Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3201: Systems Engineering and Aerospace Design

April 16th, 2012, 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 **(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).
Give a <u>concise</u> but <u>complete</u> answer to each one of the questions. ***(25 points)***

<u>The ANT-2 CubeSat camera payload</u>

Nanosatellites with cubical CubeSat build standard (1U=10 x 10 x 10 cm^3) are easy to breadboard and a promise for future space missions. A reliable mid-resolution Earth observation instrument ANT-2 (Advanced Nano Telescope version 2) was designed to operate on such small, low cost satellite platform. The instrument, robust and compact 1.5U (10 x 10 x 15 cm^3), is meant to serve niche Earth observation markets with a rapid and cheap solution. The current design covers a low to medium spatial resolution (5 to 10 m) within a wavelength band from Blue (400 nm) to Near Infra-Red (1000 nm). The 1.5U plug-and-play design contains a folded light-path instead of a deployable optical system. The result is an ultra-stable design in terms of thermo-mechanical stability. The light weighted structure complies with an integration into a standard triple unit (3U) Cubesat like the Delfi N3Xt developed by TU Delft. The ANT-2 design comprises principles of miniaturization and intelligent distribution in order to compete with a single large scale instrument. The critical thermal-mechanical design is designed such that the instrument functions in the hostile space environment from altitudes of 540 to 1440 km. The ANT-2 smart modular structure allows a mission designer to simply purchase the instrument and plug (and play) it into a satellite. Since all required electronic components are already present in the instrument the host satellite only needs to provide power, a compliant (standard) data bus I/F and pointing capability by its ADCS (=Attitude Determination and Control System) to achieve a fully functional system. Some of the technical requirements are summarized in the table below.

Table 1 – Technical requirements for the ANT-2 instrument

Requirement	**Value**	**Remarks**
Single cubesat camera mass	< 2 kg	Driven by market competitive data.
Ground resolution	5-10 m (pixel size) @ 540 km height	
Reliability	no SPF	SPF=Single Point of Failure
Sustainability	>80%	Radiation tolerant design. Optical transmission at End-Of-Life (EOL)
Pointing accuracy and (in)stability (ADCS)	0.1^0 $<0.05^0$ / min	Requires a system trade-off including structural and optical stability items.
Vibration levels	Ariane-V	'Piggy -back' option
Hardware cost	< 200 k€	
Operational lifetime	2 years	

The thermo-dynamical stability range within (100-200 μm) is further improved by actively moving the sensor or lens elements. This ensures that the system remains in focus regardless of the temperature. The latter adds complexity to the design asking for a two-step (coarse, fine) control strategy with multiple MEMS (Micro-Electro-Mechanical Systems).

A single ANT-2 instrument can take mid-resolution images, but its real value will show up when it is launched in a constellation of ANT-2's allowed by the low cost per unit. Therefore it has the potential to be the cornerstone solution to support a future synthetic aperture Earth observation network.

The ANT-2 will be accommodated in a P-POD (off-the-shelf CubeSat deployment system) mounted on the payload interface of a selected launcher. The launcher will place the flight CubeSat in a near-circular, high inclination Low Earth Orbit (LEO).

Questions

(a) Give the Mission Statement for the ANT-2 instrument development. **(5 points)**

(b) Mention at least 5 key requirements for the ANT-2 instrument. **(5 points)**

(c) Build a Requirements Discovery Tree for the ANT-2 instrument and use it to identify at least two main and two derived development requirements. **(5 points)**

(d) Make a Functional Flow Block Diagram of an ANT-2 constellation from payload integration up to nominal operation, including launch. **(5 points)**

(e) Make a Risk Map for a successful operation of the ANT-2 payload. **(5 points)**

Part 2 - Aircraft Questions

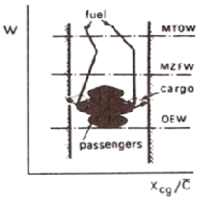
1. In order to obtain a proper weight estimation for a wing it is necessary to know first the weight of the wing. This might seem a paradox, but it just one of the many “chicken-and egg” problems that can be found in aircraft design. Briefly explain the statement above (hint: plot the forces applied to a wing) and propose a solution to tackle this wing weight estimation issue. **(3 points)**

