Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3201: Systems Engineering and Aerospace Design

April 16th, 2013, 9:00am

General Rules and Instructions

- ✓ This is a "closed book" exam. You are not allowed to use any books, lecture notes or other study materials.
- ✓ Exam duration is 3 hours.
- ✓ This exam consists of three parts:

  Part 1) A sample case of SE space problem with open questions **(25 points)**;

  Part 2) A set of aircraft questions **(35 points)**;

  Part 3) A set of multiple choice questions **(40 points)**.

- ✓ Please give your answers to the three parts of the exam on different sheets. For the multiple-choice questions, use the answer sheet provided to you.
- ✓ Don't forget to put your name and student number on each page!!
- ✓ Answers shall be given in English only.

Part 1 – Space Sample Case

Carefully read the case description below and use the provided information to answer the final questions (a), (b), (c), (d), (e), (f).
Give a concise but complete answer to each one of the questions. ***(25 points)***

The DelFFi mission and its Attitude and Orbit Control Subsystem

CubeSats are a novel spacecraft standard coming either as single- (1U), double- (2U), or triple unit (3U) spacecraft (1U = 10 x 10 x 10 cm^3, 3U = 10 x 10 x 30 cm^3). CubeSats are easy to breadboard by students and provide them an excellent educational environment. CubeSats are a promise for future space missions. TU Delft is recognised as a flagship worldwide in CubeSat developments for its *Delfi* programme which comprises *Delfi-C3* (fully operational in orbit since 5 years ago), *Delfi-Next* (finalized, awaiting launch) and *DelFFi*. DelFFi is a CubeSat mission, planned for launch in 2015, which comprises 2 identical triple-unit CubeSats, named *Delta* and *Phi*, each with a mass of about 3.5 kg.

TU Delft wants to demonstrate formation flying with the 2 spacecrafts, i.e. keeping a specific relative motion of the 2 spacecrafts with respect to each other. Formation Flying has never been demonstrated for spacecrafts that small. For DelFFi, each spacecraft's relative orbit needs to be confined, using its own propulsion system, in a control box of typically about 100 x 100 x 100 km. Nominally, after the so-called formation acquisition phase, the 2 spacecraft are about 1000 km separated from each other in along-track direction (i.e. along the orbital path). The DelFFi satellites will be accommodated in a P-POD (off-the-shelf CubeSat deployment system) mounted on the payload interface of a selected launcher. The launcher will place *Delta* and *Phi* in a near-circular, high inclination Low Earth Orbit (LEO) at a very low altitude orbit of about 350 (!) km.

Each spacecraft is equipped, among others, with a propulsion system as prime payload. The propulsion system has one nozzle only. Each spacecraft also has a capable Attitude and Orbit Control Subsystem (AOCS). The communications system on *Delta* and *Phi* uses a directional S-band link to its ground station at Delft. The spacecraft has deployable solar arrays which, however, will not provide fully spherical coverage. The spacecraft do NOT have an inter-satellite communications link but will use ground-in-the-loop for the control of their formation flying. Assume that each spacecraft is equipped with a GPS receiver for navigation purposes.

Questions

(a) Provide a Mission Statement for the DelFFi mission. ***(4 points)***

(b) Identify 3 benefits and 3 challenges imposed by the low altitude of the DelFFi mission. For each of them, motivate your reasons in 1 sentence. ***(6 points)***

(c) Build a Requirements Discovery Tree for the DelFFi AOCS and use it to identify and state at least three main AOCS requirements. (Hint: Think about the key functionalities that the AOCS must support) ***(3 points)***

(d) Write down a proper sub-system requirement for the AOCS pointing accuracy for the propulsion functionality in the formation flying mode. The requirement shall include a numerical figure for the pointing accuracy, which must be given in degrees. To compute this accuracy, assume that the unit vector along the symmetry axis of the propulsion system of *Delta* must point to within the control box of the *Phi* satellite (and vice versa). ***(6 points)***

(e) Both Delta and Phi will carry a commercial-off-the-shelf GPS receiver, typically used for terrestrial applications. Identify and state at least 3 key reasons why the operation of such receivers in space is challenging. ***(3 points)***

(f) Sketch a complete hardware-in-the-loop verification architecture for the GPS receiver on *Delta*. (Hint: To limit risk, you must include a functionality which generates GPS signals such as if they would be received by *Delta* in space). ***(3 points)***

Part 2 - Aircraft Questions

1. Different weight estimation methods are used during the conceptual aircraft design (so far you learnt about Class I and Class II methods). ***(7 points)***

    a. Summarize the required input, the generated output and the approach on which a Class I weight estimation method is based.

    b. Do the same as above for a Class II method. It is not expected that you provide all input and output values involved in a Class II method, just provide some which are representative for the method.

