Delft University of Technology
Faculty of Aerospace Engineering

1st Year Examination: AE1201
Aerospace Design and System Engineering Elements I

Date: 25 August 2010, Time: 9.00, Duration: 3 hrs.

General Remarks and Instructions

- **This is a “closed book” exam. You are only allowed to use a normal calculator and the formula sheet provided to you.**
- **All cell phones and other external communication systems shall be turned off.**
- **THIS EXAM CONSISTS OF TWO PARTS:**
  1. **The first part consists of 20 multiple choice questions. Answers shall be given on the answer sheet provided.**
  2. **The second part consists of 2 open questions, which each shall be answered on a separate page. Assumptions and approximations must be clearly indicated and motivated.**
- **Don’t forget to put your name and student number on each page!**

Values of some important constants

Gravitational acceleration at sea level: g_o = 9.81 m/s^2
Stefan Boltzmann constant: σ = 5.67 x 10^{-8} W/m^2-K
Solar constant: I = 1400 W/m^2
1 AU = 150,000,000 km
Velocity of light in vacuum: c = 300,000 km/s

Multiple Choice questions

This part contains 20 multiple choice/answer questions. The majority of questions are multiple choice questions. In case of multiple answer questions, this is specifically noted in the question.

1. One of the following statements is wrong:
    a. Generally, there is no linear correlation between aircraft payload weight and range
    b. Generally, there is a linear correlation between the aircraft empty weight and take off weight
    c. When performing regression analysis of statistical data, values of Q squared very close to one indicate low scatter
    d. For a given class of aircraft, the ratio of empty weight and maximum take off weight strongly depends on the range
    e. CS25 and CS23 are not specific to jet and propeller aircraft, respectively.

2. Which one of the statement below is wrong?
    a. The overside angle is related to side stability of the aircraft on the ground
    b. The required overnose angle is related to the approach speed of the aircraft
    c. In a tail wheel gear configuration, when brakes are applied, the load on the main landing gears increases, making the braking more effective (reduce skidding)
    d. The tail cone angle of the fuselage (also called divergence angle) should be smaller than 24 degrees to allow good aerodynamic performance
    e. The so-called aircraft rotation angle depends on the position of the aircraft main landing gear

3. Indicate the correct statement. In order to achieve high climb gradients:
    a. Jet airplanes should have high aspect ratio, for propeller aircraft it does not matter
    b. both propeller and jet aircraft should have high aspect ratio
    c. Low values of the ratio of climb rate to stall speed are important
    d. Airplane should fly at lower value than the maximum aerodynamic efficiency
    e. airplanes should fully deploy their high lift devices

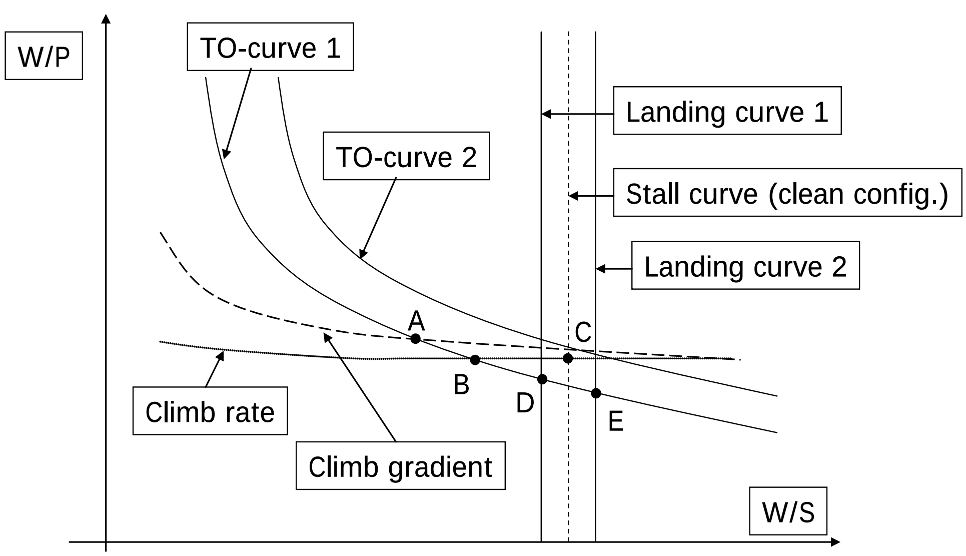
4. Why can an auxiliary power unit (APU) be a critical safety device on a twin-engine, extended-range aircraft?
    a. Two engines cannot generate enough power to operate all electric systems on board the aircraft
    b. The APU provides critical power for the emergency systems
    c. The APU provides additional thrust in case of a one-engine-inoperative (OEI) condition
    d. The APU provides energy for all the systems in case of a one-engine-inoperative condition (OEI)
    e. None of the above

