Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3211-I: Systems Engineering and Aerospace Design

April 9th, 2015, 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.
- ✓ 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 OLFAR Mission

New interesting astronomical science drivers for very low frequency radio astronomy have emerged, ranging from studies of the astronomical dark ages, the epoch of re-ionization, exoplanets, to ultra-high energy cosmic rays. However, astronomical observations with Earth-bound radio telescopes at very low frequencies are hampered by the ionospheric plasma, which scatters impinging celestial radio waves. Below about 5 MHz, the ionosphere is even opaque for radio waves.

A radio telescope in space, such as around the Moon or at a Lagrange Point, would not be hampered by the Earths ionosphere, but up to now such a telescope was technologically and financially not feasible. However, extrapolation of current technological advancements in signal processing and small satellite systems imply that distributed low frequency radio telescopes in space could be feasible in the future. Thus, an autonomous distributed sensor system in space, called OLFAR (Orbiting Low Frequency ARray), and comprising several small satellites, is proposed to explore this new low-frequency band for radio astronomy. The satellites must be controlled to stay within certain virtual spatial areas (the so-called control windows).

You are project leader for OLFAR at ASTRON, the Netherlands Institute for Radio Astronomy. The project is at a very early stage.

Questions

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

(b) Name 2 reasons from a mission perspective why the satellites should stay in their control windows. Motivate them in 1 sentence each. ***(4 points)***

(c) Name 2 reasons why – from a dynamics perspective - the satellites need to be controlled to stay in their control boxes. So, why would they not stay where they are? Motivate them in 1 sentence each. ***(4 points)***

(d) Identify a key stakeholder (not ASTRON) and write down a proper stakeholder requirement for that stakeholder. ***(3 points)***

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

(f) Suppose the control box size of individual satellites is d = 10 km in each axis. Consider only the one-dimensional problem though. Assume that your satellite, at an initial time t_0 = 0 s, is located just at the border of the control box. At this time, it has a velocity v_0 = 2 m/s directed to the other side of the control box, which it would reach in a certain time Δt.

What is the time Δt required to traverse the control window? ***(2 points)***

The velocity v_0 is uncertain by a value of δv (1σ). What is the requirement on the value of δv you can accept, when the control box is not violated nearly certain by more than 5%? *Hint 1: Linear dynamics is a good approximation for relative satellite motion for short times. Hint 2: Only consider simple 1st order effects. Hint 3: Make a sketch!* ***(4 points)***

(g) Consider that OLFAR will be implemented **not** in a LEO, MEO or GEO, but a lunar or deep space orbit. Sketch a Design Option Tree for a navigation systems at least on 2 levels, not counting the level on the top of the tree. Mark the non-feasible ones and motivate your reasons. ***(6 points)***

(h) Which criteria would you propose for a graphical trade-off of navigation system concepts and their associated weights? Motivate your criteria and weights! ***(4 points)***

Part 2 - Aircraft Questions

1. Consider the loading diagrams in Figure 1. They have been generated for the same aircraft, in correspondence of three different longitudinal wing positions. ***(4 points)***
    a. Which loading diagram does correspond to the most forward (LEMAC at 45% of the total fuselage length), intermediate (LEMAC at 50% of the total fuselage length) and most aft longitudinal wing position (LEMAC at 55% of the total fuselage length), respectively? Briefly justify your answer (points are earned only in case of correct explanations). ***(1 out of 4 points)***
    b. This set of loading diagrams belongs to one of the three aircraft configurations shown in the figure. Indicate which one and briefly justify your answer (points are earned only in case of correct explanations). ***(2 out of 4 points)***
    c. Making use of the provided set of loading diagrams, generate a plot showing the variation of the center of gravity (c.g.) range versus the longitudinal wing position. Include the axes' labels; indicate the points derived from the three loading diagrams and the curves interpolating such points. ***(1 out of 4 points)***

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2. Consider Plot B in Figure 1. ***(5 points)***
    a. Indicate on that plot the most critical position of the main landing gear, which, if trespassed, would make the operative empty aircraft unstable on the ground.
    b. What would be the negative consequence(s) (if any) of moving the landing gear slightly forward?
    c. What would be the negative consequence(s) (if any) of moving the landing gear significantly forward?
    d. What would be the negative consequence(s) (if any) of moving the landing gear slightly backward?
    e. What would be the negative consequence(s) (if any) of moving the landing gear significantly backward?

