Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3211-I: Systems Engineering and Aerospace Design

April 7th, 2014, 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 <u>3 hours</u>.
- ✓ 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 <u>different</u> 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 FAST Formation Flying Mission

Individual micro-satellites typically have very limited capability of producing scientific output. Therefore, previously micro-satellites have been primarily used for technology demonstration purposes. However, when flying a number of micro-satellites in a formation, in addition to the technological value, the scientific output from micro-satellite missions can be significantly increased and, sometimes, fundamental scientific questions can be addressed inaccessible to a single big satellite. A micro-satellite is defined as having a mass between 10-100 kg. Formation flying is defined as a coordinated, controlled and flexible way to jointly operate at least 2 satellites at regional distances to achieve a common objective.

FAST (Formation for Atmospheric Science and Technology demonstration) is an international micro-satellites formation flying mission proposed by TU Delft and Tsinghua University of China. Currently two satellites are envisaged to be in the formation, one (called FAST-D) to be developed in The Netherlands and the other one (called FAST-T) in China. The two satellites will differ in design and characteristics. After being launched together into a near-circular highly-inclined Low-Earth Orbit at 450 km altitude, the two satellites will demonstrate various new technologies such as autonomous formation flying. Meanwhile, using spectro-polarimeter and altimeter payloads on both satellites, the formation flying architecture will provide enhanced scientific return through the observation of atmospheric aerosols and seasonal variations of height profiles in the cryosphere. Furthermore, through the FAST mission, students in TU Delft and Tsinghua will be taught cutting-edge technologies, and the international view of students and staff members will be broadened.

Questions

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

(b) Formation Flying requires a propulsion system. Name 3 reasons for this and motivate them in 1 sentence each. ***(3 points)***

(c) Formation flying involves the following 4 spatial aspects/dimensions, each one of them being larger or smaller than the 3 other ones: control window, navigation accuracy, control accuracy, baseline. Put the 4 aspects in the right order/sequence, starting with the largest and ending with the smallest. In a first simple assessment, if no other constraints are known, what would you suggest on how the ratio (i.e. a numerical value) of the neighboring aspects should be selected? ***(4 points)***

(d) Draw a Functional Flow Block Diagram (FFBD) for the operations of the FAST mission. The diagram should comprise about 4-7 functions. Pick one of those functions, and break the FFBD down into a lower level. ***(4 points)***

(e) Suppose you want to reconfigure your formation. To do that, you apply a continuous thrust T at your satellite with mass m over a time t_1, such that a change of distance dx_1 is built up over that time. Write down the equation for dx_1 (T,m,t) and compute it for T = 1 N, m = 50 kg and t_1 = 90 s. After t_1, you stop thrusting and let the satellite drift for t_2 = 300 s which changes distance by another dx_2. What is the final change of distance $d=d_1+d_2$ accumulated over $(t_1+ t_2)$?
Hint: Linear dynamics is a good approximation for relative satellite motion for short times. ***(6 points)***

(f) Which subsystems are most affected by the propulsion system and why? ***(2 points)***

(g) Sketch a complete hardware-in-the-loop verification architecture for formation flying of the GPS receivers on the two satellites. *(Hint: To limit risk, you must include a functionality which generates GPS signals such as if they would be received by the satellites in space)* ***(6 points)***

(h) Assume you have been given the task to validate the choice of using GPS receivers for FAST. To do that, you develop a design option tree (DOT) for providing onboard absolute and relative navigation functionality and you start at the highest possible level. You are breaking the tree down until you have reached GPS receivers as an option. Draw the DOT and mark at each of its elements why you consider this a valid or not valid option. Would you see other equally suitable alternatives to GPS and, if so, which and why? Note: Make sure you capture **ALL** options. ***(6 points)***

