheel, it need to two power supply. One line is 5V supply to control part. Another line is 28V supply to motor. The highest rotation speed is 5000 rpm.

Table 3.1-8 will shows more the specifications of Reaction wheels used in MDG satellite.

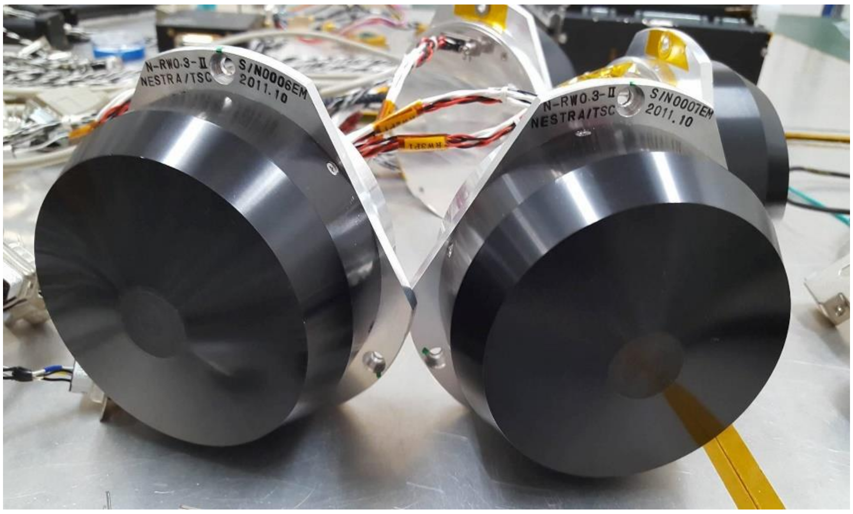

Figure 3.1-10: Reaction wheels

Table 3.1-8: The specification of Reaction Wheel

Size	Φ100 x 60 [mm]
Weight	0.98 Kg
Power	2.3 W (@ 0 rpm) 3.5 W (@ 4000 rpm)
Temperature	-10 to 50 [degree Celsius]
Performance	Angular momentum: 0.307 Nms (@ 4000 rpm) Max rate: 5000 [rpm] Torque scale factor: 0.03 [Nm/A] Output torque: >0.003 Nm (@ 4000 rpm) Loss torque: <0.005 Nm (@ 4000 rpm) Time constant: 4.9s (mechanical), 0.167 ms (electrical)

3.1.3.8 Magnetorquer

The magnetorquers (MTW) is used to generate a torque that can be used for attitude control. MDG satellite used three MTQ to provide a torque in three axis. However, the torque generated by the magnetorquers is very small and dependent of the satellite's position. So, MTQ will be used in the detumbling mode and the safe mode since MTQ's power consumption is minimal.

Figure 3.1-11 shows the view of Magnetorquer used in MDG satellite.

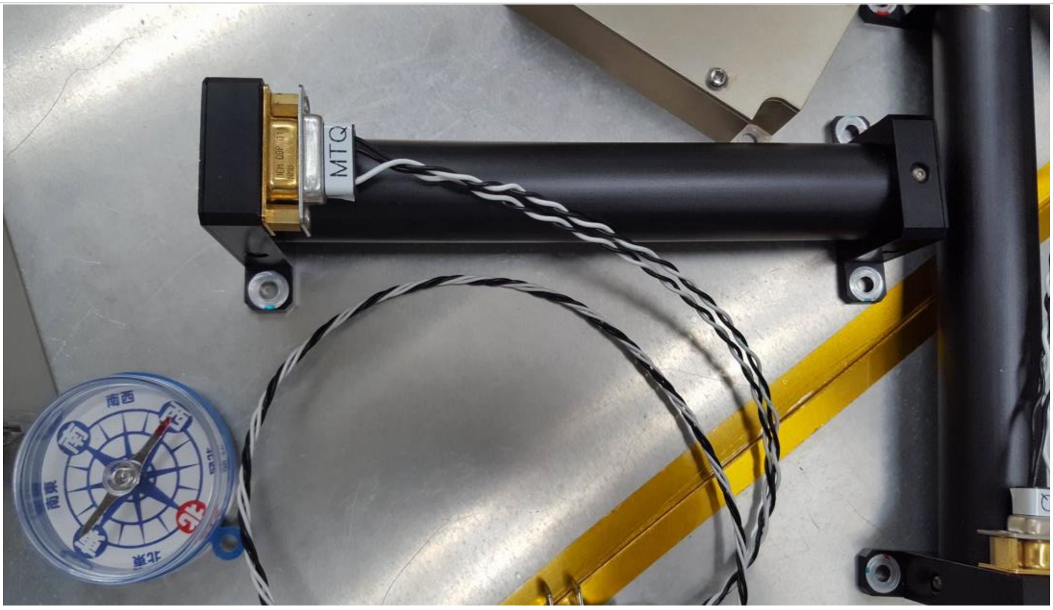

Figure 3.1-11: Magnetorquer used in MDG satellite

Those MTQ's specification will be shown in Table 3.1-9:

Table 3.1-9: The specification of MTQ

Size	176 x 54 x 47 [mm]
Weight	0.4 [kg]
Power	0.5 [W]
Temperature	-10 to 50 [degree Celsius]
Performance	Magnetic moment: 5.0 ± 20% [Am^2] Impedance: 95 ± 20% [Ω]

3.1.4 Mode Operation of Attitude Determination and Control System

3.1.4.1 List of Attitude Determination and Control System Mode Operations in MDG satellite

The mode operation of ADCS in MDG satellite is defined from the satellite functional and mission requirements. Then, the function, components and control algorithms to be used in each mode are selected. At the time of writing this thesis, there are seven mode operations in MDG satellite.

- **Recovery mode:** the recovery mode is defined from satellite is released from the rocket to go to safe mode. In this mode, components of ADCS such as: sensors, actuators are turned off. OBC is activated by timer command. Functions of ADCS in recovery mode are sending housekeeping data (Status of battery: voltage, current, temperature) to ground station though communication subsystem and waiting a pass of trigger to open the Solar Array Panels (SAP)

Figure 3.1-12 shows reliability of satellite from rocket

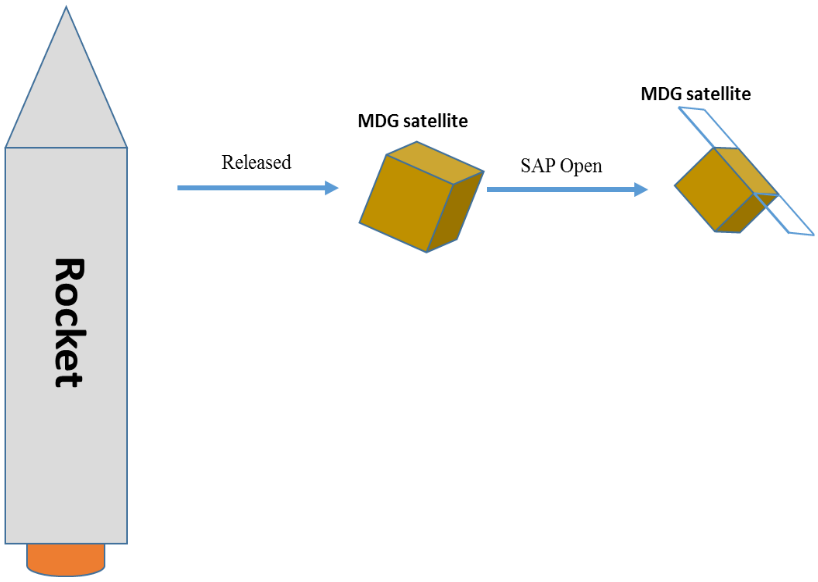

Figure 3.1-12: The reliability of satellite form rocket

- **Safe mode:** After trigger 1 is satisfied, satellite go to safe mode. Safe mode in MDG satellite is a mode with minimum power consumption and SAP is opened. Safe mode is defined as a survive mode of satellite, every mode can go to safe mode directly or when satellite encounters an emergency.
- **Attitude log mode:** This mode is used to check status of GAS, MTQ and RWs. After checking, the status will be transmit to ground station and GAS, FOY are turned off. MTQs are turned on.

- **Detumbling mode:** Before go to detumbling mode, the angular rate can be up to 10 deg/s. the purpose of this mode is to reduce that angular rate tend to 0.2 deg/s. Only GAS and MTQ are used in this mode.
- **Coarse Sun pointing mode:** The purpose of Sun pointing mode are to direct SAP toward to the Sun while the satellite is stabilized by spinning itself around –Z axis. There are four kinds of component of ADCS will be activated: GAS, NSAS, FOG, MTQ.

Figure 3.1-13 shows of Coarse Sun pointing mode

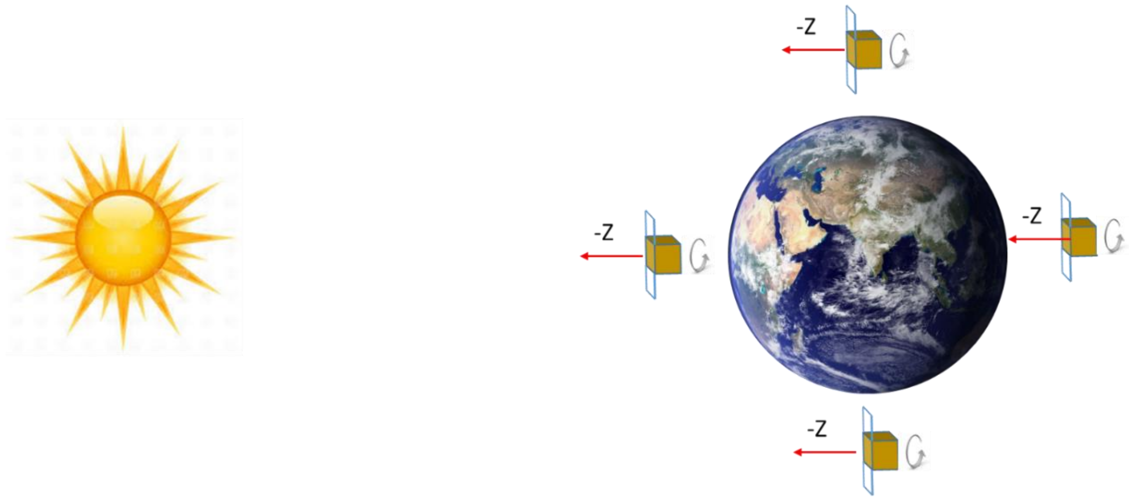

Figure 3.1-13: Coarse Sun pointing mode

Fine Sun pointing mode: The purpose of this mode are to direct SAP direction to Sun to generate maximum power and to keep body of satellite stable. There are three kinds of sensor: GAS, NSAS, FOG and two kinds of actuators: MTW, RWs will be activated. Figure 3.1-14 shows of Fine Sun pointing mode

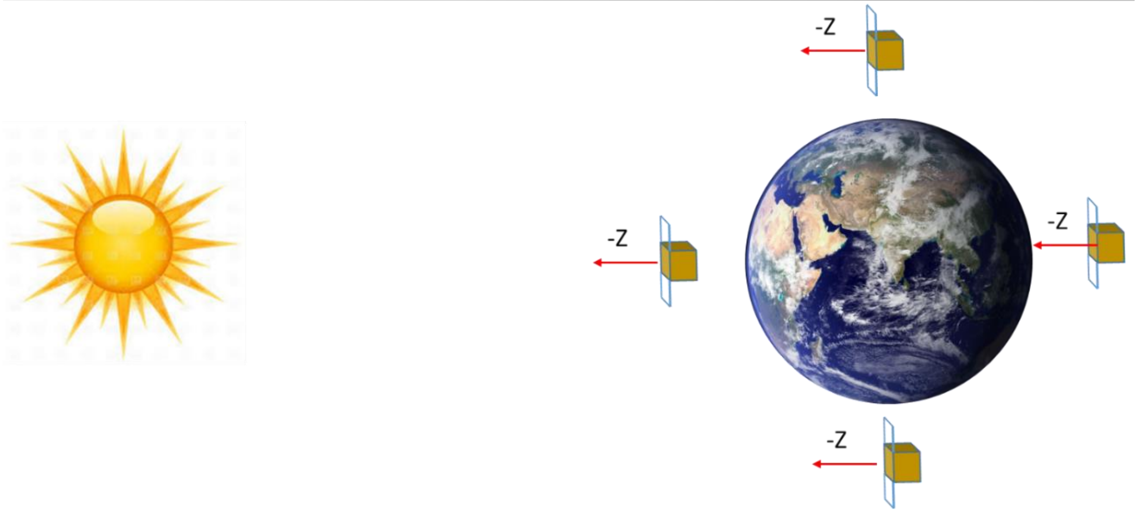

Figure 3.1-14: The Fine Sun pointing mode

- **Earth Pointing mode:** the purpose of this mode is to point the +Z direction of satellite to a fixed target on the surface of the Earth. All of components and actuators in ADCS will be activated on this mode.

Figure 3.1-15 shows the Earth Sun pointing mode of satellite

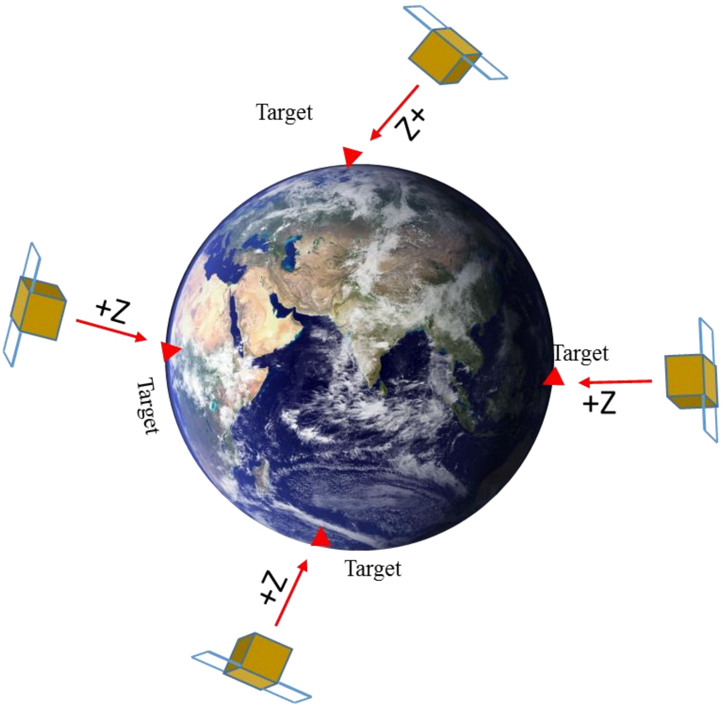

Figure 3.1-15: The Earth Sun pointing mode

Table 3.1-10 shows the list of activated component and actuators in each mode

Table 3.1-10: Activated components and actuators char

	GAS	NSAS	FOG	GPS	STT	MTQ	RW	OBC
Recovery mode	X	X	X	X	X	X	X	O
Safe Mode	O	X	O	X	X	O	X	O
Attitude log mode	O	X	X	X	X	O	X	O
Detumbling mode	O	O	X	X	X	O	X	O
Coarse Sun pointing mode	O	O	X	X	X	O	X	O
Fine Sun pointing mode	O	O	O	O	X	O	O	O
Earth Pointing mode	O	O	O	O	O	O	O	O

3.1.4.2 Mode Transition

To switch among mode operation in MDG satellite, the trigger is defined. The trigger can be a command form the ground station or be defined in specific condition, emergency case.

Figure 3.1-16 shows the mode sequence working in MDG satellite:

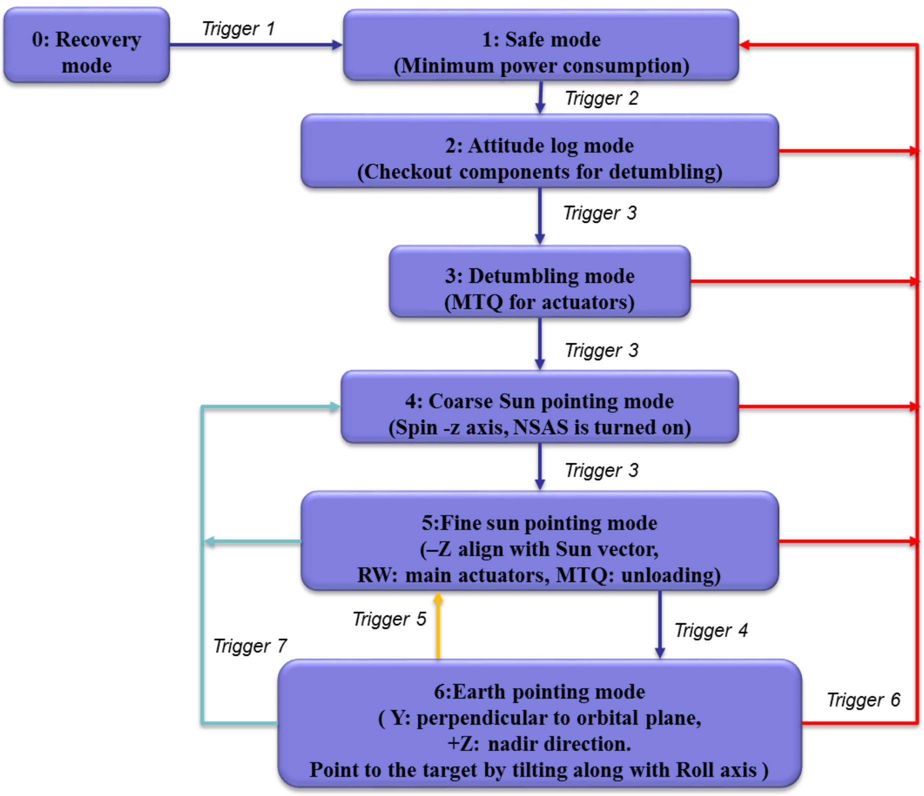

Figure 3.1-16: The mode sequence working in MDG satellite

Trigger 1: Uplink CMD to open SAP

- If battery voltage more than 28V.

(This condition can be disabled, if battery voltage doesn't get 28V after a long waiting time).

Trigger 2: Uplink CMD

- If SAP deployment is successful

(OBC will detect the successful of SAP deployment by monitoring power generation and battery voltage)

Trigger 4: Uplink CMD or timeline CMD

If Ground station requires the satellite do a mission

Trigger 5: Transition by automatic/CMD when finishing the mission.

Trigger 6: If battery voltage is less than 28V, MDG will go to Safe mode to save power consumption automatically.

Trigger 7: When having hardware failure (STT, GPSR, FOG, and RWs) go to Coarse sun mode automatically to maintain Spin –Z axis for waiting CMD from GS.

3.2 System Design of MDG-ADCS

In order to design MDG-ADCS system, the research will go through two phase:

Phase 1: Requirements Analysis

This phase is conceptual process, the life cycle of ADCS will be define. After that it will go follow four step:

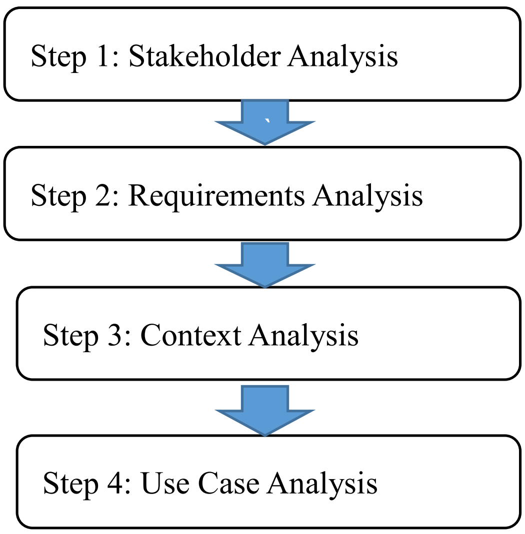

Figure 3.2-1: The steps in Requirements phase

Phase 2: Architecture Design

This phase will design a functional design, physical design and Architectural design. The result will show an interface among subsystem in MDG-ADCS. It will go follow three step:

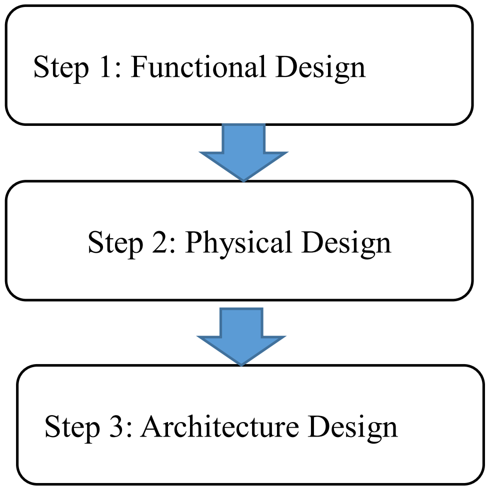

Figure 3.2-2: The steps in Architecture Design

3.2.1 Requirements Analysis

The life cycle of MDG satellite have five phases. ADCS start working from phase C to phase E.

Phase A: Development

Phase B: Launch

The rocket will carry MDG satellite go to orbit

Phase C: Deployment

MDG satellite will be deployed from rocket

Phase D: Nominal Operations

MDG-ADCS work in orbit

Phase E: De-Orbit and close out

MDG-ADCS will be closed and retired.