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3. Consider the following "versions" of the Raymer's Class II method to predict the weight of fighter aircraft wings. All of them include one or more evident errors. Spot these errors and justify your answer (points are earned only when correct justifications are provided). ***(5 points)***
    a. $W_{wing} = 0.0103\ K_{dw}K_{vs}\ W_{dg}^{0.5}\ S_W^{0.622}\ A^{0.785}\ (t/c)_{root}^{0.4}\ (1+\lambda)^{0.05}\ (\cos\Lambda)^{1.0}\ S_{csw}^{0.04}$
    b. $W_{wing} = 0.0103\ K_{dw}K_{vs}\ (W_{dg}N_z)^{0.5}\ S_W^{0.622}\ A^{-0.785}\ (t/c)_{root}^{-0.4}\ (1+\lambda)^{0.05}(\cos\Lambda)^{-1.0}S_{csw}^{0.04}$
    c. $W_{wing} = 0.0103\ K_{dw}K_{vs}\ (W_{dg}N_z)^{-0.5}\ S_W^{0.622}A^{-0.785}\ (t/c)_{root}^{0.4}\ (1+\lambda)^{0.05}(\cos\Lambda)^{-1.0}S_{csw}^{0.04}$
    d. $W_{wing} = 0.0103\ K_{dw}K_{vs}\ W_{dg}^{0.5}\ S_W^{0.622}A^{0.785}\ (t/c)_{root}^{-0.4}\ (1+\lambda)^{0.05}\ (\cos\Lambda)^{1.0}\ S_{csw}^{0.04}$

    Where *Kdw* = 0.768 for delta wings and 1.0 otherwise; *Kvs* = 1.19 for variable sweep wings and 1 otherwise; W_{dg} = Design gross weight; S_w = trapezoidal wing area; S_{csw} = control surface area; *λ* = taper ratio; *Λ* = sweep angle. The other coefficients are obvious.

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4. Consider the plot and the equation given in Figure 2. The given curves are those of a given general aviation aircraft featuring a conventional tail configuration. ***(6 points)***
    a. Draw on the same plot (use the grid for accuracy) the curve representing the contribution of the aircraft without tail AND justify your drawing. ***(1 out of 6 points)***

b. Explain whether the aircraft without tail is stable/unstable or neutrally stable. ***(1 out of 6 points)***

c. Explain whether, at the given trim point, the tail is generating zero, positive or negative lift. ***(2 out of 6 points)***

d. Assuming a negative value of the aircraft pitching moment Cm_{ac}, explain whether the center of gravity is located in front, behind or on top of the aerodynamic center of the aircraft less tailplane. ***(2 out of 6 points)***

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5. In the process to determine the best longitudinal wing position and minimum tail size for longitudinal stability and control, it is convenient to organize the various components of the aircraft operative empty weight in two groups: the *wing group* and the *fuselage group*. ***(6 points)***

a. Can you explain why? ***(3 out of 6 points)***

b. Consider the 3 airplanes in Figure 3. For each one, list at least 3 main components belonging to the wing and fuselage group. ***(3 out of 6 points)***

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6. Explain why the following statements are correct or wrong ***(6 points)***:

a) The relative position of the wing aerodynamic center with respect to the aircraft center of gravity determines the static longitudinal stability of an aircraft.

b) When the center of gravity and the trim point of an aircraft coincide, such aircraft is said to be neutrally stable.

c) A tailless aircraft (ignore the effect of the propulsion system) can be longitudinally statically stable only when its neutral point is located sufficiently after its aerodynamic center.

d) At trim condition, the total moment of the aerodynamic forces acting on the aircraft is null.

e) The aerodynamic pitching moment caused by deployed flaps affect the stability of the aircraft.

f) By increasing the static stability margin it is possible to extend the allowable backward shift of the aircraft center of gravity without increasing the tail surface.