5. Complete the statement below by picking the correct answer.
   CS23 stipulate that the stall speed of small propeller airplanes should not be higher than 113Km/h. Assuming the use of flaps (CLmax = 1.5) and a value of 1.23Kg/m^3 for the air density, we derive that.....
    a. The wing loading must be higher than 1201.16 Kg/m^2
    b. The wing loading must be higher than 92.68 Kg/m^2
    c. The wing loading must be lower than 122.48 N/m^2
    d. The wing loading cannot be higher than 1201.16 Kg/m^2
    e. The wing loading cannot be higher than 908.90 N/m^2

6. Consider the following civil transport aircraft:
   - 3 jet engines
   - MTOW = 413 tonnes
   - Wing surface = 540 m^2 ,
   - Wing span = 65 m
   - Oswald factor in clean wing configuration = 0.80
   - Swet/S = 6.3

   According to CS25 regulations, this aircraft must be able, in one engine inoperative condition (OEI) to achieve a minimum climb gradient of 2.7% in the second takeoff segment (landing gears up, flaps deployed in take off condition).
   Making the conservative assumption of having the most draggy flaps, we can conclude that, in order to satisfy this condition:
   a. The installed thrust loading should not be lower than 0.13
   b. The wing loading should not be higher than 764.8 Km/m^2
   c. The installed thrust loading should not be lower than 0.12
   d. The installed thrust loading should not be lower than 0.18
   e. The installed thrust loading should not be lower than 4.19

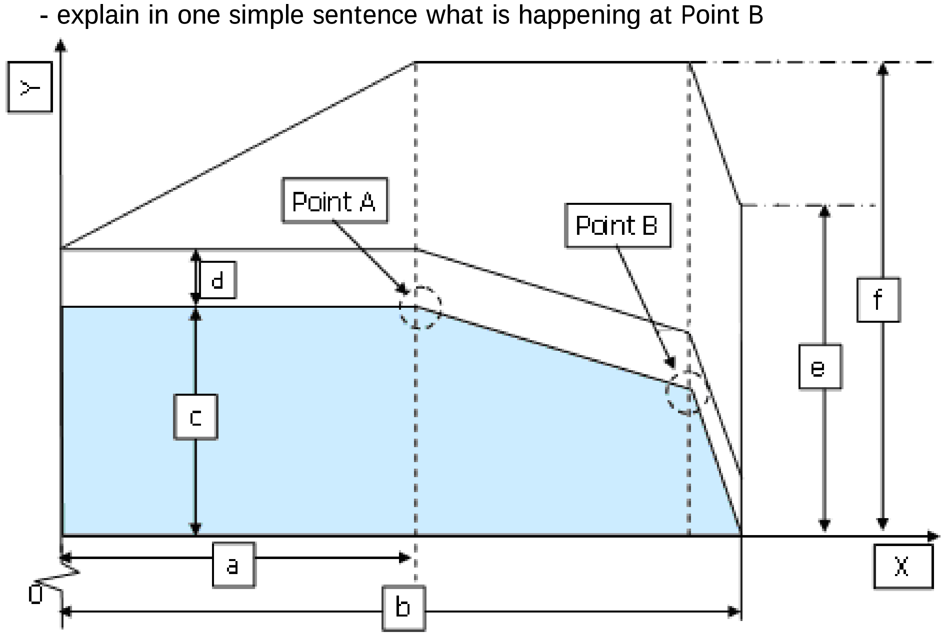
7. Given the following propeller aircraft W/P- W/S plot, and the various points defined as intersection between curves, find out the correct statement
   a. Point E is a feasible point when using the landing curve with the highest landing maximum lifting coefficient.
   b. Using the landing curve corresponding to the highest lift coefficient, point E could not become a feasible point, even when the stall speed is lowered.
   c. Point D is a more convenient point than B because of the lower power required
   d. By slightly increasing the wing aspect ratio, Point A would shift towards higher wing loading value
   e. For a given installed power, lowering the aspect ratio would cause a higher climb rate



8. Using the same W/P- W/S plot of previous question, find out the wrong statement:
    a. Point C would be a feasible point only when using the take off and landing curves with the highest lift coefficient
    b. Point A is not a feasible point
    c. Even when Landing curve 2 applies, Point C would not be feasible
    d. As in any type of aircraft, the amount of thrust required to meet the climb gradient requirement depends on the wing/loading. Lower wing loading would always allow installing less powerful engines
    e. Increasing the aspect ratio, Point B would shift towards lower wing loading value ratio.

