SUPERVISOR'S OPINION OF FINAL THESIS

I. IDENTIFICATION DATA

Thesis name:	**Simulation of Attitude and Orbit Control for APEXCubeSat**
Author's name:	**Niels de Graaf**
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Control Engineering
Thesis supervisor:	Ing. Daniel Štefl, Ph.D.
Supervisor's department:	Huld s.r.o (previously Space Systems Czech s.r.o.)

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment **challenging**

Evaluation of thesis difficulty of assignment.

The assignment was to create a Software Verification Facility and demonstrate the relevance of using opensource software and standardized communication using the APEX CubeSat that will orbit the asteroid Didymos as mission basis. Deep space missions are relatively rare and up to now were developed by national and international agencies like NASA, JAXA or ESA. The latest similar space probe built by the ESA was Rosetta launched in 2000 to perform a detailed study of comet 67P/Churyumov–Gerasimenko (67P).

It is obviously challenging to create a model of the dynamics of the CubeSat and its disturbance environment to plot its trajectories using python libraries developed for orbital dynamics. The attitude and orbital control were implemented as hardware in the loop programmed on a microcontroller to calculate the new trajectories for the simulation, increasing further the complexity of the task.

Satisfaction of assignment **fulfilled**

Assess that handed thesis meets assignment. Present points of assignment that fell short or were extended. Try to assess importance, impact or cause of each shortcoming.

The thesis completely met the assignment and exceeded it by adding performance comparison of the Python libraries by created equivalent application on his platform as well as on Matlab and STK. The author chose Poliastro open source libraries and implemented asteroid environment simulation based on them. After comparison of relevant microcontrollers, he decided to implement the hardware testing facility on STM32F446RET6, which is a choice closely matching the APEX hardware. The CAN bus communication was enabled by adding MCP2551 connected on breadboard.

Activity and independence when creating final thesis **A - excellent.**

Assess that student had positive approach, time limits were met, conception was regularly consulted and was well prepared for consultations. Assess student's ability to work independently.

The student was autonomous in both implementing the platform and writing the report. Where needed, he sought support from senior staff and were always perfectly prepared.

Technical level **A - excellent.**

Assess level of thesis specialty, use of knowledge gained by study and by expert literature, use of sources and data gained by experience.

The technical level of the work is very high. The final solution required studying a lot of materials to solve the assignment and to understand all the related complexity.

Formal and language level, scope of thesis **A - excellent.**

Assess correctness of usage of formal notation. Assess typographical and language arrangement of thesis.

The report is written in English using perfect grammar and expected formal language. The typographical level of the report is excellent with high quality diagrams documenting the work done in easy to understand way.

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Selection of sources, citation correctness **A - excellent.**

Present your opinion to student's activity when obtaining and using study materials for thesis creation. Characterize selection of sources. Assess that student used all relevant sources. Verify that all used elements are correctly distinguished from own results and thoughts. Assess that citation ethics has not been breached and that all bibliographic citations are complete and in accordance with citation convention and standards.

The bibliography is relevant. It has 38 items and covers the studied binary asteroid mission, orbital mechanics, ECSS standards of the ESA and the engineering sources necessary to implement the verification facility.

Additional commentary and evaluation

Present your opinion to achieved primary goals of thesis, e.g. level of theoretical results, level and functionality of technical or software conception, publication performance, experimental dexterity etc.

The thesis is exceptional. It is given by the selection of the topic, which combines two future trends is space – asteroid exploration and nanosatellites, and it is also given by the excellent implementation of the verification facility and its perfect documentation in the final report. I estimate that the time allocation to deliver such exceptional work is above 1000 working hours.

If there is an award given by CVUT for exceptional master thesis or a prize of the dean, I would like to nominate Niels de Graaf to it.