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7. Consider the plot in Figure 4 ***(3 points)***:

a. What do the two curves 0-A-D-E-F-H and 1-B'-C'-D'-E'-F'-G' represent? ***(1 out of 3 points)***

b. Explain how this plot is used for the application of Class II weight estimation methods. ***(2 out of 3 points)***

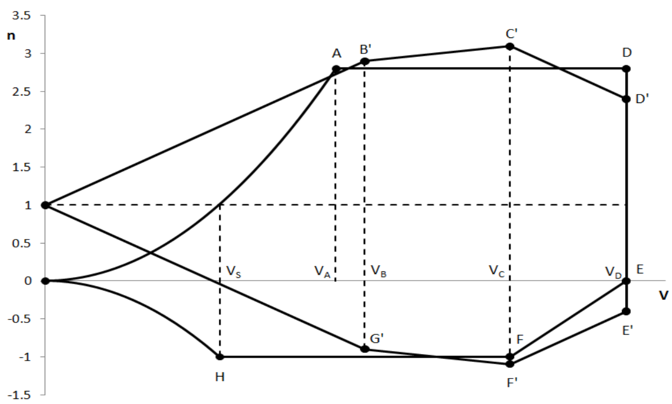

Figure 4

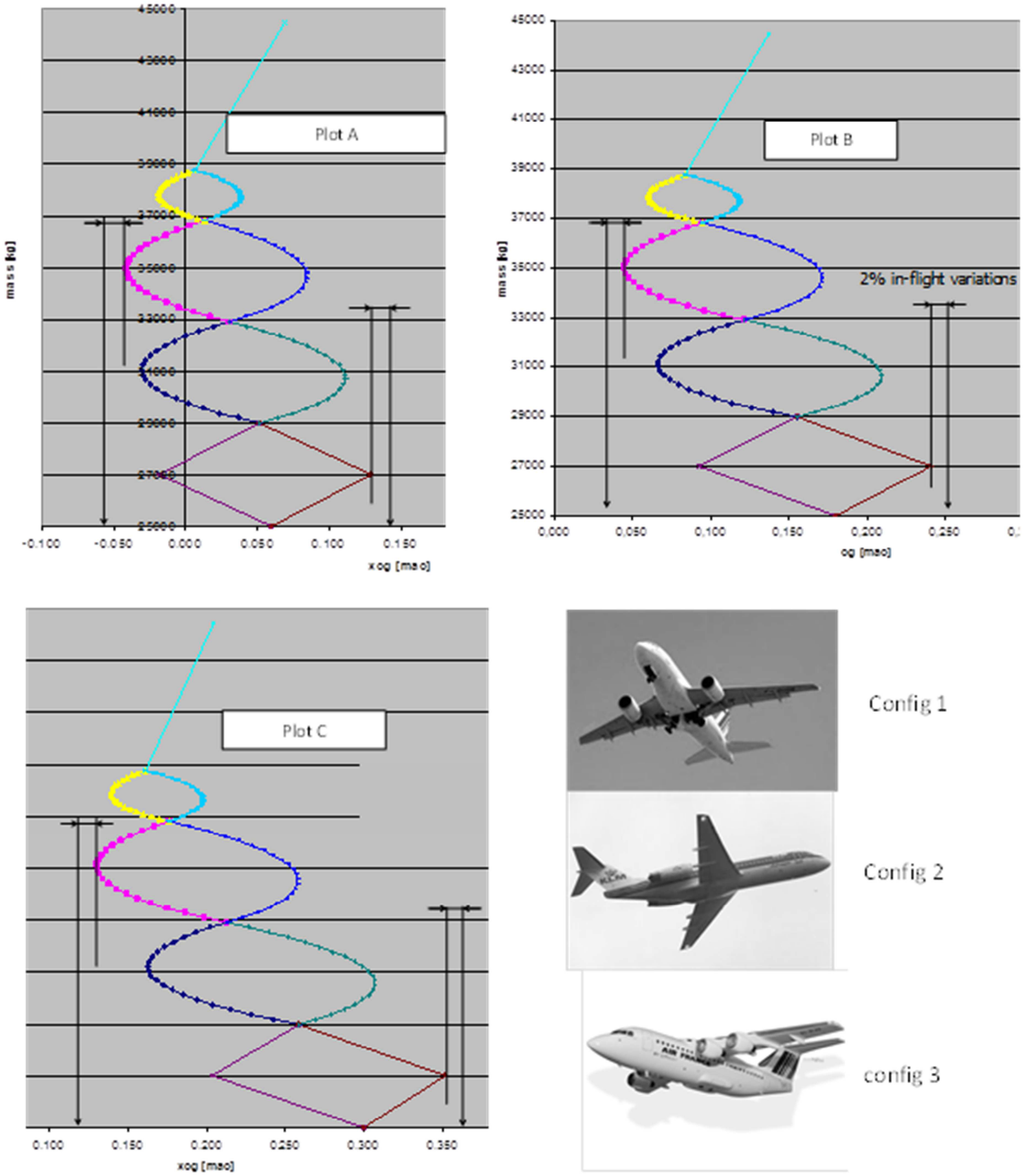
Plot A
mass [kg]
xcg [mac]
Plot B
2% in-flight variations
mass [kg]
cg [mac]
Plot C
xcg [mac]
Config 1
Config 2
config 3

