Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3211-I: Systems Engineering and Aerospace Design
April 13th, 2017, 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 **(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.
- ✓ Please add your solution to the graph given on Page.7 and thus include that page to your answer booklet.
- ✓ 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), (i). Give a concise but complete answer to each one of the questions.
Read the entire space part including all questions, before starting to answer them.

Breakthrough Starshot

Breakthrough Starshot, announced April 12, 2016, is a US$100 million program within the Breakthrough Foundation to develop a proof-of-concept light sail spacecraft fleet capable of making the journey to Alpha Centauri at 20% the speed of light taking about 20 years to get there, and about 3.7 years to notify Earth of a successful arrival.

Breakthrough Starshot aims to demonstrate proof of concept for ultra-fast light-driven nano-spacecraft, and lay the foundations for a first launch to Alpha Centauri within the next generation. Secondary goals are Solar System exploration and detection of Earth-crossing asteroids.

The spacecraft fleet would have 1000 craft, and each craft, named StarChip, would be a very small centimeter-sized craft. They would be propelled by several ground-based lasers of up to 100 gigawatts. Each tiny spacecraft would transmit data back to Earth using a compact on-board laser communications system.

Ground-based lasers would focus a light beam on the craft's solar sails to accelerate them one by one to the target speed within 10 minutes, with an average acceleration on the order of 100 km/s2, and an illumination energy on the order of 1 TJ delivered to each sail, estimated to have a surface area of 4 m × 4 m. For this exam, the sail is assumed to consist of aluminum foil of 30 nm thickness with a density of 2.7 gr/cm^3.

You are member of a team doing a Phase-A study for the Breakthrough Starshot Mission and work for Pete Worden, the former director of NASA AMES Research Center, now Executive Director of Breakthrough Starshot. The project is at a very early stage.

Questions

(a) Provide a Mission Statement for Breakthrough Starshot. ***(4 points)***

(b) What is the expected mass of the StarChip including its solar sail? Provide your answer in grams including expected lower and upper mass boundaries. Briefly state and motivate your assumptions and show the process, you followed. ***(8 points)***

(c) Draw a high-level System Description diagram of such mission (=system) including all relevant mission architecture elements and label them. ***(4 points)***

(d) Identify a key stakeholder (outside of the Breakthrough Foundation) and write down a proper stakeholder requirement for that stakeholder. If needed, document an associated assumption you made.

(4 points)

(e) Write down a system requirement and a subsystem requirement, which is a child of the system requirement. ***(4 points)***

(f) Which verification method do you chose to verify the child requirement you provided in your answer to question (e)? ***(2 points)***

(g) Draw a subset of the N2-chart related to the following subsystems:

- Communications
- Attitude
- Propulsion

and add the relevant interfaces. Which interface appears most critical to you and why? ***(5 points)***

(h) What is the pointing accuracy required for StarChip to communicate? Provide your answer in mrad!

(2 points)

(i) Typical current lasers have a divergence angle of 0.1-1 mrad. What do you conclude from your result under (g) with respect to the feasibility of the concept and what could be ways out? ***(2 points)***

Part 2 –Aircraft Questions

1. The plot provided in Figure 1 illustrates the variation of pitching moment coefficient Cm_{cg} and tail lift coefficient CL_{tail} (i.e. CL_h)of a certain aircraft, as function of 3 different values of the aircraft lift coefficient CL_{T-0} (i.e. CL_{A-h}). Observe the plot and answer the following questions **(6 points)**:
    a. What is the most critical flight condition that sizes the tail and why? (1 point)
    b. What is the reason why the aerodynamic pitching moment coefficient varies so drastically from cruise to landing condition? (1 point)
    c. What type of airfoil would you select for the tail of this aircraft? (1 point)
    d. What is the meaning of $\bar{V}_h$ =1 and how is this coefficient defined? (1 point)
    e. Explain why the plot in the figure is relative to a T-tail aircraft (*hint: derive the trim equation)* (2 points)

Figure 1: question 1

2. Different weight estimation methods are used during conceptual aircraft design. (**6 points)**
   a. Summarize the required <u>input</u>, the generated <u>output</u> and the <u>approach</u> on which a Class I weight estimation method is based
   b. Do the same as above for Class II methods. Please note that is not expected you provide all input and output values involved in a class II method, but at least some of those which are representative for the method.
   c. In general the operative empty weight value obtained using Class I and II methods do not coincide. Can you explain why? (2 points)
   d. How should you handle the difference in the output of the two methods? Illustrate the approach by means of a simple N2 chart (2 points).

3. Explain why the following statements are correct or wrong. Please note that by only stating true/false no points are scored **(7 points):**
   a. The concept of neutral point is important for the controllability of an aircraft
   b. When the locations of the center of gravity and the neutral point coincide, the aerodynamic moment coefficient of the aircraft computed around that point, by definition, is zero.
   c. A tailless aircraft (ignore here any effect of the propulsion system) has neutral longitudinal static stability when the positions of neutral point and aerodynamic center coincide
   d. At trim conditions, by definition, the aircraft is able to react with an opposite moment to any angle of attack perturbation
   e. By lowering the static stability margin it is possible to extend the backward shift of the aircraft center of gravity without increasing the tail surface and still guaranteeing longitudinal static stability
   f. Reducing the horizontal tail surface allows reducing the aircraft trim drag
   g. In order to guarantee the longitudinal static stability of a canard aircraft, contrarily to conventional aircraft, the center of gravity must be located behind the neutral point.

