Aerospace Design and Systems Engineering Elements II

Spacecraft Tutorial Assignment – September 2019

General Instructions

- ✓ This document provides you with all necessary information you will need to execute the AE2111-II Spacecraft Tutorial. Read this entire document carefully before starting to work at the tutorial.
- ✓ When you need additional information, you may use the lecture slides of this or other courses, the reference books indicated on the last page of this document, or internet. *Remember: carefully document in your final report all the sources of information used!*
- ✓ This tutorial is intended as a group work, with each group made of 5 students. The assessment will be based on the report that you produce as a group, and all group members will receive the same grade for it.
- ✓ You are responsible, as a group, of the quality of the work delivered by each member: make sure that everybody contributes in a sufficient way!!
- ✓ The tutorial is based on 5 different study cases, one for each group member (see following sections "Task Description" and "Study Cases"). For groups with less than 5 members, you are allowed to reduce the number of study cases to be studied. *Example: if your group is made of 4 members, you can select at your own choice 4 study cases among the proposed ones.*

Tutorial Deliverables and Deadlines

- ✓ The deliverable of your tutorial work shall be a **report** delivered as an **electronic file** (PDF format). The report shall include all the results and the information indicated in the following section "Task Description". *Pay particular attention to the given requirements on the maximum number of pages!!*
- ✓ The report shall include, on the cover page, the names and student numbers of all the group members who contributed to the work. *Remember: not being included among the names on the front page will result in not receiving any grade for the tutorial!!*
- ✓ The file name of your report shall be in the form "Group XX_Spacecraft Tutorial". *Example: for group 12, the file name shall be "Group 12_Spacecraft Tutorial".*
- ✓ The group numbers and the names of the members of each group will be finalized and announced on Brightspace on Friday, September 27th 2019.
- ✓ Deliver your final report by uploading it in the assignment submission folder of your group on Brightspace **and** sending it to the e-mail address A.Cervone@tudelft.nl (both actions are required!)
- ✓ Latest deadline for delivering your report is **Monday, October 21st 2019 at 12:00**.

Task Description

Task 1 : Link Budget Tool ***(2 points out of 10)***

→ In this task, you are required to develop a tool for a generic link budget analysis

Using what you have studied during the Spacecraft Telecommunications part of the course, you will develop as a group a tool for the link budget analysis of a generic space mission. The tool shall be adaptable to different mission characteristics/requirements and shall include - as a minimum - all the loss and gain factors that have been described in the lecture slides. The final output provided by the tool shall be the link margin of the mission under consideration (for both the uplink and the downlink communications), as it results from the given input parameters. You may develop the tool in Excel or in any other format that you deem convenient for your scope.

Hint: take a careful look at the information and the sample link budget calculation in the last lecture of the course, which represent a good starting point for your work.

The outcomes of this task shall be described in the final report in no more than 4 pages of text (figures and tables are not included in the page count), including as a minimum the following information:

- A brief description of the **tool development process**, clearly explaining all relevant decisions taken by the group (examples: which parameters/factors have been included in the model and which ones have not been considered, and why; which assumptions have you made to develop the tool, and why; etc.)
- An **"user manual"** of the tool, with a short but clear description of its capabilities and what the user has to do to apply it to a given space mission.
- One or more **screenshots** of the tool user interface.

Task 2 : Study Cases - Telecommunications ***(5 points out of 10, equally distributed among the study cases)***

→ In this task, you are required to apply your link budget tool to some given study cases

You will now use the tool developed in Task 1 to study the link budget of five study cases (or less, for groups with less than five members), starting from the main parameters and requirements provided in the "Study Cases" section of this document. You may decide to analyze the study cases together as a group or distribute them (one for each group member).

A) For each study case, analyze both the downlink and the uplink. In case you need parameters that are not provided in the "Study Cases" section, you can look for them in the lecture slides, reference books or internet. If necessary you can also make assumptions, but don't forget to justify and document them!!

B) If a link budget does not close, propose one or more corrective actions and show, by means of your link budget tool, that they are effective to close the budget. As a corrective action, you are allowed to modify one or more of the design parameters provided in the table for that specific study case. However, you are required to provide evidence that the proposed corrective action is feasible, for example by documenting that the new values are used by a real space mission similar to the study case, or by making reference to literature, internet, existing hardware, or by showing analysis or calculations performed to justify your choice.