Figure 1

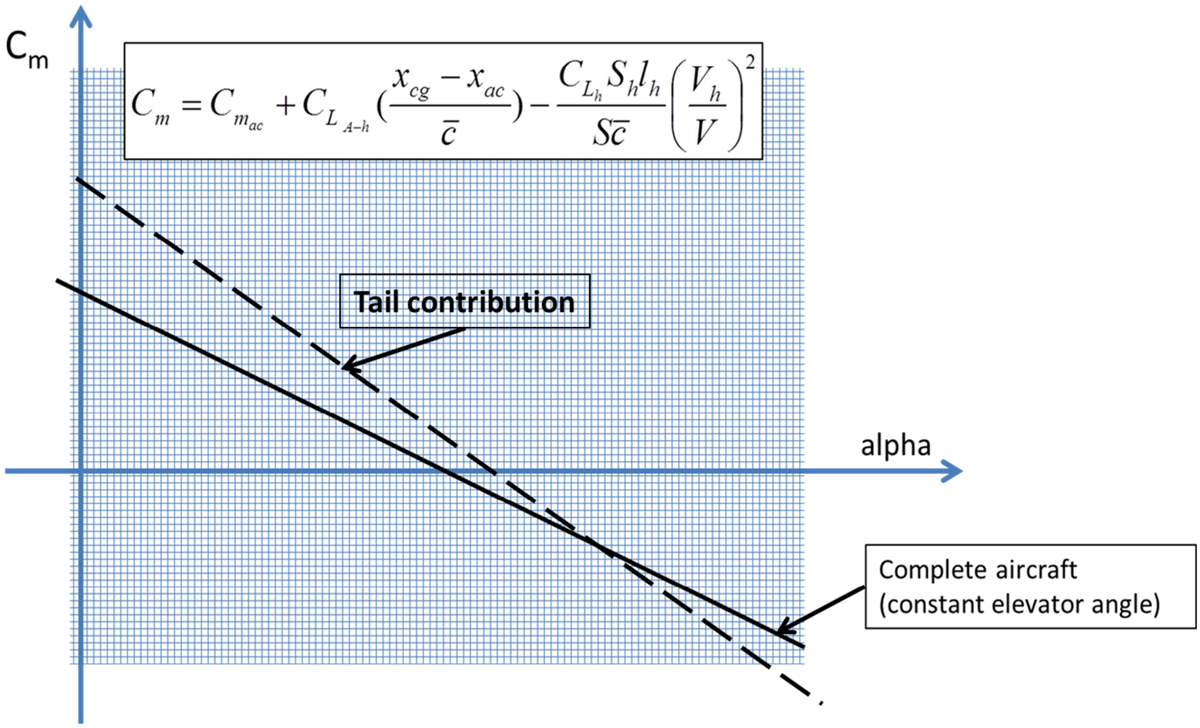

Figure 2

	Wing group: ……………………………… ……………………………… ……………………………… …………………………………	Fuselage group ……………………………… ……………………………… ……………………………… …………………………………
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	Wing group: ……………………………… ……………………………… ……………………………… …………………………………	Fuselage group ……………………………… ……………………………… ……………………………… …………………………………