2. In order to support the horizontal tail sizing process, it is convenient, during the balancing of the aircraft, to organize the weight contributions of the main aircraft components into one fuselage group and one wing group. **(6 points)**
    a. Can you briefly explain why the convenience of this approach? **(4 points)**
    b. Can you list the main components belonging to the fuselage group and to the wing group for Aircraft A and Aircraft B and explain the rationale of this grouping? **(2 points)**

Aircraft A (Piaggio Avanti)

Aircraft B (Cessna Citation)

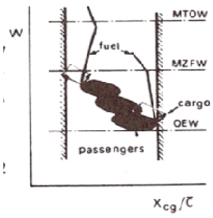
3. The 3 loading diagrams below (A,B,C) are typical for 3 of the 6 aircraft in the illustration. Indicate which aircraft corresponds to which diagram. **(3 points)**



A

1

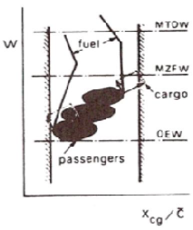
2



B

3

4



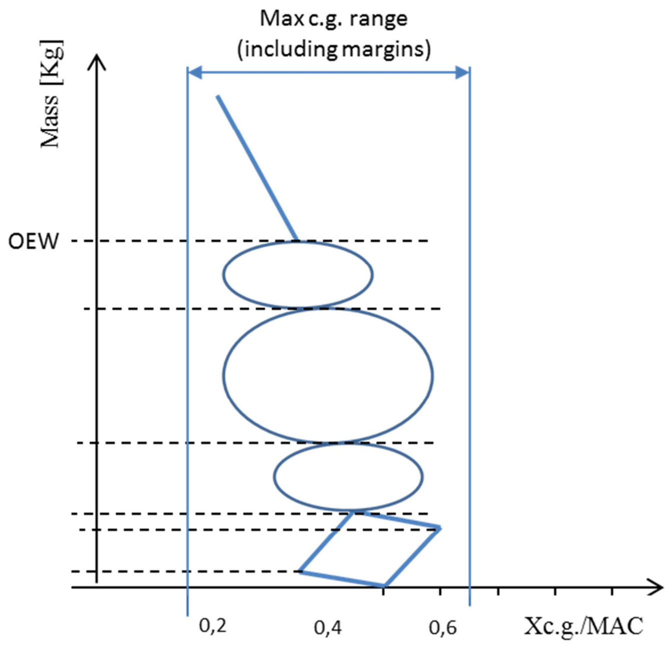
C

5

6

4. One of your colleague is asking you to check the loading diagram (see figure below) that he generated for a twin aisle passenger aircraft with the following characteristics:
    - Single class, passengers seated in a 2+3+2 configuration
    - Cruise speed M=0.82
    - Two cargo holds (one with large capacity in front of the wing; one with small capacity behind the wing)
    - Fuel tanks integrated in the wings
    - Fuselage podded engines
    - T-tail configuration

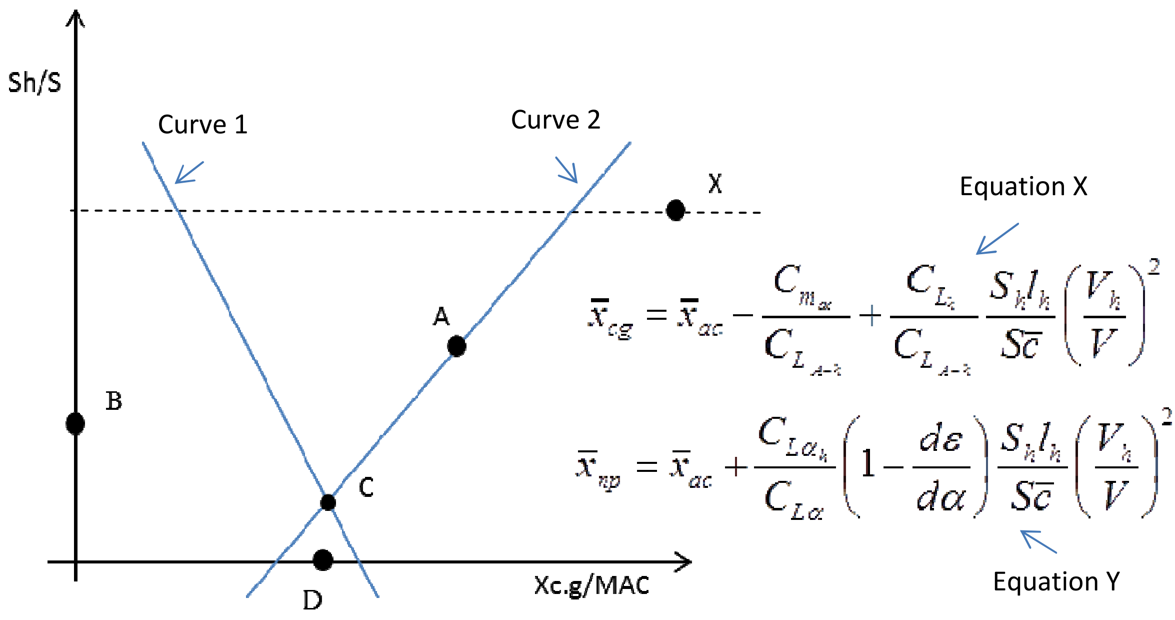
   At a glance, without even looking at the numbers, you can spot 4 evident errors in his diagram. Can you explain them to your colleague? **(4 points)**