    c. It is possible that the operative empty weight value obtained using Class I and II methods do not coincide. Can you explain why? Briefly explain how you would address this problem in your design. ***(3 out of 7 points)***

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2. Provide a definition of trim drag, both in your own words as well as by means of a mathematical formula (you shall indicate the meaning of each coefficient in your formula). Provide two reasons why a T-tail configuration can offer advantages, with respect to a classical fuselage mounted horizontal tail, in terms of reducing the trim drag. ***(4 points)***

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3. While visiting a museum of aviation, you notice a bizarre warning tag printed on the fuselage of a 1st World War 2-seats biplane aircraft. This aircraft was designed to accommodate a gunner in the front seat and the pilot in the back seat. The tag states "*This machine must not be flown without passenger or equivalent weight in gunner cockpit*". What is the reason of this recommendation? In other words, what would be the issue of this aircraft when ignoring such warning? ***(2 points)***

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4. Generate a qualitative scissor plot for a conventional passenger aircraft with fixed tail and positive margin of stability, where you will show both the static stability and the neutral stability curve. Do not forget to label the plot axes and the three curves. Indicate which of the following equations is relative to the stability and which to controllability part of the scissor plot. ***(1 point)***

$$\overline{x}_{cg} = \overline{x}_{ac} - \frac{C_{m_{ac}}}{C_{L_{A-h}}} + \frac{C_{L_h}}{C_{L_{A-h}}} \frac{S_h l_h}{S\overline{c}} \left(\frac{V_h}{V} \right)^2 \qquad \overline{x}_{cg} = \overline{x}_{ac} + \frac{C_{L\alpha_h}}{C_{L\alpha}} \left(1 - \frac{d\varepsilon}{d\alpha} \right) \frac{S_h l_h}{S\overline{c}} \left(\frac{V_h}{V} \right)^2 - 0.05$$

Assume this given aircraft mounts very powerful triple slotted flaps. Now, due to a relaxed landing field length requirement, it becomes apparent that a much simple flaps system is sufficient. Show on the same plot the expected change(s) caused by this design change. What (if any) would be the consequences in terms of longitudinal stability and/or controllability? ***(2 points)***

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5. For obvious ground stability reasons, it is not recommended that the center of gravity of an aircraft travels behind the position of the main landing gear. But, what if the center of gravity is located too far to the front of the main gear? Explain one important negative consequence. ***(2 points)***

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6. Indicate whether the following statements are correct and briefly explain why. (Note: points are yielded only if your explanations are correct) ***(12 points)***
    a. In order to guarantee the longitudinal static stability of a canard aircraft (i.e., an aircraft featuring a tail plane set in front of the main wing), contrarily to a conventional aircraft (with the tail set behind the main wing), it is necessary to ensure that the center of gravity (c.g.) is NOT shifting in front of the neutral point.
    b. When the c.g. and the neutral point coincide, the moment coefficient of the aircraft computed around that point, by definition, is equal to zero.
    c. A particularly long fuselage section in front of the wing is positive in term of longitudinally static stability (i.e., it would increase the aircraft stability).
    d. The horizontal tailplanes of passenger aircraft are generally designed using symmetrical airfoils.
    e. For a given c.g. range, a larger stability margin requires a smaller tail surface.
    f. The higher the downwash effect caused by the wing onto the tail, the more effective is the stabilizing action of the tail.

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7. Consider the plot and the equation given in the figure on next page. The given curves are those of a given general aviation aircraft featuring a conventional tail configuration. ***(5 points)***
    a. Indicate on the plot the trim point AND explain your choice by giving a definition of trim point. ***(2 out of 5 points)***
    b. Draw on the same plot (use the grid for accuracy) the curve representing the tail contribution AND justify your drawing.
    c. Indicate whether, at the given trim point, the tail is generating zero, positive or negative lift AND justify your answer.
    d. Assuming a negative value of the aircraft pitching moment Cm_{ac}, state whether the center of gravity is located in front, behind or on top of the aerodynamic center of the aircraft less tailplane AND justify your answer.