Part 2 - Aircraft Questions

1. Draw the loading diagram of the regional jet with the characteristics listed below <u>and briefly explain/justify</u> the reason of its shape. The diagram can be drawn qualitatively but to scale, hence the weight values must be computed according to the provided data and properly indicated on the plot (do not forget units!) ***(5 points)***
    - Aft-fuselage podded engines and T-tail
    - Seating abreast configuration = 2+3
    - Payload = 105 passengers (80 kg + 15 kg luggage) in single class
    - The aircraft has one front cargo hold with double the capacity of the aft cargo hold; both cargo holds are used to carry only the passenger luggage
    - 95% of the fuel is stored in the wing, the rest in the tailplane tank
    - Aircraft MTOW = 46 tons, Aircraft OEW = 25 tons
    - Location of the aircraft center of gravity at OEW = 40% of MAC

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2. Draw a qualitative scissor plot for a canard aircraft (include also the neutral stability curve). ***(7 points)***
    a. Indicate which curve is what, and provide labels and units on the plot axes. ***(1 out of 7 points)***
    b. Is there any difference between this plot and the one generated for a conventional aircraft? In case, explain/justify the difference (think in terms of curve coefficients). ***(2 out of 7 points)***
    c. Show qualitatively on the scissor plot the effect of a longer wing-canard arm. Will it be beneficial for stability, or controllability, or both, or none of the two? ***(2 out of 7 points)***
    d. Can you explain why the use of leading edge wing strakes can be convenient for the balance of a canard aircraft? ***(2 out of 7 points)***

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3. Explain if and why the following items/parameters affect the weight of the wing. ***(3 points)***
    a) The installation of the engines under the wing
    b) The thickness of the wing root section
    c) The aircraft wing loading

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4. The tail of a passenger aircraft is a well proven solution to fulfill two important requirements, namely stability and controllability. The design challenge here is that it is not possible to consider just one design condition/configuration to perform a correct tail sizing. Indicate three of the various flight conditions/configurations which should be accounted by the designer when sizing the aircraft horizontal tail and explain why/how they affect the aircraft stability and/or controllability. ***(3 points)***

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5. Look at the plot provided in the figure on next page, and answer the following questions. ***(3 points)***
    a) What is the most critical flight condition that sizes the tail and why? ***(1 out of 3 points)***
    b) What is the reason why the aerodynamic pitching moment coefficient varies so drastically from cruise to landing condition? ***(1 out of 3 points)***
    c) What type of airfoil would you select for the tail of this aircraft? ***(1 out of 3 points)***