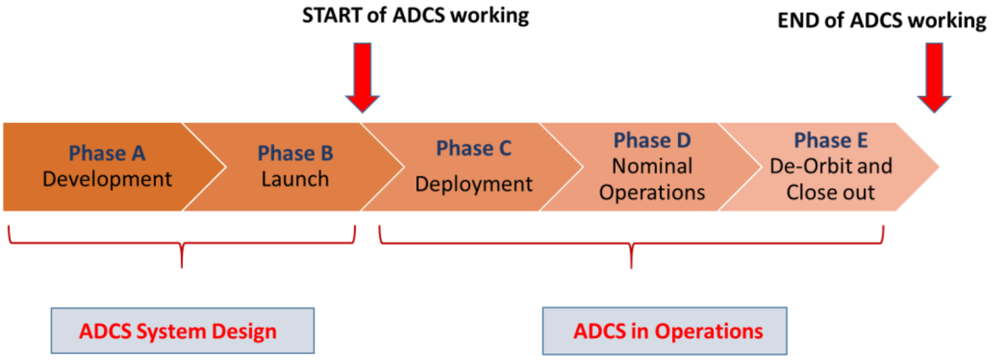

Figure 3.2-3: The life cycle of MDG satellite

The System of Interest (SoI) of MDG-ADCS have three elements: ADCS hardware, ADCS software and On board computer:

Figure 3.2-4 show the SoI of MDG- ADCS:

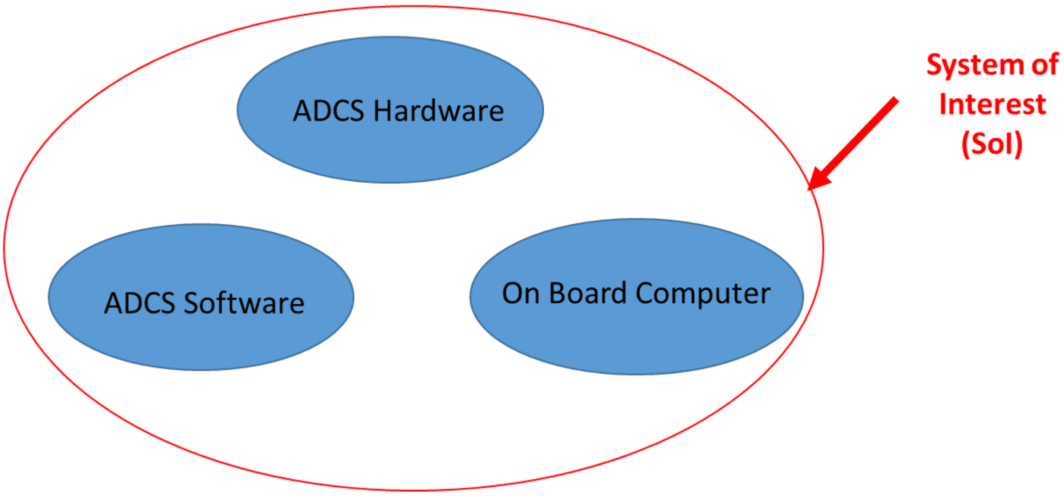

Figure 3.2-4: The system of Interest of MDG-ADCS

3.2.1.1 Stakeholder Analysis

Stakeholder in MDG-ADCS is a party or person that has an interest in MDG-ADCS project. The primary stakeholders in MDG-ADCS is VNSC- the organization start MDG project. Another stakeholders are: MDG satellite operator, MDG another subsystems, tester and certifier, supplier and MDG satellite user. By defining all of stakeholders in MDG-ADCS, it will give ADCS team a requirements for each stakeholders.

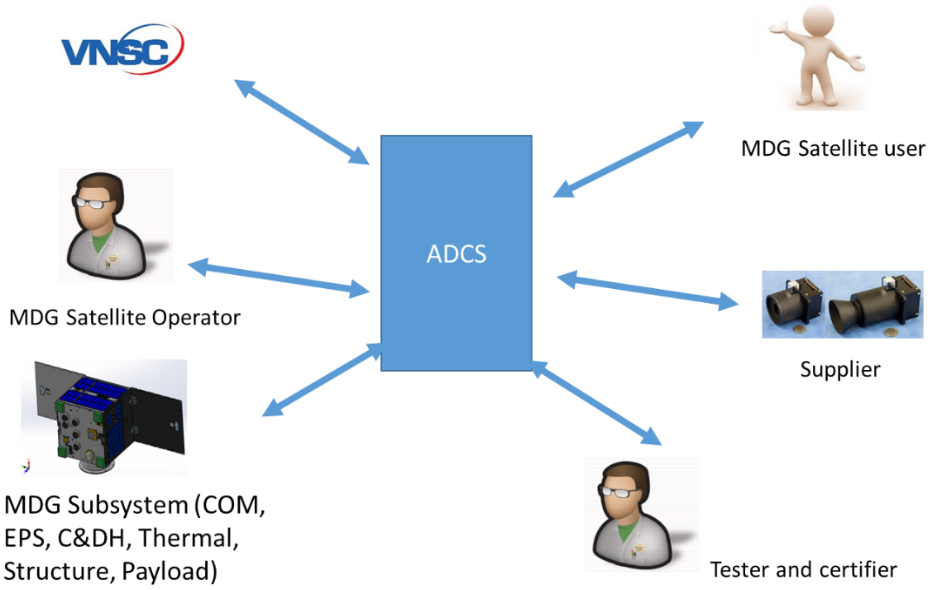

Figure 3.2-5: The stakeholders in MDG-ADCS

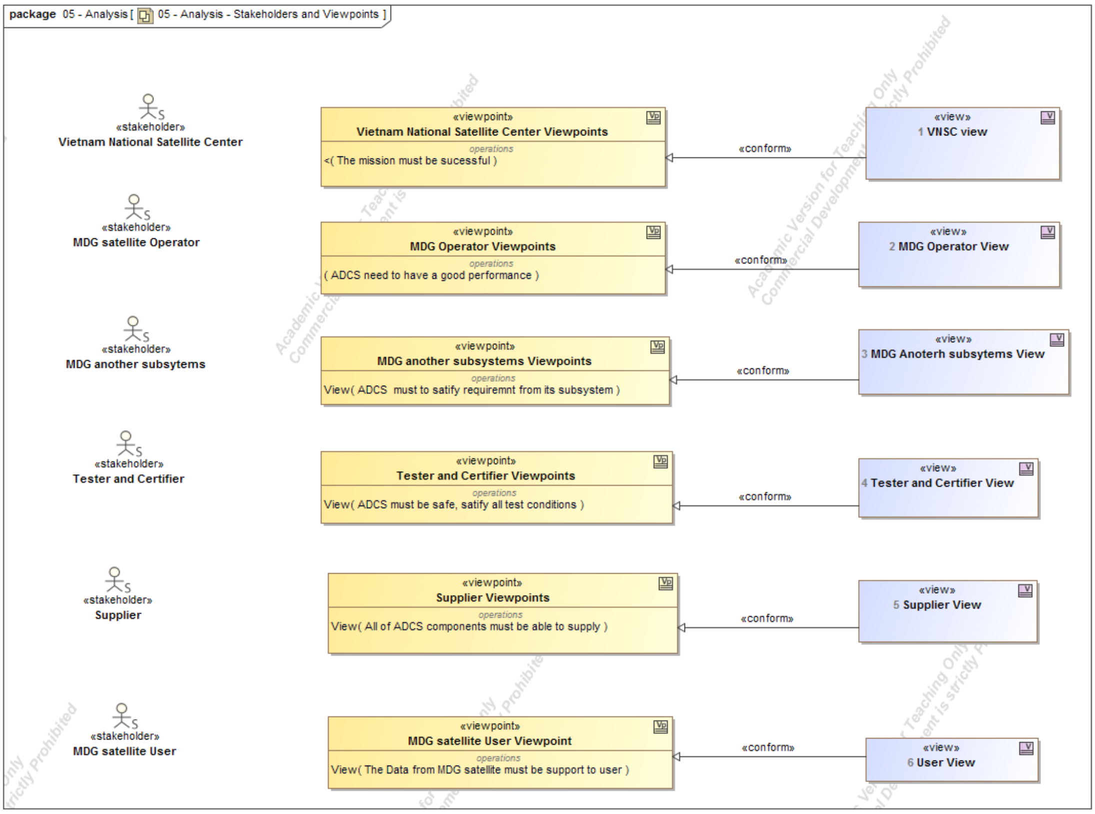

Figure 3.2-6: Stakeholders and Viewpoints

Figure 3.2-7 shows the "what is stakeholders need to achieve" in MDG satellite projects:

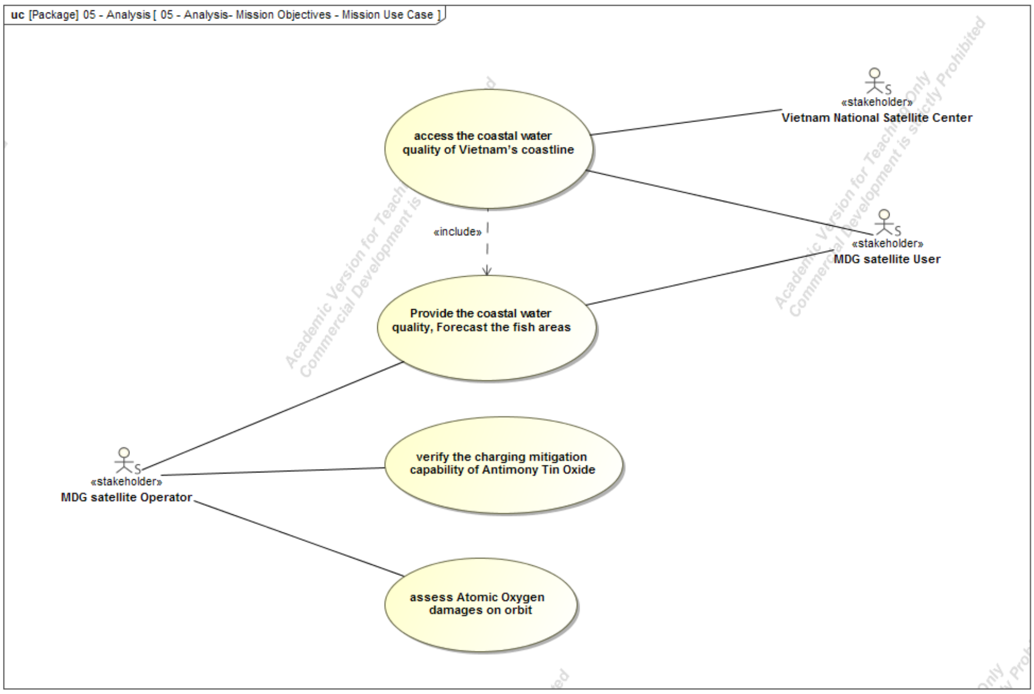

Figure 3.2-7: The stakeholder need in MDG

3.2.1.2 Requirements Analysis

For requirements analysis process, the expectations of each stakeholder will be determined in more detailed and relevant. Table 3.2-1 shows the high level of requirement for MDG-ADCS. Then each requirement will be decomposed. Figure 3.2-8 shows the requirements analysis decomposed are designed by SysML.

Table 3.2-1: The high level requirement for ADCS

Source	Name	Detail
User	Req_User_01	High quality picture of Vietnam sea
User	Req_User_02	Access the quality of water
VNSC	Req_Vnsc_01	Mission Success
	Req_Vnsc_02	Life of MDG is more than 5 years
Payload	Req_Payload_01	Accuracy of 0.1 deg
	Req_Payload_02	Stability of 0.019 deg/s
EPS	Req_Eps_01	Direct Solar panel direction to the Sun
Communication	Req_Com_01	Direct antenna face to the Ground station

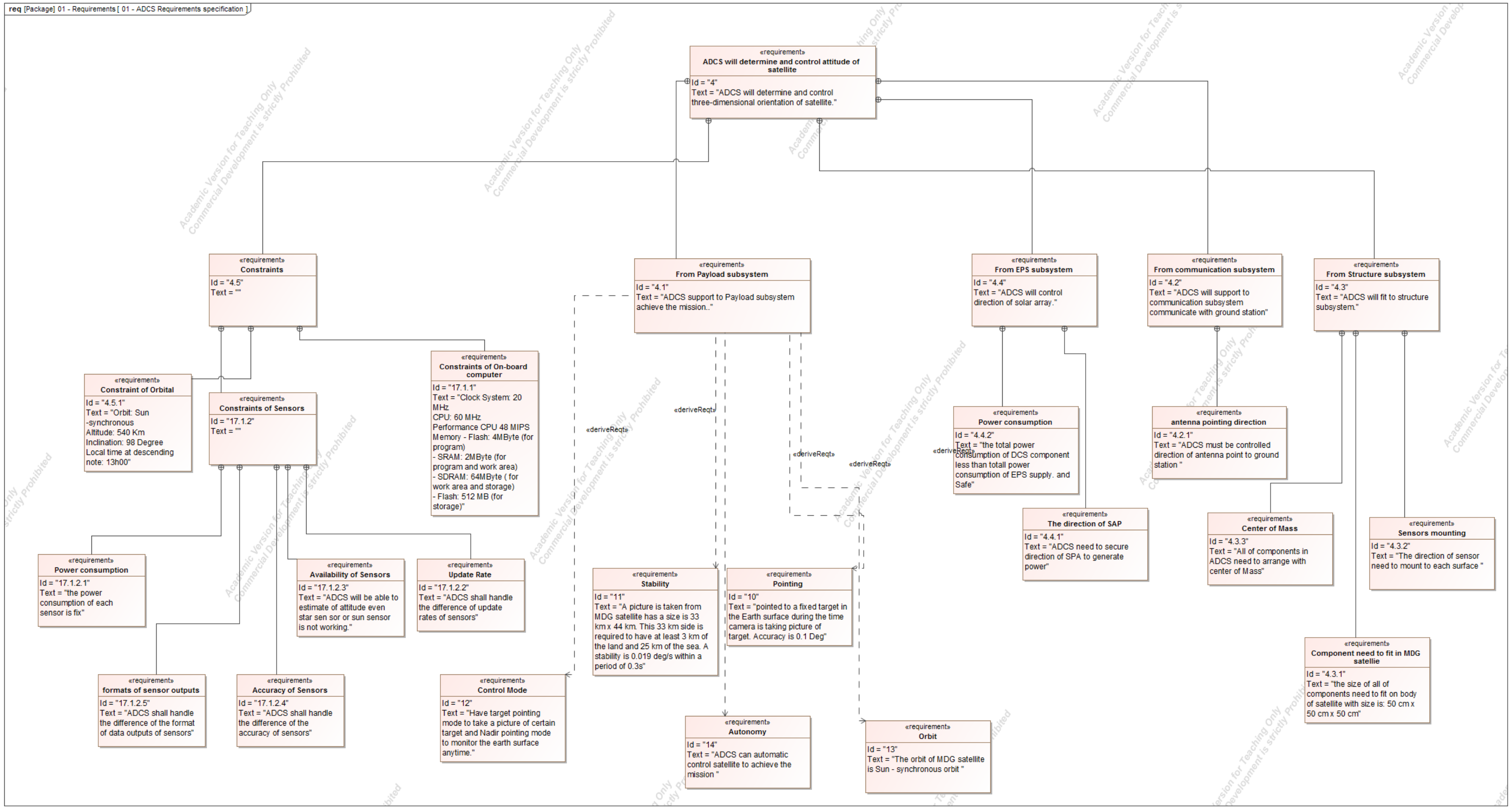

Figure 3.2-8: The requirements analysis

3.2.1.3 Context Analysis

Context analysis is method to analyse the environment in which ADCS operate. This method will considers the entire environment of ADCS, its internal and external environment.

The life cycle and system of interest of MDG-ADCS are defined already in the first part of 3.2.1. , the research will do context analysis for each phase

Phase A: Development

In development phase, the MDG-ADCS is on the earth, It have not started working yet. So there are no function of ADCS in this phase.

Phase B: Launch

In launch phase, the satellite will be attached on rocket and carried on to orbit. All of components in ADCS are turned off. There is no function and context of ADCS in this phase

Phase C: Deployment

In deployment phase, the satellite will be separated with rocket and go to the right orbit. At this time, some components of satellite are turned on. Component of EPS is turned on first to supply power to another components. Then, OBC will be turned on. OBC will send the command to ADCS hardware to start measure the signal and control the orientation of satellite.

The system of interest have two elements: onboard computer and ADCS hardware. The interface between onboard computer and ADCS hardware are CMD and Data. Onboard computer will send the control signal to ADCS hardware to turn on ADCS components, to control ADCS components. Then ADCS hardware is turned on. It start working and send the measure signal and send data to onboard computer.

The external environments of SoI have three elements: Space environments, rocket and Electric power subsystem. In space environments, it have sunlight, radiation, and magnetic field form the Earth. So the interface between space environments and SoI are: temperature, radiation wave and magnetic field. Rocket will put the satellite – include ADCS onto right orbit. So the interface between rocket and SoI is push. EPS will supply power to OBC and ADCS hardware, so the interface between EPS and SoI is supply power.

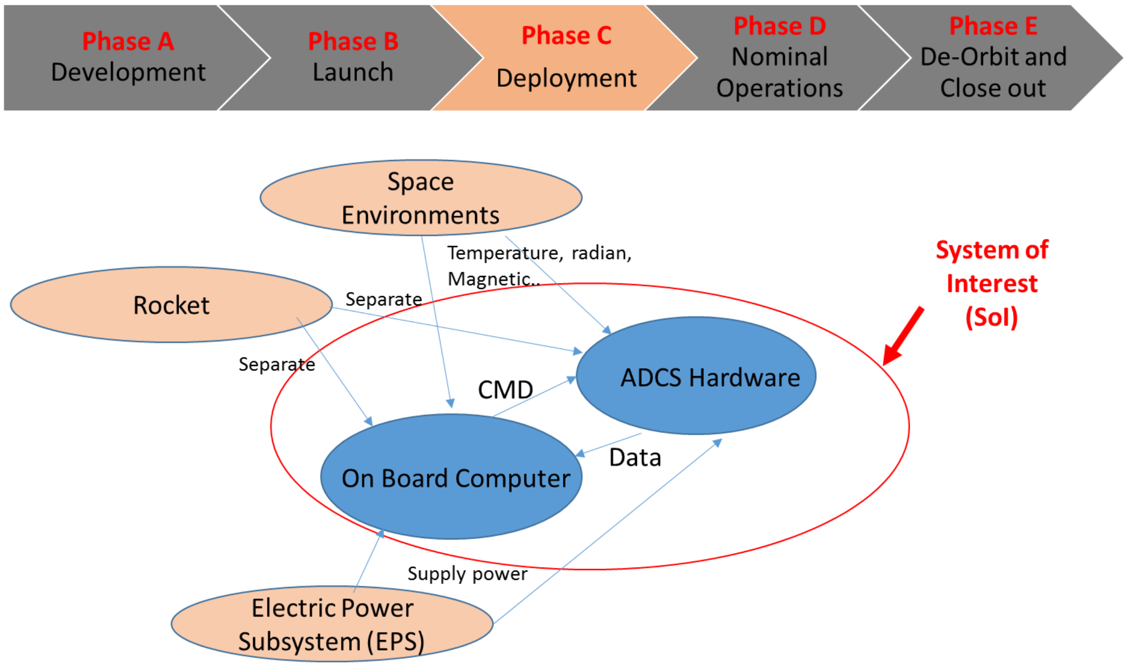

Figure 3.2-9: Context analysis in deployment phase - Phase C

Phase D: Nominal Operations

In nominal operations phase, the satellite is working in orbit. MDG-ADCS will work with all function.

The system of interest have two elements: onboard computer and ADCS hardware. The interface between onboard computer and ADCS hardware are Data and CMD. The amount of data and CMD between onboard computer and ADCS hardware in this phase is largest.

The external environments of SoI have four elements: space environments, GPS satellite, another MDG subsystem and operation in ground stations. The interface between space environments and SoI are the same in deployments phase: temperature, radiation wave and magnetic field. In this phase, MDG-ADCS will receive the data from global navigation satellite system to calculate the position and current time in the orbit. Global navigation satellite can be: GPS satellites, GLONASS satellites. The interface between global navigation satellite system and SoI is navigation signal. The interface between another MDG subsystem and SoI are TLM, CMD, Data and supply power. Onboard computer will send the CMD to another MDG subsystem to control direction of the satellite. Another MDG subsystem will send the data, TLM to OBC. EPS will supply power for onboard computer and ADCS hardware. Through ground station, operation will send the CMD to SoI to control all of things in satellites. The on bard computer will send TLM and Data to operator.

Figure 3.2-10 represent the context analysis in nominal operations.

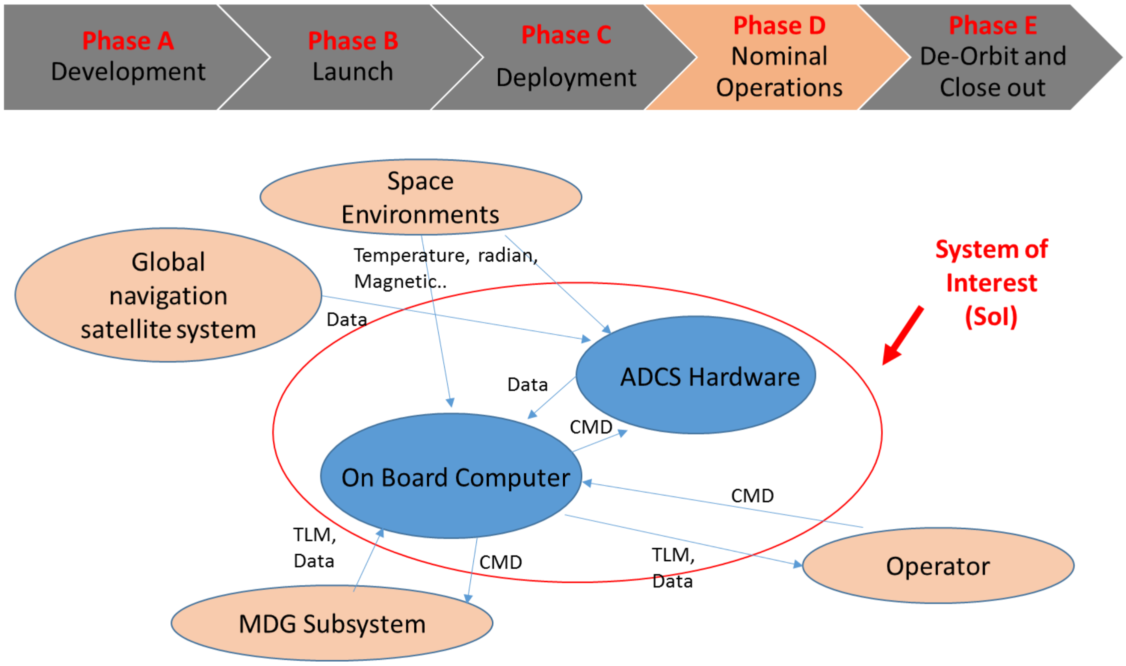

Figure 3.2-10: context analysis in nominal operations – phase D

Phase E: De-Orbit and close out

In de-Orbit and close out phase, satellite will be retired and finished the mission. All of components are turned off. De-Orbit mechanism will active.

The system of interest have two elements: onboard computer and ADCS hardware. The interface between onboard computer and ADCS hardware are Data and CMD.

The external of SoI have four elements: Space environments, earth environment, structure subsystem and operator. In the first of this phase, the satellite still work on orbit, space environment effect to all part in satellite. The interface between space environments and SoI are: temperature, radiation wave and magnetic field. When satellite go to atmosphere, the effects of the earth environment are stronger. So the interphase between Earth environments and SoI is atmosphere friction.

To control De-Orbit mechanism in structure subsystem, onboard computer will send the control signal to active de-orbit mechanism. So the interphase between structure subsystem and SoI is CMD.

To finish the mission, operator in ground station will send CMD to turn off components in satellite and onboard computer will send the status of satellite, all information needed before the satellite completed turn off.

