Delft University of Technology

Faculty of Aerospace Engineering

Exam AE3201: Systems Engineering and Aerospace Design

August 30th, 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 concise but complete answer to each one of the questions. ***(25 points)***

The NASA Mars Exploration Rover mission

The big science question for the Mars Exploration Rovers is how past water activity on Mars has influenced the red planet's environment over time. While there is no liquid water on the surface of Mars today, the record of past water activity on Mars can be found in the rocks, minerals, and geologic landforms, particularly in those that can only form in the presence of water. That's why the rovers are specially equipped with tools to study a diverse collection of rocks and soils that may hold clues to past water activity on Mars. Because scientists cannot go to Mars themselves at this point in time, they have to rely on robot geologists - the rovers - to look for signs of past water activity on Mars for them. To do their job, the rovers carry a number of science instruments that will analyse rocks and soils on the Martian surface and perform other important tasks and studies. The rovers offer unique contributions in pursuit of the overall Mars science strategy to "Follow the Water." Understanding the history of water on Mars is important to meet the four science goals of NASA's long-term Mars Exploration Program:

- Determine whether life ever arose on Mars
- Characterize the climate of Mars
- Characterize the geology of Mars
- Prepare for human exploration of Mars

The primary science objectives of the mission are given by:

1. Search for and characterize a variety of rocks and soils that hold clues to past water activity. In particular, samples sought will include those that have minerals deposited by water-related processes such as precipitation, evaporation, sedimentary cementation, or hydrothermal activity.
2. Determine the distribution and composition of minerals, rocks, and soils surrounding the landing sites.
3. Determine what geologic processes have shaped the local terrain and influenced the chemistry. Such processes could include water or wind erosion, sedimentation, hydrothermal mechanisms, volcanism, and cratering.
4. Perform "ground truth" – i.e. calibration and validation - of surface observations made by Mars obiter instruments. This will help determine the accuracy and effectiveness of various instruments that survey Martian geology from orbit.
5. Search for iron-containing minerals, identify and quantify relative amounts of specific mineral types that contain water or were formed in water, such as iron-bearing carbonates.

6. Characterize the mineralogy and textures of rocks and soils and determine the processes that created them.
7. Search for geological clues to the environmental conditions that existed when liquid water was present. Assess whether those environments were conducive to life.

The Rover "talks" to the Mars Odyssey spacecraft (orbiter), which is constantly orbiting the red planet. In the 16 minutes it takes for the orbiter to go from horizon to horizon, the rover and orbiter can "converse" for about 10 minutes. The vast majority of science data is being returned to the mission team on Earth through the rovers' UHF antenna, which communicates with Odyssey.

Questions

(a) Give the Mission Statement for the Mars Rover mission. **(5 points)**

(b) Build a Requirements Discovery Tree for the successful operation of the Mars Rover and show how the four science goals are related to the primary science objectives. **(5 points)**

(c) Make a Functional Flow Block Diagram for the Rover operation on Mars surface. **(5 points)**

(d) Make a Risk Map for a successful operation of the Mars Rover. **(5 points)**

(e) Mention at least 4 verification methods which are essential for the successful operation of the Mars Rover. **(5 points)**

Part 2 - Aircraft Questions

1. Different weight estimation methods are used during the conceptual aircraft design (so far you learnt about class I and Class II methods). **(6 points)**
   a. Summarize the required input, the generated output and the approach on which a Class I weight estimation method is based.
   b. Do the same as above for a Class II method. Of course it is not expected that you provide all input and output values involved in a class II method. Just provide some which are representative for the method.
   c. It is possible that the operative empty weight value obtained using Class I and II methods do not coincide. Can you explain why?
   d. An iterative approach is generally required to have the results of the two methods converging. Illustrate by means of a simple N2 chart how the iterations take place (indicate the main design steps along the diagonal and the main parameters/info exchanged via feedback links and feed forward links. **(3 out of the 6 points)**

2. Provide two definitions of longitudinal static stability, one in your own words and one (analytical) expressed in terms of aerodynamic derivatives. **(3 points)**

3. Provide a definition, both in words AND in analytical form of trim drag. **(3 points)**

4. Your team is designing a passenger aircraft, with a classical configuration similar to the Airbus A320 and Boeing 737. Unfortunately, you realize that your design is showing too high values of trim drag. To tackle this problem, the following two options are considered. But, are these good or bad options? You will explain for each option, why it is or it is not beneficial for reducing the trim drag? (**4 points)**
   a. Move the c.g. of the aircraft slightly forward (i.e. toward the aircraft nose) such to increase the stability margin.
   b. Increase the horizontal tail volume.