9. A jet UAV aircraft is being designed to perform an observation mission on top of very specific area, while remaining at an altitude of 8000m. It must fly at a speed not higher that M=0.54 (about 700Km/h) because of its measurement systems limitation and must stay in continuous operation on top of the target area for 8hrs. For the baseline design, which has a maximum aerodynamic efficiency value of 20, the selected engine has a specific fuel consumption equal to $2.1 \cdot 10^{-5}$ Kg/Ns.
Evaluate which is the most convenient way to reduce the fuel fraction of the observation stage, among the following options (Assume $g = 9.81 m/s^2$) :
    a. Reduce the speed of the aircraft by 10%
    b. Alter the overall aerodynamic design such to increase the maximum aerodynamic efficiency coefficient up to 23
    c. Adopt a more efficient engine, hence lowering by 5% the current fuel specific consumption
    d. Accept a lower observation time (6hrs rather than 8hrs), but use a cheaper but less efficient engine with a specific fuel consumption equal to $2.6 \cdot 10^{-5}$ Kg/Ns
    e. Increase the aerodynamic efficiency by 5% and lower the specific fuel consumption by 3%.

10. Given the "cripted" payload-range diagram below, give the missing definitions (write your answers in the same paper as for the Aircraft open question):
- X : x-axis label and [unit]
- Y: Y-axis label and [unit]
- a, b, c, d, e, f
- explain in one simple sentence what is happening at Point A
- explain in one simple sentence what is happening at Point B



11 To increase launcher availability, we should …

a) reduce launcher repair time
b) reduce launch cost
c) reduce launcher failure probability
d) reduce launch cost, repair time and failure probability
e) reduce repair time and increase launcher reliability

12 A rocket is propelled by 3 rocket motors with <u>each</u> an effective exhaust velocity of 1000m/s. Vehicle mass ratio is 5. The ideal velocity change accomplished by this rocket is …

a) 333 m/s
b) 536 m/s
c) 1.609 km/s
d) 3.0 km/s
e) 4.828 km/s

13 The European Ariane 5 rocket incorporates both parallel and serial staging to launch a payload into orbit. The first sub-rocket essentially consists of a central core stage with a thrust of 1MN and two parallel booster stages each with a thrust of 5.4MN. Effective exhaust velocities of the core stage is 4000 m/s and of each of the two booster stages 3000m/s. Calculate average effective exhaust velocity of the first sub-rocket.

a) 3.06 km/s
b) 4000 m/s + 2 x 3000 m/s = 10000 m/s
c) 3333 m/s
d) (4000 m/s + 3000 m/s) / 2 = 3500 m/s
e) 3.156 km/s

14 You are to design a single stage launcher capable of providing an ideal velocity increment of 9.8 km/s to a payload of mass 1000 kg. For this rocket you have managed to design a construction with a mass of just 5% of the propellant mass. Calculate the initial mass of this rocket given a rocket exhaust velocity of 4.5 km/s.

a) 1541 kg
b) 1200 kg
c) 8827 kg
d) 10592 kg
e) 14502 kg

15 You are designing an Apollo Lunar Module consisting of a lander module and a single stage ascent launch vehicle sitting on top. The lander module should accomplish an ideal velocity change of 2.5 km/s and the launcher of 2.2 km/s. From earlier designs you have found that the structural mass makes up 20% of the total lander module mass and 40% of the launcher mass. Calculate the total initial mass of lander and launcher together given an actual payload mass returned from the Moon of 500 kg and that you select for both lander and launcher a hydrazine-nitrogentetroxide propellant combination with an effective velocity of 3000 m/s.

a) 28.95 ton
b) 26.5 ton
c) 14.31 ton
d) 11519 kg
e) 6220 kg

16 A rocket of diameter 5m is flying with a velocity of 1km/s at an altitude of 10km. Air density at this altitude is 0.4135 kg/m^3 (Standard Atmosphere, 0 deg C) and the drag coefficient of the rocket is 0.3 based on the frontal area of the rocket. Calculate for this rocket the drag force.

