

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** [during your first tutorial, you have verified that the empty weight ratio is generally not depending on the range of the aircraft. Actually there is a pretty linear relation between empty weight and take off weight of different aircraft within the same category, but with different range value]
  - 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** [this angle is related to the side visibility of the pilot in the cockpit]
  - 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 [this is generally not true, because high lift devices spoil the aerodynamic efficiency of the aircraft, hence lower the climb gradient of the aircraft. That is why only partially deployed HL devices are used at take off]
  
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 ( $CL_{max} = 1.5$ ) and a value of  $1.23\text{Kg/m}^3$  for the air density, we derive that.....
  - a. The wing loading must be higher than  $1201.16\text{ Kg/m}^2$
  - b. The wing loading must be higher than  $92.68\text{ Kg/m}^2$
  - c. The wing loading must be lower than  $122.48\text{ N/m}^2$
  - d. The wing loading cannot be higher than  $1201.16\text{ Kg/m}^2$
  - e. **The wing loading cannot be higher than  $908.90\text{ N/m}^2$**  [see the worked out solution later in this document]

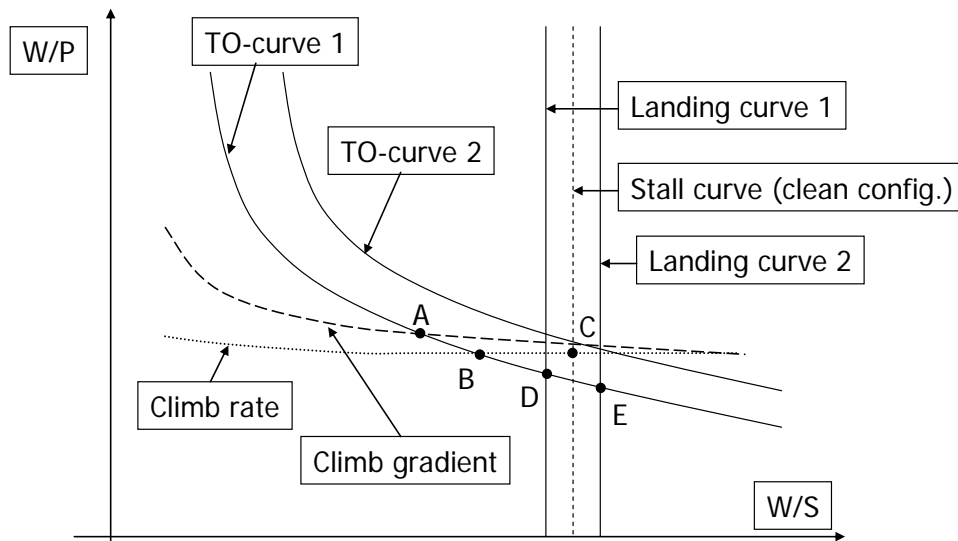
6. Consider the following civil transport aircraft:

- 3 jet engines
- MTOW = 413 tonnes
- Wing surface =  $540 \text{ m}^2$ ,
- Wing span = 65 m
- Oswald factor in clean wing configuration = 0.80
- $S_{wet}/S = 6.3$

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  $764.8 \text{ Km/m}^2$
  - c. The installed thrust loading should not be lower than 0.12
  - d. **The installed thrust loading should not be lower than 0.18** [see the worked out solution later in this document]
  - 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 [see the worked out solution later in this document].
  - 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.** [point E is not feasible because stall in clean wing. Decreasing the stall speed would actually make the situation even worse: the stall curve would move further left of point E]
  - c. Point D is a more convenient point than B because of the lower power required [at D, W/P is lower than @B, hence P is higher @D]
  - d. By slightly increasing the wing aspect ratio, Point A would shift towards higher wing loading value [climb gradient curve would shift up, hence intersecting the TO-curve 1 at a lower wing loading value]
  - e. For a given installed power, lowering the aspect ratio would cause a higher climb rate [by looking at the formula for the climb rate of a propeller aircraft, we see that the second and negative contribution is depending on the aspect ratio (actually depends on of  $CL^{3/2}$ , which depends on the aspect ratio). The lower the aspect ratio, the larger is this negative contribution, hence the lower is the climb rate]