The outcomes of this task shall be described in the final report in <u>no more than 2 pages of text for each study case</u> (10 pages of text in total, figures and tables not included in the page count), including as a minimum the following information:

- Tables with the ***complete*** **uplink and downlink budgets** (including ***<u>all</u>*** quantities **<u>expressed in dB</u>**) obtained using the study case parameters provided in this document.
- In case a link does not close, description of the **proposed corrective actions** (including their motivation) and **new link budget table** obtained after the corrective actions.

*Hint: pay particular attention to the <u>numerical values</u> in your link budget tables, and make sure they are correctly calculated. An important learning objective of this assignment is to get a feeling of the order of magnitude of the numbers you can expect in the link budget of a real spacecraft; thus, **calculation mistakes will be significantly penalized in this tutorial**!*
*Make sure your tables are <u>complete</u> (including all quantities contributing to the link budget) and that all quantities are <u>provided in dB</u>; **if not, your grade will be penalized**!*

<u>Task 3 : Study Cases - ADCS</u> ***(3 points out of 10, equally distributed among study cases)***

→ In this task, you are required to perform a preliminary analysis and design of the <u>ADCS sub-system</u> for the given study cases

A) Based on the general requirements and spacecraft characteristics provided in the "Study Cases" section of this document (ADCS part), propose a preliminary list of ADCS components (<u>number</u> and <u>type</u> of sensors and actuators) for <u>each</u> of the study cases considered. Motivate your choices and, in particular, the reasons why certain types of sensors/actuators have been preferred and certain others have not been used. *<u>Make sure that your proposed components include sufficient redundancy to avoid single points of failure</u>.*

B) For <u>each</u> of the study cases, perform a <u>preliminary design</u> of one reaction wheel and one pair of thrusters for attitude control around <u>one</u> of the spacecraft axes, considering two cases: thrusters only, or wheel + thrusters for desaturation. You are free to <u>assume yourself</u> values for data not provided in this document (such as the wheel material and rotational speed, the type of thrusters used, the duration of a single burn, etc.), as far as your assumptions are <u>documented</u> and <u>realistic</u>.

The outcomes of this task shall be described in the final report in <u>no more than 1 page per each study case</u> (5 pages in total), including as a minimum the following information:

- **ADCS components** (<u>type</u> and <u>number</u> of sensors and actuators + motivation for them).
- Preliminary **wheel sizing** (including, as a minimum, diameter and maximum rotational speed), <u>and</u> **thruster sizing** (including, as a minimum, thrust level and type of thruster). Discussion and motivation of the choice among thrusters only, or wheel + thrusters.

Study Cases

Case 1 – Earth observation 3U CubeSat

Case 2 – Lunar explorer 12U CubeSat

Case 3 – Mars orbiter 6U CubeSat

Case 4 – Venus explorer

Case 5 – Europa imaging mission

→ Some relevant mission/spacecraft data for these study cases are provided in the tables on next pages. If you need additional data that are not given in the tables, you may derive them from the lecture slides, the reference books listed at the end of this document, or internet. If needed, make appropriate assumptions and justify/document them.

→ Some of the parameters provided in the tables are considered as mission-constrained, and **cannot** be changed in any case as a corrective action to improve the link budget. These are the parameters given in red-colored cells.

→ For all study cases, the spacecraft is assumed to be in a circular orbit around the indicated celestial body (Earth, Moon, Mars, Venus, Europa). Thus, the orbit altitude provided in the tables has to be intended as altitude over the surface of the given celestial body.

→ For the Europa imaging mission (Case 5), for the sake of simplicity, assume that the distance Spacecraft-Earth is the same as the distance Jupiter-Earth. Keep in mind, however, that the spacecraft is orbiting and imaging around Europa (not Jupiter!).

→ For all study cases, the total spacecraft power is given and **cannot** be changed (it is assumed to be constrained by other mission requirements). If you need to propose corrective actions to improve the link budget, you have to take this total available spacecraft power in due account. This total available power has also to be taken into account in your preliminary choice of sensors and actuators for the ADCS sub-system.