a) 1220 N
b) 4.87 N
c) 48.6 kN
d) 486.5 kN
e) 1.22 MN

17 What tasks are provided for by the avionics system of a launch vehicle?

a) Guidance navigation and control (GNC)
b) Command and data handling (C&DH)
c) Instrumentation and pre-flight checkout
d) GNC and C&DH
e) Pre-flight checkout, GNC and C&DH

18 At high altitude, the Space Shuttle's attitude is controlled by rocket thrusters rather than by aerodynamic control surfaces. Given a principal moment of inertia about the longitudinal (roll) axis of the vehicle of 1.31x 10^6 kg-m^2, calculate the minimum (roll) torque needed to rotate the vehicle over 180 degrees in 20 seconds given a constant torque level. You should consider that at the start and end of the rotation maneuver the Space Shuttle is essentially non-rotating.

a) 41.2 kN-m
b) 21.7 kN-m
c) 217 kN-m
d) 82.3 kN-m
e) 2489 kN-m

19 A S/C with a mass of 1000 kg is connected to the launch vehicle via a cylindrical shaped adapter. This adapter is made out of aluminum with a modulus of elasticity of 70E9 Pa (70 GPa). Its length is 0.5 m, diameter is 0.4 m and wall thickness is 1 mm. Calculate for this cylinder the Euler buckling load in case the lower end is fixed and the upper end (with the S/C on top) is free to move laterally. The area moment of inertia of a thin walled cylinder is given by $\pi r^3 t$ with r is cylinder radius and t is cylinder thickness.

a) 56 MN
b) 176 MN
c) 275 MN
d) 22.4 kN
e) 2.75 MN

20 Consider a cryogenic rocket stage of height 7m and diameter 5m. Determine for this stage the maximum equilibrium temperature in space at 1 AU (I = 1400 W/m^2) given that the stage is in full sunlight (albedo and Earth IR are absent) and that the symmetry axis of the stage is perpendicular to the Solar radiation. Stage wall absorptivity is 0.2 and emissivity is 0.9. You may neglect the effect of the cryogenic propellant stored in the stage as well as any heat transfer via top and bottom of the stage.

a) 20.4 K
b) 204 K
c) 272 K
d) 434 K
e) Cannot be calculated as the time that the stage is in Sunlight is not given.

Open problem 1: Aircraft design

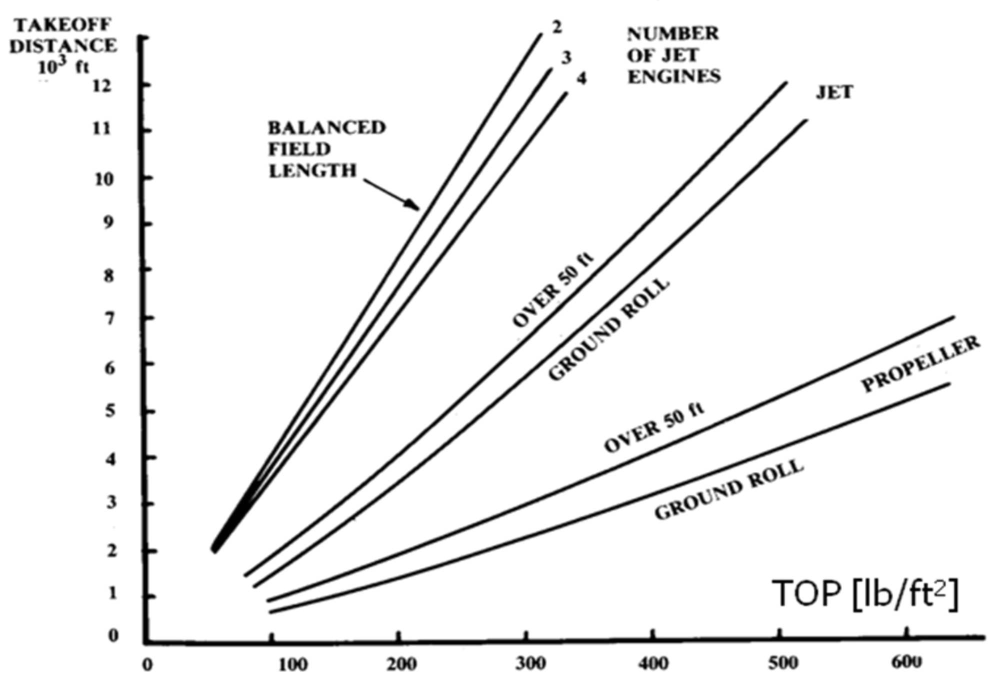
At Aerodesign Industries, you are currently reviewing the conceptual design of the product you are going to launch: a twin jet aircraft for passenger transport, with a wing surface of 428 m^2 and a span of 60 m. It has been designed to cruise for 7000 km, with a speed of 918Km/h (around 30000ft altitude). At the beginning of the cruise phase the aircraft weights 230 tonnes.