5. Provide a definition of neutral point and explain why it is relevant to know its position. **(2 points)**

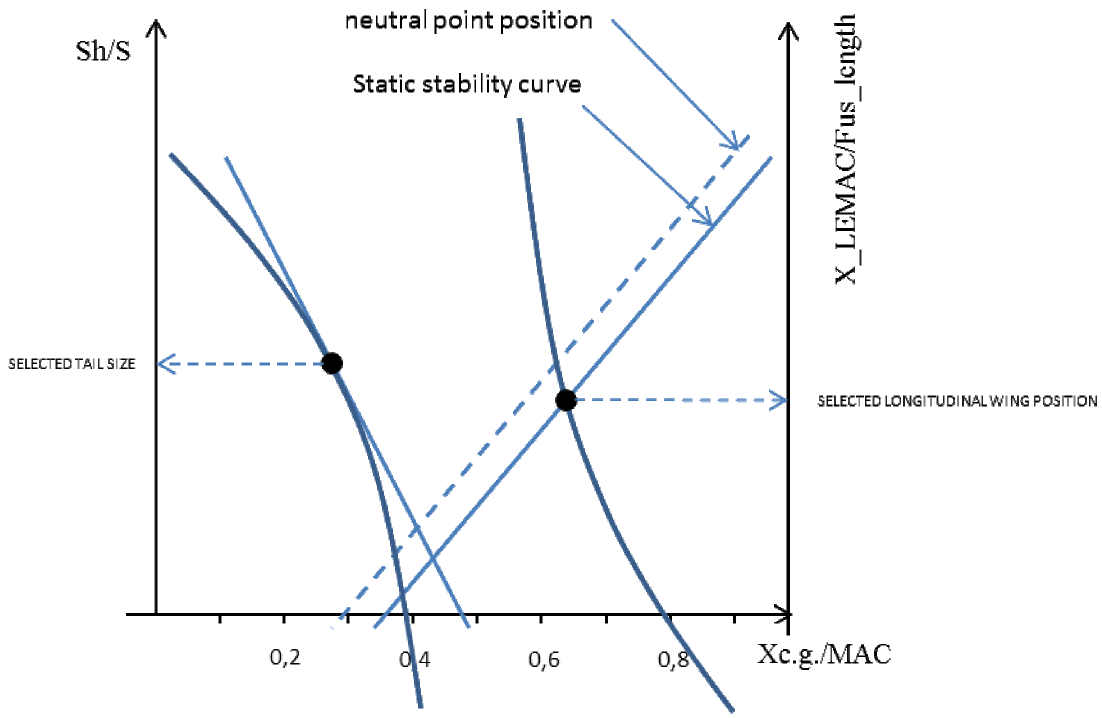
6. On a *Cm* vs. *Cl* plot you will draw qualitatively the curves relative to the 3 types of flying wing airplane listed below. **(3 points)**
   On each curve you will show the trim point. Next to each curve you will provide the sketch of a representative wing section (show the camber of the wing section), where the position of neutral point and center of gravity, as well all the applied forces (just show the resultants) and moments are clearly indicated (the presence of the propulsion system can be ignored in this case).
    a. A stable and controllable flying wing aircraft
    b. An unstable but controllable flying wing aircraft
    c. A stable but uncontrollable (for normal flight conditions) flying wing aircraft