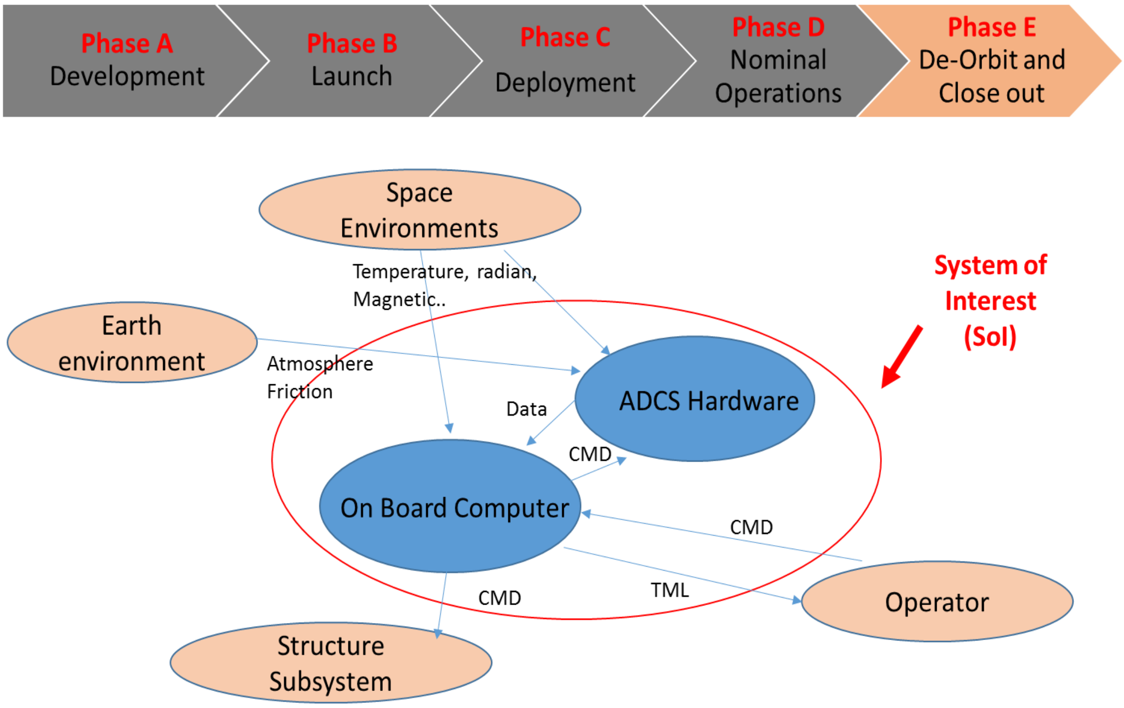

Figure 3.2-11: context analysis on De-orbit and close out – phase E

3.2.1.4 Use Case Analysis

Use case analysis is a specification of sequences of actions that a system, subsystem, or class can perform by interacting with outside actors [13]. In order to define a piece of behaviour of ADCS without revealing the internal structure in ADCS, my research will use use case diagram.

Phase A: Development

In this phase, there are no function of ADCS. So there are no use case analysis and use case diagram in this phase.

Phase B: Launch

In this phase, ADCS is turned off. So we do not have a use case in this phase

Phase C: Deployment

In the deployment phase, it have two actors: space environments and Electric power subsystem.

Figure 3.2-12 represent a use case diagram in deployment phase.

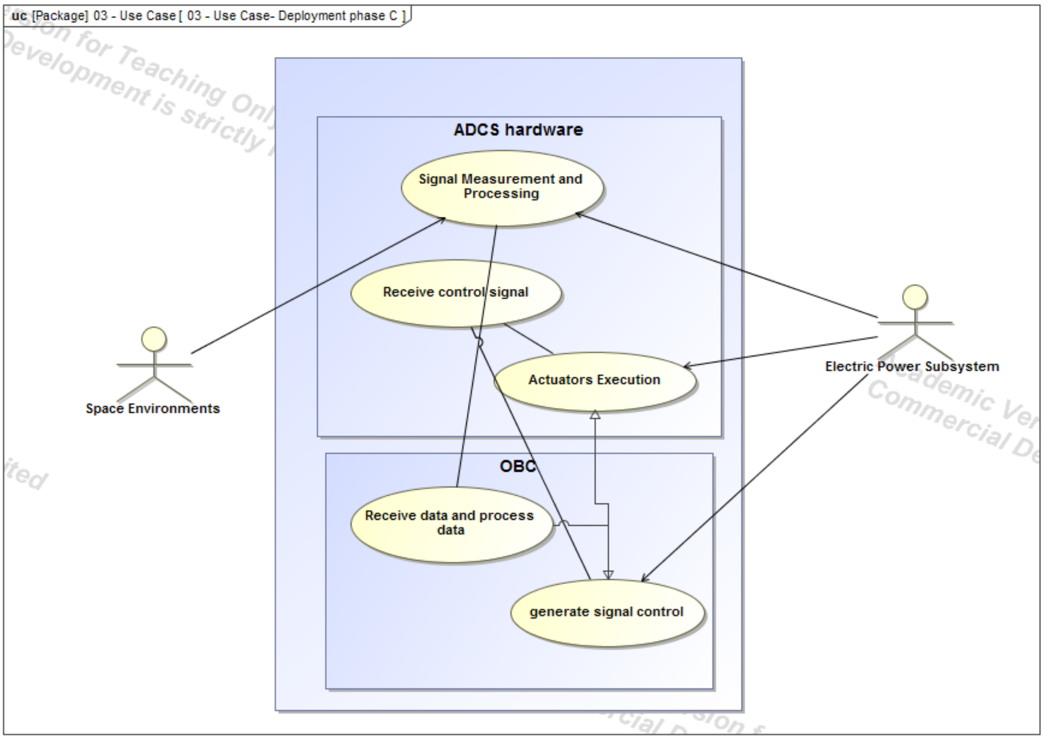

Figure 3.2-12: The use case diagram of ADCS in deployment phase – phase C

From this use case diagram, the list actions of each actor is analysed and identified.

ADCS hardware have three main functions:

F3.1: Signal Measurements and Processing

F3.2: Receive control signal

F3.3: Actuator Execution

OBC have three main functions:

F3.4: Receive and Process Data

F3.5: Generate Control Signal

F3.6: Send the Control Signal

Table 3.2-2 shows the detail of function in ADCS hardware and OBC

Table 3.2-2: The use case analysis of deployment phase- phase C

	ID	Function
ADCS Hardware	**F3.1:** Signal Measurements and Processing	1.1.1 Measure magnetic
		1.1.2 Send Data to OBC
	F3.2: Receive control signal	
	F3.3: Actuator Execution	1.3.1 Generate the magnetic
		1.3.2 Generate angular momentum
OBC	**F 3.4:** Receive and Process Data	2.1.1 Receive Data from magnetic sensor
		2.1.2 Calculate the Magnetic
	F 3.5: Generate Control Signal	2.2.1 Turn on magnetic Sensor
		2.2.2 Turn on MTQ
	F 3.6: Send the Control Signal	2.3.1 Generate the CMD
		2.3.2 Send the control signal to PDU

Phase D: Nominal operations

In nominal operations phase, MDG-ADCS have four actors: Navigation satellites, space environments, operator, MDG satellite subsystem.

Figure 3.2-13 represent use case diagram of ADCS in nominal operation phase

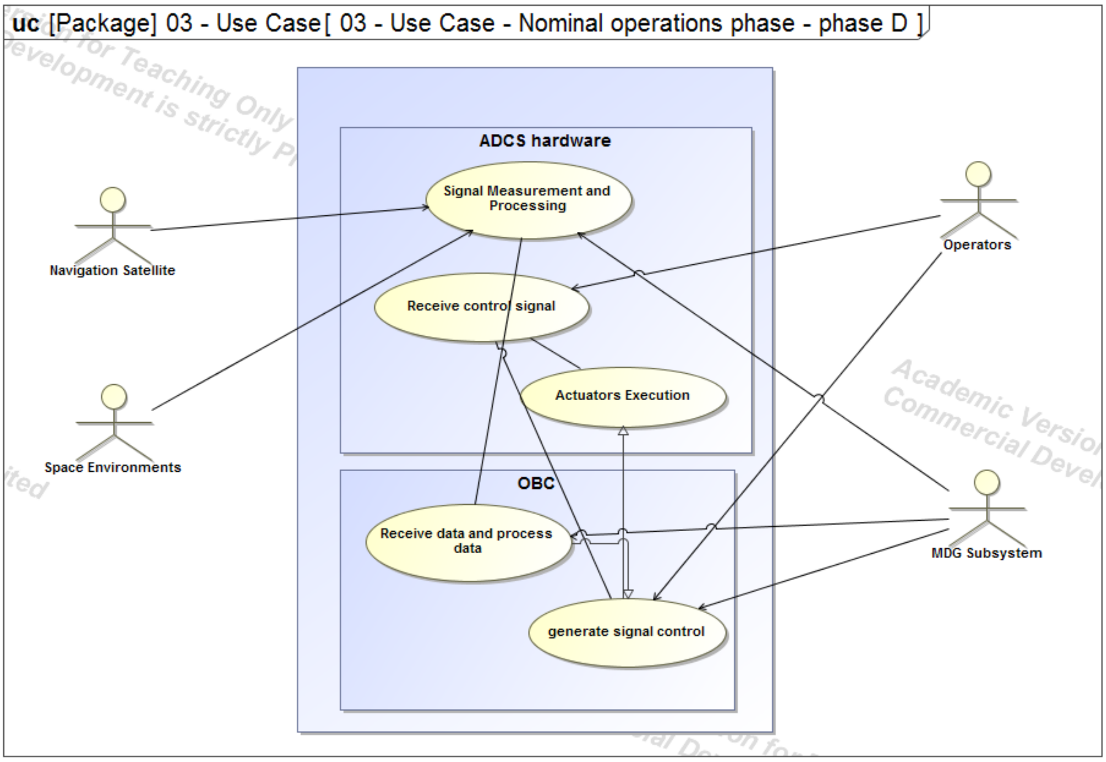

Figure 3.2-13: Use case diagram of ADCS in nominal operations phase – phase D

From this use case diagram, the list actions of each actor is analysed and identified.

ADCS hardware have three main functions:

F4.1: Signal Measurements and Processing

F4.2: Receive control signal

F4.3: Actuator Execution

OBC have three main functions:

F4.4: Receive and Process Data

F4.5: Generate Control Signal

F4.6: Send the Control Signal

Table 3.2-3 shown the use case analysis MDG-ADCS in nominal operation phase:

Table 3.2-3: Use case analysis of MDG-ADCS in nominal operation phase

	ID	Function
ADCS Hardware	**F4.1:** Signal Measurements and Processing	1.1.1 Measure Sensors signal
		1.1.2 Send Data to OBC
	F4.2: Receive control signal: receive CMD from OBC	
	F4.3: Actuator Execution	1.3.1 Generate the magnetic
		1.3.2 Generate angular momentum
OBC	**F 4.4:** Receive and Process Data	2.1.1 Receive Data from magnetic sensor
		2.1.2 Calculate the Magnetic
	F 4.5: Generate Control Signal	2.2.1 Generate CMD
		2.2.2 Change the mode
	F 4.6: Send the Control Signal	2.3.1 Send the control signal to sensors
		2.3.2 Send the control signal to actuator

Phase E: De-Orbit and Close out

In De-Orbit and Close out phase, MDG-ADCS have four actors: Earth environment, Space environments, operators, Structure subsystem.

Figure 3.2-14 represent use case diagram of ADCS in De-Orbit and close out phase

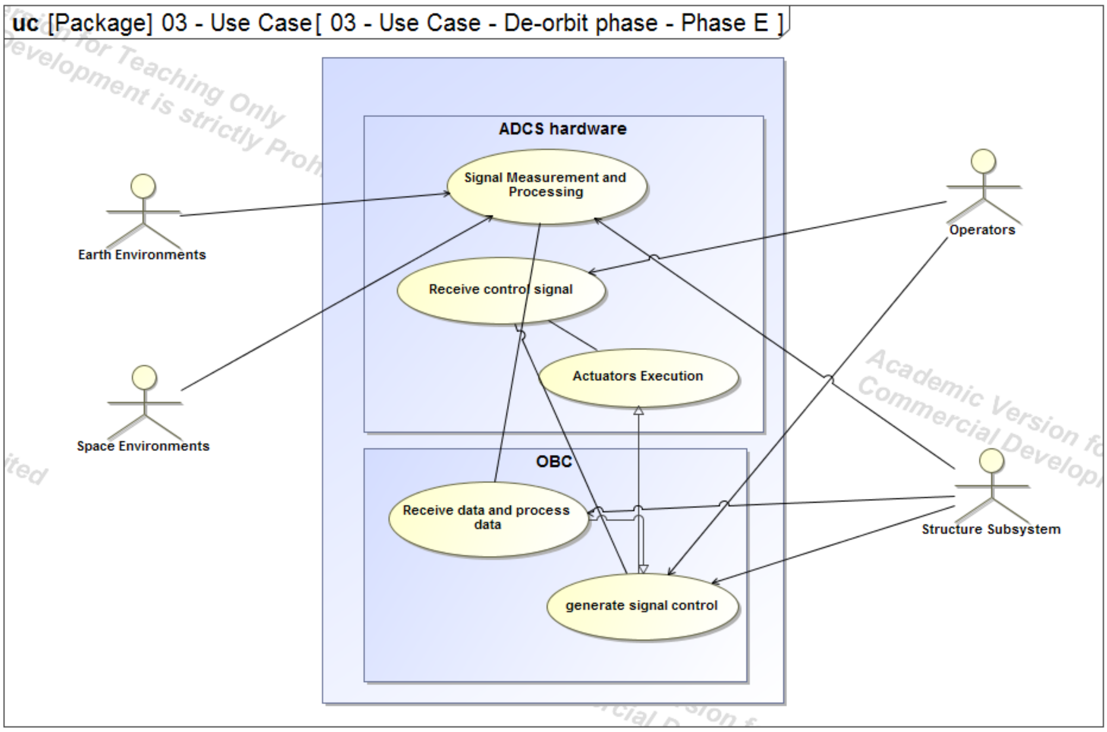

Figure 3.2-14: Use case diagram of MDG-ADCS in De-Orbit and close out phase

From this use case diagram, the list actions of each actor is analysed and identified. ADCS hardware have three main functions:

F5.1: Signal Measurements and Processing

F5.2: Receive control signal

F5.3: Actuator Execution

OBC have three main functions:

F5.4: Receive and Process Data

F5.5: Generate Control Signal

F5.6: Send the Control Signal

Table 3.2-4 shows the use case analysis of MDG-ADCS in De-Orbit and close out phase

Table 3.2-4: Use case analysis of MDG-ADCS in De-Orbit and close out phase

	ID	Function
ADCS Hardware	**F5.1:** Signal Measurements and Processing	1.1.1 Measure Sensors signal
		1.1.2 Send Data to OBC
	F5.2: Receive control signal: receive CMD from OBC	
	F5.3: Actuator Execution	1.3.1 Generate the magnetic
		1.3.2 Generate angular momentum
		1.3.3 Open the De-orbit mechanism
OBC	**F 5.4:** Receive and Process Data	2.1.1 Receive Data from magnetic sensor
		2.1.2 Calculate the Magnetic
	F 5.5: Generate Control Signal	2.2.1 Generate CMD
		2.2.2 Change the mode
	F 5.6: Send the Control Signal	2.3.1 Send the control signal to sensors
		2.3.2 Send the control signal to actuator

3.2.2 Architectural Design

3.2.2.1 Functional and Physical Design

After requirement analysis, the structure MDG-ADCS is defined. ADCS is decomposed to two subsystems: Attitude control system (ACS).

Attitude determination subsystem: the main function of this subsystem is using available sensors to provide information of satellite and actuators to control orientation of satellite. It use four kind of sensors and two kind of actuators.

Sensors:

- 06 Nonspin Solar Aspect Sensor
- 01 Star Tracker
- 01 Fiber Optic Gyroscope
- 01 GPS receiver
- 01 Geomagnetic Aspect Sensor

Actuators:

- 04 Reaction Wheel
- 03 Magnetic Torques

Attitude control subsystem: the main function of this subsystem is estimate and process data. It is combining of ADCS software, ADCS algorithm and onboard computer.

Figure 3.2-15 represent a structure of ADCS:

The next step is gather all functions are identified in requirement analysis process. The function flow is defined in each phase.

After that all the function will be allocated to each subsystem in ADCS. Each function will be responded by one subsystem but one subsystem can do many function.

Phase A: Development

There are no function of ADCS in this phase.

Phase B: Launch:

There are no function of ADCS in this phase.

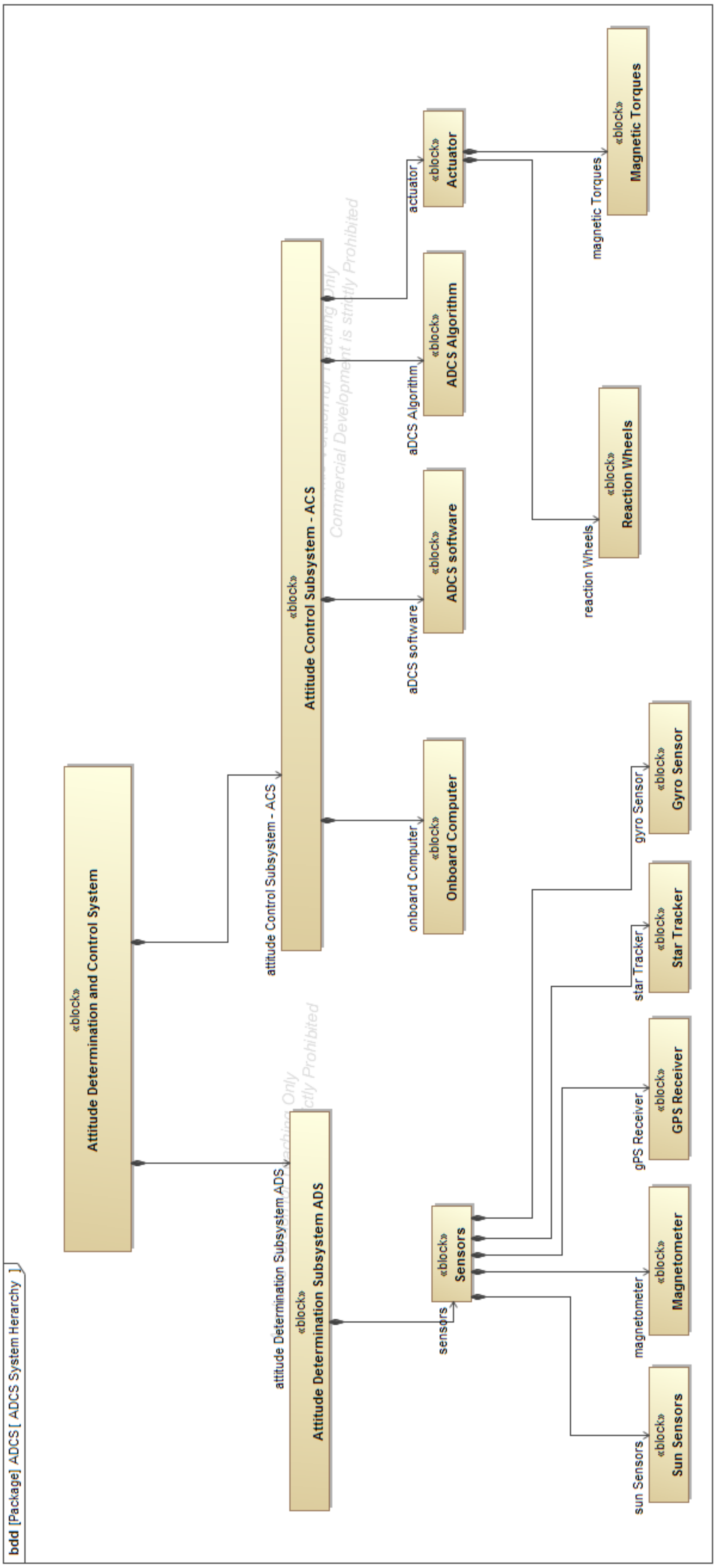

Figure 3.2-15: the structure of ADCS

Phase C: Deployment

In deployment phase, the ADCS have six main function. The function will start from function 3.1.

Figure 3.2-16 show the function flow in deployment phase.

Figure 3.2-17 show the allocation function to subsystem in deployment phase.