4. Generate a qualitative scissor plot for a UAV with a conventional configuration (fuselage, cantilever wing and aft tail), full moving horizontal tail and zero stability margin. (**6 points)**
   a. Show on your plot the controllability, the static stability and the neutral stability curves. Do not forget to label the axes of the plot, and, for each of the three curves, write the corresponding equation (*hint: look at the equations below*). (2 points)

b. Imagine you change the full moving tail configuration into a fixed horizontal tail. Show qualitatively the effect of this configuration change on your scissor plot (if there is any!) AND briefly justify your answer (2 points)

c. Show qualitatively on your scissor plot the effect (if there is any) of a larger wing downwash gradient AND briefly justify your answer (2 points).

5. While reviewing the conceptual design of a large passenger aircraft proposed by a colleague of yours, you notice that the most aft position of the centre of gravity is significantly ahead of the main landing gear position. Briefly warn your colleague about <u>at least two</u> negative consequences of this c.g. positions on the performance of his design **(4 points in total).**

6. The same sloppy colleague as above is showing you a spreadsheet with the equation he used to estimate the weight of the wing. He claimed he used the Raymer's method, but obviously he copied the equation wrong. Can you spot the error(s) and explain your colleague why that equation would not work? (points are earned <u>only</u> when a correct explanation is provided) **(2 points).**

$$W_{wing} = 0.0051 \quad W_{dg}^{\,0.557} \; S_W^{\,0.649} \; A^{0.5} \; (t/c)_{root}^{\,-0.4} \; (1+\lambda)^{0.1} \; (\cos\Lambda)^{-1.0} \; S_{csw}^{\,0.1}$$

Where W_{dg} = Design gross weight; S_w = trapezoidal wing area; A = aspect ratio; (t/c) = thickness/chord ratio; S_{csw} = control surface area; λ = taper ratio; Λ = sweep angle.

7. Consider the plot in figure 2 relative to a conventional passenger aircraft. The plot contains the curve of the complete aircraft and the curve of its tail contribution. (**4 points)**
   a. **Add on the same plot** (use the grid for accuracy) the curve representing the contribution of the aircraft-less-tail and explain how you have defined such curve (2 points)
   b. Explain why at the given trim conditions, the tail is generating upward/downward/zero lifting force (of course only one of these 3 conditions applies). (1 point)
   c. Explain why, without the contribution of the tail, the given aircraft would be stable/unstable/neutrally stable (of course only one of these 3 conditions applies). (1 point)

Student name: ....
Student numb.: ....

Please use this plot to draw your curve, then remove this page from the exam booklet and deliver it together with the Aircraft part of your exam.
Do not forget to write your name and student number.

Figure2: question 7

Part 3 –Multiple Choice Questions

(1) Only one of the following sentences related to *constraints* is correct.
Indicate the only correct sentence? ***(3 points)***

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

(B) A constraint cannot be formulated as a requirement.

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

(D) A constraint may have an impact on schedule, resources, project setting and functional performance.

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(2) 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 propellant tank shall withstand an operational pressure of 250 bar without suffering any structural damage.

(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 wet mass of 75±0.2 kg.

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(3) Only one of the following sentences related to test and analysis is *not correct*. Which one is the *only incorrect* sentence? ***(3 points)***

(A) Analysis is always preferred to test when it is practical, cost effective and safe.

(B) Test is always preferred to analysis when it is practical, cost effective and safe.

(C) Analysis shall be used when flight conditions cannot be accurately simulated.

(D) Analysis shall be used when it is not economically feasible to test the entire spectrum of flight conditions.

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(4) Which one of the following methods is not used to verify requirements? ***(3 points)***

(A) Inspection

(B) Analysis

(C) Comparison

(D) Test

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(5)) 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 mass shall be lower than 10±0.1 kg.

(B) REQ-B: Propulsion system total impulse shall be higher than 10 Ns.

(C) REQ-C: Propulsion system vacuum specific impulse shall be higher than 10 s.

(D) REQ-D: Propulsion system minimum impulse bit duration shall be lower than 10 ms.

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(6) Which one of the following hypothetic requirements for the propulsion system of a new launcher rocket **<u>is considered acceptable</u>** with respect to the VALID criteria: indicate it ***(3 points)***

- **(A)** The propulsion system shall provide a feasible thrust 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 sufficiently more at full power level than at 75% power level.
- **(D)** The mechanical interface between nozzle and combustion chamber shall withstand each and every level of acceleration without any failures.

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(7) In many development programs, resource contingencies are assigned to incorporate the effect of uncertainty into the design. Contingency allowances are a function of ***(3 points)***

- **(A)** Design disciplines and project length
- **(B)** Project objectives and design disciplines
- **(C)** Design maturity and type of hardware/software
- **(D)** Number of design concepts and project length

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(8) Which probability distribution is typically used to model *random failures* of technical components? (***3 points)***

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

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(9) 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

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(10) Which TPM parameter is typically *<u>not</u>* important for spacecraft? ***(3 points)***

- **(A)** Direct maintenance cost
- **(B)** On-board computer capacity
- **(C)** Communication link
- **(D)** Electrical power