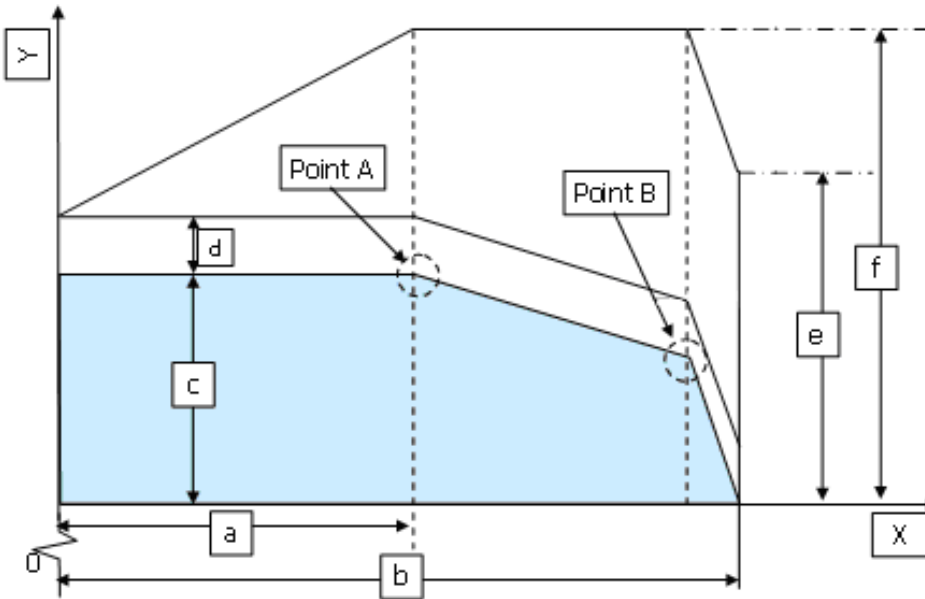


8. Using the same W/P- W/S plot of previous question, find out the wrong statement:
- Point C would be a feasible point only when using the take off and landing curves with the highest lift coefficient [indeed, point C would be feasible only using To-curve2 and landing curve-2]
  - Point A is not a feasible point [indeed it's not! Climb rate req not satisfied]
  - Even when Landing curve 2 applies, Point C would not be feasible [this is generally true. Only using also TO-curve2 point C could become feasible]
  - 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** [this is only true for propeller aircraft. In jet airplanes,  $c/v$  is not depending on W/s]
  - Increasing the aspect ratio, Point B would shift towards lower wing loading value ratio. [this is correct. The climb rate curve would intersect TO-curve 1 at a higher W/P value and a lower W/S value]
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 than  $M=0.54$  (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  $g = 9.81\text{m/s}^2$ ) :
- Reduce the speed of the aircraft by 10%
  - Alter the overall aerodynamic design such to increase the maximum aerodynamic efficiency coefficient up to 23** [see the worked out solution later in this document]
  - Adopt a more efficient engine, hence lowering by 5% the current fuel specific consumption
  - 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
  - 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

[\[see the worked out solution later in this document\]](#)



**Open problem 1: Aircraft design**

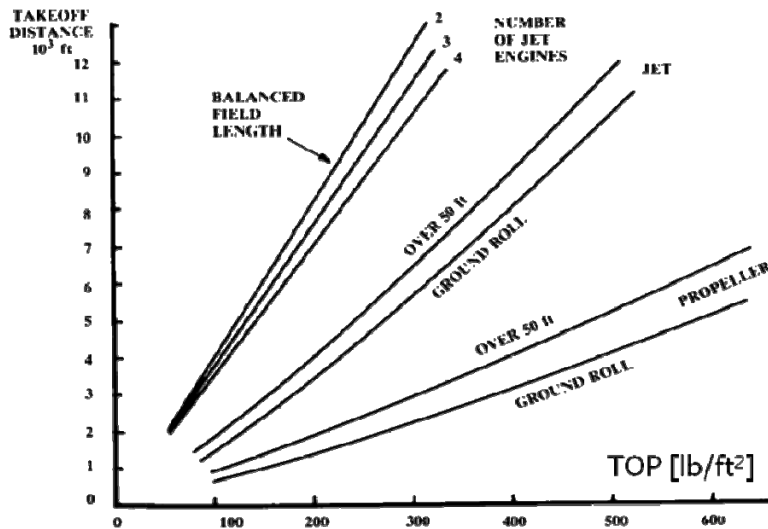
At Aerodesign Industries, you are currently reviewing the conceptual design of the product you are going to launch: a twin jet aircraft for passenger transport, with a wing surface of 428 m<sup>2</sup> and a span of 60 m. It has been designed to cruise for 7000 km, with a speed of 918Km/h (around 30000ft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