5. Consider the loading diagrams in the figure below (Figure 1). They are relative to the same aircraft, but for three different longitudinal positions of the wing. Answer the following questions and briefly justify each answer. N.B. points are yielded <u>only</u> if your explanations are correct. **(4 points)**
   a. Which loading diagram does correspond to the most forward, intermediate and most after longitudinal wing position, respectively?
   b. What is likely to be the seating abreast configuration?
   c. In which cargo hold is accommodated most of the freight mass?
   d. What type of aircraft configuration do you think plots A, B and C belong: a/c 1, a/c 2 or a/c 3?

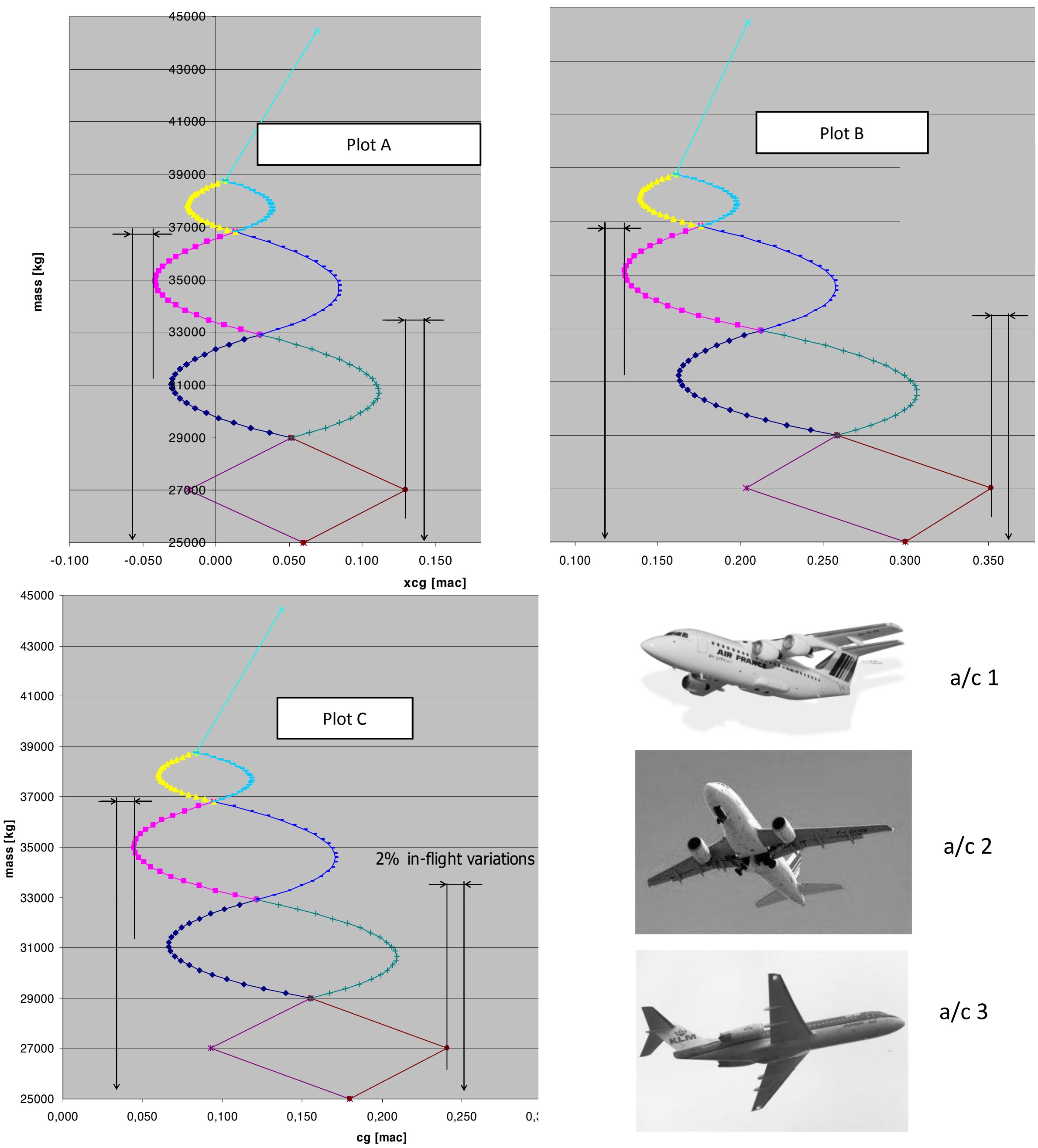


Figure 1: question 5

6. Which one(s) of the following statements is (are) correct and why? N.B. points are yielded <u>only</u> if your explanations are correct. **(6 points)**

   a. In order to guarantee the longitudinal static stability of a canard aircraft, the center of gravity must never travel behind the neutral point. Exactly the same as for a conventional aircraft

   b. When the c.g. and the neutral point coincide, the moment coefficient of the aircraft computed around that point, by definition, is equal to zero.

