Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3201: Systems Engineering and Aerospace Design

October 1st, 2013, 18:30pm

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), (g). Give a concise but complete answer to each question. ***(25 points)***

The DelFFi-Next mission

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) and *Delfi-Next* (finalized, scheduled for launch in November 2013).

Delfi-Next will be based on the same core design aspects as Delfi-C3, but will incorporate lessons learned from the Delfi-C3 mission. Its payload will be represented by critical new flight technologies, such as a new generation of radio transponder, a solar cell experiment and a propulsion system. The satellite will be unique in the propulsion system it uses, product of a joint development of TNO, TU Delft and University of Twente.

Questions

(a) Provide a Mission Statement for the Delfi-Next mission. ***(3 points)***

(b) Make a design option tree for the propulsion system of Delfi-Next, including at least 2 sub-levels. Your tree will show, among others, propulsion using liquids or using gas. However, neither liquids nor a pressurized system at launch are allowed by regulations. Which realistic options for the propulsion system remain? ***(6 points)***

(c) What is the difference of flying a propulsion system as payload or as a part of the bus? Name 2 key differences! ***(2 points)***

(d) The function of the propulsion system will be *demonstrated* in space and *evaluated* later on on-ground. To that extent, the spacecraft has to be re-oriented to a thruster-pointing mode and, after thrusting, be pointed back to the nominal pointing mode. Draw a functional flow diagram for the demonstration and evaluation of the propulsion system. ***(4 points)***

(e) Your thrust provides a minute velocity increment to the spacecraft which shall be directed in along-track (i.e. flight) direction. Allowed deviations of the velocity increment perpendicular to this direction shall be 5% at maximum. Which attitude pointing accuracy (in degrees) can be derived from this requirement? ***(4 points)***

(You will receive ***2 bonus points*** *if you can properly argue why the direction shall be along-track and not radial or cross-track).*

(f) Write down, for general propulsion systems on spacecraft, 1 sample sentence which refers to the verification of the propulsion system and 1 sample sentence which refers to the validation of the propulsion system! ***(2 points)***

(g) Your task is to validate the design of a reaction wheel for Delfi-Next. To this end, you are using a mathematical model of the wheel. You are also using a shaker facility. How can you validate your mathematical model? Do you need to validate your shaker? ***(4 points)***

Part 2 - Aircraft Questions

1. One of your senior fellow students has been telling you about a multidisciplinary software system that he developed to investigate the effect of two wing parameters, namely wing surface (S) and aspect ratio (A), on the amount of fuel required (Wf) to achieve a certain range (R). You listened very carefully to his description of the software system and took the following notes:

   - *There is one performance module that, using Breguet's equation, is able to compute the amount of fuel (Wf) that is necessary to fly a certain range (R); however, this module needs information concerning the Lift over Drag ratio (L/D) of the aircraft, as well as the aircraft maximum take off weight (W). Of course, the cruise speed (V) and Engine Specific Fuel Consumption (C) are required input.*
   - *There is one aerodynamic module that is able to compute the Lift (L) and the Drag (D) of the aircraft. The only geometrical input required are the surface (S) and the aspect ratio (A) of the wing. However, this module needs the aircraft maximum take off weight (W), the fuel weight (Wf) and the cruise speed (V) value in order to compute the required lift that has to be generated.*
   - *There is a user interface module, where the user can specify the geometry data of the wing (S, A), as well as the engine specific fuel consumption (C), the cruise speed (V) and the mission range (R), values that are required by the various system modules. Once the weight of the fuel required for the mission (Wf) is computed, its value is sent back to this interface module for display.*
   - *In order to compute the aircraft maximum take off weight (W), there is a dedicated structural sizing module, which needs as input the value of the lift (L), as well as the geometry of the wing (S, A).*

   Although apparently simple, this system is quite complex and it seems some iterations are going on… Generate a detailed N2 chart in order to render your notes into a complete, clear and compact graphical representation of the abovementioned software system with all its modules' interaction. ***(4 points)***

   Note: you can draw your N2 chart on the Figure at page 5.