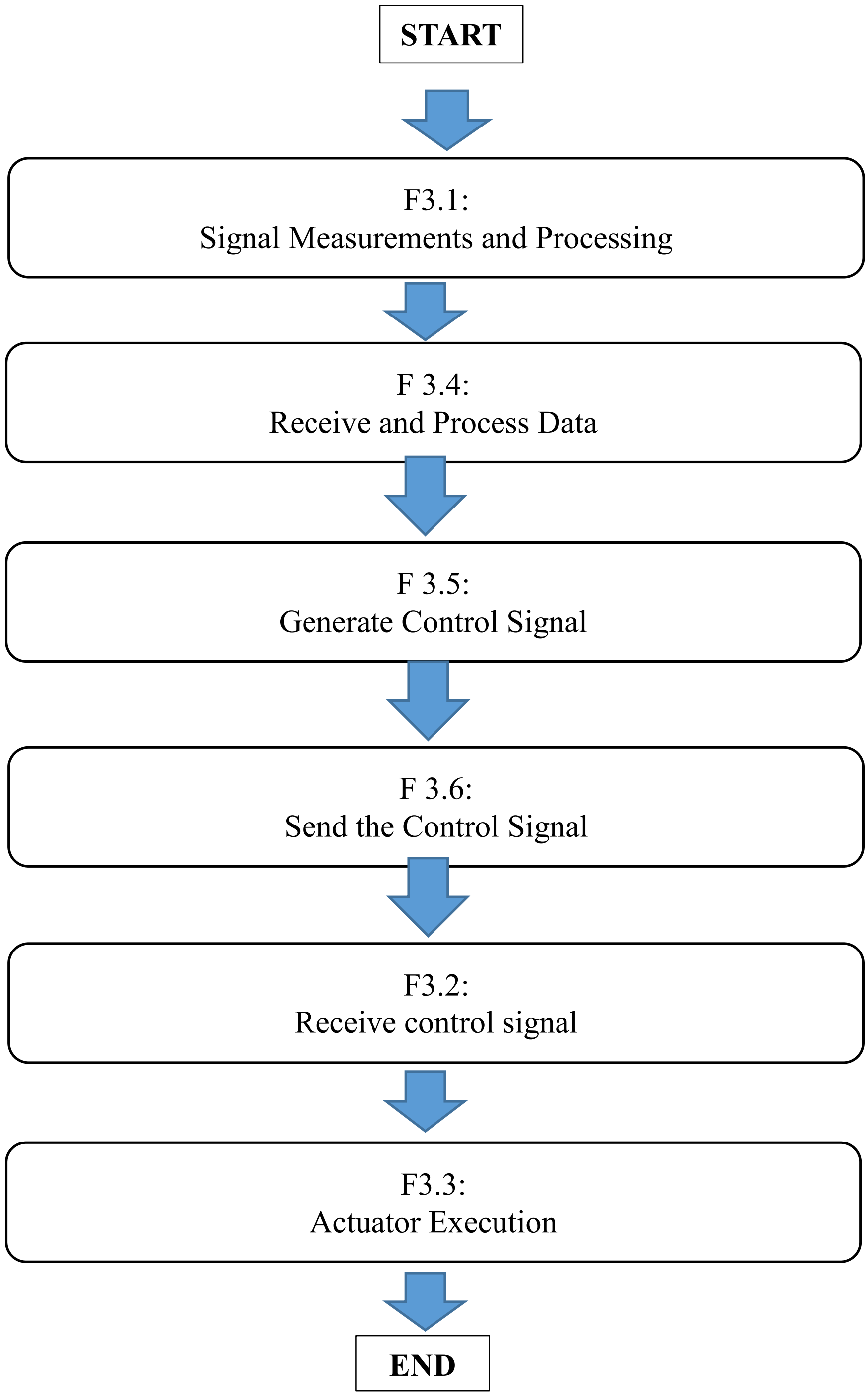

Figure 3.2-16: The function flow in deployment phase

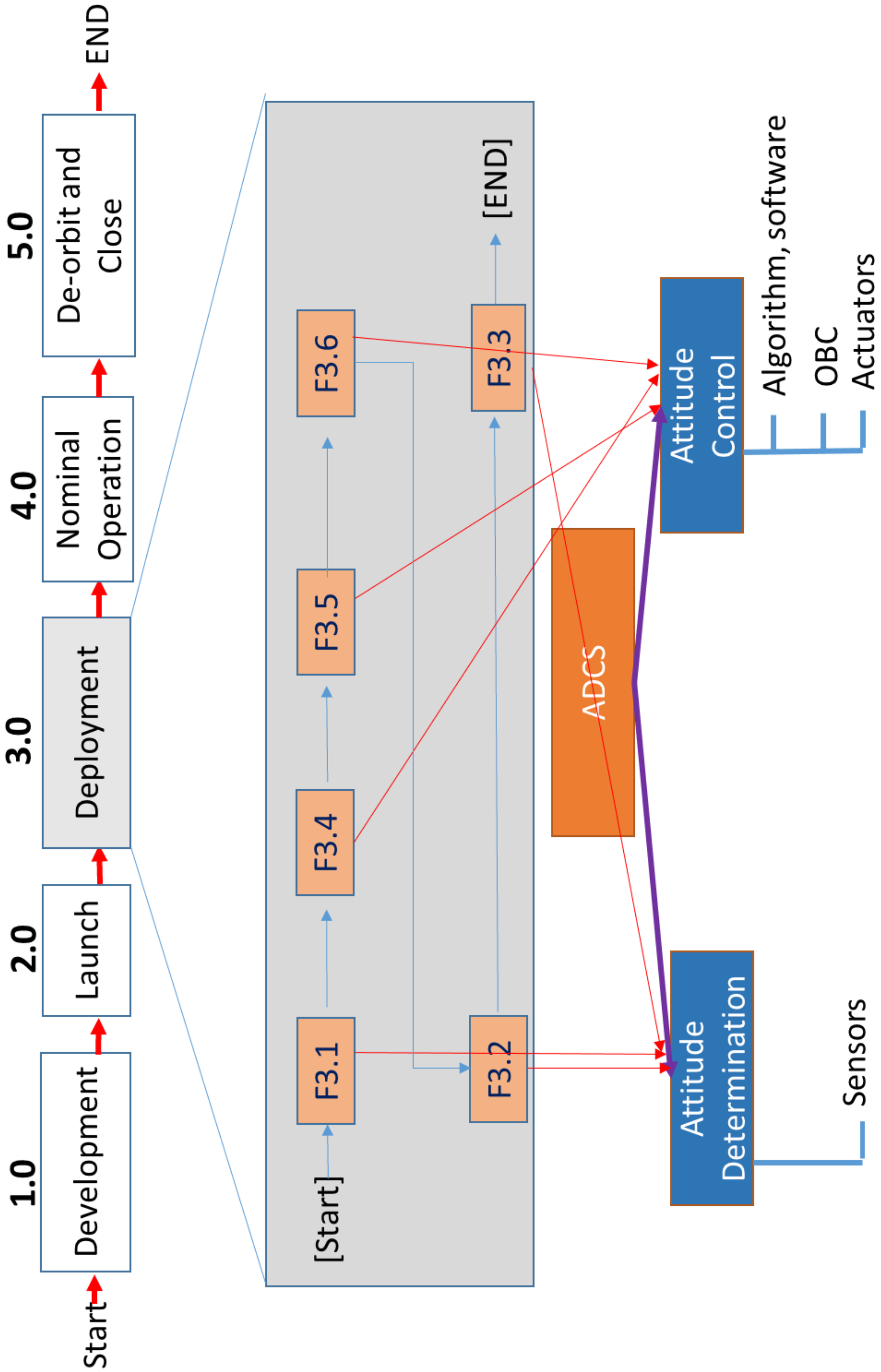

Figure 3.2-17: The allocations of function and subsystem in deployment

Phase D: Nominal operation

In nominal operation phase, the ADCS have six main function. The function will start from function 4.1.

Figure 3.2-18 shows the function flow in nominal operation phase

Figure 3.2-19 shows the allocation of function and subsystem in nominal operation phase

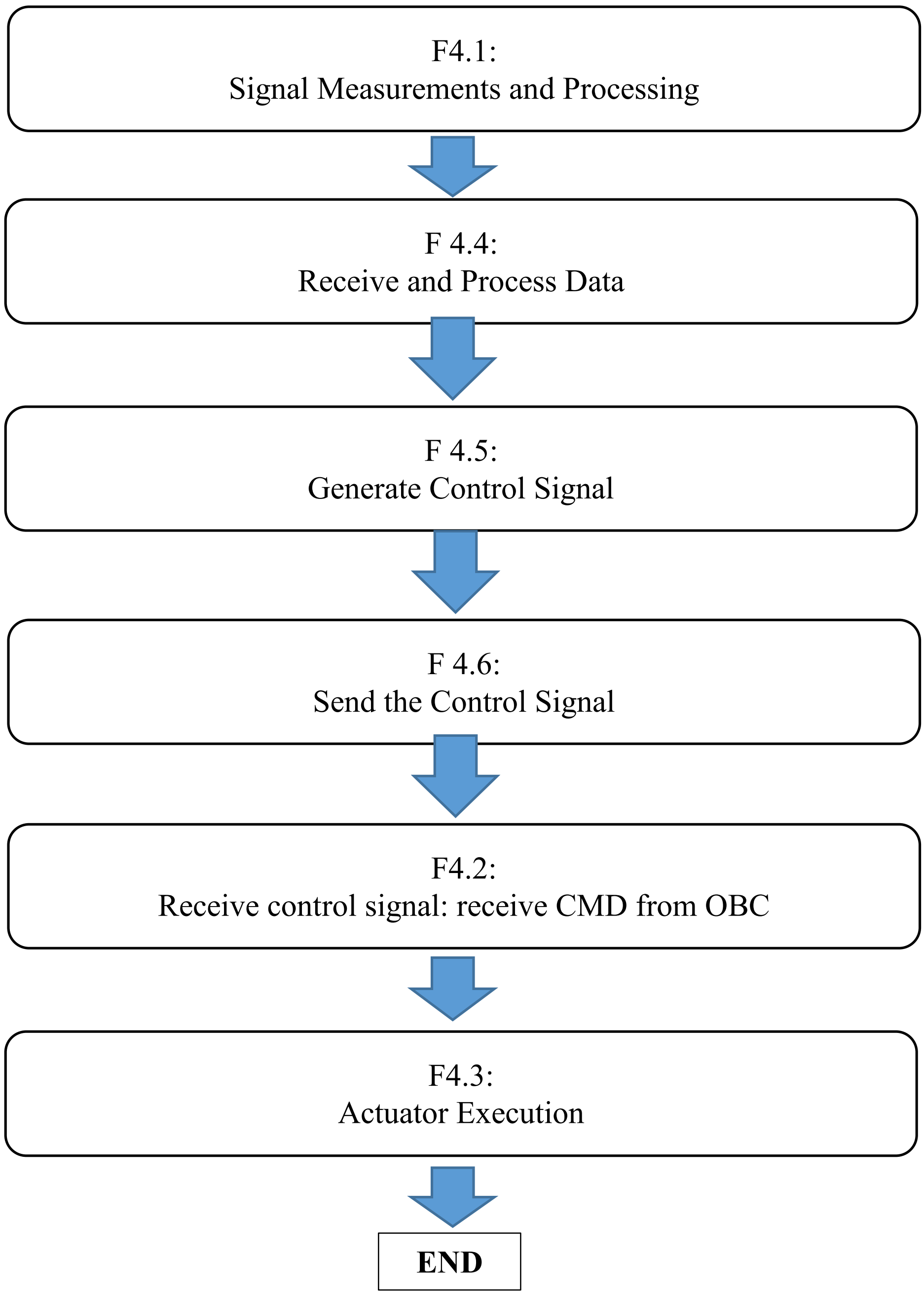

Figure 3.2-18: function follow in nominal operation phase

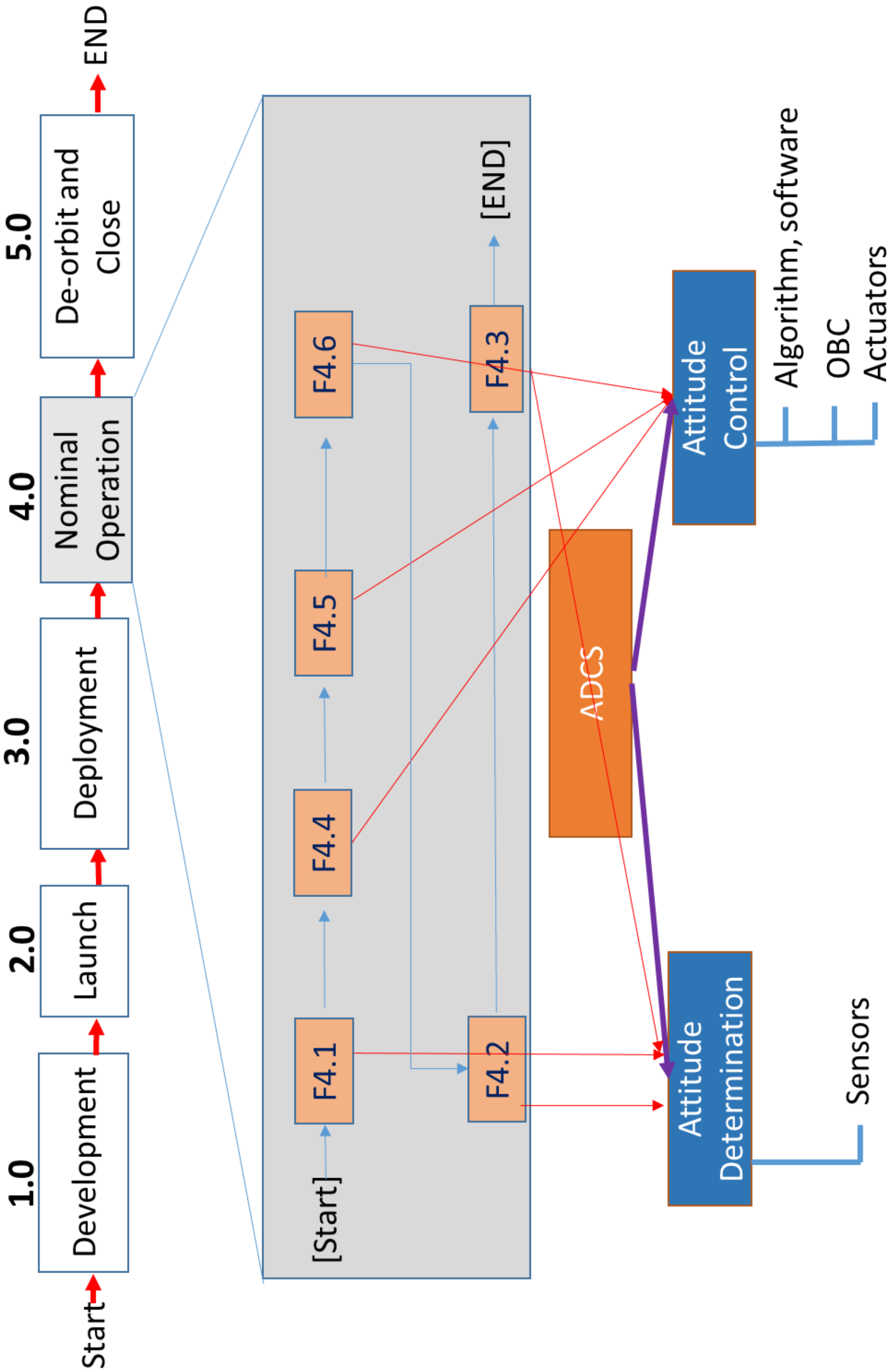

Figure 3.2-19: The allocations function and subsystem in nominal operation phase

Phase E: De-Orbit and close out

In nominal operation phase, the ADCS have six main function. The function will start from function 5.1 and the end in function 5.3

Figure 3.2-20 shows the function follow in de-Orbit close phase

Figure 3.2-21 show the allocations of function and subsystem in De-orbit close phase

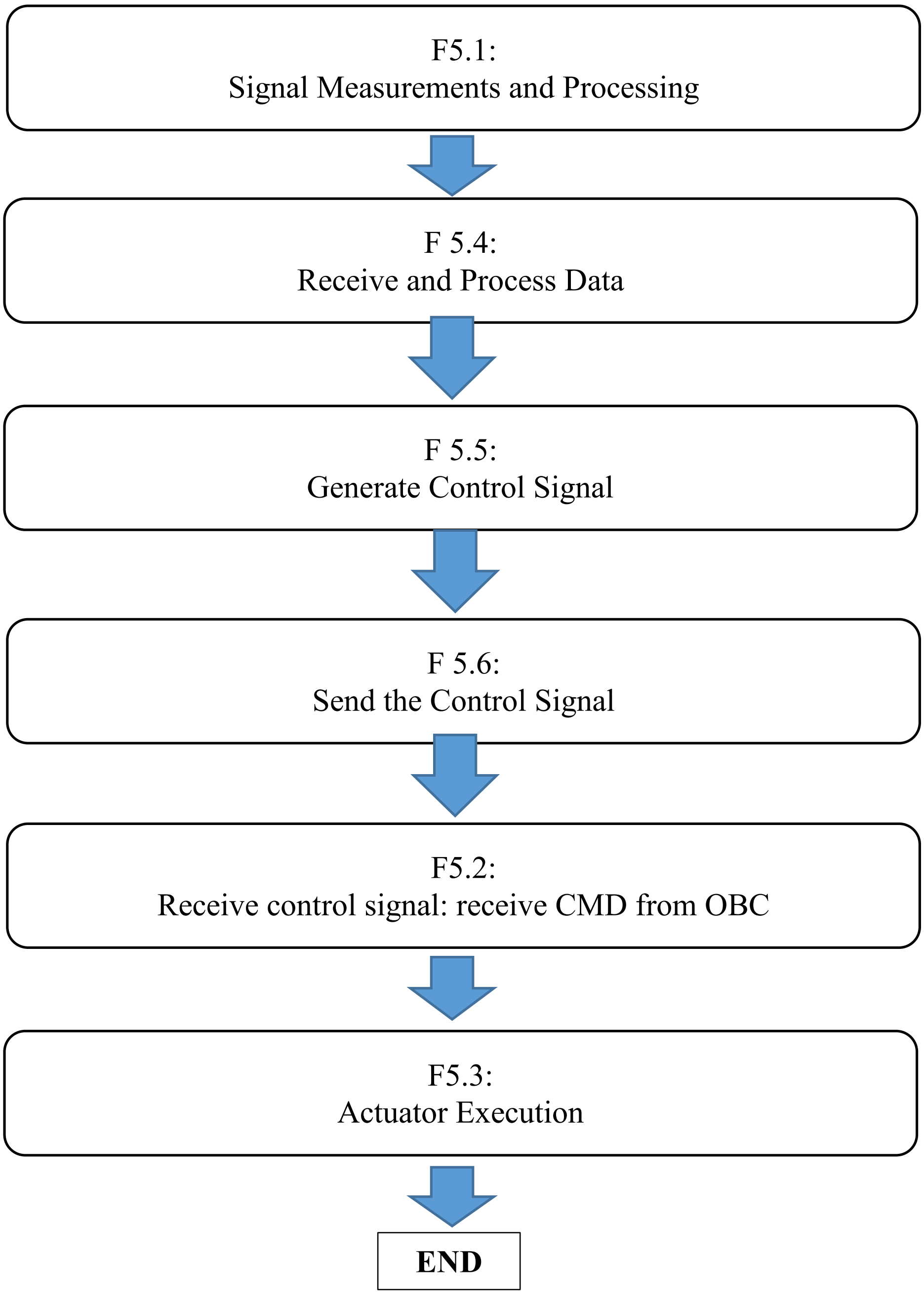

Figure 3.2-20: Function follow in De-orbit and close phase

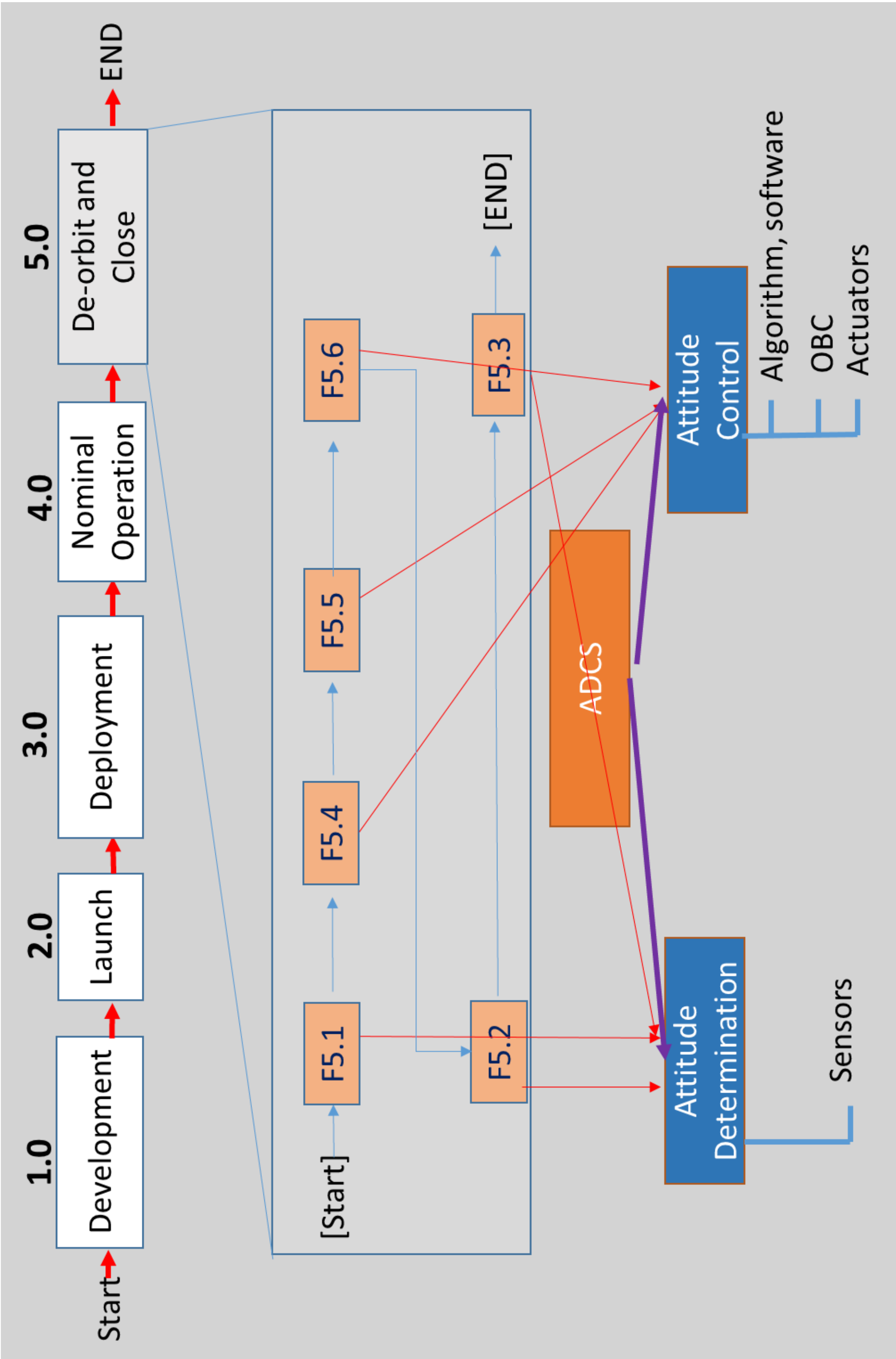

Figure 3.2-21: The allocations of function and subsystem in De-Obit and close phase

3.2.2.2 Architectural Diagram

Architecture diagram is a summary of ADCS. All function will be gathered on each subsystem. The interface among subsystem in ADCS is defined.

Attitude control subsystem have three interfaces with attitude determination subsystem.

Attitude determination subsystem have three interface with attitude control subsystem

Figure 3.2-22 shows the architectural diagram of ADCS in MDG satellite.

