Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3211-I: Systems Engineering and Aerospace Design

August 12th, 2014, 14:00

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 **(35 points)**;

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

  Part 3) A set of multiple choice questions **(30 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), (g), (h). Give a concise but complete answer to each one of the questions.

The QB50 and DelFFi Missions

QB50 is an international space mission which foresees the launch of 50 Cubesats in 2016 by a single launcher, developed by 50 different universities worldwide. The mission is co-financed from the European Commission, as part of the so-called FP7 program. Cubesats are satellites based on the CubeSat standard with a core size of 10x10x10 cm and a mass of about 1 kg. CubeSats within QB50 will be double (i.e. 10x10x20 cm) or triple unit cubesats. Although each CubeSat will be different, they all carry a common sensor to scientifically characterize the lower thermosphere, i.e. an altitude region of 330 km and below, about which little is known. The launch thus will be into a very low-Earth orbit with a limited lifetime. Apart from the science objectives, combining around 50 teams worldwide into a joint mission is both a technological and managerial challenge. The 50 CubeSats will also demonstrate new technology or capabilities. An example is the DelFFi mission of TU Delft which is an integral part of QB50, where 2 triple-unit satellites will demonstrate autonomous formation flying based on a powerful attitude control system (ACS) and propulsion system on each spacecraft, an objective never done before in space with such satellites. Experimentally, the satellites will also have an inter-satellite communication system.

Questions

(a) Provide 2 Mission Statements: one for QB50 and one for the DelFFi mission. ***(6 points)***

(b) Formation Flying requires a propulsion system and an attitude control system. Name, for each system, 2 key reasons why such a system is needed. ***(4 points)***

(c) Requirements on the propulsion system and ACS are interlinked. Imagine to ideally thrust in along-track (flight) direction with a velocity increment Δv. Which angular attitude control accuracy $\delta\alpha$ do you need in order to provide a maximum relative velocity increment error, perpendicular to flight direction, of 1%? Write down the equation to compute the attitude control accuracy $\delta\alpha$ and compute its value in arc-minutes. (Hint: Make a sketch of the situation) ***(4 points)***

(d) Draw a Functional Flow Block Diagram (FFBD) for the satellite operations comprising a single thruster activity of one of the DelFFi satellites which should deliver a velocity increment in flight direction. Consider that the satellite is prior and after such activity in "science mode", with payload pointing in flight direction. The nozzle of the propulsion system has, however, an inclination of 90 deg with respect to the payload axis. The diagram should comprise about 4-7 functions. Pick one of those functions, and break the FFBD down into a lower level. (Hint: Make a sketch of the situation) ***(5 points)***

(e) You want to receive the signal from the 2 DelFFi satellites with one ground station antenna at Delft. However, due to interference, only one satellite shall be visible to the ground station at a time. Which minimum separation of the 2 satellites along the orbit (i.e. curvilinear) can you tolerate to secure proper communications? Provide your answer in [km] and in [s], assuming the satellites are flying one after the other in the same orbital plane. Use the following values: Earth radius *Re* = 6378 km, satellite altitude *h* = 330 km. ***(4 points)***

(f) Specify the needs from the propulsion system to ALL other sub-systems on the satellite. Identify the 2 most important ones and specify why they are most important? (Example, Structures and Mechanics: the need is to provide structural stability) ***(4 points)***

(g) Which types of test do you have to perform for a reaction wheel assembly, which is part of your ACS and why? Make a list and argue! ***(4 points)***

(h) Assume you have been given the task to design the formation flying demonstration. Your design is based on 2 levels: Communications (e.g. ground station, inter-satellite link) and propulsion operations (thrusting with thruster on 1 spacecraft, thrusting with thrusters on both spacecraft simultaneously). To do that, you develop a design option tree (DOT). Draw a design option tree using those 2 levels and identify, on the lowest level, which is the most simple and which the most complex option and why, respectively. Note: Make sure you capture **ALL** options. ***(4 points)***