→ For all study cases, the payload is represented by a line-scanning imager, the characteristics of which (swath width, pixel size, bits per pixel, duty cycle, downlink time per day) are provided in the first table. Assume that the required downlink data rate is driven by this payload only, and derive it based on the simplified equations discussed in the lecture slides. The required uplink data rate is directly provided in the tables. *Note: the swath width and the pixel size are given in terms of angles. Their actual values in terms of length will therefore depend on these angles and on the orbital altitude of the spacecraft.*

Table 1 – General and Telecommunications Data

Parameter	***Unit***	**Case 1 Earth 3U CubeSat**	**Case 2 Moon 12U CubeSat**	**Case 3 Mars 6U CubeSat**	**Case 4 Venus explorer**	**Case 5 Europa imager**
Total spacecraft power	*W*	10	40	20	1200	800
Transmitter power (spacecraft)	*W*	2	8	5	350	150
Transmitter power (ground station)	*W*	400	400	400	1000	1000
Loss factor transmitter	-	0.8	0.8	0.8	0.9	0.9
Loss factor receiver	-	0.7	0.7	0.7	0.7	0.7
Downlink frequency	*GHz*	2.2 (S-Band)	2.2 (S-Band)	8.4 (X-Band)	8.5 (X-Band)	8.4 (X-Band)
Turn around ratio (uplink/downlink frequency)	-	221/240	221/240	749/880	749/880	749/880
Antenna diameter spacecraft (parabolic antenna)	*m*	0.1	0.3	1 (deployable antenna)	1.5	3
Antenna diameter ground station (parabolic antenna)	*m*	1	5	10	34	70
Orbit altitude	*km*	350	1000	500	800	500
Elongation angle (angle between spacecraft-Sun line and Earth-Sun line)	*deg*	N/A	N/A	10	20	10
Pointing offset angle (spacecraft)	*deg*	5	1	1	0.05	0.05
Required uplink data rate	*bit/s*	10^7	10^6	10^5	10^4	10^3
Payload swath width angle	*deg*	20	30	30	45	45
Payload pixel size	*arcmin*	0.1	0.1	0.2	0.05	0.01
Payload bits per pixel	-	8	8	8	8	8
Payload duty cycle	-	100%	50%	100%	50%	75%
Payload downlink time	-	0.5 hr/day*	6 hr/day*	12 hr/day*	24 hr/day*	24 hr/day*
Modulation/coding type	-	8FSK	8FSK	8FSK	8FSK	8FSK
Required BER	-	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}

**Note: "day" = "Earth's day" = 24 hours*

Table 2 – Additional info for Task 3 (ADCS)

Parameter	*Unit*	Case 1 Earth 3U CubeSat	Case 2 Moon 12U CubeSat	Case 3 Mars 6U CubeSat	Case 4 Venus explorer	Case 5 Europa imager
Spacecraft moment of inertia (equal for all axes, $I_{xx} = I_{yy} = I_{zz}$)	$kg \cdot m^2$	10^{-2}	10^{-1}	$5 \cdot 10^{-2}$	400	1500
*Worst-case amplitude of **periodical** disturbance torque*	$N \cdot m$	10^{-6}	10^{-8}	10^{-5}	$5 \cdot 10^{-4}$	10^{-1}
Moment arm (distance thruster axis - rotation axis)	*m*	0.05	0.1	0.1	0.75	1.5
Required rotation maneuver rate	*deg/s*	30° in 5 s	90° in 60 s	10° in 30 s	180° in 10 s	180° in 60 s
Required pointing knowledge (around all axes)	*arcsec*	3600	1800	1800	50	50

Reference Books

- Wertz J. R., Larson W. J., *Space Mission Analysis and Design (Third Edition)*, Microcosm, Inc. (1999)
- Fortescue P., Stark J., Swinerd G., *Spacecraft Systems Engineering (Third Edition)*, John Wiley & Sons (2003)
- Turner P., *Communication*, Section 4.7 in "Handbook of Space Technology", John Wiley & Sons (2009)
- Maral G., Bousquet M., *Satellite Communications System*, John Wiley & Sons (2003)