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2. The so called tail volume coefficients have such a name because:

   a. They are a measure of the volume contained in the given tail empennage (indeed some aircraft use the tail as extra fuel storage space).

   b. Their typical unit is $[m]^3$

   c. Because…. [write your explanation]

   Explain why the following statement is true/wrong: "The vertical tail volume coefficient is useful to determine the longitudinal position of the vertical tail (with respect to the fuselage), once the planform area of the vertical tail is known". ***(3 points)***

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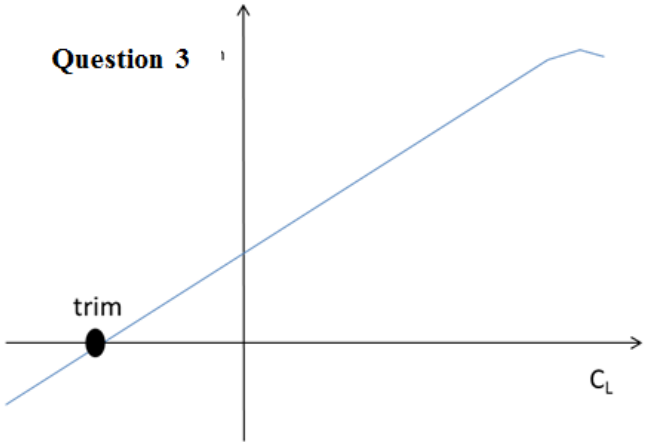
3. Consider the plot to the right ***(3 points)***:

   a. Explain why this plot is/is not typical of a statically longitudinal stable aircraft.

   b. Explain why this plot is/is not typical of a controllable aircraft.



4. Briefly explain why the following statements related to the center of gravity (c.g.) range are correct/wrong ***(3 points)*****:**
   a. A large c.g. range is positive in terms of operational flexibility
   b. A large c.g. range has always a negative effect on the controllability of the aircraft
   c. A large c.g. range is positive in terms of aircraft weight

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5. What is the difference between "aerodynamic center" and "neutral point" and why these two concepts are of any use? ***(6 points)***

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6. Consider the scissor plot given in the figure on page 5, which is typical for a longitudinally statically stable canard aircraft. ***(6 points)***
   a. Specify the missing labels of the vertical and horizontal axis of the plot; indicate what kind of constraint is represented by each curve; show the part of the design space they eliminate; indicate to which curve the two provided equations do correspond. ***(2 points)***
   b. Add in the plot the curve relative to neutral stability AND write the corresponding equation. ***(1 point)***
   c. Explain why the following statement is wrong/correct: "the allowable c.g. range of a canard aircraft is quite in front of the leading edge of the mean aerodynamic chord, hence, storing fuel in the wing is not as convenient as for a normal aircraft". ***(1.5 points)***
   d. Explain why the following statement is wrong/correct: "Contrarily to conventional aircraft, the use of powerful high lift devices is beneficial for the controllability of a canard aircraft, because it would shift the scissor plot controllability curve to the left, hence allowing a larger c.g. range for a given canard size". ***(1.5 points)***

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7. In the Cm vs. Alpha plot shown in the figure on page 6, two curves are shown, which are relative to a conventional aircraft configuration: one is representing the contribution of the aircraft_without_tail, the other is representing the curve of the overall aircraft (hence including the tail contribution) for a certain tail setting. ***(6 points)***
   a. Draw in the plot the curve corresponding to the tail contribution and indicate the trim point.
   b. Explain whether, at the given trim condition, the tail is generating positive/negative/null lift.
   c. Explain whether, at the given trim condition, the aircraft center of gravity is ahead/on top/behind the aerodynamic center of the aircraft_without_tail.