III. OVERALL EVALUATION, QUESTIONS FOR DEFENSE, CLASSIFICATION SUGGESTION

The thesis addresses important space engineering topics and solves them with open source tools and low-cost hardware. Therefore, it contributes to further democratizing access to space. Technically, it is on a very high level and can be used as a basis for further work on a similar mission.

I evaluate handed thesis with classification grade **A - excellent.**

Date: **28.8.2020** Signature: Daniel Štefl

LULEÅ UNIVERSITY OF TECHNOLOGY

Czech Technical University
Faculty of Electrical Engineering
Department of Control Engineering

CTU Diploma Project review- 2nd reviewer's evaluation of master thesis with title "S imulation of Attitude and Orbit Control for APEX CubeSat" by Space Master student Niels de Graaf.

I find that the goal of the thesis project fulfills the requirements of a master thesis in space technology. The work concerns implementation of an open source, low cost demonstrator platform to be used for developing and testing onboard software on physical hardware. In this thesis the focus is on the AOCS and the system bus communication (CAN bus).
A simple microcomputer system including a CAN-bus and two microcomputers communicating with each other (and a PC) is set up, but the main part of the project concerns writing software modules in python for the orbital simulation and the communication over the CAN-bus.
The student is using available python libraries for orbital propagation, low level CAN communication, serial communication and plotting, and is adding code for perturbations (presented in Ch.2).

The design of the Hardware-Software testing facility are shown in the UML tree in Figure 3.2. The system is de-composed into two components, which in turn is aggregated into more components. I find the decomposition (the levels and objects in the tree) indicated by this figure relevant, but I do not understand the choice of aggregation for the "leaves" in the tree, where direct links exists between the objects in the Hardware simulator and the orbital simulator (I assume that the arrows represents associations (links) between the objects). Moreover, I cannot see that this design is shown in the final implementation of the system.

The main concern regarding the project is the software design and implementation. A very important aspect of software design is to clearly define the responsibilities of different parts of the software and the interfaces. General guidelines for software design includes decomposition and modularization, encapsulation/information hiding, and separation of concerns.
Ths means that the complete implementation shall be divided into modules (functions, components, objects etc) with clear responsibilities (functionality) and well defined interfaces. This is not the case for the software implemented. Also, literals and constants (such as orbital elements, satellite parameters, chosen perturbation etc) are spread throughout the code; this should be gathered in a configuration, or system initiation file.
One example is in the orbit_data_sim.py code, where the perturbation algorithm is hard-coded into the code, and the density etc is given as numbers in the code. This means that if parameters are changed, the user needs to search for all places in the code where parameters are set, which is error prone. It is also advisable to gather information regarding the asteroid etc into one structure, instead of using many variables.
It is also of importance to document the code, using file headers and extensive commenting. When equations are used, it is good practice to include references to literature in the code.

Regarding the thesis format, small editing, language and spelling mistakes are present in the thesis.

Summary:
The student has put in a sufficient effort into the task.

The main objectives was to create a model of the dynamics of the APEX CubeSat subjected to the disturbance for the asteroid environment to plot its trajectories using python libraries developed for orbital dynamics. Attitude and Orbital control applications should be programmed on a microcontroller to calculate the new trajectories for the simulation. An Interface should be made to send simulated data using the standard protocols developed for spacecrafts and using the communication bus used on the APEX spacecraft. The result of the thesis fulfills the first objective, and the second objective concerning basic orbital control. The third objective is not fulfilled (using standard protocols), only low level, basic communication test routines using CAN-messages are implemented.

The result of the thesis project may contribute to a future solution to the problem addressed, since a basic, working testing environment for further development is set up. But, the software needs to be re-designed before developing the system any further.

Based on the review above I recommend to grade the thesis by C(good). The oral presentation is still to be graded.

This review serves solely for the purposes of the diploma project defense at CTU. LTU official evaluation for the SpaceMaster double degree will follow the thesis defense and may differ from this review report and suggested grade.

Kiruna, September 25 2020

Dr. Anita Enmark
Luleå University of Technology