Figure 3

Part 3 - Multiple-Choice Questions

(1) Assume you are working in a German company, developing a small satellite that will demonstrate active space debris removal in orbit, by approaching and manipulating a given debris object. For this project your company is cooperating with a German university, which owns a defunct CubeSat in LEO that will be used as sample debris for the demonstration. This demonstration project is funded by the German government. Which one of the following can be considered a key customer of the project? ***(3 points)***

(A) Your company
(B) The German university
(C) The German government
(D) The space community, including the International Institute of Space Law

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(2) Only one of the following hypothetic requirements for the ADCS sub-system of a CubeSat can be considered as correctly formulated. Which is the only correct requirement? ***(3 points)***

(A) REQ-A: The ADCS sub-system should have a sufficient pointing stability.
(B) REQ-B: The ADCS sub-system shall have a total take-off weight lower than 5 N.
(C) REQ-C: The ADCS sub-system must have a pointing accuracy of 1 arcsec.
(D) REQ-D: The ADCS sub-system shall have a pointing accuracy of 1 arcsec and a pointing stability of 2 arcsec/s.

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(3) Which one of the following functions (to be included in a hypothetical Functional Breakdown Structure of a spacecraft) is not correctly formulated? ***(3 points)***

(A) 1.0 - Orbit modification from LEO to GEO
(B) 1.1 - Transfer the spacecraft from LEO to GEO
(C) 1.2 - Perform the orbital change from LEO to GEO
(D) 1.3 - Check the orbital parameters of the spacecraft

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(4) Which one of the following verification methods is not mentioned by the ESA ECSS standards related to propulsion systems? ***(3 points)***

(A) Demonstration
(B) Review of Design
(C) Inspection
(D) Analysis

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(5) All of the following are possible validation activities. For which one of them are the so-called VALID criteria relevant? ***(3 points)***

(A) Validation of a requirement
(B) Validation of a model
(C) Validation of a product
(D) Validation of a simulation result

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(6) At a certain moment, a project is exactly on time (i.e., all the scheduled activities have been regularly performed), with a total cost of the scheduled work equal to 100 kEuro, as compared to a budgeted cost for that work of 80 kEuro. What are the Cost Variance and the Schedule Variance of this project at the given time? ***(3 points)***

(A) Cost Variance = 20 kEuro; Schedule Variance = 0 kEuro
(B) Cost Variance = -20 kEuro; Schedule Variance = 0 kEuro
(C) Cost Variance = 0 kEuro; Schedule Variance = 20 kEuro
(D) Cost Variance = 20 kEuro; Schedule Variance = 20 kEuro

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(7) Which categories of risk are typically encountered in complex engineering projects? ***(3 points)***

(A) Project management, technical, financial
(B) System-wide, component-specific, technology-oriented
(C) Technical, schedule, cost
(D) Program, performance, schedule

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(8) To account for uncertainty in development, contingencies are often used. These are typically a function of… ? ***(3 points)***

(A) Design complexity; type of structure
(B) Type of materials; system functionality
(C) System functionality; design complexity
(D) Design maturity; type of hardware

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(9) Which elements underlie the development of the Concurrent Design Facility at ESA? ***(3 points)***

(A) A multi-disciplinary team and an integrated design model
(B) A concurrent process and strict application interface specifications
(C) A joint set of design objectives and a shared facility
(D) All of the above

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(10) In Technical Performance Measurement (TPM), which of the following values take into account contingencies? ***(3 points)***

(A) Specification value and actual value
(B) Target value and specification value
(C) Current value and target value
(D) Specification value and current value
