Delft University of Technology
Faculty of Aerospace Engineering

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

Date: 21 June 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 Which of the following statements are correct (more correct statements are possible)?

a) The climb gradient affects the maximum altitude that can be achieved in the shortest time
b) Certification regulations generally stipulate limits to the maximum value of climbing gradient
c) Certification regulations generally stipulate limits to the minimum value of climbing gradient
d) Higher aspect ratio values are beneficial to lower the thrust over weight ratio required to achieve a certain climb gradient.
e) Interceptor aircraft are characterized by very high climb rate performance

2 Which one of the following statement is correct? When an aircraft deploys flaps at landing…..

a) The friction drag decreases but the span efficiency factor (i.e. the Oswald factor) increases
b) The friction drag decreases, such that the aircraft can better climb
c) The aircraft stability changes, whereas drag is not affected
d) Friction drag increases and Oswald factor decreases
e) Both statement a. and b. are true

3 Which one of the following statements is correct?

a) A very high stall speed is beneficial in view of reaching higher cruise speed
b) A low stall speed allows lowering the approach speed
c) The stall speed depends on the weight of the aircraft but not on the size of the wing
d) The stall speed depends on the size of the wing but not on the weight of the aircraft
e) The stall speed at sea level is higher than at high altitude

4 Chose the right statement to complete the sentence below:
In the typical organization of the aircraft development process in industry, the *baseline design* is...

a) The main input to enter the detail design phase of an aircraft development program
b) The main input to the preliminary design phase
c) The result of the base drag computation process
d) The configuration of a reference aircraft selected for the development of the new aircraft
e) None of the statements above

5 Which one of the statements below is correct?

a) The longer the fuselage length, the higher the pressure drag contribution
b) The shorter the fuselage length, the higher the friction drag
c) The higher the slenderness ratio of the fuselage (L/d, where L is the total fuselage length and d is the average cross section diameter), the higher the ratio between pressure drag and friction drag
d) The higher the slenderness ratio of the fuselage (L/d, where L is the total fuselage length and d is the average cross section diameter), the higher the ratio between friction drag and pressure drag.
e) None of the statements above is correct

6 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

7 Which of the statements below are correct (more correct statements are possible. You can make use of the table 1 from CS.25)?

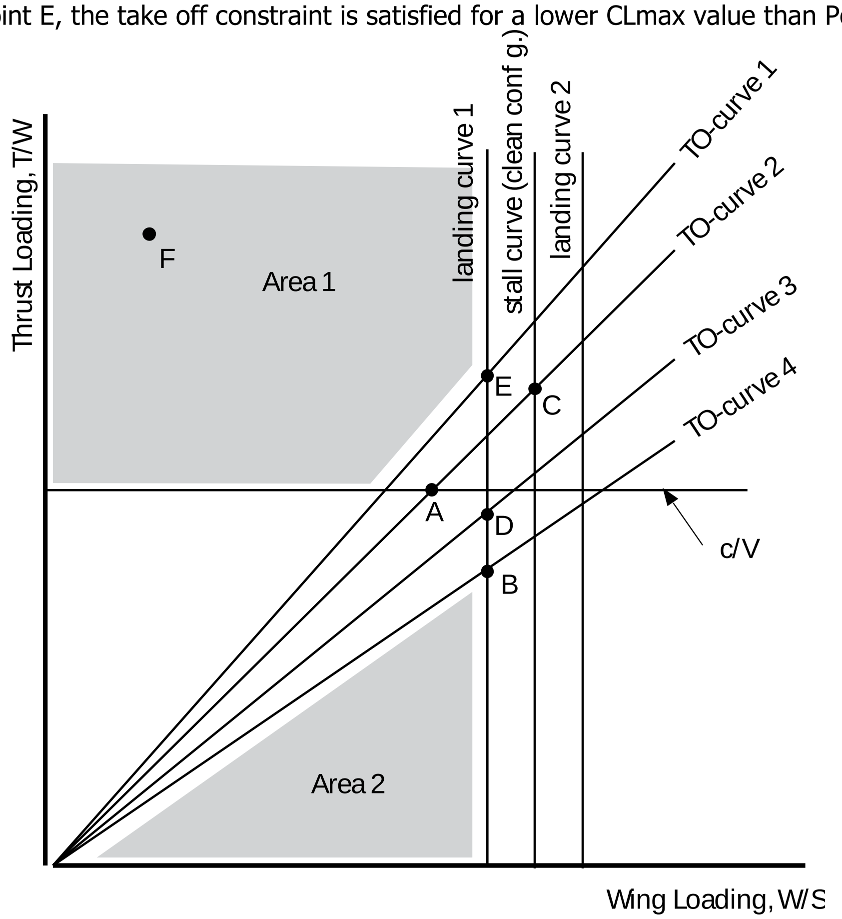
a) Two Type I and two Type III exits (per side) should be accounted for during the development of a 170 passengers aircraft (pax distributed in 2 classes)
b) More than 2 Type I and Two Type III exits (per side) should be accounted for during the development of a 170 passengers aircraft (pax distributed in 2 classes)
c) Less than 2 Type I and Two Type III exits (per side) can be accounted during the development of a 170 passengers aircraft (pax distributed in 2 classes), if it can be demonstrated that, in case of emergency, all passengers can be evacuated within 90 seconds.
d) The requirements concerning the minimum size for ejection seats for small military trainers can be found in CS23. For larger military trainers (MTOW>19000lb), they can be found in CS25.
e) The amount and type of emergency exits can influence the number of flight attendants required to operate the aircraft