7. Consider the two solid curves and relative equations provided in the figure below. **(4 points)**
   a. Indicate which equation corresponds to which curve, and explain what the two given curves represent concerning the position of the aircraft center of gravity. **(1 point)**
   b. Add the curve (plot it qualitatively) relative to a positive margin of stability (e.g. 5%). **(1 point)**
   c. Assume that the horizontal tail size is defined by the dashed horizontal line through point X. Describe the situation of the aircraft just in terms of controllability and stability when the c.g. is located in point A, B, C and D, respectively. **(2 points)**



8. Assume that the scissor plot provided for the previous question is that of the Fokker F100 aircraft. Would the plot change as a consequence of replacing the currently installed relatively small flaps with triple slotted flaps? Why not or why yes? If you expect changes, show them qualitatively in the plot. **(3 points)**

9. One of your colleague is showing you the results of his optimal horizontal tail sizing exercise, where he made use of the two plots matching techniques presented in this course. See his result in the figure below. He is not sure whether he applied the method correctly. **(7 points)**
   a. Indeed, he made some evident errors. Can you spot them and explain your colleague what he did wrong?**(5 points)**
   b. Let now assume that the relative positioning of the static stability, controllability, max aft and max forward c.g. position curves are correct. If the tail size is assumed equal to that indicated in the plot by your colleague, would be aircraft be able to comply to the longitudinally static stability and/or controllability requirements? Explain the situation. (**2 points)**


neutral point position
Static stability curve
Sh/S
X_LEMAC/Fus_length
SELECTED TAIL SIZE
SELECTED LONGITUDINAL WING POSITION
0,2
0,4
0,6
0,8
Xc.g./MAC

Part 3 - Multiple-Choice Questions

(1) Only one of the following is NOT a component of a typical pump-fed liquid bipropellant propulsion system: indicate it. **(2 points)**

(A) High pressure gas tank

(B) Fuel tank

(C) Fill/Drain valve

(D) Hot gas turbine

(E) Thrust valve

(2) For each one of the following sentences, indicate if they are referring to something “complex” or “complicated”: **(1.5 points)**

i) The determination of the oxidizer/fuel flow conditions for an efficient combustion in the Space Shuttle Main Engine is: **(0.5 points)**

(A) Complex (B) Complicated

ii) The Space Shuttle Main Engine is: **(0.5 points)**

(A) Complex (B) Complicated

iii) The interface control documentation of the Space Shuttle is: **(0.5 points)**

(A) Complex (B) Complicated

(3) Only one of the following words is not (necessarily) applicable to a validated requirement: indicate it. **(1.5 points)**