You are required to perform the following tasks:

- Calculate the aircraft weight (in [Kg\_force]) at the end of the cruise
- 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)
- Write the simplified equation of the aircraft drag polar and calculate the maximum aerodynamic efficiency of the aircraft.
- 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.
- 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).
- 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
- $C_j = 0.000021 \text{ Kg/Ns}$
- $Swet/S = 5.5$
- $CL_{max}$  in clean configuration = 1.8;  $CL_{max}$  in take off = 2.2
- Cruise stage performed at constant altitude and speed (altitude = 9134m; density = 0.459 Kg/m<sup>3</sup>)
- Ignore any wave drag effect for the polar calculations
- 1m=3.281ft      1kg\_force/m<sup>2</sup>= 0.205lb/ft<sup>2</sup>



## QUESTION 5

$$L = W$$

TO AVOID STALL

$$\frac{W}{S} \leq \frac{1}{2} \rho V_{\text{STALL}}^2 C_{L_{\text{MAX}}} \quad 1,5$$

$1,23 \text{ kg/m}^3$        $(113 \text{ km/h})^2$

$$\frac{W}{S} \leq \frac{1}{2} \cdot 1,23 \frac{\text{kg}}{\text{m}^3} \cdot \left( 31,38 \frac{\text{m}}{\text{s}} \right)^2 \cdot 1,5$$

$$\frac{W}{S} \leq 908,90 \frac{\text{N}}{\text{m}^2}$$

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# QUESTION 6

3-JET ENGINES

$$M_{TOW} = 413 \text{ t} \cdot S = 540 \text{ m}^2 \quad b = 65 \text{ m}$$

OSWALD FACT 0,80 (CLEAN)

$$S_{WING} / S = 6,3$$

$$G = 27\% \quad \left( = \frac{C}{V} \right)$$

$$C_{D0 \text{ CLEAN}} = C_{Fe} \cdot \frac{S_{WING}}{S} = 0,003 \cdot 6,3 = 0,0189$$

FROM TABLE OF EQUIVALENT  
SKIN FRICTION COEFFICIENT

(FLAPS OUT AFFECT POLAR!)

T-O FLAP EFFECT ON  $C_{D0}$  = 0,02 (HIGHEST VALUE FROM  
TABLE OF  $\Delta C_{D0}$  AND  $e$   
CORRECTIONS)

T-O FLAP " ON OSWALD = 0,05

$$\rightarrow C_{D0 \text{ FLAP}} = 0,0389$$

OSWALD FACTOR WITH  
FLAP OUT:  $e = 0,75$

$$(= 0,80 - 0,05)$$

$$\text{ASPECT RATIO} = \frac{b^2}{S} = 7,8$$

$$\frac{T}{W} \geq \frac{N}{N-1} \left( \frac{C}{V} + 2 \sqrt{\frac{C_{D0}}{\pi A e}} \right)$$

NECESSARY  
CONDITION ON  $\frac{T}{W}$   
TO ACHIEVE A CERTAIN  
 $\frac{C}{V}$  WITH  $N-1$  ENGINES  
AVAILABLE

$$\frac{T}{W} \geq \frac{3}{3-1} \left( 0,027 + 2 \sqrt{\frac{0,0389}{\pi \cdot 7,8 \cdot 0,75}} \right)$$

$$\frac{T}{W} \geq 0,18$$

(FOR 3-JET AIRCRAFT, WING LOADING IS NOT  
RELEVANT FOR CLIMBING GRADIENT!)