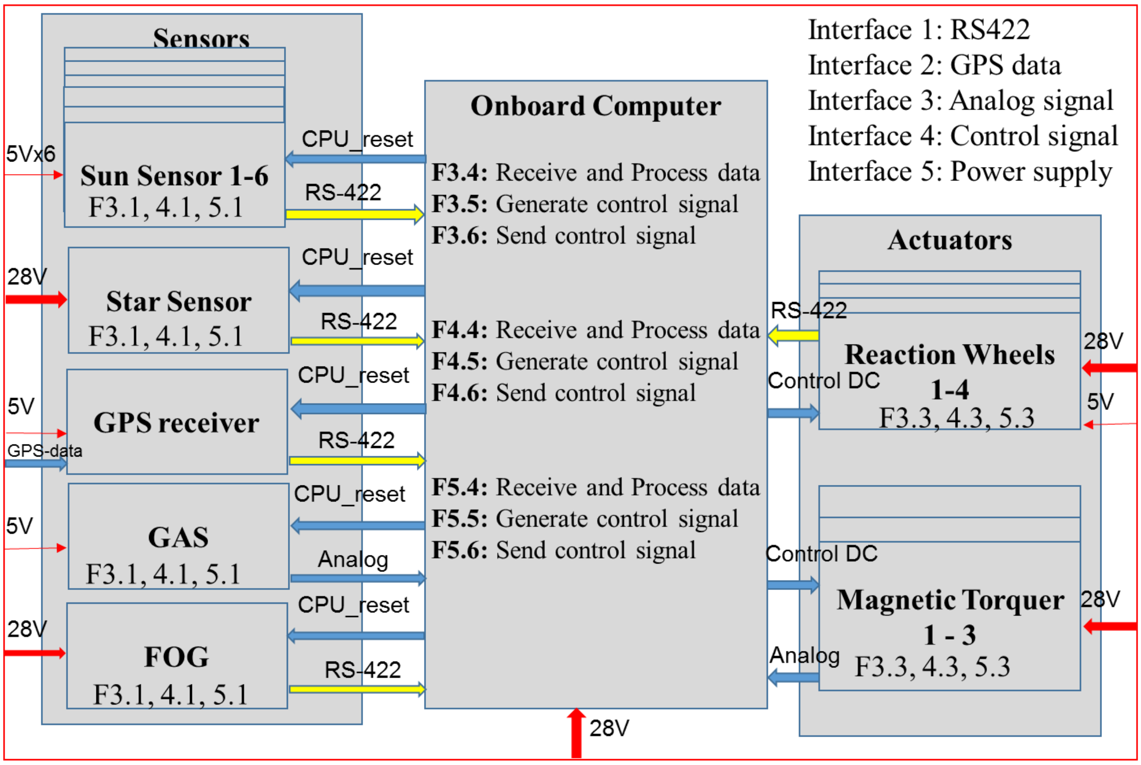

Figure 3.2-22: the Architectural diagram of ADCS in MDG satellite

3.3 An ADCS model design by using SysML

In the research, ADCS model of MDG satellite will be designed by using SysML. The model is intended to help specify and architect systems of MDG-ADCS and specify their components. Model focus on ADCS requirement and ADCS components behaviors.

3.3.1 System model organization

The ADCS model conduct eleven elements:

1. Requirement: the requirements package represented all requirement of ADCS though ADCS requirements specification diagram, high level requirements of ADCS table, requirements satisfy matrix.
2. Structure: the structure package represented structure of ADCS, name of all components is used in MDG-ADCS.
3. Use Case: from architecture is designed in 3.2, the use case for each phase of MDG-ADCS in life cycle will be represented.
4. Behaviour: this behaviour package conduct behaviour of all function of sensor in MDG-ADCS satellite, the sequence diagram of function
5. Analysis:
6. ADCS:
7. ADCS - On Board Computer: the specification and function of OBC
8. ADCS – Sensors: the function and sequence process of sensors
9. ADCS - ADCS Actuators: : the function and sequence process of sensors
10. Support Elements: the package conduct all document to support MDG-ADCS It have three elements:
    - Interface definitions
    - Value types
    - Viewpoints
11. Verification and Validation: the package conduct all process for verification and validation. It have three elements:
    - Requirements verification matrix
    - Traceability of requirements
    - Validation process.

Figure 3.3-1 shows the system model organization of MAG_ADCS:

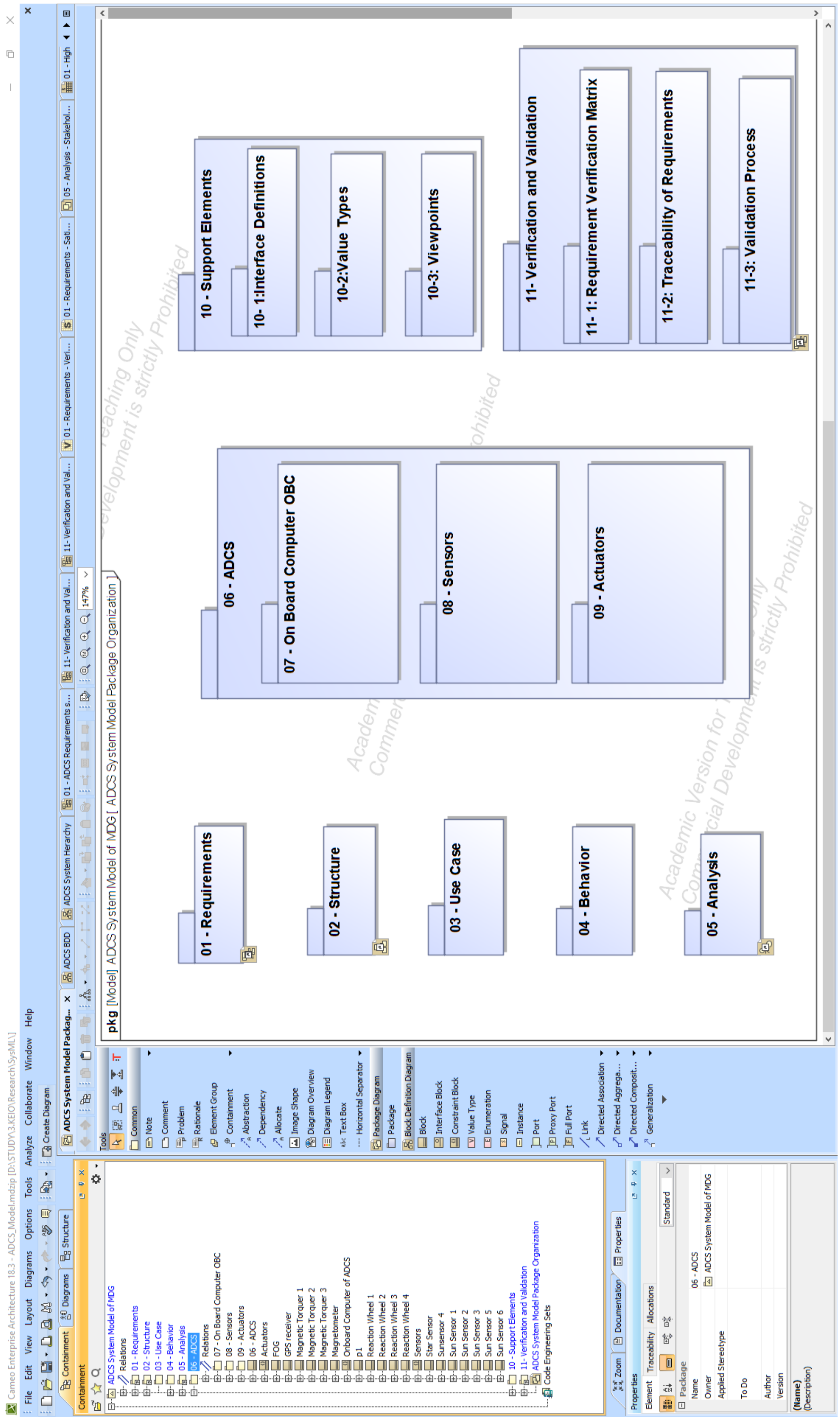

Figure 3.3-1: System model organization

3.3.2 ADCS requirement diagram

Text – based high level requirements of ADCS is represented in Table 3.3-1. In the high level, ADCS have six requirements. Those requirements come from mission of ADCS and another subsystem in MDG satellite. After that, each requirements are analysis and made it in detail.

Table 3.3-1: High Level Requirements

No	Id	Name	Text
1	4	ADCS *will determine and control attitude of satellite*	ADCS will determine and control three-dimensional orientation of *satellite.*
2	4.1	From *Payload subsystem*	ADCS support to *Payload subsystem achieve the mission..*
3	4.2	From *communication subsystem*	ADCS will support *to communication subsystem communicate with ground station*
4	4.3	From *Structure subsystem*	ADCS will fit *to structure subsystem.*
5	4.4	From *EPS subsystem*	ADCS will control *direction of solar array.*
6	4.5	Constraints	ADCS *have constraints: Orbit , Sensors specification, OBC specification.*

Figure 3.3-2 is represented requirements in detail in ADCS model.

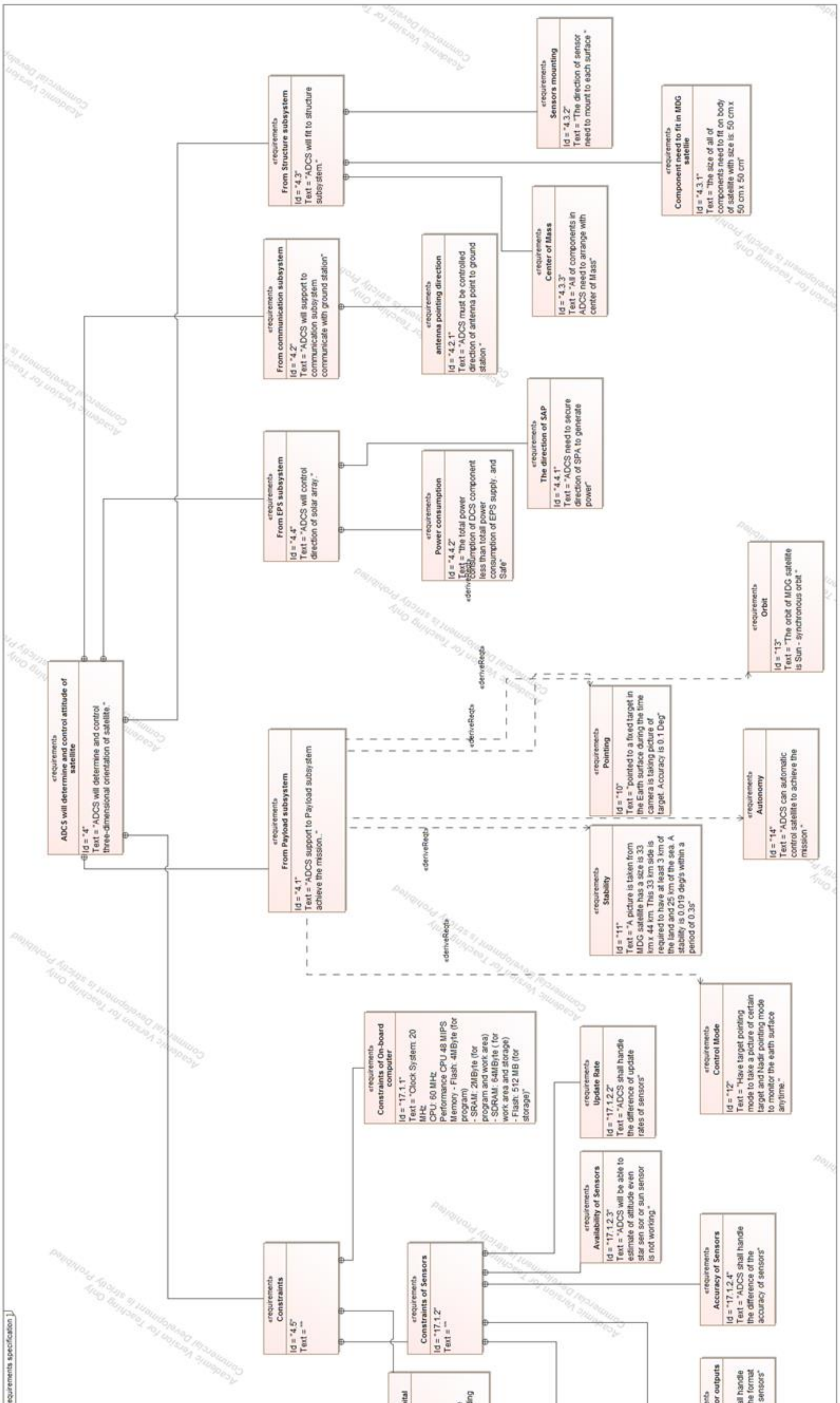

Figure 3.3-2: The requirements in detail

3.3.3 ADCS behaviour

As mentioned above in 3.1.3, ADCS hardware components are decided already. There are three kinds of hardware ADCS components: Onboard Computer, Sensors and actuators. Figure 3.3-3 shows the hardware decomposition of ADCS hardware components and the interconections between those components.

- Onboard Computer of ADCS block
- Sensors of ADCS block
    - Six sun sensors block (sun sensor 1, sun sensor 2, sun sensor 3, sun sensor 4, sun sensor 5, sun sensor 6).
    - Star sensor block.
    - GPS receiver block.
    - Magnetometer block.
    - FOG block.
- Actuators block
    - Magnetic Torquer 1 block.
    - Magnetic Torquer 2 block.
    - Magnetic Torquer 3 block.
    - Reation Wheel 1 block.
    - Reation Wheel 2 block.
    - Reation Wheel 3 block.
    - Reation Wheel 4 block.

The activities of GPS receiver processing are shown in Figure 3.3-4.

The activities of Sun sensors processing are shown in Figure 3.3-5.

The activities of Star Tracker processing are shown in Figure 3.3-6.

The activities of GYRO sensor processing are shown in Figure 3.3-7.

The activities of Magnetometer processing are shown in Figure 3.3-8.

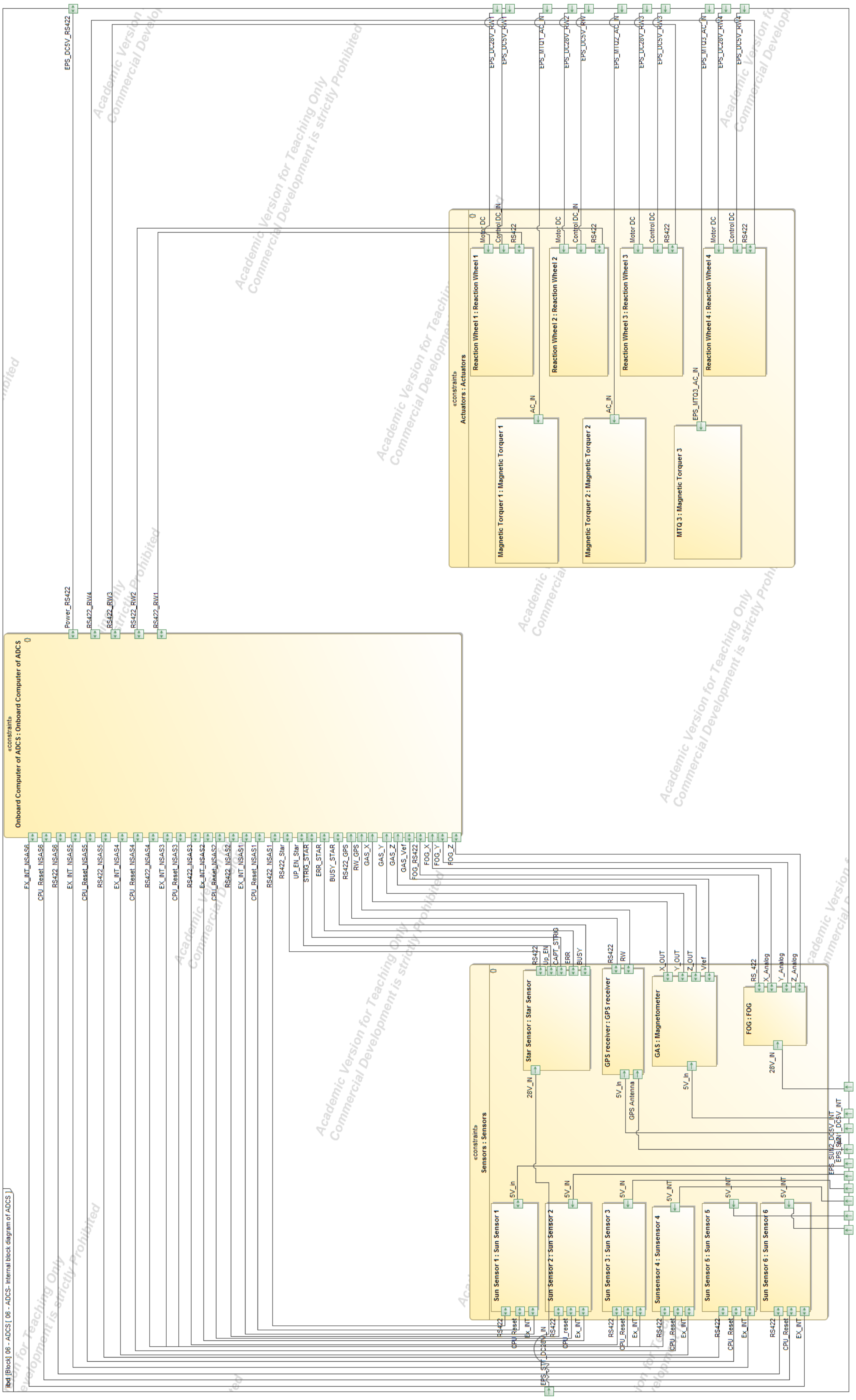

Figure 3.3-3: Internal block diagram of ADCS

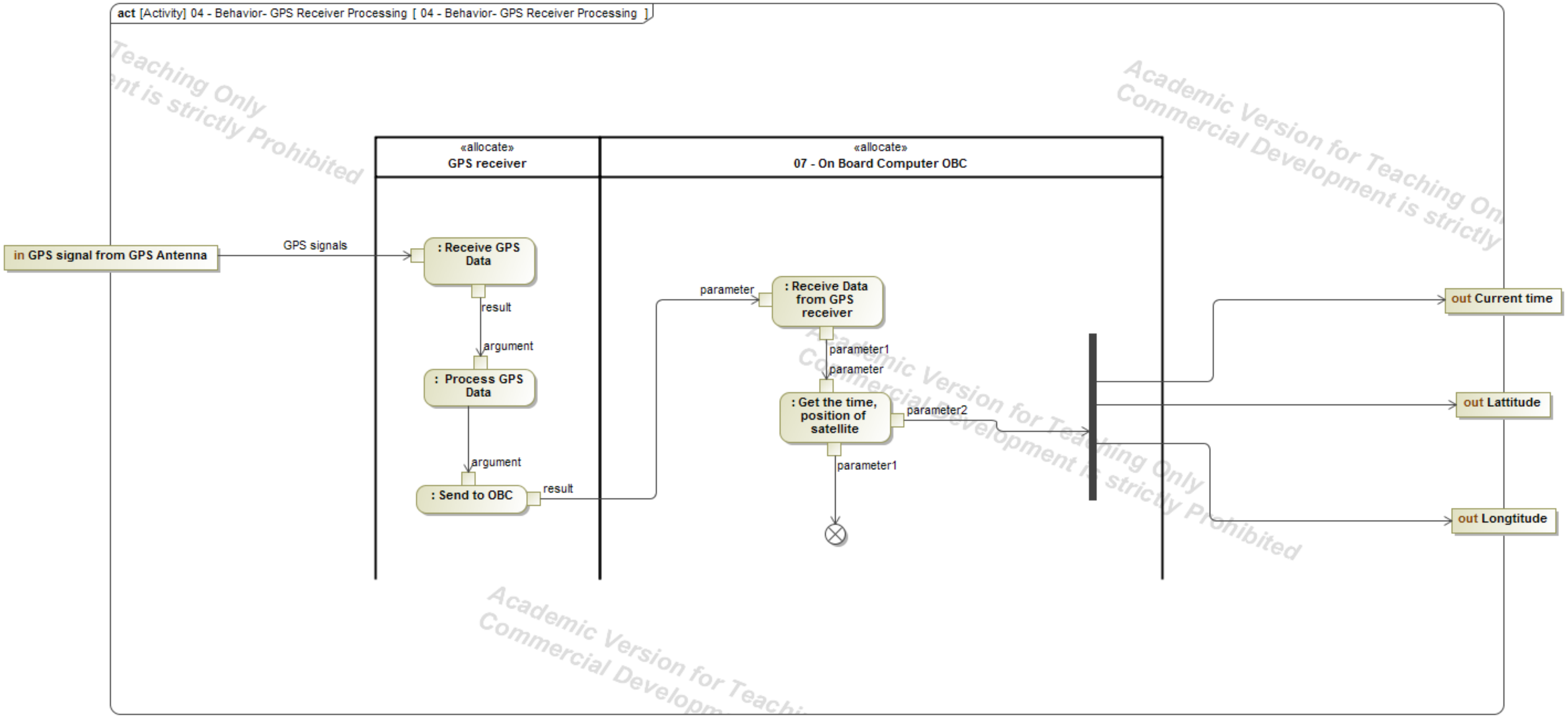

Figure 3.3-4: The activity diagram of "GPS Receiver Processing"