No. Pass.	Type I	Type II	Type III	Type IV
1–9				1
10–19			1	
20–39		1	1	
40–79	1		1	
80–109	1		2	
110–139	2		1	
140–179	2		2	
180–299	Add exits so that 179 plus "seat credits" ≥ passenger number.			

	Seat Credit	Exit Type
	12	Single Ventral
	15	Single Tailcone
	35	Pair Type III
	40	Pair Type II
	45	Pair Type I
	110	Pair Type A
≥ 300	Use pairs of Type A or Type I with the sum of "seat credits" ≥ passenger number.	

8 Looking at the W/S-T/W plot below, indicate which of the following statements are correct (more correct statements possible)

a) A design point could be picked both in *Area 1* and *Area 2*, but design points in *Area 1* would demand a too high thrust loading
b) A design point could be picked only in *Area 2*, elsewhere the take off constraint would be violated.
c) A design point could only be picked in *Area 1* in order to comply with the takeoff, landing and wing loading requirements
d) In point D the climb gradient requirement is violated
e) In point E, the take off constraint is satisfied for a lower CLmax value than Point A



9 Looking at the same W/S-T/W plot as for the previous question, indicate which one of the statements below is wrong.

a) Point E is an allowed design point
b) Point A can be an allowed design point only for a higher $CLmax_{take\text{-}off}$ value than that used to build *TO-curve 1*
c) Point C violates the landing constraint indicated by *Landing-Curve 2*
d) Allowing a lower stall speed, point C would shift towards higher wing-loading values
e) Point F is a possible design point

10 A propeller driven airplane must have a power off stall speed of no more than 50 knots at sea level (air density 1,23 Kg/m^3) with full flaps down (CLmax = 2 at landing). With flaps up (CLmax=1.6) the stall speed is to be less than 60 Knots (1 Knot = 0.514444m/s).
In order to meet both requirements at take-off gross weight, it is necessary that …

a) W/S < 95.6 Kg/m^2
b) W/S < 813.81 N/m^2
c) 82.98Kg/m^2 < W/S < 937.50N/m^2
d) W/S > 937.50N/m^2
e) CS23 does not allow measuring the stall speed in power off condition

11 In requirements generation the acronym SMART stands for ....

a) specific, maintainable, available, realistic, testable
b) safe, maintainable, achievable, reliable, testable
c) specific, measurable, achievable, realistic, time-bound
d) solvable, measurable, available, reliable, time-bound
e) safe, maintainable, available, realistic, time-bound

12 A S/C has to perform various maneuvers using a rocket propulsion system. Below the maneuvers are given in terms of delta-V (ΔV) as well as the specific impulse (I_{sp}) of the propulsion system used for the maneuver:

- Injection into target orbit: ΔV = 1000 m/s, I_{sp} = 300s
- Orbit maintenance: ΔV = 200 m/s, I_{sp} = 200s
- De-orbit at EOL: ΔV = 250 m/s, I_{sp} = 200s

You have estimated a S/C empty mass of 500 kg. Calculate the initial vehicle mass given that g_o = 10m/s^2.

a) 279 kg
b) 317 kg
c) 503 kg
d) 874 kg
e) 1264 kg

13 In spacecraft attitude control, it is important to consider the direction in which an instrument is pointing. In case an instrument is pointed in Nadir direction, it means that the instrument is pointing...

a) along the direction of the flight velocity vector
b) perpendicular to the local horizontal
c) down to Earth
d) towards the Sun
e) away from the Sun

14 A 3-axis stabilized cubical S/C with principal MMOI of 1000 kg-m^2 (about each of the three vehicle axis) experiences a disturbance torque of 0.05 Nm. Assuming worst case conditions, determine the angle over which the S/C rotates about a single axis when this torque acts on the S/C for 5 minutes?

a) 3 x 10^{-3} rad
b) 3.0 deg
c) 0.09 rad
d) 128.9 deg
e) Cannot be calculated as the dimensions of the spacecraft and hence the torque arm are not known

15 For a spacecraft are given:

- 739Mbits/sec (Mbps) of payload data generated on average (during daylight)
- Payload not operative during eclipse periods (no data generated)
- 10Mbps Telemetry (TM) data generated continuously
- Orbital period is 90minutes
- Eclipse period per orbit is <u>maximum</u> 40minutes (some orbits have no eclipse period)
- Ground contact is minimum 7 minutes/orbit

Determine for this spacecraft the required size of the data storage.