# QUESTION 9 (UAV endurance)

→ BY SIMPLIFYING USING BRUGNOT FOR ENDURANCE

DESIGN DESIGN

- 8hns

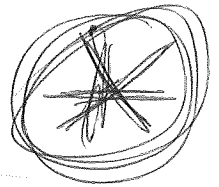
-  $C_S = 0,000021 \text{ kg/Ns}$

-  $L/D = 20$

$$\rightarrow \left( \frac{W_{FIN}}{W_{IN}} \right)_{L/D} = 0,743301$$

b) ~~100~~ SPEEDS HAS NO INFLUENCE ON L/D

b)  $L/D \rightarrow 23$   $\left( \frac{W_{FIN}}{W_{IN}} \right) = 0,7726$



c)  $G_{L/D} 5\%$   
 $= 0,00001995$   $\left( \frac{W_{FIN}}{W_{IN}} \right) = 0,7544$

d) 6hns  $C_S = 0,000026$   $\left( \frac{W_{FIN}}{W_{IN}} \right) = 0,7592$

e)  $5\% \uparrow L/D \rightarrow 21$   
 $C_S 3\% \downarrow = 0,00002037$   $\rightarrow (0,7603)$



## QUESTION 10 PAYLOAD - RANGE DIAGRAM

X = ~~range~~ RANGE [km, nm, ...] 1

Y = WEIGHT [kg, N, ...] 2

a = MAXIMUM RANGE ACHIEVABLE WITH MAX PAYLOAD (HARMONIC RANGE) 3

b = MAXIMUM RANGE ACHIEVABLE WITH NO PAYLOAD (FERRY) 4

c = MAXIMUM PAYLOAD WEIGHT 5

d = RESERVE FUEL WEIGHT 6

e = MAXIMUM FUEL WEIGHT (WITH ALL FUEL TANKS FILLED) 7  
(USEFUL FUEL CAPACITY)

~~g~~

f = MAXIMUM TAKE OFF WEIGHT (ALLOWED BY STRUCTURAL DESIGN) 8

~~g~~

POINT A = THE MTOW HAS BEEN REACHED. IN ORDER TO EMBARK MORE FUEL (FOR LONGER RANGE) PAYLOADS <sup>WEIGHT</sup> MUST BE LOWERED 9

POINT B = THE FUEL TANKS ARE FILLED. IT'S NOT POSSIBLE TO ADD ANY EXTRA FUEL. EVEN LOWERING FURTHER THE PAYLOAD TO INCREASE RANGE FURTHER, PAYLOADS MUST BE REDUCED EVEN FURTHER 10

# OPEN QUESTION AERO:

250T ENHANC PAX A/C

11

DATA: RANGE 7000 km  
SPEED 918 km/h

$l = 0,8$   
 $W_{START CRUISE} = 230'000 \text{ kg}$

$\rho @ 30000 \text{ ft} = 0,459 \text{ kg/m}^3$   
 $S = 428 \text{ m}^2$   
 $b = 60 \text{ m}$

a) CALCULATE R/C WEIGHT AT END OF CRUISE

→ BY APPLYING BROUQUET EQUATION FOR RANGE

$$7000 \text{ km} = \left( \frac{918 \text{ km/h}}{3,1 \frac{\text{m}}{\text{s}} \cdot 2,1 \cdot 10^{-5} \text{ kg/Ns}} \right) \left( 17 \right)_{\text{CRUISE}} \ln \left( \frac{230 \text{ tonnes}}{W_{\text{END CRUISE}}} \right)$$

$$W_{\text{END CRUISE}} = 164'913,628 \text{ kg}$$

b) RAMP WEIGHT

CONSIDER THE FOLLOWING FUEL FRACTION FOR A PAX A/C:

- ENGINE START & WARM UP 0,990
- TAXI 0,990
- TAKE OFF 0,995
- CLIMB ACCELERATE TO CRUISE 0,990

$$\rightarrow W_{\text{START CRUISE}} = (W)_{\text{AFTER CLIMB \& ACCELERATION TO CRUISE}}$$

$$= \frac{W_{\text{START}}}{W_{\text{RAMP}}} = \frac{W_{\text{START}}}{W_{\text{TO}}} \cdot \frac{W_{\text{TO}}}{W_{\text{TAXI}}} \cdot \frac{W_{\text{TAXI}}}{W_{\text{WARMUP}}} \cdot \frac{W_{\text{WARMUP}}}{W_{\text{RAMP}}}$$

$\downarrow$  0,990       $\downarrow$  0,995       $\downarrow$  0,990       $\downarrow$  0,990

$$\Pi = 0,956$$

$$\text{RAMP WEIGHT} = \frac{W_{\text{START CRUISE}}}{0,956} = 240662,426 \text{ kg}$$

c)

$$C_D = C_{D0} + \frac{1}{\pi A e} C_L^2 = C_{fe} \frac{S_{WING}}{S} + \frac{1}{\pi l \frac{b^2}{S}} C_L^2$$

$$C_D = 0,003 \cdot 5,5 + \frac{1}{\pi \cdot 0,8 \frac{(60 \text{ m})^2}{428 \text{ m}^2}} C_L^2 \Rightarrow \boxed{C_D = 0,0165 + 0,0473 C_L^2}$$

FOR MAX AERO EFFICIENCY:  $C_D = 2 C_{D0}$        $C_L = \sqrt{C_{D0} \pi A e}$

$$E_{\text{MAX}} = \frac{C_L}{C_D} = \frac{0,5806}{0,033} = 17,90$$

d)

$$mW = L = \frac{1}{2} \rho V^2 C_{Lmax} S \rightarrow C_{Lmax} = m \left( \frac{W}{S} \right) \cdot \frac{1}{\rho} = \frac{2,3 \cdot 537,383}{708,333} = \boxed{1,74}$$

START CRUISE

$$C_L = 1,74 \leq 1,8 \text{ (} C_{Lmax} \text{ cruise wing)}$$

SUSTAINED TURN

⇒ ok!

IN A SUSTAINED TURN:  $T = D$  (OR THE X/C WILL SLOW DOWN...)

$$T = D = C_D q S = \left( C_{D0} + \frac{C_L^2}{\pi A e} \right) q S \Rightarrow \frac{T}{W} = \frac{C_{D0} q}{(W/S)} + \frac{m^2 (W/S)^2 q}{\pi A e q^2 (W/S)}$$

POINT C

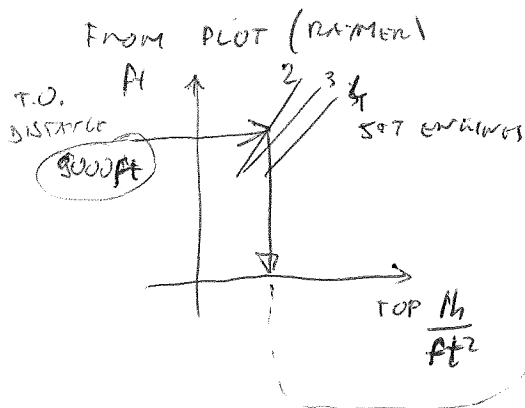
$$\frac{T}{W} = \frac{C_{D0} q}{(W/S)} + \left( \frac{W}{S} \right) \frac{m^2}{\pi A e q} = 0,21$$

START CRUISE

e) BY DEFINITION OF TOP

$$TOP_{TOT} = \left(\frac{W}{S}\right)_{TO} \frac{1}{(T/W)_{TO}} \frac{1}{C_{LMAX}|_{TO}} \cdot \frac{1}{g}$$

$$\left(\frac{W}{S}\right)_{TO} = \frac{W_{RAMP}}{S} \cdot 0,990 \cdot 0,990 \left( = \frac{W_{START CRUISE}}{S} \right) = 551,106 \frac{kg}{m^2}$$



$$TO \text{ DISTANCE} = 2743 \text{ m} \\ = 9000 \text{ ft}$$

$$TOP \approx 210 \frac{lb}{ft^2} \approx 1024,39 \frac{kg}{m^2}$$

$$\left(\frac{T}{W}\right)_{TO} = \left(\frac{W}{S}\right)_{TO} \cdot \frac{1}{C_{LMAX}|_{TO}} \cdot \frac{1}{TOP} = 0,244$$