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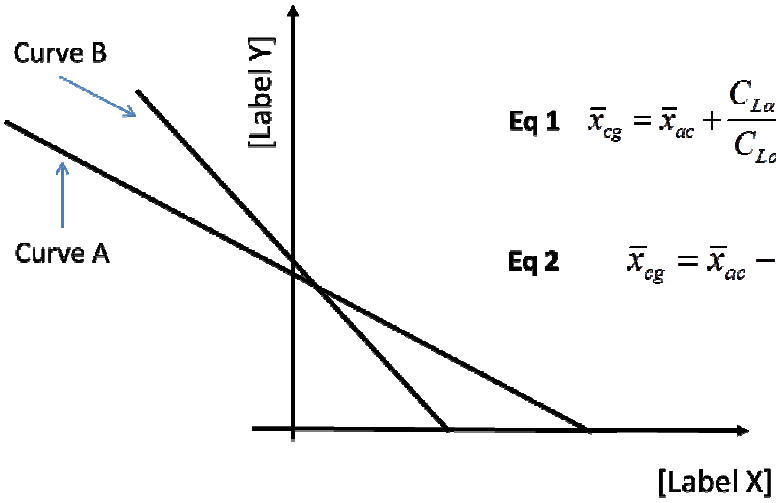
8. Consider the matching of the scissor plot with the c.g. range vs. wing position plot illustrated in the figure on page 6. You received it from some of your fellow students who took part to the aircraft tutorial. They were supposed to find the minimum horizontal tail size (and corresponding longitudinal wing position) to guarantee controllability and neutral stability of a given aircraft. ***(4 points)***
   a. Can you explain what is wrong with the matching of the plots? ***(2 points)***
   b. Sketch on the same figure a modified hypothetical stability curve, which would yield a proper matching of the plots and a horizontal tail area equal to 25% of the wing area. Assume the same position of the aerodynamic center of the aircraft without tail. ***(2 points)***

NOTE: you may detach the following page with the graphs related to questions 1, 6, 7 and 8, use it for answering these questions and attach it to the other exam sheets. If you do so, don't forget to write your name and student number on the figures page too!