Part 2 - Aircraft Questions

1. In order to support the horizontal tail sizing process, it is convenient, during the balancing of the aircraft, to split the operative empty weight contributions of the main aircraft components into one fuselage group and one wing group. ***(6 points)***
    a) In which of the two groups should you include the weight of the payload and why? ***(1 out of 6 points)***
    b) In which of the two groups should you include the weight of the fuel and why? ***(1 out of 6 points)***
    c) In which of the two groups should you include the weight of the main landing gear and why? ***(2 out of 6 points)***
    d) Explain why the following statement is correct or wrong: *In a three lifting surface aircraft, such as the Piaggio Avanti P180, the weight contributions of aft tail, wing and canard should be all included in the wing group.* ***(2 out of 6 points)***

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2. Provide a definition of trim drag, both in your own words ***(2 points)*** and by means of a mathematical expression, for which you shall indicate the meaning of each coefficient ***(1 point)***. Provide one reason ***(2 points)*** why a T-tail configuration can offer advantages, with respect to a classical fuselage mounted horizontal tail, in terms of reducing the trim drag. ***(total for this question: 5 points)***

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3. Looking at the plot provided in the following figure: ***(3 points)***
    a) Explain why this plot is/is not typical of a statically longitudinal stable aircraft (do not just provide a formula, clarify in your own words).
    b) Explain why this plot is/is not typical of a controllable aircraft (do not just provide a formula, clarify in your own words).

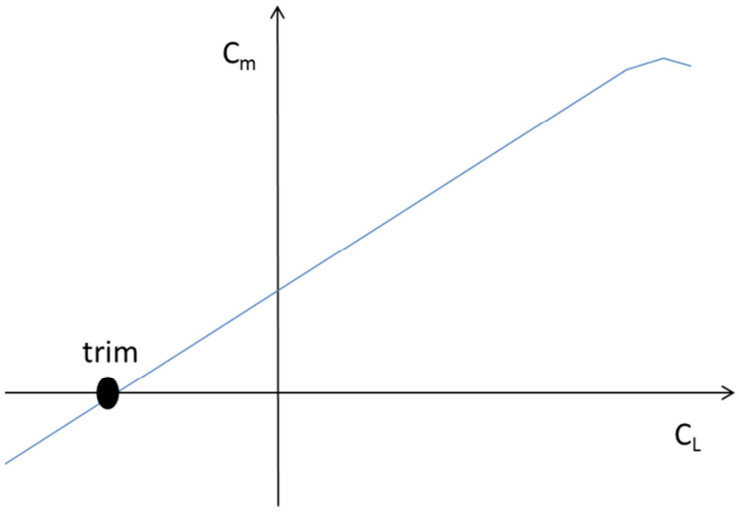

Figure 1: question 3

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4. Explain why the following statements are correct/wrong. ***(6 points)***
   a. When the c.g. and the neutral point coincide, the moment coefficient of the forces acting on the aircraft is null.
   b. For a given horizontal tail size, the larger the static stability margin, the larger the allowed c.g. range. Use a qualitative scissor plot to support your explanation.
   c. The type of tail (fixed, adjustable, full moving) has an influence on the stability characteristics of the aircraft. Use a qualitative scissor plot to support your explanation.

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5. Can you explain what the so called tail volume coefficients are? Can you also briefly explain their use in the conceptual design process of an aircraft? ***(4 points, 2 per question)***

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6. Explain if and why the following items/parameters affect the weight of the wing. ***(6 points)***
   a. The thickness (i.e. the depth) of the wing root section.
   b. The ultimate loading factor.
   c. Provide a definition of loading factor and make a qualitative sketch of the diagram generally used for its estimation.