   c. Any aircraft is said to be neutrally stable when the c.g. and the wing aerodynamic center coincide

d. Knowing the relative position of c.g. and neutral point is important to determine the longitudinal static stability and controllability characteristics of the aircraft
e. For a given horizontal tail size, the larger the static stability margin, the larger the allowed c.g. range

7. Generate a qualitative scissor plot for a conventional aircraft with fixed tail and positive margin of stability (show the controllability curve, the static stability curve and the neutral stability curve). Do not forget to label the axes and the plot curves. **(1 point)**

   Show on the same plot the expected changes when substituting the fixed tail with a full moving tail design. What (if any) would be the consequences in terms of longitudinal stability and controllability? **(2 points)**

8. Consider the plot and the equation given in the figure below (figure 2) relative to a given UAV aircraft with a conventional tail configuration; ignore for the moment the curve called "Curve CA2". **(6 points)**
   a. Is this aircraft longitudinally statically stable, unstable or neutrally stable? Explain your answer.
   b. Indicate on the plot the trim point AND explain your choice by giving a definition of trim point.
   c. Draw on the same plot (use the grid for accuracy) the curve representing the tail contribution AND briefly justify your drawing.
   d. Indicate whether, at the given trim point, the tail is generating zero, positive or negative lift AND justify your answer.
   e. State where the center of gravity is located with respect to the aerodynamic center of the aircraft less tailplane AND justify your answer
   f. Now consider "curve CA2", which represents the same aircraft trimmed at a different angle. Explain whether, at this new trimmed configuration, you expect higher, lower or equal value of the trim drag.