Question 1 draw here your N2 chart

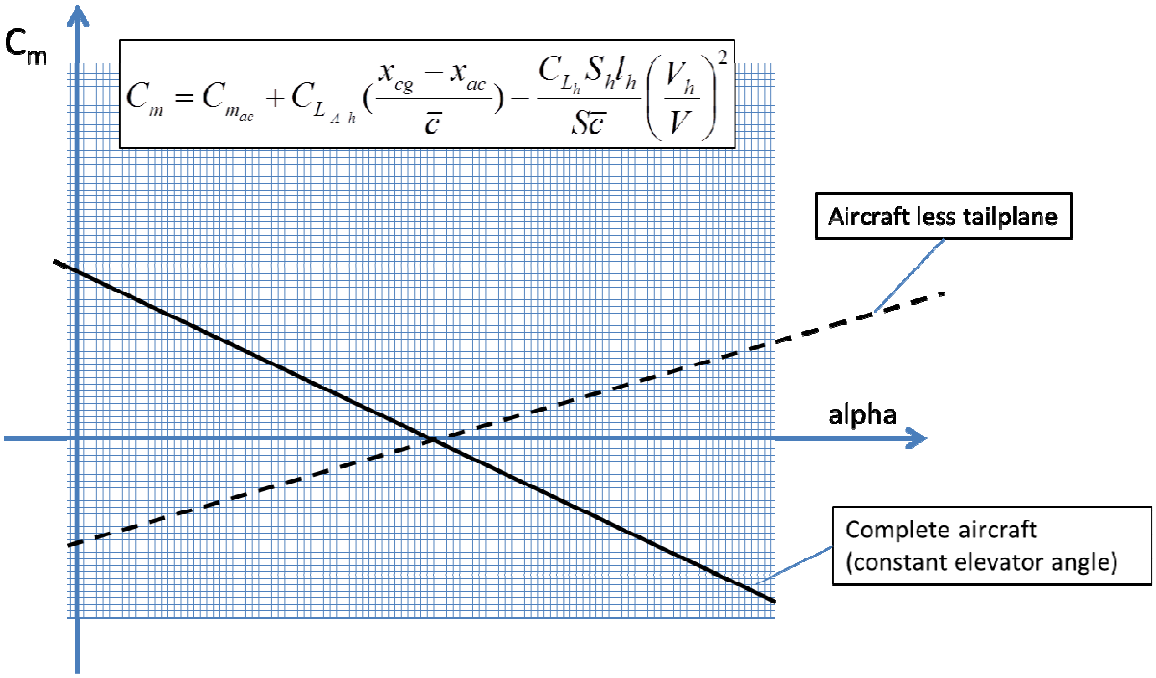
Question 6



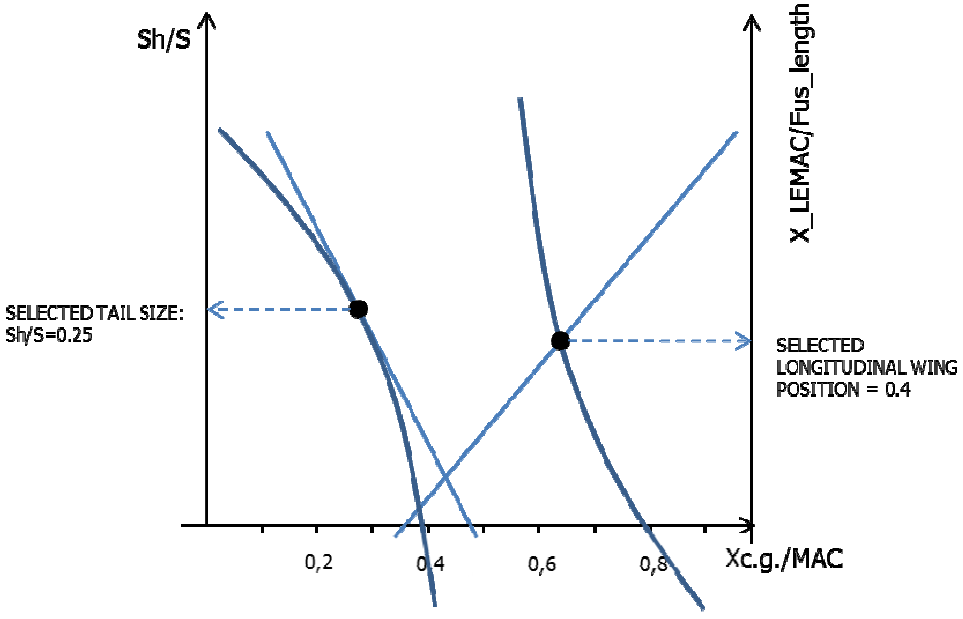
Eq 1 $$\bar{x}_{cg} = \bar{x}_{ac} + \frac{C_{L\alpha_h}}{C_{L\alpha}}\left(1 - \frac{d\varepsilon}{d\alpha}\right)\frac{S_h l_h}{S\bar{c}}\left(\frac{V_h}{V}\right)^2 - 0.05$$

Eq 2 $$\bar{x}_{cg} = \bar{x}_{ac} - \frac{C_{m_{ac}}}{C_{L_{A-h}}} + \frac{C_{L_h}}{C_{L_{A-h}}}\frac{S_h l_h}{S\bar{c}}\left(\frac{V_h}{V}\right)^2$$

Question 7



Question 8



Part 3 - Multiple-Choice Questions

(1) In the VALID acronym, what does the "D" stand for? ***(3 points)***

(A) Discussed

(B) Definitive

(C) Derivable

(D) Deterministic

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(2) 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

(D) An appropriate solid propellant shall be used in the boosters, since the toxicity of the exhaust gases is considered an important design issue

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(3) Only one of the following sentences related to *constraints* is correct: indicate it. ***(3 points)***

(A) A constraint may have an impact on schedule and resources, but never on functional performance.