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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. ***(1 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. ***(1 out of 5 points)***
   c) Explain why, at the given trim point, the tail is generating zero/positive/negative lift. ***(1 out of 5 points)***
   d) Assuming a negative value of the aircraft pitching moment Cm_{ac}, explain why the center of gravity is located in front, behind or on top of the aerodynamic center of the aircraft less tailplane. ***(2 out of 5 points)***

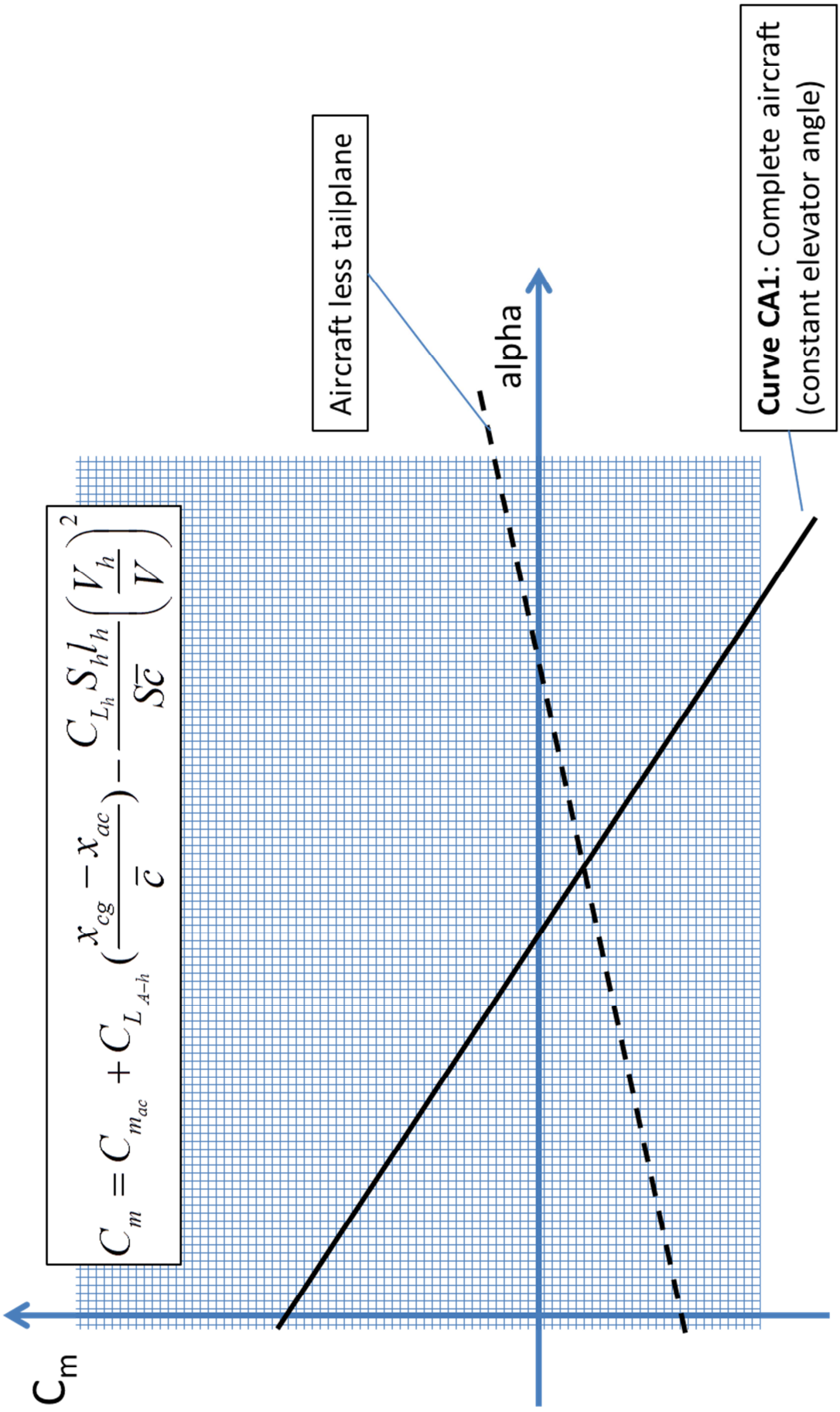

Figure 2: question 7

Part 3 - Multiple-Choice Questions

(1) In the formulation of a stakeholder requirement, which one of the following criteria is **not** correct? ***(3 points)***