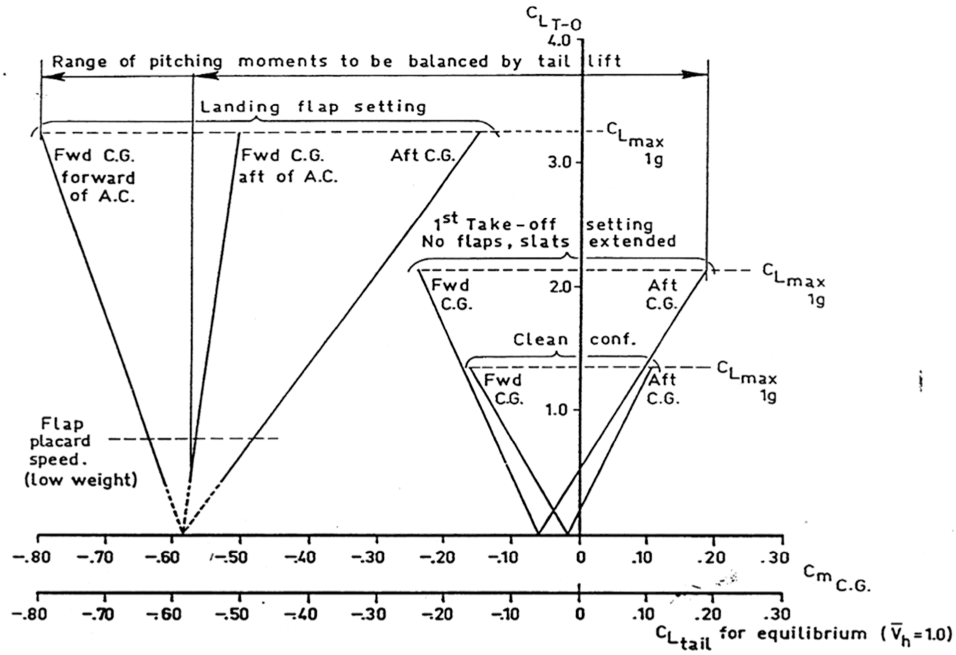

Figure 1: question 5

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6. Explain <u>why</u> the following statements are correct or wrong (Note: just stating true or false will not yield any points!) ***(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 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 conditions, by definition, the aircraft is able to react to any perturbation of its angle of attack with an opposite moment
   e) By increasing the static stability margin it is possible to extend the backward shift of the aircraft center of gravity without increasing the tail surface
   f) Increasing the horizontal tail surface allows reducing the aircraft trim drag

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7. Consider the matching of the scissor plot with the c.g. range vs. wing position plot illustrated in the figure on next page. You received it from a team of 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 stability of a given aircraft. ***(7 points)***
   a) Indicate what does each of the 5 curves represent. ***(1 out of 7 points)***
   b) Explain why is this plot matching correct or wrong. ***(2 out of 7 points)***
   c) Sketch on the same figure two modified hypothetical controllability curves, which would yield a proper matching of the plots with the wing LEMAC positioned at 50% of the fuselage length. For this, you will assume the same position of the aerodynamic center of the aircraft without tail. ***(2 out of 7 points)***
   d) List two design parameters that you could change to achieve the matching described at point c) without affecting the aircraft stability. Explain why/how these parameters affect the controllability performance of the aircraft. ***(2 out of 7 points)***