You are required to perform the following tasks:

a. Calculate the aircraft weight (in [Kg_force]) at the end of the cruise
b. Calculate the ramp weight (in [Kg_force]) of the aircraft (i.e., the MTOW plus the fuel required to warm up the engines and taxi)
c. Write the simplified equation of the aircraft drag polar and calculate the maximum aerodynamic efficiency of the aircraft.
d. Verify that the aircraft maximum lift coefficient is sufficient to perform a sustained turn with a load factor n = 2.3, while flying at a speed of 200Km/h (weight and altitude as at the beginning of the cruise) and compute the required thrust loading.
e. Calculate the minimum thrust per engine (in [kg_force]) required to takeoff at sea level, using a takeoff distance not longer than 2743m (Make use of the plot below from Raymer).
f. In case the installed thrust computed at point e) exceeds or is not sufficient to meet the sustained turn requirement of point d), re-compute the maximum load factor achievable with the T/W computed at point e). Check if the clean wing max lift coefficient is sufficient to deal with the new maximum load factor during the sustained turn.

Write your assumption, computations and results on a different paper than for the Space part. Make use of the following assumptions:

- L/D in cruise = 17
- Oswald factor clean wing= 0.80
- Cj = 0.000021 Kg/Ns
- Swet/S = 5.5
- CLmax in clean configuration = 1.8; CLmax in take off = 2.2
- Cruise stage performed at constant altitude and speed (altitude = 9134m; density = 0.459 Kg/m^3)
- Ignore any wave drag effect for the polar calculations
- 1m=3.281ft 1kg_force/m^2= 0.205lb/ft^2



Open problem 2: Spacecraft design

You are member of a team working at “Spatiale” Industries on the design of a deep space probe to Venus. For this mission, the following data are known.

- Distance to Venus: 0.431 AU
- Mission duration: 6 year
- Payload mass: 140 kg

Some other useful values may be found on the page providing you with values of important constants.

2a) Describe the main types of requirements that are distinguished in S/C design and explain the role of requirements generation in design. (20 %)

To come up with a first mass estimate, you have collected mass data of 5 existing space probes. The data are given in the next table.

Vehicle	Target	Payload mass [kg]	Total empty mass [kg]
Mars Express (probe + lander)	Mars	176	637
Venus Express	Venus	93	700
Rosetta (probe + lander)	Comet	265	1330
Chandrayaan-1	Moon	89	503
ESMO	Moon	11.5	101

Using Excel you have determined the following linear regression relationship between payload mass M_{PL} and total empty mass:

$$\left(M_e\right)_{SC} = 4.29 \cdot M_{PL} + 190.5 \text{ (All masses in kg)}$$

2b) Determine the Standard Error of Estimate (SEE) of this relationship. (20%)

2c) For electrical power provision, you consider the use of photo-voltaic cells. The total power that should be provided for by the solar array is 2500 W. Given that you have available a silicon-based solar array with a power density of 100 W/m^2, and a specific power of 40 W/kg (at BOL and @ 1 AU), and a life degradation of 3% per year, calculate the required solar array area. (15%)

2d) The CDHS of the probe provides a gross bit rate of 200 kbps to the communications system for transmission down to ground. Spectrum utilization is 0.5 bits/Hz. What is the minimum bandwidth needed to downlink this signal? (10%)

2e) The probe has a transmission power of 100 W and an antenna gain factor of 100. Given a line loss factor of 0.8, calculate the EIRP. (10%)

2f) Given that the probe has an EIRP of 200 W calculate the power flux density received at the ground station back on Earth. (10%)

2g) To allow for a sweeping motion of the camera about Venus, the spacecraft must rotate over an angle of +/- 30 deg about one of its principal axis. At the end of the sweep, the spacecraft must quickly be returned to its starting position. This requires the spacecraft to slew over an angle of 60 degrees in 5 seconds. Given an MMOI about the principal axis considered of 350 kg-m^2, determine the minimum (constant) torque needed to slew the spacecraft. (15%)