(B) For Systems Engineering, a constraint always originates from engineering considerations and should never originate from economical, legal or cultural aspects.

(C) A constraint can be formulated as a requirement.

(D) A constraint increases the number of degrees of freedom in providing a solution.

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(4) In the Design Option Tree for the electrical power subsystem of a new TU Delft nano-satellite with an extended lifetime of at least 5 years (to be launched in 2016), only one of the following options will NOT be discarded during the first "eliminating concepts" phase and will advance to the final selection process: indicate it. ***(3 points)***

(A) Use of a very long cable connecting the satellite to the power station on ground.

(B) Use of thin-film solar panels body-mounted on 5 of the 6 faces of the satellite.

(C) Use of a wireless system for transferring the necessary power from the International Space Station to the satellite. Rumours say that NASA is developing such a system and it will be qualified for flight within the next 5 years.

(D) No use of any power generation systems (all the required power for the entire lifetime is stored in batteries that are charged before launch).

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

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

(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 actual cost of the work performed

(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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(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) Requirement sentences can include a description of the design.

(B) Requirement sentences shall be short.

(C) Requirement sentences shall not include the reason for the requirement.

(D) Requirement sentences can include one or more requirements.

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(7) Which one of the following is a correct definition of *complexity*? ***(3 points)***

(A) Something which includes parts in an intricate arrangement.

(B) Something which is uncertain but easily predictable.

(C) Something which is not simple but totally independent.

(D) Something which is not simple but still fully knowable.

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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 be considered acceptable with respect to the VALID criteria: indicate it. ***(3 points)***

(A) The AOCS subsystem shall have a measurable pointing accuracy.

(B) The AOCS subsystem shall survive unexpected loads.

(C) The AOCS subsystem shall require a reasonably low power during the Safe Mode.

(D) The AOCS subsystem shall have a lower mass than the ones used for the previous *Delfi C3* and *Delfi-Next* satellites developed by TU Delft.

(9) On which kind of test item is the Acceptance Test performed? ***(3 points)***

(A) The Flight Model

(B) The Qualification Model

(C) A prototype of the system, subsystem or component to be tested

(D) A mock-up model

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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 "verification" 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 not a key element of the Concurrent Design Facility (CDF) at the European Space Agency (ESA)? ***(3 points)***

(A) A finalized design

(B) A process

(C) An infrastructure

(D) An integrated design model

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(12) What Life Cycle Cost (LCC) description best describes the JUICE mission of the European Space Agency, intended to send in 2022 one satellite in orbit around Jupiter's satellite Ganymede?
(3 points)

(A) High development and operational costs, very low production costs.

(B) Low development and operational costs, with high production costs.

(C) High development costs, significant production costs, and relatively low operational costs.

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

(13) Which one of the following sentences correctly explains the *objective* of Technical Performance Measurement (TPM)? ***(3 points)***

(A) Ensure that product achieves *acceptable* performance with the *specified* use of resources.

(B) Ensure that product achieves *best* performance with a *minimum* use of resources.

(C) Ensure that product achieves *specified* performance with *acceptable* use of resources.

(D) Ensure that product achieves *specified* performance with *minimum* use of resources.

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(14) Which one of the following is a correct and complete definition of "reliability"? ***(3 points)***

(A) Probability that a system performs in a satisfactory manner for a given period of time when used under all possible operating conditions.

(B) Probability that a system performs in a satisfactory manner for a given period of time when used under specified operating conditions.

(C) Probability that a system performs in a satisfactory manner for the longest possible period of time when used under specified operating conditions.

(D) Probability that a system performs in a satisfactory manner for an indefinite period of time when used under all possible operating conditions.