2,2 FROM FORMULA SHEET

$w_{TO}$

$$T = 0,244 \cdot 235873,24 = 57680,030 \text{ Kg-f}$$

$$\text{SINGLE ENGINE THRUST} = T/2 = 28840,015 \text{ Kg-f}$$

$$f) \frac{T}{W} = \frac{C_{D0} q}{(W/S)} + \left(\frac{W}{S}\right) \frac{n^2}{\pi A e q} \rightarrow n = \sqrt{\left(\frac{T}{W} - \frac{C_{D0} q}{W/S}\right) \frac{\pi A e q}{W/S}}$$

$$n = \sqrt{\left(0,244 - \frac{0,0165 \cdot 708,33}{551,106}\right) \frac{\pi A e q}{W/S}} = \sqrt{2,463}$$

$$C_{LMAX}|_{CLIM} = 2,463 \left(\frac{W}{S}\right) \frac{1}{g} = 2,466 \cdot \frac{551,106}{708,333} = 1,92 > 1,8$$

FOR A SUSTAINED RATE SOME FLAPS WOULD BE REQUIRED!

AE1201: Solutions Multiple Choice questions August 2010 exam

Question ID	Answer
11	E
12	C
13	A
14	E
15	B
16	E
17	E
18	A
19	Omitted from the exam
20	B

2a)

The main types of requirements that can be distinguished are functional and non-functional requirements. The first category is related to the function(s) of the object/system to be designed. For a spacecraft, for instance, these are to deliver electrical power, provide for propulsion, communications, and command and data handling. The second category encompasses the operational requirements, the interface requirements and the constraints. Operational requirements relate to how well the spacecraft can be operated and include requirements concerning reliability, availability, maintainability and safety. Interface requirements related to how the spacecraft interfaces with the other elements in a space system, like the ground segment, the launcher, etc. Constraints relate to cost, mass, size, life, etc.

Requirements generation is one of the first steps in design. Requirements are needed to provide direction to the design. People should know what to design for. In the end, requirements are used to verify the design. Requirements generation involves many parties including the customer as well as regulators. It helps to solidify what the customer wants and ensures that the design will be in line with the law etc. It makes it possible for all parties to get involved.

	$f(x_i)$	$y_i$	$\left(\frac{y_i}{f(x_i)} - 1\right)^2$
2b) Mars Express	945.54	637	0.106
Venus "	589.47	700	0.035
Rosetta	1327.4	1330	$3.98 \times 10^{-6}$
Chandrayaan	572.3	503	0.015
ESMO	239.8	101	0.335
			$\frac{\sqrt{0.491}}{3} = 0.405$
			<u>40.5%</u>

2c) Total power to be delivered: 2500 W  
 panel delivers 100 W/m<sup>2</sup> @ 1 AU BOL  
 @ 0.431 AU, panel delivers  $\frac{100}{(0.431)^2} = 538 \text{ W/m}^2$  (BOL)  
 @ EOL, panel delivers  $538 \text{ W/m}^2 / (1 - 0.03)^6 = 448 \text{ W/m}^2$

2d)  $\frac{200 \text{ kbps}}{0.5 \text{ bits/Hz}} = 400 \text{ kHz}$

2e)  $EIRP = P \cdot L \cdot G = 100 (0.8) (100) = 8000 \text{ W}$

2f)  $\frac{P}{4\pi R^2} = \frac{200 \text{ W}}{4\pi (0.431 \text{ AU} \times 150 \times 10^9 \text{ m})^2} = 3.81 \times 10^{-21} \text{ W/m}^2$

2g)  $d = \frac{1}{2} \ddot{\alpha} t^2 = \left(\frac{30}{100}\right) (\pi) = \frac{1}{2} \ddot{\alpha} (2.5)^2 \Rightarrow \ddot{\alpha} = 0.1676 \text{ rad/s}^2$

$T = I \cdot \ddot{\alpha} = 350 (0.1676) = 58.64 \text{ Nm}$