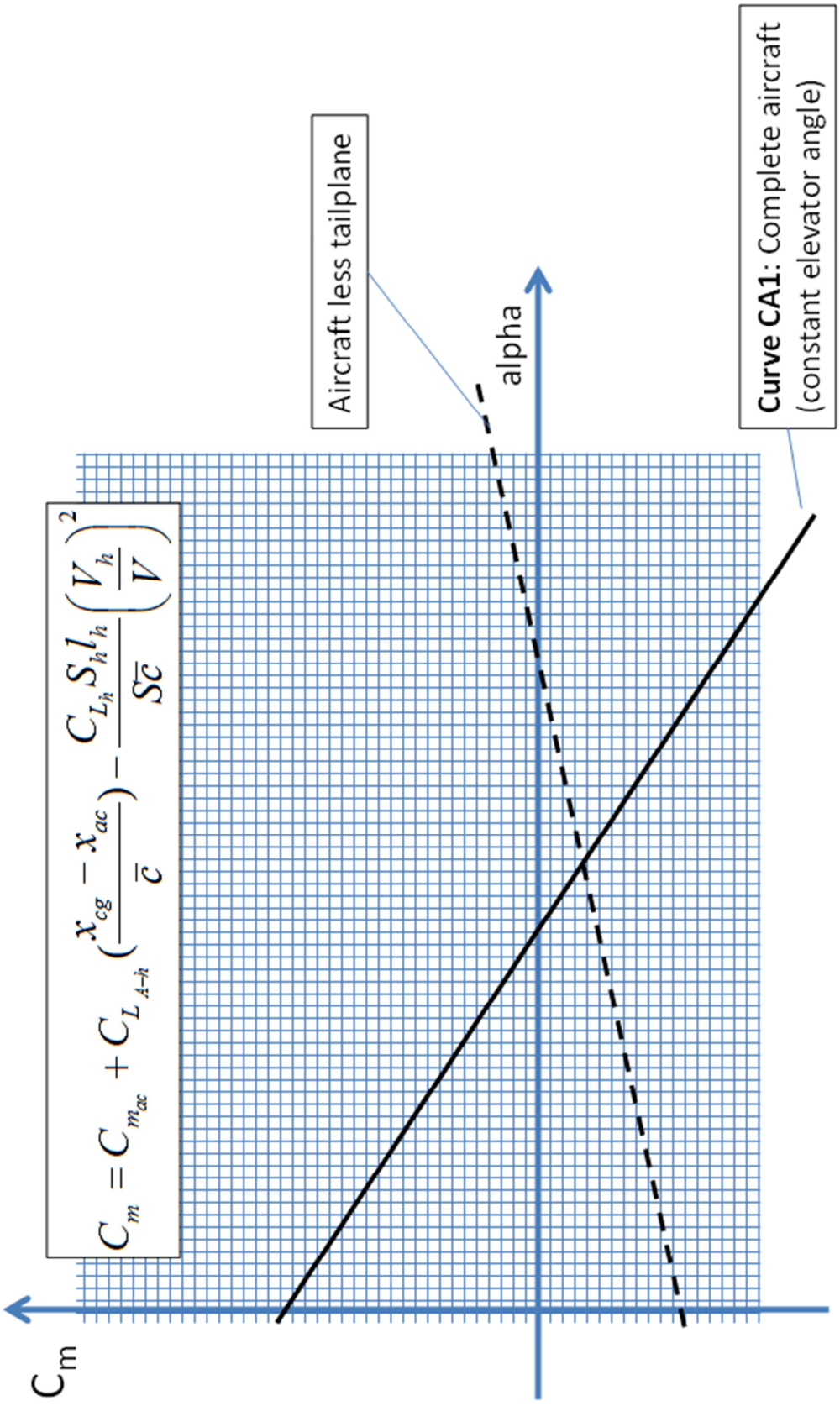

Figure 1: question 7

Part 3 - Multiple-Choice Questions

(1) Which one of the following propulsion system test phases is performed on *prototypes* of the system (or prototypes of one of its components)? ***(3 points)***

(A) Development Tests

(B) Qualification Test

(C) Acceptance Test

(D) None of the above

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(2) For each one of the following sentences, indicate if they are referring to something "complex" or "complicated": ***(3 points)***

(i) The International Space Station is: ***(1 point)***

(A) Complex **(B)** Complicated

(ii) The equations to determine the exact attitude of the International Space Station as a function of the disturbance forces acting on it are: ***(1 point)***

(A) Complex **(B)** Complicated

(iii) The internal cabling of the International Space Station is: ***(1 point)***

(A) Complex **(B)** Complicated

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(3) Only one of the following words is not applicable to a validated requirement (according to the acronym VALID): indicate it. ***(3 points)***

(A) Verifiable

(B) Achievable

(C) Interesting

(D) Definitive

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(4) Only one of the following hypothetic requirements for the propulsion system of a new launcher rocket can not be considered acceptable with respect to the VALID criteria: indicate it. ***(3 points)***

(A) The propulsion system shall provide a thrust of 5000 kN at sea level

(B) The number of 1st stage engines shall be sufficient to provide a total velocity change of at least 4 km/s when one of the engines shuts off due to a failure

(C) The propulsion system lifetime shall be more than 20000 s at full power level, and more than 30000 s at 75% power level

(D) The mechanical interface between nozzle and combustion chamber shall withstand each and every level of acceleration without any failures