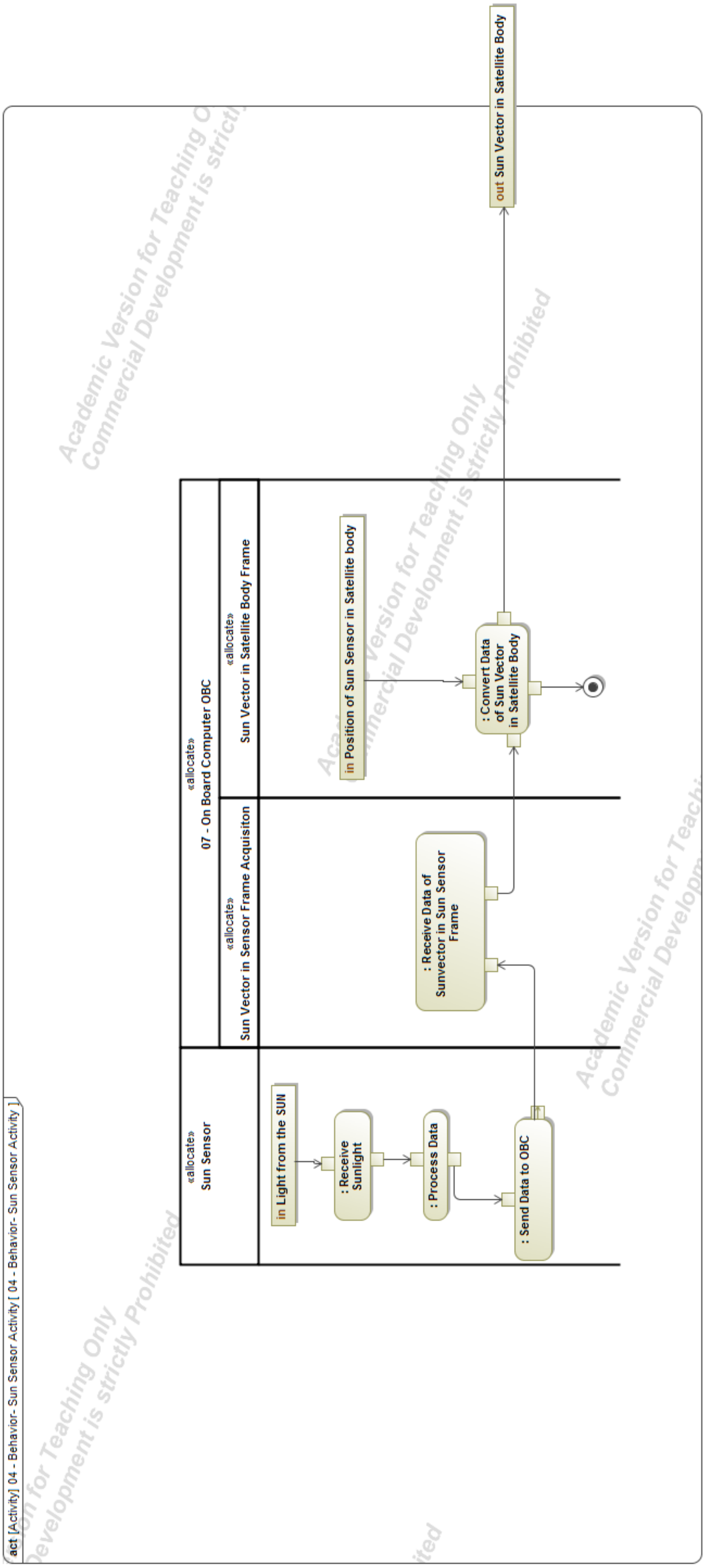

Figure 3.3-5: The activity diagram of Sun sensor activity

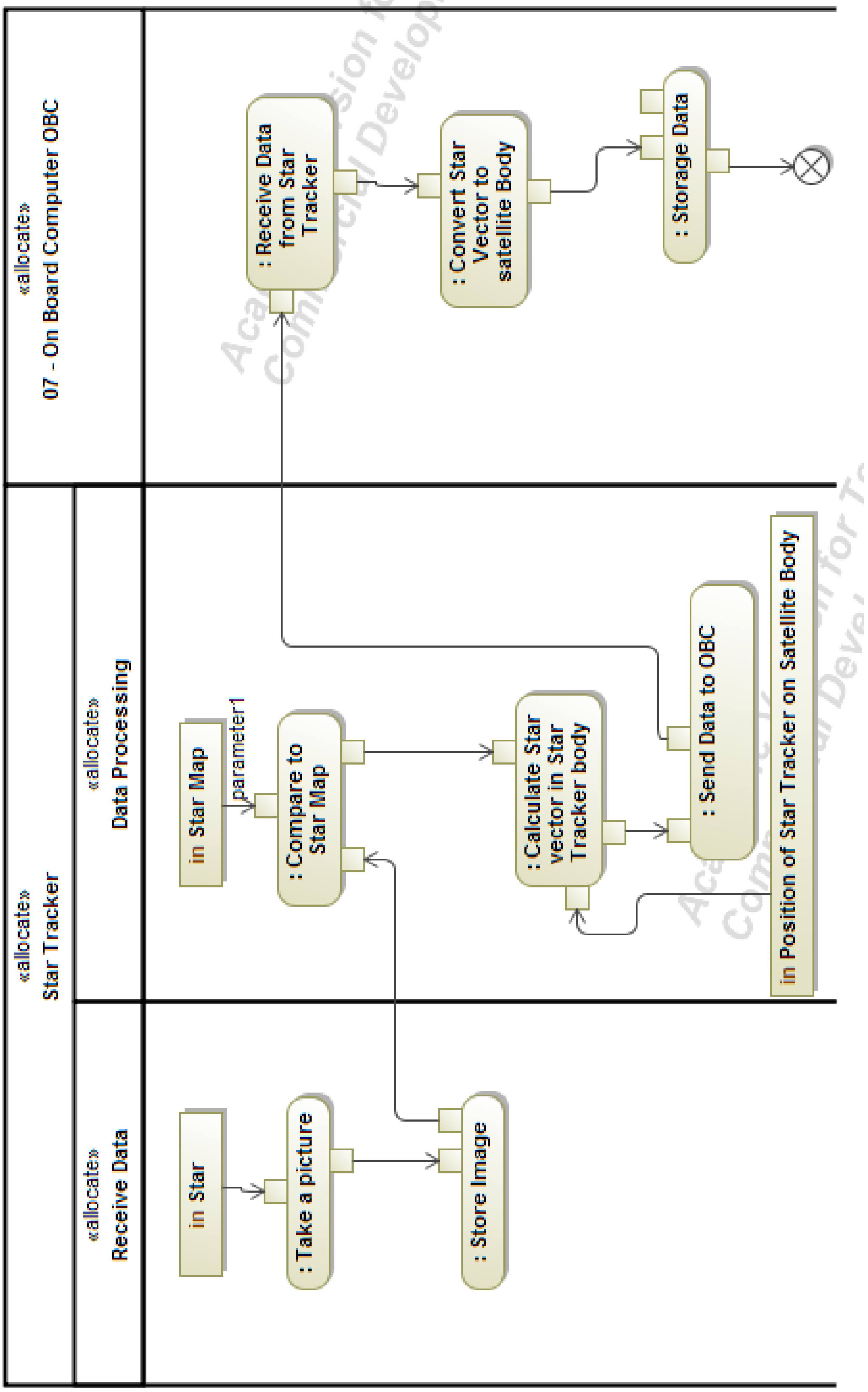

Figure 3.3-6: The activity diagram of Star Tracker processing

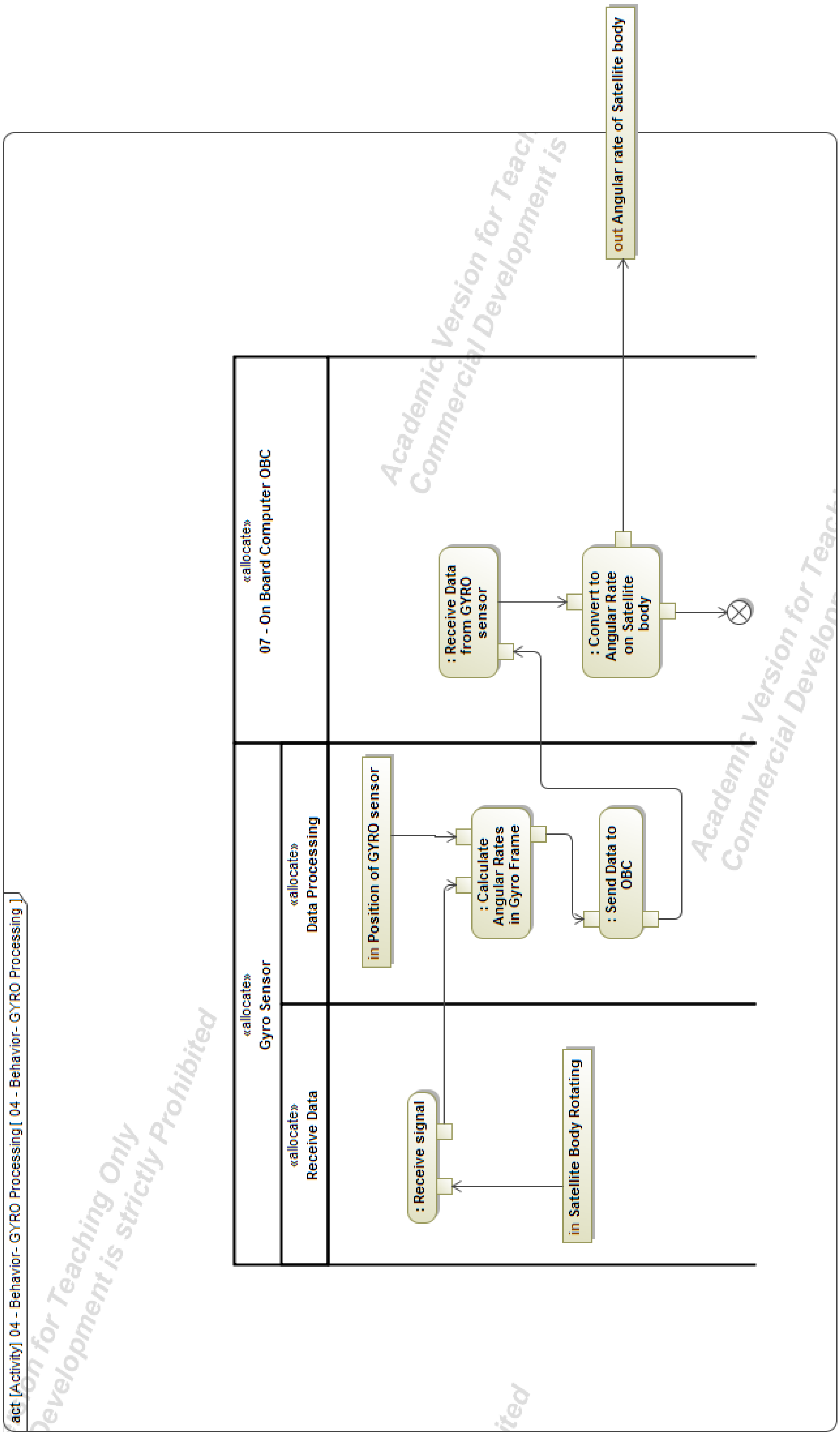

Figure 3.3-7: The activity diagram of Gyro Sensor Processing

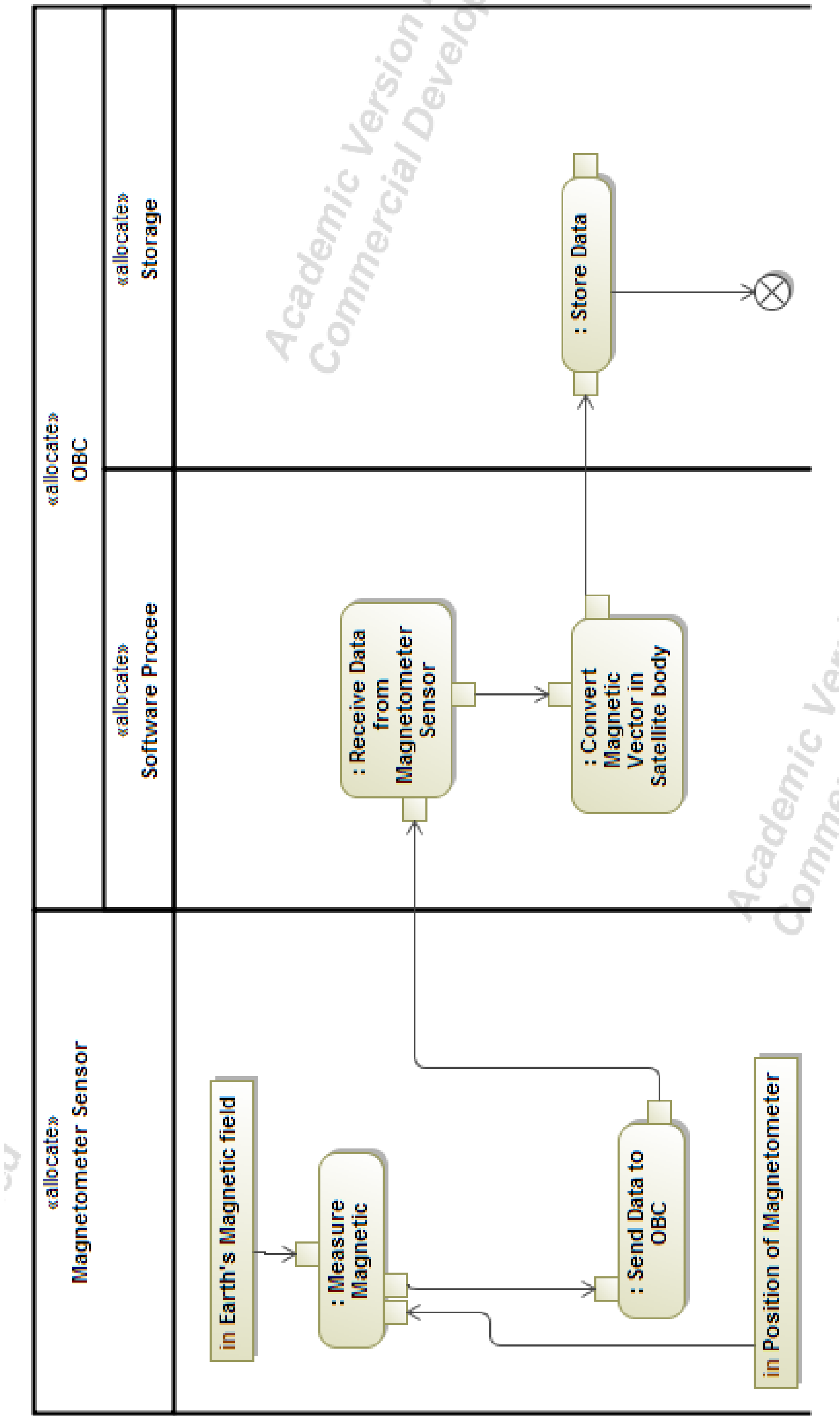

Figure 3.3-8: The activity diagram of Magnetometer Sensor Processing

Chapter 4 Verification and Validation

The research use a Vee model for verification and validation process. Vertical dimension is definition and decomposition of ADCS. Horizontal dimension is system development process. Figure 4-1 represents a Vee model for this research.

Allocate functions to components will be verified by inspection, the research will make a satisfy matrix to check all of allocation.

Development of system requirements and system architectures will be verified by inspection. The research will make a trace between requirements and functions to check every requirement need to satisfy.

Finally, the research have two users to validate:

- Validated by interviewing with ADCS members in MDG project to proof of the approach can support them to development of ADCS

- Validated by interviewing with VNSC mangers to proof the model is designed can be used.

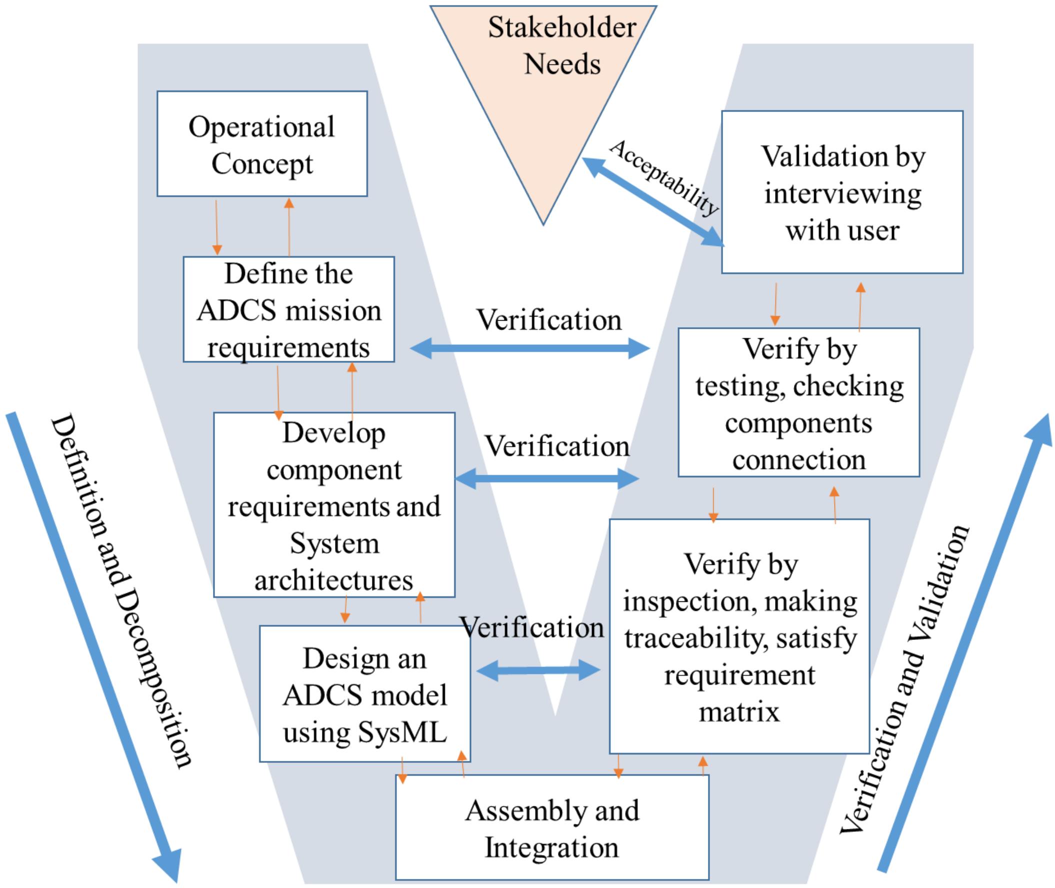

Figure 4-1: Vee model for verification and validation of research

4.1 Verification of ADCS requirements.

The research is verified by inspection, it will be observed from seven point of view:

- Stakeholder Needs
- Requirements High level
- Develop system requirements
- Functions
- Design Architecture of ADCS
- Subsystem
- Components

The relationships among those point of views are showed on below

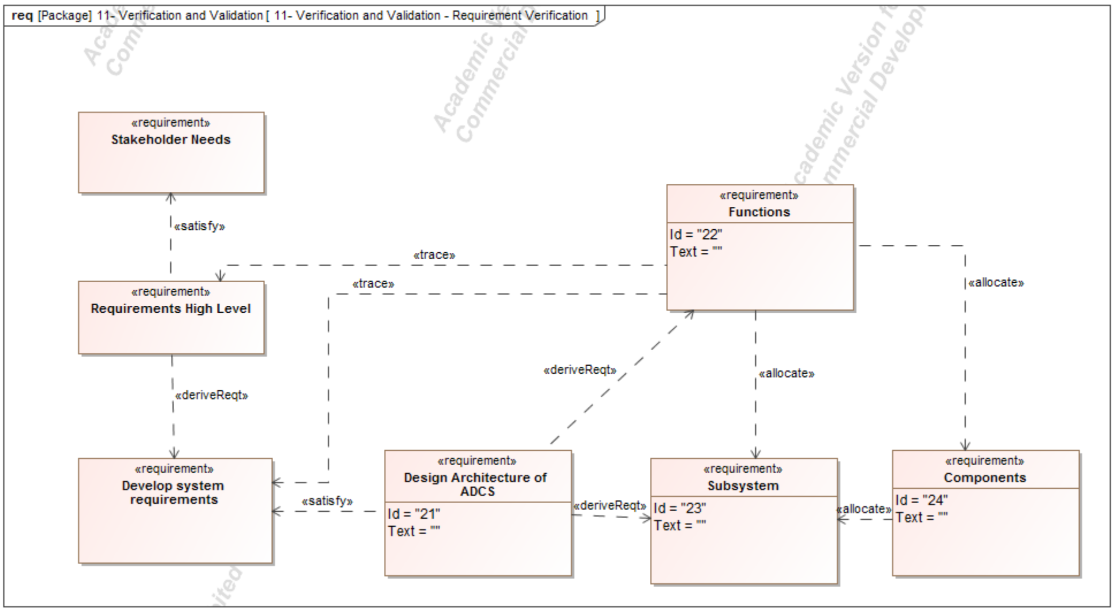

Figure 4.1-1: The relationships among those point of views

4.1.1 Traceability between requirements and performance

Process of maintaining requirements traceability supports ADCS team to confirm that all of requirements identified in context analysis phase are satisfies. The model will not be verified if have any the requirement is not satisfied.

The result of making requirements traceability is shown in Figure 4.1-2

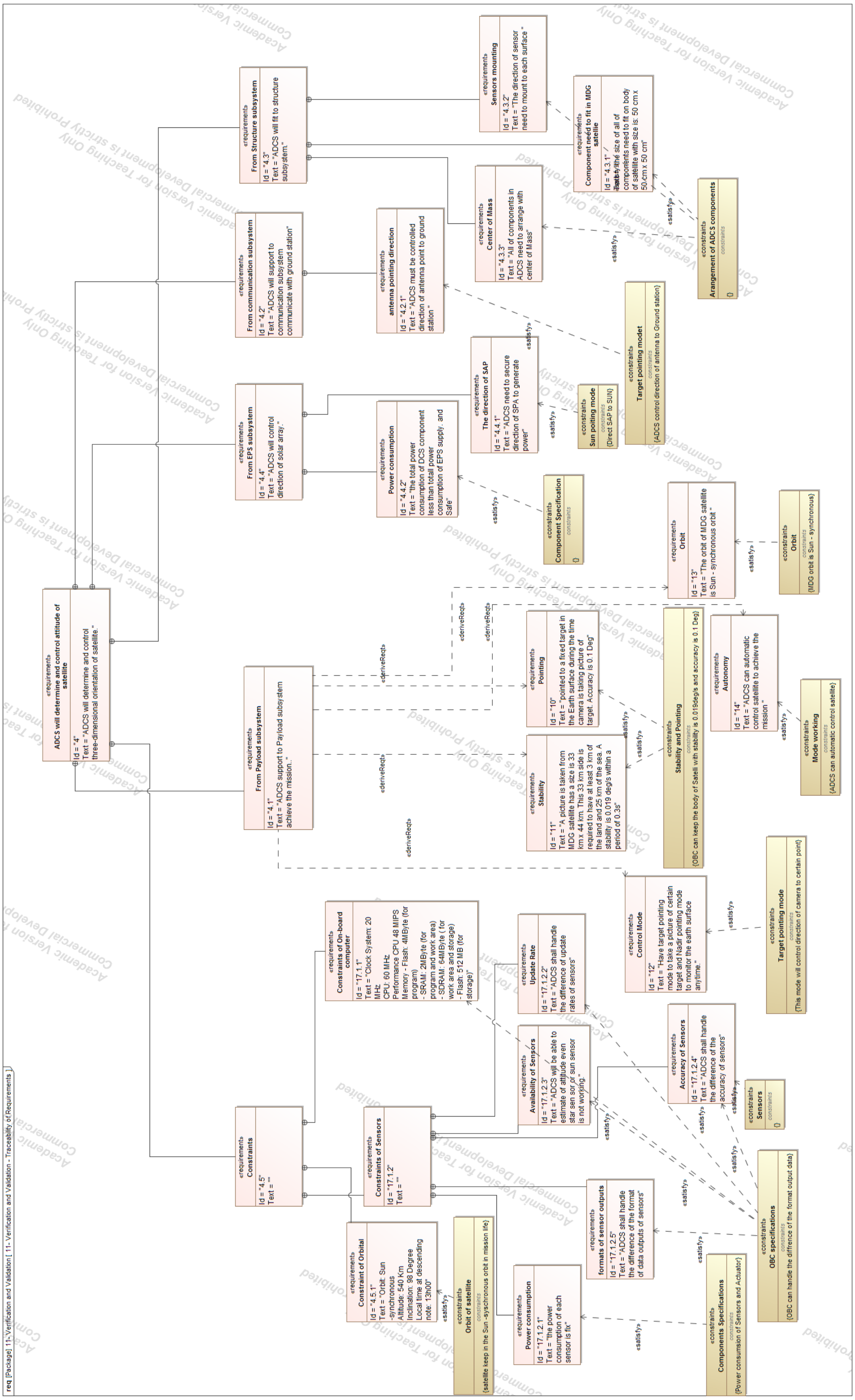

Figure 4.1-2: Traceability of requirements

4.1.2 Satisfy requirements matrix

Satisfy requirements matrix is a tool in SysML to check the status between requirements and components. By using this tool, the requirements of ADCS will be check the satisfaction status. Horizontal dimension of matrix is all of ADCS requirements. Vertical dimension is all of components in ADCS.