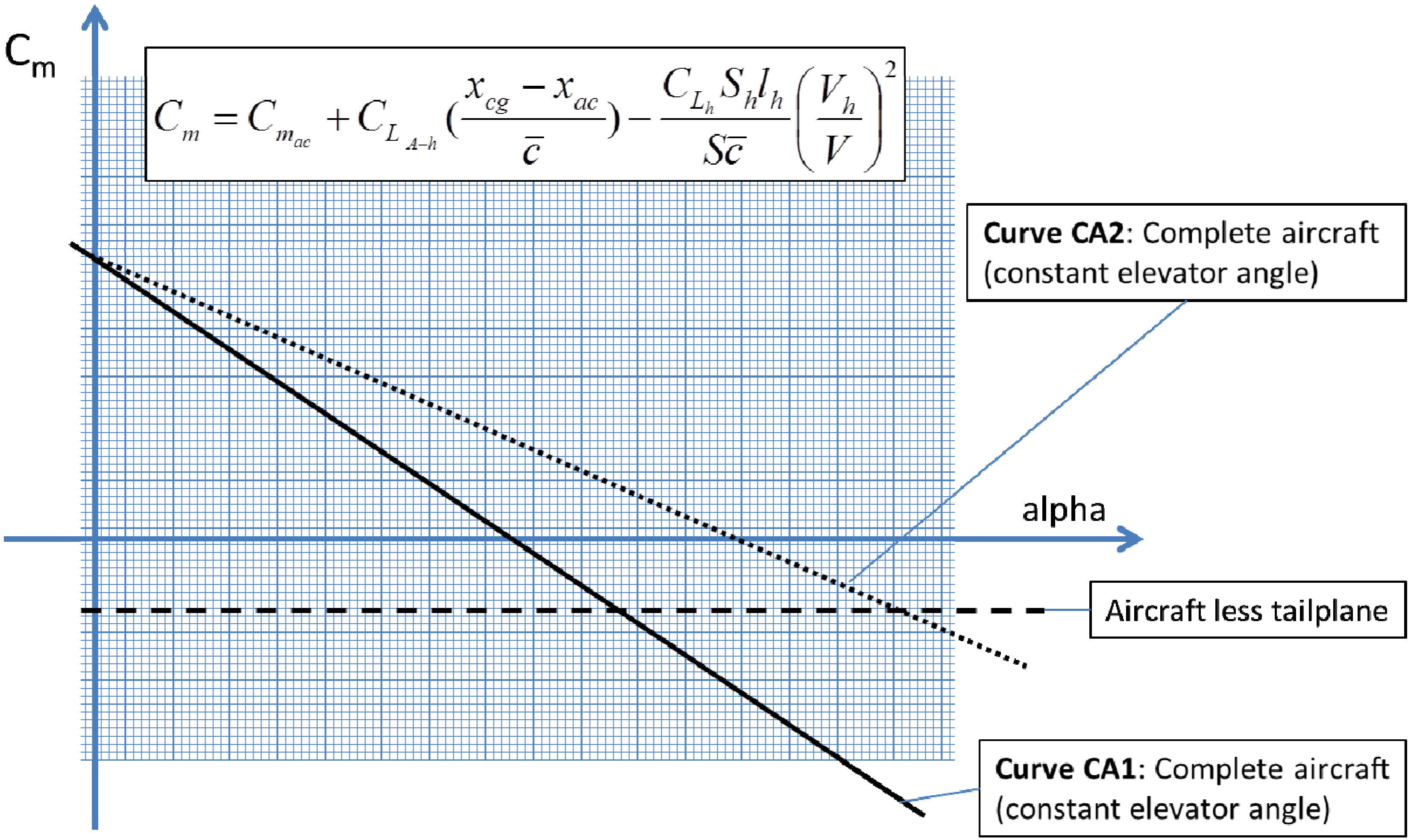


Figure 2: question 8

Part 3 - Multiple-Choice Questions

(1) Only one of the following sentences does NOT represent a correct definition of “verification”: indicate it. **(2 points)**

(A) Verification = Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use have been fulfilled.

(B) Verification = Proof of compliance with design solution specifications and descriptive documents.

(C) Verification = Confirmation by examination and provision of objective evidence that the specified requirements have been fulfilled.

(2) Only one of the following sentences related to the qualification and acceptance testing of the Ariane 5 solid propellant boosters is NOT correct: indicate it. **(3 points)**

(A) The qualification tests are usually limited to no more than 1-2 rockets for performance demonstration.

(B) Qualification and acceptance tests are usually performed in the ESA Booster Engine Test Stand in Kourou (French Guyana).

(C) A typical qualification test is made of a first burn until consumption of half the propellant, then a pause of at least 30 minutes, then a second burn until complete propellant consumption.

(D) The qualification tests are performed on a Qualification Model, which is discarded after the test.

(3) For the design of a new-generation commercial aircraft, only one of the following is a correctly formulated need for the stakeholder “airline passengers”: indicate it. **(2 points)**

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

(B) The aircraft toilet functionality shall be increased by allowing different levels of washing water temperature

(C) The aircraft design shall allow for at least double redundancy on all top-level critical components

(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

(4) For a hypothetic *New International Space Station* to be developed during the 2020-2030 decade, 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 New International Space Station shall be naked-eye visible at least twice a year from the territory of each one of the countries which will contribute to its development. **(1 point)**

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

ii) The international space science community wants to have a larger and more functional space station available into Earth's orbit before year 2030. **(1 point)**

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

iii) The solar arrays assembly of the New International Space Station shall generate a power of at least 15 kW as an average during each orbit. **(1 point)**

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

(5) The European Space Agency standards on Configuration Management identify three different Configuration Baselines: the Functional Configuration Baseline, the Development Configuration Baseline and the Production Configuration Baseline. Which one of these baselines includes the final version of the *Interface Control Documents* (ICD)? **(2 points)**

(A) The Functional Configuration Baseline.

(B) The Development Configuration Baseline.

(C) The Production Configuration Baseline.

(6) There are "requirements on requirements", in order to ensure the effective use of requirement in the design process. Among the following sentences, only one is NOT a correctly formulated requirement on requirements: indicate it. **(2 points)**

(A) Requirements must be verifiable

(B) Requirements must be short

(C) Requirements shall have a unique identifier

(D) Requirements must be measurable

(E) Requirements shall be complete

(7) When you think to something which is *not simple but still fully knowable*, are you thinking to something *complex* or *complicated*? **(2 points)**

(A) Complex

(B) Complicated

(8) Only one of the following hypothetic requirements for the AOCS subsystem of the *Delfi N3Xt* satellite developed by TU Delft can NOT be considered acceptable with respect to the VALID criteria: indicate it. **(3 points)**

(A) The AOCS of *Delfi N3Xt* shall provide and receive all data in the 64-bits floating point format.

(B) The AOCS of *Delfi N3Xt* shall provide the attitude angles of the satellite at least every 0.5 seconds.

(C) The AOCS of *Delfi N3Xt* shall have at least the same pointing accuracy as the previous *Delfi C3* satellite developed by TU Delft.

(D) The AOCS of *Delfi N3Xt* shall use reaction wheels with the smallest available diameter.