(5) For a *Lunar Water* mission aiming at detecting the eventual (past or present) presence of water on the Moon, indicate for each one of the following sentences if it represents a *Need Statement*, a *Mission Statement*, a *Stakeholder Requirement* or a *System Requirement*. ***(3 points)***

(i) *Lunar Water* will send in year 2020 a probe to the surface of Moon and an orbiter around it. Optical observations and physical analysis of the Lunar soil will allow for the detection of water on the Moon. ***(1 point)***

(A) Need Statement **(B)** Mission Statement **(C)** Stakeholder Requirement **(D)** System Requirement

(ii) The detailed results obtained by *Lunar Water* shall be made available to the scientific community, in order to give scientists the possibility to draw important conclusions on the history of the Solar System and the Earth. ***(1 point)***

(A) Need Statement **(B)** Mission Statement **(C)** Stakeholder Requirement **(D)** System Requirement

(iii) The engines installed on the Transfer Module travelling from the Earth to the Moon shall be able to provide a total velocity increment of at least 6 km/s. ***(1 point)***

(A) Need Statement **(B)** Mission Statement **(C)** Stakeholder Requirement **(D)** System Requirement

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(6) There are "requirements on requirements", in order to ensure the effective use of requirements in the design process. Among the following sentences, only one is a correctly formulated requirement on requirements: indicate it. ***(3 points)***

(A) A requirement sentence shall not include the reason for the requirement

(B) A requirement sentence shall include a description of the design

(C) A requirement sentence can include one or more requirements

(D) A requirement sentence is usually interpretable

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(7) According to the Earned Value Management theory, how is the Schedule Variance defined? ***(2 points)***

(A) Difference between the actual cost of the work performed and the budget for the work performed

(B) Difference between the actual cost of the work performed and the budget for the work planned up to that point

(C) Difference between the budget for the work actually performed and the budget for the work planned up to that point

(D) Difference between the actual cost of the work performed and the actual cost of the work planned up to that point

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(8) Only one of the following hypothetic requirements for the AOCS subsystem of the *DelFFi* satellites developed by TU Delft can not be considered acceptable with respect to the VALID criteria: indicate it. ***(3 points)***

(A) The AOCS subsystem shall enable Earth-pointing mode and Safe mode

(B) The AOCS subsystem shall survive to vibrations

(C) The AOCS subsystem shall have the same accuracy than the ones used for the previous *Delfi C3* and *Delfi-Next* satellites developed by TU Delft

(D) The AOCS subsystem shall withstand a maximum acceleration of 6*g* without any mechanical damage to its components

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(9) Only one of the following is a proper way to express stakeholder needs: indicate it. ***(3 points)***

(A) Stakeholder needs shall clearly indicate the problem and the solution to that problem

(B) Stakeholder needs shall express the "How", not the "What"

(C) Stakeholder needs shall be formulated in the "language" of the stakeholder, not in the "language" of the engineer

(D) Stakeholder needs shall always include a specific indication of the range of acceptable values for the physical quantities related to them

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(10) According to the European Space Agency standards, in a typical space project which is the formal closing milestone for the "Phase A" activities? ***(2 points)***

(A) The Preliminary Requirements Review (PRR)

(B) The Preliminary Design Review (PDR)

(C) The Critical Design Review (CDR)

(D) The Qualification Review (QR)

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(11) Which one of the following is a correct definition of "Risk" ? ***(3 points)***

(A) Risk = (Likelihood of the event) * (Consequence of the event)

(B) Risk = (Likelihood of the event) / (Consequence of the event)

(C) Risk = (Consequence of the event) / (Likelihood of the event)

(D) Risk = (Consequence of the event) - (Likelihood of the event)

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(12) Only one of the following was not a specific objective that led to the creation of the Concurrent Design Facility (CDF) at the European Space Agency (ESA): indicate it. ***(3 points)***

(A) Create an experimental mission design environment in which the conceptual design of space missions can be performed in a more effective way

(B) Apply Concurrent Engineering to a number of test cases to identify the potential of this approach

(C) Ensure a non-simultaneous involvement of the team members from their recessed work places

(D) Gather the information needed to evaluate the required resources to create a permanent facility available to all programmes

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(13) Which kind of failure rate behaviour as a function of time is modelled by a *normal distribution* of the failure density? ***(3 points)***

(A) Increasing failure rate

(B) Decreasing failure rate

(C) Minimum failure rate

(D) Constant failure rate

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(14) Assume that the U.S. Air Force is planning to develop a new type of Air Fighter plane intended to replace all the currently used ones by the year 2025. What Life Cycle Cost (LCC) description best describes this project? ***(3 points)***

(A) High System and Development costs

(B) High system and development costs, with high production costs

(C) Low development cost, high production costs, and medium operational costs

(D) High operational costs, significant production costs and relatively low development cost

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