For example:

The pointing requirements of ADCS is ID 10

Contents:

ADCS need to point to a fixed target in the Earth surface during the time camera is taking picture of target. Accuracy is 0.1 Deg

Components:

Actuators, Onboard computer and Sensors

This mean the pointing requirements of ADCS will be satisfied by components are Actuators, Onboard computer and Sensors.

The results of satisfy requirements are shown on satisfy requirements matrix in Figure 4.1-3.

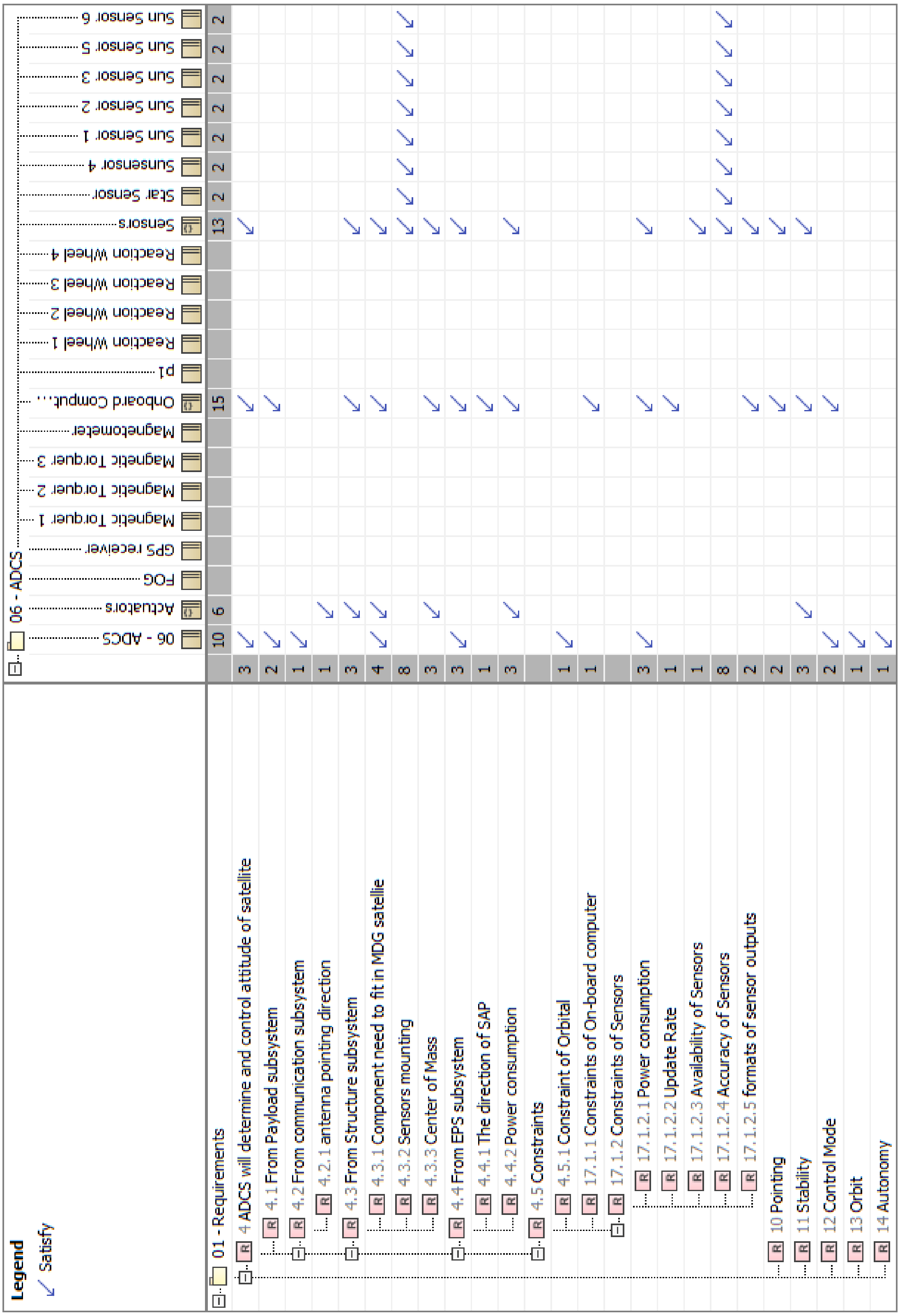

Figure 4.1-3: Satisfy matrix of requirements and components

4.2 Verification of MDG-ADCS connections

Verification of MDG-ADCS architecture by implementation ADCS components on Table Sat in Tokyo University.

There are two room in Table Sat:

Satellite room:

All of ADCS components are implemented in satellite rooms, sensors and actuators are connected to OBC via RS422 connection.

ADCS components configuration on table sat are shown in Figure 4.2-2

Ground Station room:

There are DAS computer and DC power source in ground station room. DAS computer is connected to OBC via cable.

To test the interface and physical allocation of MDG – ADCS, a test layout is implemented as the Figure 4.2-1.

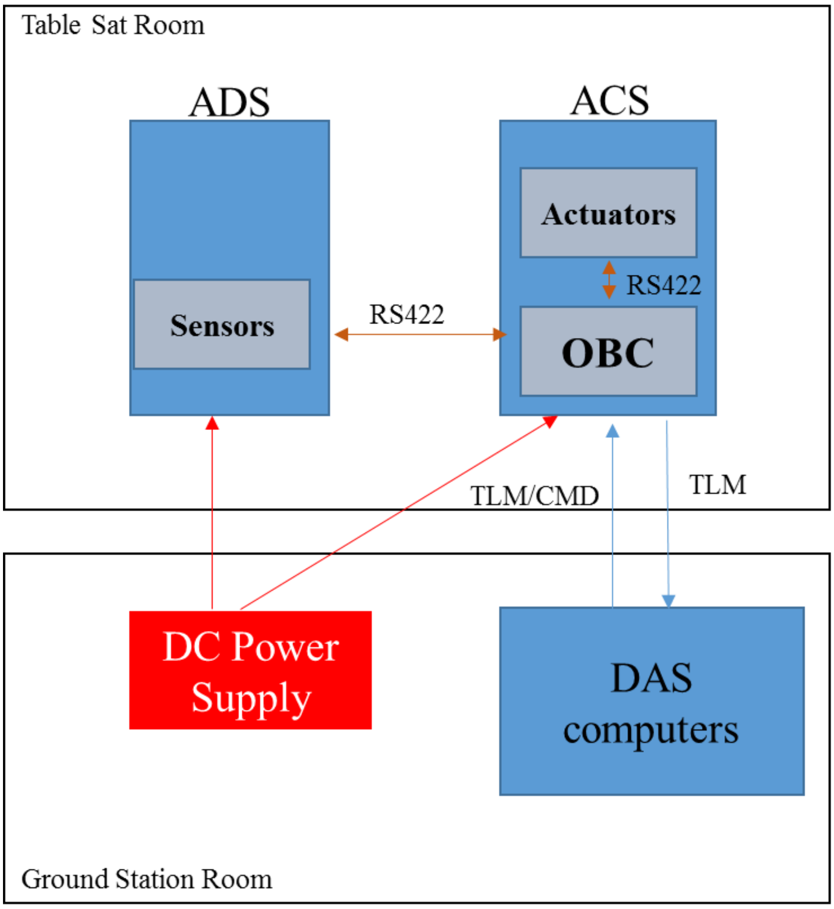

Figure 4.2-1: The test layout in Table Sat

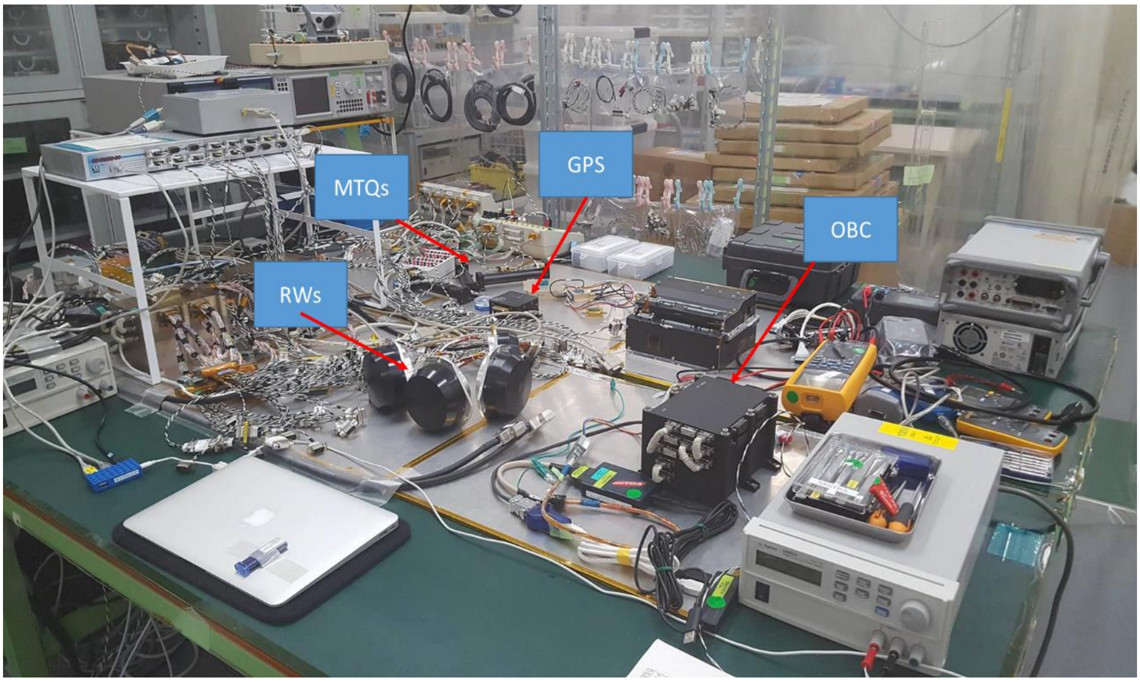

Figure 4.2-2: ADCS components connection in satellite room

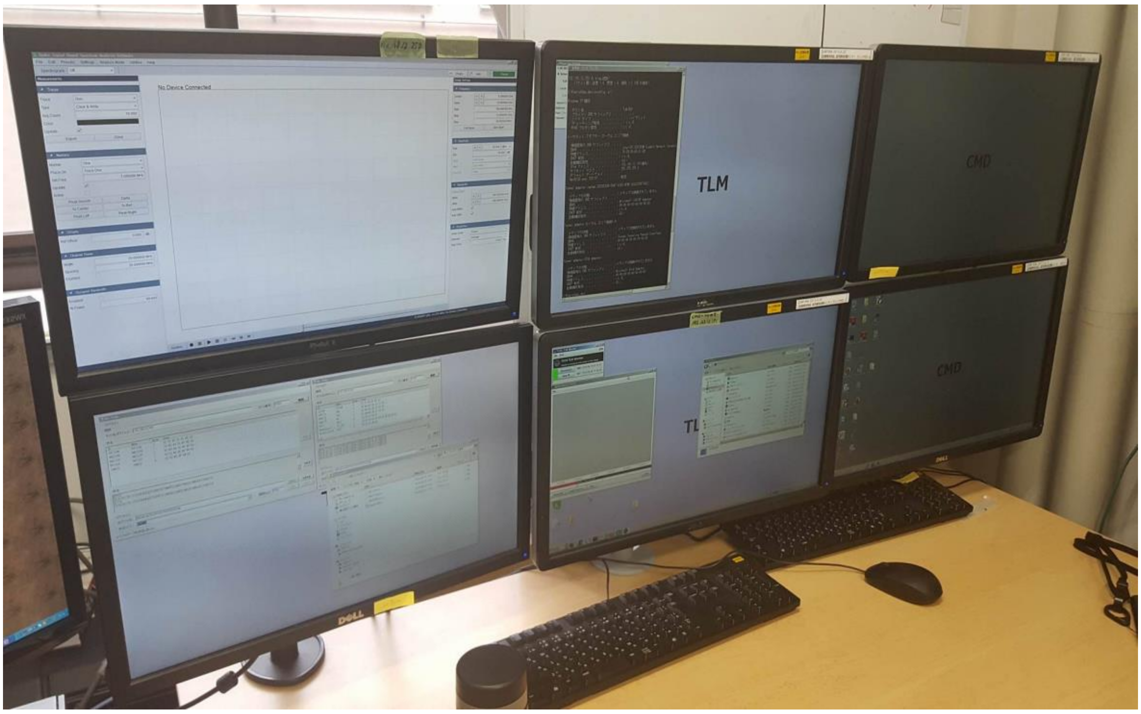

Figure 4.2-3: DAS computer on ground station room

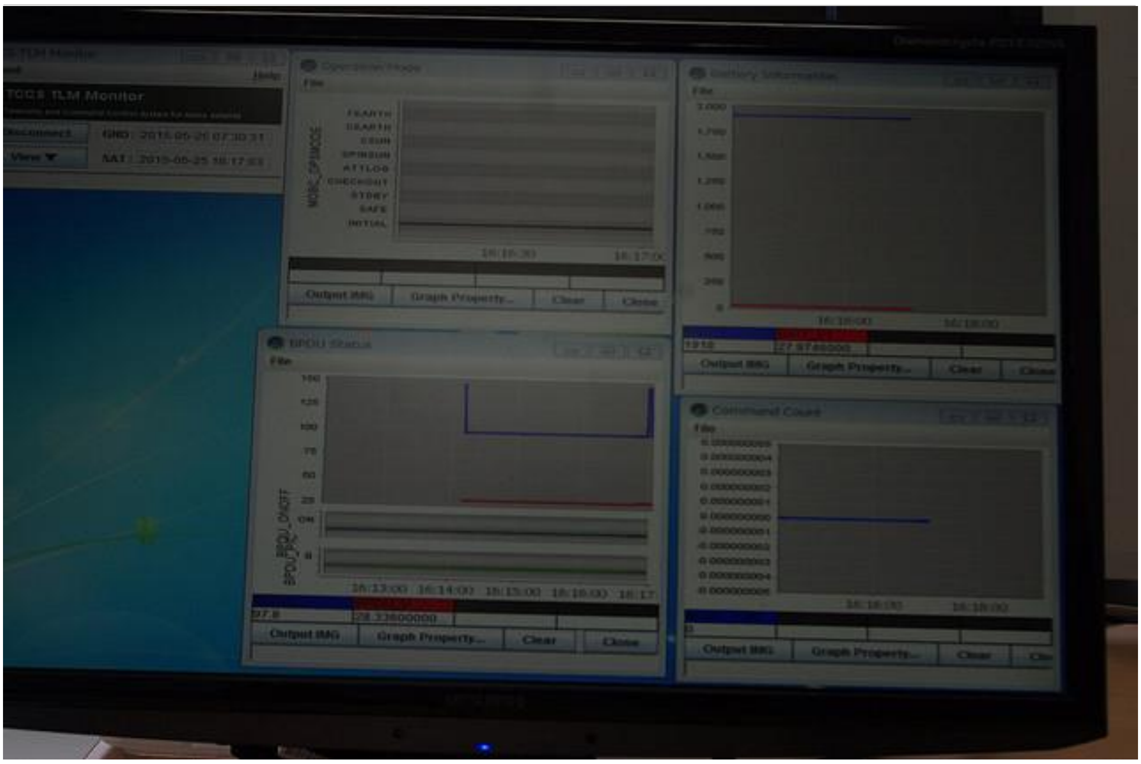

Figure 4.2-4: Monitoring TLM received in DAS computer

Checking ADCS components allocation:

Checking all of ADCS components connections

Testing CMD/TLM interface:

Send CMD from DAS computer to OBC to turn on/off ADCS components then checking TLM received in DAS computer to monitor status of ADCS components.

TLM received in DAS computer are shown in Figure 4.2-4.

Result:

All of ADCS components connection can be connected. When DAS computer send CMD to OBC, OBC can work in the correct CMD. OBC can receive signal from sensor and control actuators then send the TLM to DAS computer to monitor all status of ADCS components. Since the interfaces in ADCS are worked.

4.3 Validation by doing the interview

As mentioned on above of chapter 4, the research tend to support ADCS members to developments of ADCS and the model is designed can be reused to another satellite project in future of Vietnam national satellite center. The user of research are

- ADCS members
- Vietnam national satellite center

I conducted two kinds of interview with user to proof of user satisfaction

Interview 1: Interview with all of ADCS members in MDG project

Interview 2: Interview with two manager of Vietnam national satellite center

Validations criteria:

Interview with ADCS members:

- At least six of eight interviewees choose answer A or B or C in question one. This questions is established to assess the problems are defined in the research can meet problems ADCS faced.

- At least six of eight interviewees choose answer A in question two. This questions is established to assess how well the research can show ADCS development process.

- At least six of eight interviewees choose answer A in question three. This questions is established to assess how well the research can show the trace among ADCS requirements, functions and performance of components.

- At least six of eight interviewees choose answer A in question four. This questions is established to assess how well the research can reduce the volume of document compared with Document –Based.

- At least six of eight interviewees choose answer A or B in question six. This questions is established to assess how well the research can support for inexperienced members understand ADCS development process.

Interview with VNSC managers:

- VNSC manager agree with the second research objective. The model is designed can be reused and MBSE is good approach to support ADCS members.

4.3.1 Interview with MDG-ADCS project members

Purposes:

- To proof of MBSE approach using in this research can support MDG-ADCS member who are inexperience person.
- To get feedback/comment to improve the model

Interviewees:

Table 4.3-1: Interviewees

No	Interviewee	ADCS experience
1	ADCS member 1 - Leader	First time
2	ADCS member 2 – Sub Leader	First time
3	ADCS member 3	First time
4	ADCS member 4	First time
5	ADCS member 5	First time
6	ADCS member 6	First time
7	ADCS member 7	First time
8	ADCS member 8	First time

Question:

There are six question for each interviewee. Questions in the interview include both closed and open-ended typed. The answer is multiple choice.

The form and content of questionnaire are shown on Table 4.3-2.

Table 4.3-2: Questionnaire for ADCS members

No	Question
1	Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS? A. ADCS members lack of knowledge in ADCS development process B. Making a trace among ADCS requirements, functions and performance of components. C. Sharing documents among members D. Document-Based generated many text documents. E. Other
	Comment:
Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)	
2	How does the approach show you ADCS development process? A. The approach shows ADCS development process clearly B. No, Not at all C. Other
	Comment:

3	How does the approach show you the trace among ADCS requirements, functions and performance of components? A. The approach assures traceability among ADCS requirements, functions and performance of components B. The approach assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment:
4	Does the approach can reduce the volume of document compared with Document –Based? A. Yes, the approach reduce the volume of document compare with Document –Based B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based
5	Do you want to use MBSE to development of ADCS in the future? A. Yes, I want to use B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment:

6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process B. Yes, but not 100%. C. I don't know D. No, not at all E. Others	
	Comment:	

Figure 4.3-1: The results of questionnaire with ADCS members

Conclusions from results of interviews:

- Using Document-Based approach to developments of ADCS, it show some difficult for ADCS members in MDG project such as: difficult to understand ADCS development process, difficult to share document among members and Document-Based generated too much text documents. 62.5% of ADCS members felt they are lacking of knowledge in ADCS development process. 75 % of ADCS members felt difficult to make a trace among ADCS requirements, functions and performance of components.
- 87.5 % of ADCS members agree with this approach shows them ADCS development clearly.
- 100% of ADCS members agree with this approach show you the trace among ADCS requirements, functions and performance of components and reduce the volume of document compared with Document-Based.
- 87.5 % ADCS members agree with this research can support for inexperienced members. They want to use MBSE in the next project in the future.

The first objective of the research is support for inexperienced members is validated.

4.3.2 Interview with manager from Vietnam National Satellite Center

Interview 2: Interview with manager of Vietnam national satellite center

Purposes:

- To prove the model is designed can be reusable
- To get feedback/comment to improve the model

Interviewees:

No	Interviewees	Position in VNSC
1	Manager 1	Head of Space Design Department Vietnam National Satellite Center Vietnam Academy of Science and Technology
2	Manager 2	Head of Satellite Assembly, Integration and Test Department Vietnam National Satellite Center Vietnam Academy of Science and Technology

Questionnaire:

There are four questions in interview. Questions in the interview include both closed and open-ended typed. The answer is multiple choice

The questions and answers of interview with manager 1 are shown in Table 4.3-3.

Table 4.3-3: The questions and answer of interview with manager 1

No.	**Questions**
1	To development of Attitude Determination and Control Subsystem (ADCS) in satellite, Document-Based systems engineering shows some disadvantage for ADCS members such as: Too many text documents are generated, difficult to make traceability among ADCS requirements, functions and performance, difficult to reuse those documents for another project. What do you think need to be improved in Document-Based systems engineering approach? Are you looking for other approach to development of ADCS in the future?
	Answer: For me, the most difficult point to development of ADCS is how to verify the characteristics of system components and verify performance of integrated system. System engineering may only around 10% of workload in development of ADCS process. At this time, I did not think the document-based systems engineering approach is a problem for ADCS. However, if other methods show their advantage, we can try to move to new method.

2	This research has proposed and Model-Based system Engineering approach to development of ADCS. How do you think about Model-Based system Engineering approach? (In term of volume of documents are generated, traceability among ADCS requirements, functions and performance, convenient for operators)
	Answer: I do not have enough time to study and understand in detail about model-based system engineering approach, however I believe that better in term of traceability and convenient than document-based method because it is supported by SysML software.
3	70% members of ADCS had trained to using Model-Based systems engineering. How do you think about moving from Document-Based systems engineering to Model-Based systems engineering to development of Attitude Determination and Control Subsystem in satellite in Vietnam National Satellite Center (VNSC)? (In term of convenient for operators, effective of performance. etc.)
	Answer: As a manager, I am looking for optimal and cost effective solutions. Therefore, the 70% members of ADCS, who had trained MBSE, need to show VNSC management board the advantage of MBSE method, especially through the MicroDragon project. On the other hand, the price of software is also needed to be taken into account.