(9) All the following requirements for a bipropellant 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)**

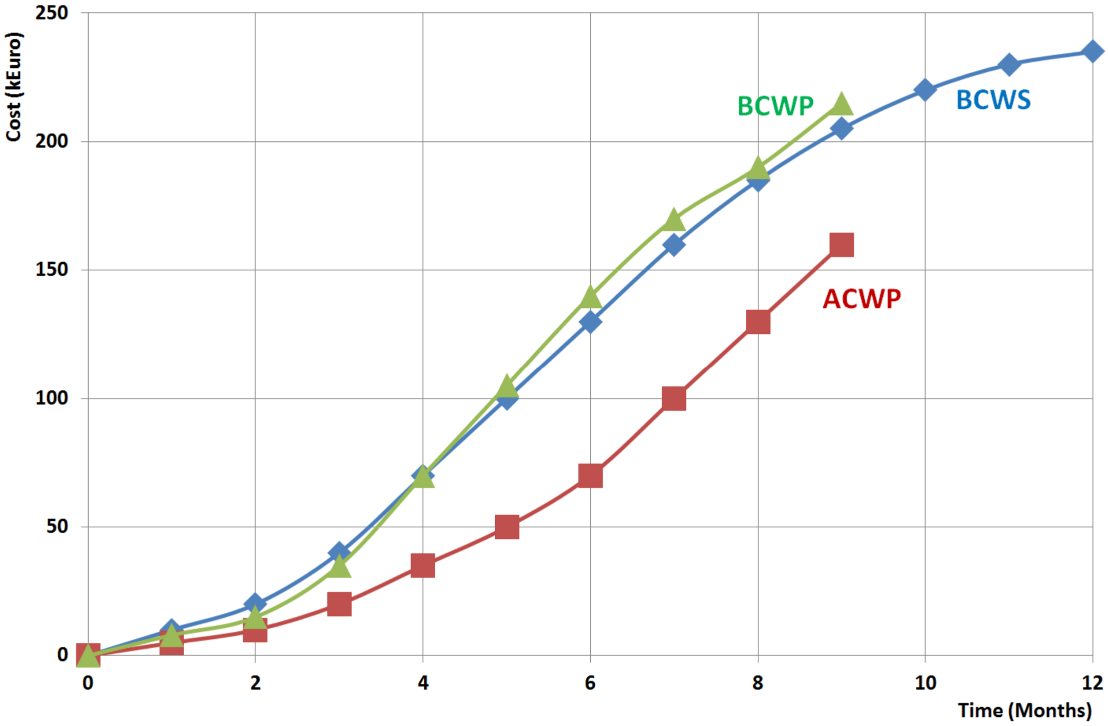
(A) The pressure losses in all lines from the oxidizer tank to the thrust valve shall not exceed 20 bars under the nominal operational flow conditions.

(B) The maximum vibrations that can be withstood without any damage by the propulsion system components shall not have an amplitude higher than 5 mm and a frequency higher than 400 Hz under the nominal operational flow conditions.

(C) The propulsion system life shall allow for at least 20000 seconds of continuous firing under the nominal operational flow conditions.

(D) The propulsion system shall provide a thrust of 2000±25 N under the nominal operational flow conditions.

(10) 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. **(5 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 10 kEuro lower 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? **(2 points)**

(A) The project is slightly 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.

(11) 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 verification activities supposed to take place? **(2 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.

(12) Only one of the following set of characteristics perfectly match the definition of *Concurrent Engineering*: indicate it. **(3 points)**

(A) Consecutive activities, separate involvement, clearly defined design responsibility, integrated use of information technology.

(B) Consecutive activities, simultaneous involvement, clearly defined design responsibility, only marginal use of the information technology.

(C) Simultaneous activities, simultaneous involvement, cyclic change of the design responsibilities, integrated use of information technology.

(D) Simultaneous activities, simultaneous involvement, clearly defined design responsibility, integrated use of information technology.

(13) What Life Cycle Cost (LCC) description best describes spacecrafts (low quantity of items produced), but <u>not</u> aircrafts (multiple copies, long term deployment)? **(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 cost.

(14) In technical performance management, what is the relationship between the *current* and the *actual* value? **(3 points)**

(A) The current value excludes any uncertainties, so it is without contingency; the actual value may eventually include any needed contingency.

(B) The current value is equal to the actual value including a contingency, reflecting on the actual status of the design.

(C) The current and actual values are always equal.

(D) The current value is equal to the actual value minus a contingency, derived from previous similar product developments.

(15) Which of the following distributions is often used in reliability analysis to model processes with an increasing failure rate in time? **(3 points)**

(A) Normal distribution

(B) Weibull distribution

(C) Gamma distribution

(D) Negative exponential distribution