(A) Verifiable

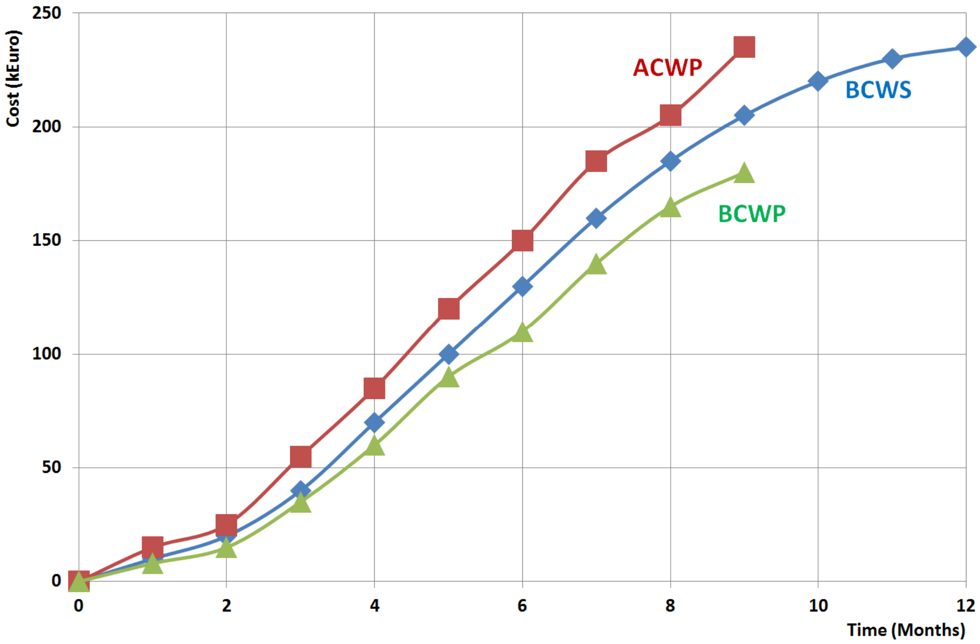
(B) Achievable

(C) Logical

(D) Interpretable

(E) Definitive

(4) The following chart shows the Budgeted Cost Work Scheduled (BCWS) for a certain 12-months aerospace project, together with the Actual Cost Work Performed (ACWP) and the Budgeted Cost Work Performed (BCWP) evaluated after the first 9 months of the project. Based on the information provided by the chart, answer to the following questions. **(4 points)**



i) Can this be considered a "healthy" project by the point of view of Earned Value Management? **(1 point)**

(A) Yes (B) No

ii) Based on the "cost variance" of the project, which one of the following sentences is correct? **(2 points)**

(A) The project cost after 9 months is approximately equal to the planned one.

(B) The project cost after 9 months is about 30 kEuro higher than the planned one.

(C) The project cost after 9 months is about 50 kEuro lower than the planned one.

(D) The project cost after 9 months is about 50 kEuro higher than the planned one.

iii) Based on the "schedule variance" of the project, which one of the following sentences is correct? **(1 point)**

(A) The project is ahead of schedule.

(B) The project is behind schedule and will most probably last more than the expected 12 months.

(C) The project is perfectly on schedule.

(5) All the following requirements for a propellant tank of a monopropellant propulsion system shall be verified by testing or inspection, except one which can be verified by analysis. Indicate the only requirement verifiable by analysis. **(2 points)**

(A) The propellant tank shall withstand an operational pressure of 200 bar without suffering any structural damage.

(B) The mass of the empty propellant tank shall be equal to 2500±25 g.

(C) The center of mass of the propellant tank should not move more than 200 mm due to propellant consumption during the entire spacecraft life.

(D) The total humidity level in the propellant tank after its complete unloading shall be not higher than 2.5%.

(6) For a *Mars Sample Return* mission aiming at collecting and taking back safely to the Earth a sample of Martian soil, indicate for each one of the following sentences if it represents a *Need Statement*, a *Mission Statement*, a *Stakeholder Requirement* or a *System Requirement*. **(3 points)**

i) The Mars Sample Return mission will allow for a vehicle to land on Mars surface, collect a sample of Martian soil, take off from Mars surface and return safely the sample to the Earth by the year 2025. **(1 point)**

(A) Need Statement (B) Mission Statement (C) Stakeholder Requirement (D) System Requirement

ii) The scientific community urges to have the possibility of directly examining a sample of Martian soil, in order to better understand if water was once present on Mars. **(1 point)**

(A) Need Statement (B) Mission Statement (C) Stakeholder Requirement (D) System Requirement

iii) The total size of the Mars landing vehicle shall be no larger than the available payload space on the launcher selected for the mission. **(1 point)**

(A) Need Statement (B) Mission Statement (C) Stakeholder Requirement (D) System Requirement

(7) In the Design Option Tree for the propulsion subsystem of a Lunar Ascent Vehicle (intended for taking off from the Moon surface into a lunar orbit), 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. **(2 points)**

(A) Use of a special new air-breathing scramjet engine expressly designed for this mission.

(B) Use of a new type of rocket engine working with on-site propellants (i.e., propellants directly obtained on Moon’s surface from lunar rocks), based on a concept demonstrated by tests carried out at NASA using available samples of lunar rock.

(C) Use of an anti-matter rocket based on a conceptual study carried out by NASA.

(8) According to the European Space Agency standards, a typical space project goes through several phases: Phase 0 (*Mission Analysis*), Phase A (*Feasibility*), Phase B (*Preliminary Definition*), Phase C (*Detailed Definition*), Phase D (*Production and Qualification*), Phase E (*Utilisation*), Phase F (*Disposal*). During which phase(s) are the requirements identified and evaluated? **(1 points)**

(A) In the first part of the project (from its beginning to the end of Phase B).

(B) During Phases A, B and C.

(C) During Phases C and D.

(D) During Phases D, E and F.

(E) Throughout the entire project, from Phase 0 to Phase F.