4	The model is designed by using Model – Based System Engineering approach with a tool is System Modelling language (SysML) in the research. Do you think the model can be reused to another satellite project of VNSC in the future? A. Yes, it can reuse B. Yes, but it is need to improve C. No, Not at all D. Other comments
	Comment: Answer: D. As I mention above, VNSC should be got more impressive before we can make the decision.

Table 4.3-4: List of questions and answers with manager 2

No.	Questions
1	To development of Attitude Determination and Control Subsystem (ADCS) in satellite, Document-Based systems engineering shows some disadvantage for ADCS members such as: Too many text documents are generated, difficult to make traceability among ADCS requirements, functions and performance, difficult to reuse those documents for another project. What do you think need to be improved in Document-Based systems engineering approach? Are you looking for other approach to development of ADCS in the future?
	Answer: ADCS is one of the most important subsystems in satellite. In order to develop ADCS well, it is still necessary to adopt Document-Based approach although this approach shows several limitations as the mentions. And with considerable improvements, we can eliminate those drawbacks to achieve better results. Vietnam is still developing country and we are on a very first step of satellite technology, we do not have many experts in satellite technology and capacity building is necessary so that looking for other approach for ADCS or satellite development is very fruitful.

2	This research has proposed and Model-Based system Engineering approach to development of ADCS. How do you think about Model-Based system Engineering approach? (In term of volume of documents are generated, traceability among ADCS requirements, functions and performance, convenient for operators)
	Answer: Comparing with Document –Based approach, MBSE shows some advantages to development of ADCS. It can make trace among ADCS requirements, functions, and performance and reduce of volume of text documents generated. This approach also use graph to represent knowledge so that it is so easy to transfer knowledge and make more understanding. However, the member needs to be trained well to use MBSE and this training will take some times.

3	70% members of ADCS had trained to using Model-Based systems engineering. How do you think about moving from Document-Based systems engineering to Model-Based systems engineering to development of Attitude Determination and Control Subsystem in satellite in Vietnam National Satellite Center (VNSC)? (Interim of convenient for operators, effective of performance. etc.)
	Answer: 70% members of ADCS had trained to using MBSE is good resource. Moving to MBSE will be more beneficial but it still needs time. In current status, combine both of MBSE and Document-Based is good way.
4	The model is designed by using Model – Based System Engineering approach with a tool is System Modelling language (SysML) in the research. Do you think the model can be reused to another satellite project of VNSC in the future? E. Yes, it can reuse **F. Yes, but it is need to improve** G. No, Not at all H. Other comments
	Comment: Some part of model can be reused to another satellite project of VNSE in the future such as: function analysis, activities of sensor processing. However, it need to be improved.

Conclusion for interview with managers of VNSC

- The model is designed in the research show some advantage for VNSC project such as: reduce volume of documents are generated, make a traceability among ADCS requirements, functions and performance, convenient for operators.
- Some part of the model can be reusable to next satellite project. The model need to be improved.

From the resulted of interview with managers of VNSC, the model is validated.

Finally, after two interview with users of the research, a Model-Based system engineering approach to development of attitude determination and control subsystem is validated.

Chapter 5 Conclusion

5.1 Summary of Research

This research uses MBSE approach to development of ADCS for first micro-satellite in Vietnam, and its architectural design is completed through stakeholder needs analysis, requirements analysis, use case analysis, and function analysis.

A model of ADCS is made by using MBSE with SysML. The model is made with emphases on requirements analysis and functions analysis so that it can support inexperienced ADCS members to understand appropriate ADCS development process and to reuse the process for other micro-satellite projects in the future.

To verify the model and MBSE methodology approach in ADCS development, firstly the trace among requirements, functions and performance of physical components are made. And then tests in a table sat environment are conducted by checking physical connections of ADCS components. From those result, the consistency and understandability of the model and the MBSE approach are evaluated.

To validate the ADCS model, two kinds of interviews were conducted:

- Interview with ADCS members in MDG project: the purpose of this interviews is to confirm that the model and the MBSE approach can support them to develop ADCS of MDG satellite.
- Interview with two managers of VNSC: the purpose of this interviews is to confirm that the model and MBSE approach can be reused and applied to future satellite projects in VNSC.

All of ADCS members shared the same expression that the MBSE approach can support inexperienced members to develop ADCS. VNSC managers replied that VNSC is currently planning to develop a new satellite and that this ADCS model can be a good candidate as the baseline for the new satellite, as well as other micro-satellite projects in the future.

References

[1] Nguyen Dinh Chau Minh, Nguyen Thi Thao, Bui Nam Duong, Nguyen Huu Diep, "MicroDragon Project," The International Symposim on Space Technology and Science ISTS, 2015.

[2] Vietnam National Satellite Center, "VNSC," 2016. [Online]. Available: https://vnsc.org.vn/en/projects/microdragon-into-orbit-in-2018/.

[3] VNSC, "MicroDragon Satellite," [Online]. Available: https://vnsc.org.vn/en/projects/microdragon-satellite-project/.

[4] Sanford Friedenthal, Alan Moore, Rick Steiner, A Practical Guide to SysML- The Systems Modelling Language, Morgan Kaufmann Plublishers, the Object Management Goup, 2012.

[5] W. W, "Model-Based Systems Engineering," *Moca Raton, FL: CRC press,* 1993.

[6] R. Kratzke, "Systems Engineering within a Model-Based Framework," in *Systems Engineering Test and Evaluation Conference*, Melbourne, Australia, 2016.

[7] INCOSE, System Engineering Handbook, New Jersey: John Wiley & Sons, Inc., Hoboken, 2007.

[8] E.Hart, Laura, "Introduction to Model-Based System Engineering and SysML," in *Delaware Valley INCOSE Chapter Meeting*, 2015.

[9] Jeff A. Estefan, "Survey of Model-Based Systems Engineering (MBSE) Methodologies," *INCOSE MBSE Initiative,* pp. 30-36, 2008.

[10] Sara C Spangelo, David Kaslow, Chris Delp, Bjorn Cole, Louise Anderson, Elyse Forsse, Brett Sam Gilbert, Leo Harman, Theodore Kahn, James Cutler;, "Applying Model Based Systems Engineering (MBSE) to a Standard CubeSat," in *IEEE Aerospace Conference Proceedings*, 2012.

[11] Alessandro Gerlinger Romero, Mauricio Goncalves Vieira Ferreira, "Modelling an Attitude and Orbit Control System Using SysML," in *Workshop em Engenharia e Tecnologia Espaciaise*, Compos-SP, Brasil, 2011.

[12] James R. Wertz, David F. Everett, Jeffery J. Puschell, Space Mission Engineering: The New SMAD, Microcosm Press, 2011.

[13] I. J. B. James Rumbaugh, the Unified Modeling Language referenece manual,

Boston: Pearson Education, Inc., 2004.

[14] T. H. Quan, "Development of Attitude Control System and Testing Simulator for Microsatellite MicroDragon," Tohoku university, 2015.

[15] N. V. Thuc, "Design of Adjustable Software for Fault Detection, Isolation and Recovery of Attitude Determination and Control System in MicroDragon Satellite," 2015.

[16] J. O. Clark, "System of Systems Engineering and Family of Systems Engineering form a Standards, V-Model, Dual V-model, and DoD Perspective," INCOSE Hampton Roads Area Chapter, August 26, 2009.

Index

1. The result of interview with managers in VNSC.
2. The result of interview with ADCS members in MDG project.

Interviewee: manager 1
Head of Space Systems Design Department
Vietnam National Satellite Center

Questionnaire

Purpose: To validate the reusable of model is design designed by using Model – Based System Engineering approach with a tool is System Modelling language (SysML)

No.	Questions
1	To development of Attitude Determination and Control Subsystem (ADCS) in satellite, Document-Based systems engineering shows some disadvantage for ADCS members such as: Too many text documents are generated, difficult to make traceability among ADCS requirements, functions and performance, difficult to reuse those documents for another project. What do you think need to be improved in Document-Based systems engineering approach? Are you looking for other approach to development of ADCS in the future?
	Answer: For me, the most difficult point to development of ADCS is how to verify the characteristics of system components and verify performance of integrated system. System engineering may only around 10% of workload in development of ADCS process. At this time, I did not think the document-based systems engineering approach is a problem for ADCS. However, if other methods show their advantage, we can try to move to new method.

2	This research has proposed and Model-Based system Engineering approach to development of ADCS. How do you think about Model-Based system Engineering approach? (In term of volume of documents are generated, traceability among ADCS requirements, functions and performance, convenient for operators)
	Answer: I do not have enough time to study and understand in detail about model-based system engineering approach, however I believe that better in term of traceability and convenient than document-based method because it is supported by SysML software.

3	70% members of ADCS had trained to using Model-Based systems engineering. How do you think about moving from Document-Based systems engineering to Model-Based systems engineering to development of Attitude Determination and Control Subsystem in satellite in Vietnam National Satellite Center (VNSC)? (In term of convenient for operators, effective of performance. etc.)
	Answer: As a manager, I am looking for optimal and cost effective solutions. Therefore, the 70% members of ADCS, who had trained MBSE, need to show VNSC management board the advantage of MBSE method, especially through the MicroDragon project. On the other hand, the price of software is also needed to be taken into account.

4	The model is designed by using Model – Based System Engineering approach with a tool is System Modelling language (SysML) in the research. Do you think the model can be reused to another satellite project of VNSC in the future? A. Yes, it can reuse B. Yes, but it is need to improve C. No, Not at all D. Other comments
	Comment: Answer: D. As I mention above, VNSC should be got more impressive before we can make the decision.

Interviewee: manager 2

Head of Satellite Assembly, Integration and Test Department

Questionnaire

Purpose: To validate the reusable of model is design designed by using Model – Based System Engineering approach with a tool is System Modelling language (SysML).

No.	Questions
1	To development of Attitude Determination and Control Subsystem (ADCS) in satellite, Document-Based systems engineering shows some disadvantage for ADCS members such as: Too many text documents are generated, difficult to make traceability among ADCS requirements, functions and performance, difficult to reuse those documents for another project. What do you think need to be improved in Document-Based systems engineering approach? Are you looking for other approach to development of ADCS in the future?
	Answer: ADCS is one of the most important subsystems in satellite. In order to develop ADCS well, it is still necessary to adopt Document-Based approach although this approach shows several limitations as the mentions. And with considerable improvements, we can eliminate those drawbacks to achieve better results. Vietnam is still developing country and we are on a very first step of satellite technology, we do not have many experts in satellite technology and capacity building is necessary so that looking for other approach for ADCS or satellite development is very fruitful.

2	This research has proposed and Model-Based system Engineering approach to development of ADCS. How do you think about Model-Based system Engineering approach? (In term of volume of documents are generated, traceability among ADCS requirements, functions and performance, convenient for operators)
	Answer: Comparing with Document –Based approach, MBSE shows some advantages to development of ADCS. It can make trace among ADCS requirements, functions, performance and reduce of volume of text documents generated. This approach also use graph to represent knowledge so that it is so easy to transfer knowledge and make more understanding. However, the member needs to be trained well to use MBSE and this training will take some times.

3	70% members of ADCS had trained to using Model-Based systems engineering. How do you think about moving from Document-Based systems engineering to Model-Based systems engineering to development of Attitude Determination and Control Subsystem in satellite in Vietnam National Satellite Center (VNSC)? (Interim of convenient for operators, effective of performance. etc.)
	Answer: 70% members of ADCS had trained to using MBSE is good resource. Moving to MBSE will be more beneficial but it still needs time. In current status, combine both of MBSE and Document-Based is good way.

4	The model is designed by using Model – Based System Engineering approach with a tool is System Modelling language (SysML) in the research. Do you think the model can be reused to another satellite project of VNSC in the future? A. Yes, it can reuse **B. Yes, but it is need to improve** C. No, Not at all D. Other comments
	Comment: Some part of model can be reused to another satellite project of VNSE in the future such as: function analysis, activities of sensor processing. However, it need to be improved.

Interviewee: ADCS member 1

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

<table>
<tr><th>No</th><th>Question</th></tr>
<tr><td rowspan="2">1</td><td>Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS?
A. ADCS members lack of knowledge in ADCS development process
B. Making a trace among ADCS requirements, functions and performance of components.
C. Sharing documents among members
D. Document-Based generated many text documents.
E. Other</td></tr>
<tr><td>Comment: B and C</td></tr>
<tr><td colspan="2">Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)</td></tr>
<tr><td>2</td><td>How does the approach show you ADCS development process?
A. The approach shows ADCS development process clearly
B. No, Not at all
C. Other</td></tr>
</table>

	Comment: A
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? A. The approach assures traceability among ADCS requirements, functions and performance of components B. The approach do not assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment: A
4	Does the approach can reduce the volume of document compared with Document –Based? A. Yes, the approach reduce the volume of document compare with Document –Based (A) B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? A. Yes, I want to use B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: it depends on the other team members
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: firstly, inexperienced members should understand MBSE notation

Interviewee: ADCS member 2

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

<table>
<tr><th>No</th><th>Question</th></tr>
<tr><td rowspan="2">1</td><td>Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS?
A. ADCS members lack of knowledge in ADCS development process
Ⓑ. Making a trace among ADCS requirements, functions and performance of components.
C. Sharing documents among members
D. Document-Based generated many text documents.
E. Other</td></tr>
<tr><td>Comment:</td></tr>
<tr><td colspan="2">Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)</td></tr>
<tr><td>2</td><td>How does the approach show you ADCS development process?
Ⓐ. The approach shows ADCS development process clearly
B. No, Not at all
C. Other</td></tr>
</table>

	Comment:
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? Ⓐ. The approach assures traceability among ADCS requirements, functions and performance of components B. The approach do not assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment:
4	Does the approach can reduce the volume of document compared with Document –Based? Ⓐ. Yes, the approach reduce the volume of document compare with Document –Based B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? A. Yes, I want to use B. Yes, but not 100%. Ⓒ I don't know D. No, not at all E. Others
	Comment:
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process B. Yes, but not 100%. Ⓒ I don't know D. No, not at all E. Others
	Comment:

Interviewee: ADCS member 3

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

<table>
<tr><th>No</th><th>Question</th></tr>
<tr><td rowspan="2">1</td><td>Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS?
A. ADCS members lack of knowledge in ADCS development process
B. Making a trace among ADCS requirements, functions and performance of components.
C. Sharing documents among members
(D.) Document-Based generated many text documents.
E. Other</td></tr>
<tr><td>Comment: Since document-based usually generates a lot of document, it is difficult to share them among the team, especially when members of the team work in different locations. Understanding those documents is sometimes difficult and it usually requires supports from others .</td></tr>
<tr><td colspan="2">Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)</td></tr>
<tr><td>2</td><td>How does the approach show you ADCS development process?
A. The approach shows ADCS development process clearly
B. No, Not at all
(C.) Other</td></tr>
</table>

	Comment: To people who have knowledge about MBSE and SysML, it is easy to understand and see the relationships between diagrams. Traceability of the design is shown in SysML model so that it is easy to verify.
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? (A) The approach assures traceability among ADCS requirements, functions and performance of components B. The approach assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment:
4	Does the approach can reduce the volume of document compared with Document –Based? (A) Yes, the approach reduce the volume of document compare with Document –Based B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? A. Yes, I want to use (B.) Yes, but not 100%. C. I don't know D. No, not at all E. Others	
	Comment: For me, I will use MBSE for sure. However, when working in a team, it depends on team's decision. If most of members can use MBSE, MBSE is the best choice. Otherwise, it takes time to them to learn.	
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? (A.) Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process B. Yes, but not 100%. C. I don't know D. No, not at all E. Others	
	Comment: Using MBSE, they can learn faster.	

Interviewee: ADCS Leader

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

<table>
<tr><th>No</th><th>Question</th></tr>
<tr><td rowspan="2">1</td><td>Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS?
A. ADCS members lack of knowledge in ADCS development process
B. Making a trace among ADCS requirements, functions and performance of components.
C. Sharing documents among members
D. Document-Based generated many text documents.
E. Other</td></tr>
<tr><td>Comment:</td></tr>
<tr><td colspan="2">Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)</td></tr>
<tr><td>2</td><td>How does the approach show you ADCS development process?
A. The approach shows ADCS development process clearly
B. No, Not at all
C. Other</td></tr>
</table>

	Comment:
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? **A. The approach assures traceability among ADCS requirements, functions and performance of components** B. The approach do not assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment:
4	Does the approach can reduce the volume of document compared with Document –Based? **A. Yes, the approach reduce the volume of document compare with Document –Based** B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? **A. Yes, I want to use** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment:
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? **A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment:

Interviewee: ADCS Sub-Leader

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

<table>
<tr><th>No</th><th>Question</th></tr>
<tr><td rowspan="2">1</td><td>Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS?
A. ADCS members lack of knowledge in ADCS development process
B. Making a trace among ADCS requirements, functions and performance of components.
C. Sharing documents among members
D. Document-Based generated many text documents.
E. Other</td></tr>
<tr><td>Comment:
- Now, there are many Vietnamese students belong to ADCS team, however, team members are allocated to two university in Japan. On the other hand, since difference of background among team members so sometimes lacking of knowledge in ADCS development process is a bad situation in my team.
- Relationship between ADCS and other subsystems is very important to do successful mission, is so complicate. Therefore, clarifying requirements, decomposing requirements and functions and allocate requirements and functions to components is so difficult. Option B in this question is important for ADCS design.</td></tr>
<tr><td colspan="2">Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)</td></tr>
</table>

2	How does the approach show you ADCS development process? **A. The approach shows ADCS development process clearly** B. No, Not at all C. Other
	Comment:
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? **A. The approach assures traceability among ADCS requirements, functions and performance of components** B. The approach assures do not traceability among ADCS requirements, functions and performance of components C. Other
	Comment:
4	Does the approach can reduce the volume of document compared with Document –Based? **A. Yes, the approach reduce the volume of document compare with Document –Based** B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? **A. Yes, I want to use** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others	
	Comment:	
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? **A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others	
	Comment:	

Interviewee: ADCS member 6

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

No	Question
1	Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS? **A. ADCS members lack of knowledge in ADCS development process** **B. Making a trace among ADCS requirements, functions and performance of components.** C. Sharing documents among members D. Document-Based generated many text documents. E. Other
	Comment: ADCS is one of the main subsystems in satellite technology and designing ADCS for satellite is very difficult and complicated. While ADCS members are lack of knowledge and experiences about ADCS development process.
Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)	
2	How does the approach show you ADCS development process? **A. The approach shows ADCS development process clearly** B. No, Not at all C. Other

	Comment: The approach has general perspective for ADCS development process.
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? **A. The approach assures traceability among ADCS requirements, functions and performance of components** B. The approach do not assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment: Yes, the approach assures traceability and was clearly organized for showing the relationship between all of function blocks.
4	Does the approach can reduce the volume of document compared with Document –Based? **A. Yes, the approach reduce the volume of document compare with Document –Based** B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? **A. Yes, I want to use** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: MBSE is intuitive approach for designing ADCS subsystem even though you are specialist or not.
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? **A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: Everything can be expressed by graphical method, therefore it very easily understandable for experienced people or not, specially engineer can approach and develop ADCS subsystem effectively.

Interviewee: ADCS member 7

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

<table>
<tr><th>No</th><th>Question</th></tr>
<tr><td rowspan="2">1</td><td>Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS?
A. ADCS members lack of knowledge in ADCS development process
B. Making a trace among ADCS requirements, functions and performance of components.
C. Sharing documents among members
D. Document-Based generated many text documents.
E. Other</td></tr>
<tr><td>Comment: Every member of ADCS team does not have much experience in ADCS development. On the other hand, ADCS system has many requirements about performance and working scenario from payload mission. The ADCS development environment is also complicated.</td></tr>
<tr><td colspan="2">Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)</td></tr>
<tr><td>2</td><td>How does the approach show you ADCS development process?
A. The approach shows ADCS development process clearly
B. No, Not at all
C. Other</td></tr>
</table>

	Comment: The approach gives a general view of ADCS development process from some main point of view.
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? A. **The approach assures traceability among ADCS requirements, functions and performance of components** B. The approach do not assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment: The approach shows the trace among ADCS requirements, functions and performance of components intuitively by graphic block diagram method.
4	Does the approach can reduce the volume of document compared with Document –Based? A. **Yes, the approach reduce the volume of document compare with Document –Based** B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based
	Comment: The approach can reduce some interface documents compared with Document-Based

5	Do you want to use MBSE to development of ADCS in the future? A. **Yes, I want to use** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: It gives a general view even for a inexperienced engineering.
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? A. **Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process** B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: With a general view of ADCS development process, the MBSE approach can make the process faster. All of new member can join the project faster and mor effective.

Interviewee: ADCS member 8

Purpose of this questionnaire: To validate using Model-Based Systems Engineering (MBSE) Approach to Development of Attitude Determination and Control Subsystem can support for ADCS member in MDG project.

No	Question
1	Your team is designing ADCS for the first time on Document-Based approach, What is difficult for your team when designing ADCS? A. ADCS members lack of knowledge in ADCS development process B. Making a trace among ADCS requirements, functions and performance of components. C. Sharing documents among members D. Document-Based generated many text documents. E. Other
	Comment: By using Document-Based approach. It shows some disadvantage for ADCS members whos are developing ADCS in first time
Purpose of this research is to use Model-Based approach to development of ADCS. What do you think about an approach? (For the question 2 to 6)	
2	How does the approach show you ADCS development process? A. The approach shows ADCS development process clearly B. No, Not at all C. Other

	Comment: The MBSE approach show the development process is clear and easy to understand.
3	How does the approach show you the trace among ADCS requirements, functions and performance of components? A. The approach assures traceability among ADCS requirements, functions and performance of components B. The approach dot not assures traceability among ADCS requirements, functions and performance of components C. Other
	Comment:
4	Does the approach can reduce the volume of document compared with Document –Based? A. Yes, the approach reduce the volume of document compare with Document –Based B. The volume of document is the same. C. No, the approach does not reduce the volume of document compare with Document –Based

5	Do you want to use MBSE to development of ADCS in the future? A. Yes, I want to use B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: I am working for Vietnam National Satellite center. In the future, we will develop another micro satellite project. I want to use this approach to development of ADCS
6	Do you think using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process? A. Yes, using the MBSE approach to development of ADCS can support for inexperienced members understand ADCS development process B. Yes, but not 100%. C. I don't know D. No, not at all E. Others
	Comment: MBSE is a good approach. It shows many advantage for development of ADCS. This approach will be more helpful for inexperienced members. By looking in the research, I have fully understating of ADCS development process.