(A) No more than 1 sentence shall be used in the requirement
(B) The requirement shall be written in the words of the stakeholder
(C) The requirement shall express a "what" and a "how"
(D) The requirement shall be solution-free

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(2) Only one of the following hypothetic requirements for a space launcher is correctly formulated. Which one is the only correct requirement? ***(3 points)***

(A) REQ-A: The propulsion system shall have a sea-level thrust not lower than 4000 kN.
(B) REQ-B: The launcher shall produce a low aerodynamic drag.
(C) REQ-C: Vacuum thrust shall be at least 5000 kN and vacuum specific impulse at least 300 s.
(D) REQ-D: The propellants shall not be toxic in order to avoid risks for the operators by being compliant to the REACH standards.

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(3) Only one of the following sentences can be linked to validation (all the other sentences are linked to verification). Which one is the only sentence linked to validation? ***(3 points)***

(A) The ADCS sub-system fulfils all its interface requirements
(B) The power sub-system produces 1 W average power when used in the Delfi-Next satellite on a Sun-synchronous orbit at 600 km altitude
(C) The communications sub-system includes two X-Band antennas
(D) The propulsion sub-system has a total dry mass of 50±0.2 kg

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(4) Only one of the following propulsion system requirements can in any case be verified by test, whatever the available resources are. Which is the requirement to be (always) verified by test? ***(3 points)***

(A) REQ-A: Propulsion system maximum length shall be 100±1 mm
(B) REQ-B: Propulsion system sea-level thrust shall be 100±1 N
(C) REQ-C: Propulsion system exhaust velocity shall be 100±1 m/s
(D) REQ-D: Propulsion system tank pressure shall be 100±1 bar

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(5) According to the ESA-ECSS standards, what is a correct sequence over time for the milestones Qualification Review (QR), Critical Design Review (CDR), Acceptance Review (AR), Operational Readiness Review (ORR)? ***(3 points)***

(A) CDR → AR → QR → ORR
(B) CDR → QR → ORR → AR
(C) QR → AR → CDR → ORR
(D) CDR → QR → AR → ORR

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(6) Which probability distribution is typically used to model *wear-out* of technical components? ***(3 points)***

(A) Negative exponential distribution
(B) Poisson distribution
(C) Normal distribution
(D) Weibull distribution

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(7) The proposed Boeing 777X (a variant of the 777) will feature newly designed composite wings instead of aluminium wings. In terms of *risk assessment*, which ordinal descriptions best match this development and its implication on functionality in case of fail? ***(3 points)***

(A) Extrapolated from existing flight design; catastrophic impact
(B) Feasible in theory; negligible impact
(C) Proven flight design; marginal impact
(D) Working laboratory model; catastrophic impact

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(8) In which manner is risk management to be performed for technical development projects? ***(3 points)***

(A) In a post-hoc manner, i.e. after completion of each project development step
(B) In a pre-hoc manner, i.e. before beginning each project development step
(C) In an ad-hoc manner, i.e. when the need arises during each project development step
(D) In a continuous manner, i.e. integrated into each project development step

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(9) Which of the following characteristics does <u>not</u> apply with respect to concurrent engineering? ***(3 points)***

(A) Integrated use of information technology
(B) Simultaneous activities
(C) Loosely defined, flexible and agile design and process responsibilities
(D) Use of Design-Build Teams

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(10) Which of the following cost estimation techniques is most suitable for use in estimating the cost of a conceptual spacecraft design for a novel application? ***(3 points)***

(A) Deterministic analytical models
(B) Parametric cost estimation
(C) Analogous cost estimation
(D) Simulation-based cost estimation