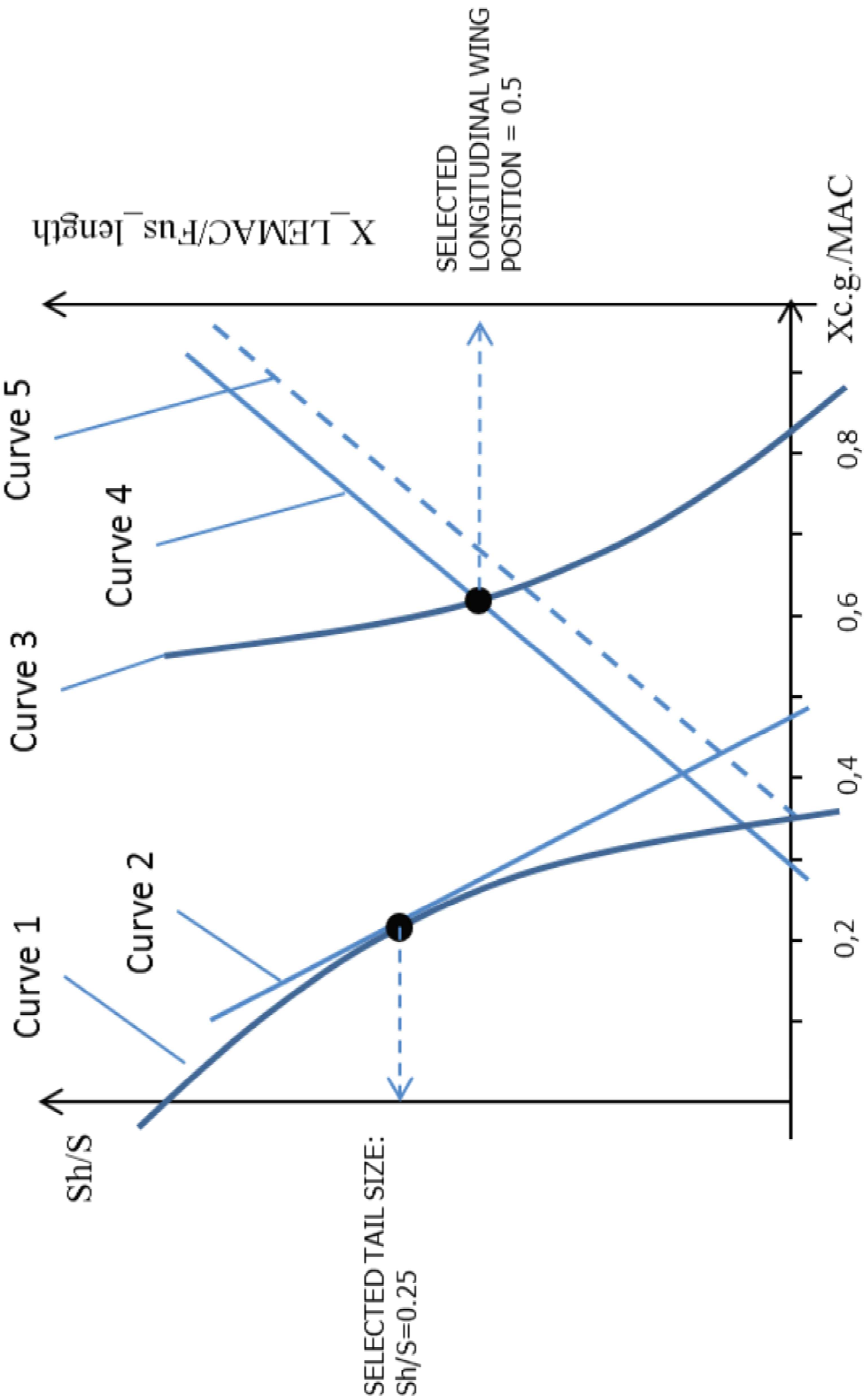

Figure 2: question 7

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 can be written as either a "shall", "must" or "should" statement
(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 specific impulse higher than 250 s
(B) REQ-B: The launcher shall have a high aerodynamic efficiency
(C) REQ-C: Sea-level thrust shall be more than 1000 kN and mass flow rate less than 100 kg/s
(D) REQ-D: The propellants shall be cryogenic in order to ensure their storability without any dedicated thermal control of the tanks.

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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 system fulfils all the requirements
(B) The transmitter has a loss factor higher than 0.8, as required
(C) The system ensures a link budget margin higher than 3 dB, when installed on the DelFFi satellites communicating with the TU Delft ground station
(D) The system has a total dry mass of 400±0.5 g

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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 exhaust velocity shall be 100±1 m/s
(B) REQ-B: Propulsion system sea-level thrust shall be 100±1 N
(C) REQ-C: Propulsion system dry mass shall be 100±1 g
(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), Flight Readiness Review (FRR), Critical Design Review (CDR), Preliminary Design Review (PDR)? ***(3 points)***

(A) PDR → CDR → QR → FRR
(B) PDR → QR → CDR → FRR
(C) PDR → CDR → FRR → QR
(D) QR → PDR → CDR → FRR

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(6) Which probability distribution can be used to model *all* failure regimes underlying the so-called bathtub curve in reliability engineering? ***(3 points)***

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

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(7) Though a popular concept to explain failure behaviour through component life, the bathtub curve only has limited applicability for aeronautical systems. Why? ***(3 points)***

(A) The vast majority of components do not show failure behaviour over time that follows the bathtub curve
(B) It is only valid for complex technical systems, not for individual components
(C) Component interactions are not considered in the bathtub curve
(D) Individual components as a rule have only one failure regime over life

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(8) Which of the following combinations displays the highest *risk*? ***(3 points)***

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

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(9) Which of the following design processes is performed in *closest* compliance with concurrent engineering principles? ***(3 points)***

(A) Simultaneous design of an aircraft wing using separate teams for structures, aerodynamics, systems and manufacturing
(B) Simultaneous design of an aircraft wing by an integrated product team using an integrated product model
(C) Structural sizing of an aircraft wing followed by manufacturing optimization
(D) Sequential design of an aircraft wing governed by a central design office

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(10) Which of the following statements about the Maintenance Steering Group (MSG-3) method is ***not*** *true*? ***(3 points)***

(A) MSG-3 is a top-down method
(B) MSG-3 considers functional failures
(C) MSG-3 is used to increase the inherent reliability of aircraft
(D) MSG-3 is used to define a scheduled maintenance program