(9) Only one of the following hypothetic requirements for the AOCS sun sensors of the *Delfi N3Xt* satellite developed by TU Delft can be considered acceptable with respect to the VALID criteria: indicate it. **(2 points)**

(A) The sun sensors of *Delfi N3Xt* shall have a measurable accuracy

(B) The sun sensors of *Delfi N3Xt* shall have a reasonable accuracy

(C) The sun sensors of *Delfi N3Xt* shall have at least the same accuracy of the ones used for the previous *Delfi C3* satellite developed by TU Delft

(D) The sun sensors of *Delfi N3Xt* shall have the best possible accuracy

(10) For the design of a new-generation commercial aircraft, only one of the following is a correctly formulated need for the stakeholder “residents close to the airport”: indicate it. **(1 points)**

(A) The aircraft shall fly at a cruise Mach speed in the range from 0.6 to 0.8

(B) Take-off noise shall be reduced by means of adequate noise filtering devices installed on the aircraft engines

(C) The risk of take-off failures shall be reduced by ensuring at least double redundancy on all top-level critical components in the aircraft design

(D) All aircraft seats shall be equipped with a multi-functional entertainment system

(E) Take-off noise at a distance of 500 m from the airport shall not exceed 10 dB

(11) According to the European Space Agency standards, in a typical space project which is the formal closing milestone for the "requirements 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).

(E) The Acceptance Review (AR).

(12) Choose the more correct definition of *concurrency* from the following options. **(3 points)**

(A) Concurrent Engineering is the concurrent running of separate phases after the product definition trajectory.

(B) Concurrent Engineering is the concurrent running of one phase within the product definition trajectory.

(C) Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and company processes, including production and maintenance. The approach aims to have designers take into account from the start all aspects of the product life cycle, from concept to disposal, including quality, cost, planning and user requirements.

(D) Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and company processes, excluding production and maintenance. The approach aims to have designers take into account from the start most aspects of the product life cycle, from concept to disposal, including quality, cost, planning and user requirements.

(13) The Concurrent Design Facility (CDF) at the European Space Agency (ESA) is based on the following key elements: **(3 points)**

(A) A process, a mono-disciplinary team and a design model.

(B) A process, a multi-disciplinary team, an integrated design model, and the facility and infrastructure.

(C) A number of separate processes, a multi-disciplinary team, a final integrated design solution, and the facility.

(D) A process, a multi-disciplinary team, an integrated design model, the facility and infrastructure, and a separate concurrent engineering team to integrate the final output.

(14) What Life Cycle Cost (LCC) description best describes aircraft (multiple copies, long term deployment), but <u>not</u> spacecraft (low quantity)? **(3 points)**

(A) High System and Development costs.

(B) High system and development costs, with high production costs.

(C) Low development cost, high production costs, and medium operational costs.

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

(15) Consider the following statement: "*following fatigue testing of a carbon-fiber reinforced plastic (CFRP) wing top cover for the A30X (intended successor of the A320), it was shown that cracks originated and propagated through the structure at an alarming rate at around 70% of intended part life, resulting in complete part failure. Though CFRP wings have been designed and operated before, a design flaw seems responsible.*"
Which risk assessment and mitigation strategy can be associated with this problem? **(3 points)**

(A) Probability of occurrence: Feasible in theory. Severity of consequence: marginal. Mitigation strategy: inspect during maintenance A-checks, patch/replace part when flaw occurs.

(B) Probability of occurrence: Extrapolated from existing flight design. Severity of consequence: catastrophic. Mitigation strategy: structural redesign using different CFRP composite, additional fatigue analysis and testing.

(C) Probability of occurrence: Based on existing non-flight engineering. Severity of consequence: critical. Mitigation strategy: additional design analysis and review.

(D) Probability of occurrence: Based on existing non-flight engineering. Severity of consequence: marginal. Mitigation strategy: inspect during maintenance A-checks, patch/replace part when flaw occurs.

(16) Which values are used to <u>monitor</u> technical performance in technical performance management? **(3 points)**

(A) Actual and current value.

(B) Target and actual value.

(C) Specification and target value.

(D) Specification and current value.

(17) Which of the following distributions is often used in reliability analysis to model processes with a constant failure rate? **(3 points)**

(A) Normal distribution

(B) Weibull distribution

(C) Gamma distribution

(D) Negative exponential distribution