a) 2247 GByte
b) 4045 GByte
c) 280.9 GByte
d) 233.1 GByte
e) 504.3 GByte

16 You are designing the EPS of a S/C in LEO that must deliver an electrical power output of 1000W at EOL. You have selected Si as the cell material. Given a solar intensity of 1400W/m^2, a power conversion efficiency of 12%, a solar cell size of 5cm square, an inherent degradation factor of 0.8 and a life degradation of 0.85, calculate the required solar array surface area to provide the required power output.

a) 0.71 m^2
b) 5.95 m^2
c) 6.39 m^2
d) 7.44 m^2
e) 8.75 m^2

17 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

18 Factors of Safety are defined to....

a) limit testing the structure
b) limit structural mass
c) cover uncertainties in loads, strength of materials and in modeling/analysis performed
d) verify the structural analyses/modeling performed
e) guarantee a safe working environment

19 A cubical spacecraft in cold space is illuminated by the Sun in a direction perpendicular to one of its side surfaces, see figure. Distance to the Sun is 1.5AU.

Calculate for this spacecraft the equilibrium temperature given that it is covered with white paint with a solar absorption factor of 0.15 and an IR emissivity of 0.9.

a) 2.5K
b) 130K
c) 162K
d) 207K
e) 253K

20 A rocket of total mass 100 ton should provide an ideal velocity change (ΔV) of 6km/s. For this rocket you select a propellant with an effective exhaust velocity of 3200m/s. Determine for this rocket the minimum burn time in case the thrust is constant throughout the launch and given a maximum allowed acceleration of 7 times Earth gravitation acceleration at sea level.

a) 257s
b) 159s
c) 87.4s
d) 46.6s
e) 32.2s

Open problem 1: Conceptual design military jet transporter

You are a conceptual aircraft designer at AeroIndustries. Together with your team, you are currently working on the development of a new generation military jet transporter. The following mission has been specified to drive the design the aircraft:

1 Engine start and warm up
2 Taxi
3 Take off at sea level (air density 1,23 Kg/m^3)
4 Climb to cruise altitude
5 Cruise for 5000Km at service ceiling, with a speed of 920Km/h (L/D = 15)
6 Descend at loiter altitude on destination airport
7 Loiter for 20 minutes (L/D = 18)
8 Descend
9 Land, taxi and shut down engines

The aircraft will be operated by a typical crew of 8, i.e., 3 pilots, 2 flight engineer and 3 loadmasters (assume 100Kg including baggage per crew member), and will be able to fly the mission specified above carrying a payload of 122500Kg.

Your first task is to compute the **maximum take off weight of the aircraft, its empty weight and its fuel weight.**

- Based on statistics you can assume the empty weight/takeoff weight ratio equal to 0,45.
- For this preliminary calculation you can ignore the weight of oil and trapped fuel.
- There is no need to include any reserve fuel for this type of mission.
- You can use the fuel fractions values reported in the *data and formula sheet* for your aircraft category.
- The engine specific fuel consumption can be assumed equal to c_J= 0,000019 Kg/Ns, constant and independent of the altitude
- The air density at sea level can be assumed equal to 1,23 Kg/m^3

Open problem 2: Space Shuttle ideal velocity change

The US Space Shuttle used to orbit spacecraft in to LEO consists of a rust-colored external tank (ET), two white, slender Solid Rocket Boosters (SRBs), and the orbiter itself. At lift off, see illustration, all engines are operating providing a total thrust of roughly 30 MN (for detailed data, see table). After 124 seconds the SRBs burn out and separate. After separation the main engines of the Orbiter (SSME) keep on functioning until main engine cut off (MECO). Final orbit insertion is achieved by another propulsion system contained on board of the Space Shuttle.

Some technical data of the Space Shuttle are provided below.

Orbiter	**External tank**	**Solid Rocket Booster**
▫ Empty mass: 78,000 kg ▫ Gross lift-off mass: 110,000 kg ▫ Main engines: Three, each with a (mission average) thrust of 1.752 MN and specific impulse of 455 s ▫ Maximum payload: 25,060 kg	▫ Empty mass: 26,535 kg ▫ Gross lift-off mass: 756,000 kg	▫ Empty mass (per booster): 63,272 kg ▫ Gross liftoff mass (per booster): 590,000 kg ▫ Thrust (per booster, sea level, lift-off): 12.5 MN ▫ Burn time: 124 sec

The next few problems are about estimating the ideal velocity change (ΔV) delivered by the Space Shuttle until MECO. For simplicity, you may assume a constant thrust level and specific impulse for both the SRBs and the main engines all during the flight. You are asked to:

1. Calculate effective exhaust velocity and mass flow rate of the Space Shuttle Main Engine (SSME)
2. Calculate effective exhaust velocity of the SRB
3. Calculate initial and final (empty) mass of the first sub-rocket
4. Calculate average effective exhaust velocity of the first sub-rocket
5. Calculate initial and final mass of the second sub-rocket
6. Calculate total ideal velocity change realized until MECO (In your answer you should clearly show the contribution of the first and second sub-rocket)