VEL TECH
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DEPARTMENT AUTOMOTIVE AND AERONAUTICAL ENGINEERING

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Solution to Examination

Short Course Aircraft Design at Vel Tech University

Date: 19.02.2016

Total duration: 180 min., duration Part 1: 80 min., total points: 69.

Hints:

- Part 1 of the examination is without notes, books, and computer. All calculations are meant to be quick hand calculations. You may simplify e.g. g = 10 m/s.
- Please return the task sheet.
- If nothing else is specified, an answer to a question yields one point.

Part 1

1.1) Translate „aircraft“ to German!

Flugzeug

1.2) Translate „Flugzeugentwurf“ to English!

aircraft design

1.3) What is the task of aircraft design in the practical sense?

The **task of aircraft design** in the **practical sense** is to supply the "*geometrical description of a new flight vehicle*".
To do this, the new aircraft is described by

- a three-view drawing,
- a fuselage cross-section,
- a cabin layout and
- a list of aircraft parameters.

1.4) What is the task of aircraft design in an abstract sense?

The **task of aircraft design** in an abstract sense is to determine the design parameters so as to ensure that

1. the *requirements* and *constraints* are met (then we have a permissible design including certification) and, furthermore,
2. the design *objectives* are optimally met (then we have an optimum design).

1.5) List all requirements that should be known when the aircraft design of a passenger aircraft is started! Hint: Requirements are from cruise performance and airport performance.

Cruise performance:

- Payload m_{PL}
- Range R
- Mach number M_{CR}

Airport performance:

- Take-off field length s_{TO}
- Landing field length s_L
- Climb gradient γ_{CLB} (2nd segment)
- Missed approach climb gradient γ_{MA}

1.6) Name 5 key design parameters that come out from preliminary sizing!

The key design parameters are:

- Take-off mass m_{TO}
- Fuel mass m_F
- Operating empty mass m_{OE}
- Wing area S_W
- Take-off thrust T_{TO}

1.7) Preliminary sizing is listed as step 5 in the design sequence as proposed in the Short Course. Please name at least 5 of the next design steps leading to „aircraft evaluation / operating costs / DOC"!

- fuselage design
- wing design
- high lift design
- empennage design (from statistics)
- mass and CG estimation
- empennage design (from stability and control requirements)
- landing gear design and integration
- drag estimation

1.8) What does it mean "to shrink" or "to stretch" an aircraft in the context of an aircraft family?

"to shrink": To eliminate some of the cylindrical section of the fuselage in front and aft of the wing in order to produce an aircraft with a smaller cabin.

"to stretch": To add a cylindrical section to the fuselage in front and aft of the wing in order to produce an aircraft with a larger cabin.

1.9) The payload-range-diagram: Why is the maximum payload limited by Maximum Zero Fuel Weight (MZFW)?

Higher payload means higher Zero Fuel Weight (ZFW). ZFW is limited because in a conventional configuration with fuselage and separate wing more payload leads to higher wing bending loads. For a light weight structure these bending loads are limited by the amount of material chosen to be used for structural design.

1.10) The payload-range-diagram: Please explain the term "ferry range"!

`Ferry range is the range obtained with full fuel tank and zero payload.`

1.11) The payload-range-diagram: Is it possible to go maximum range with maximum payload? Explain your answer!

`No, this point would be outside of the payload range diagram.`

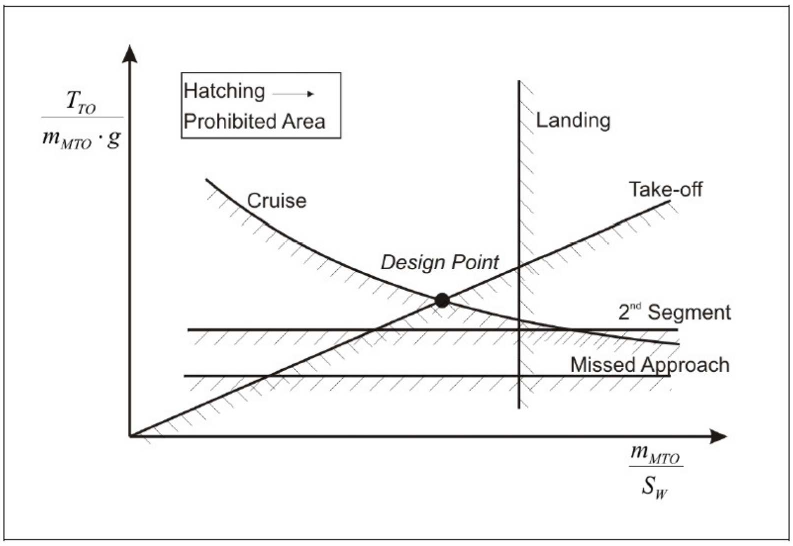
1.12) An aircraft is designed for 9 passengers and a maximum take-off mass of 5700 kg. How are the applicable European certification rules called? How are the applicable US certification rules called?

`CS-23 (normal or utility aircraft)`

1.13) How is an "unconventional configuration" defined?

`A conventional aircraft is one with only one fuselage, one wing and a horizontal and vertical tail at the back (tail aft). An unconventional aircraft differs in at least one of these aspects from the conventional configuration.`

1.14) a) Draw any possible matching chart (from aircraft preliminary sizing) with its 5 constraints and name the axis! b) Highlight the area in the chart that yields feasible designs! c) What are the two rules for finding an optimum design point? (3 points)



`The aim of optimization is to achieve the following:`

- `Priority 1: to achieve the smallest possible thrust-to-weight ratio;`
- `Priority 2: to achieve the highest possible wing loading.`

1.15) An aircraft carries 10 t of payload. Its relative fuel mass is 0.4 and its relative operating empty mass is 0.5. Calculate the maximum take-off mass! Show your calculation!

$$m_{MTO} = \frac{m_{PL}}{1 - \frac{m_F}{m_{MTO}} - \frac{m_{OE}}{m_{MTO}}}$$

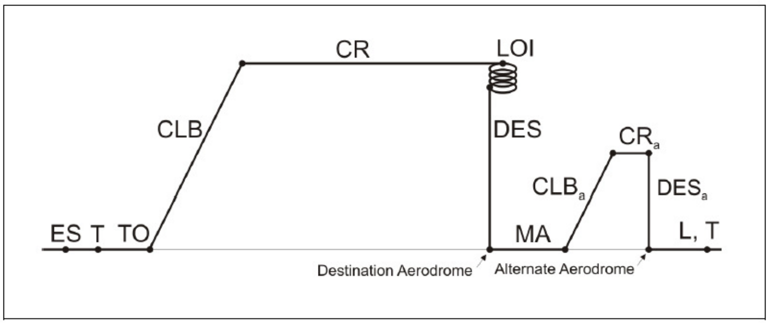
= 10 t /(1 – 0.4 – 0.5) = 100 t

1.16) An aircraft has a thrust-to-weight ratio of 0.25. What is (roughly) its relative operating empty mass? Show your calculation!

$$\frac{m_{OE}}{m_{MTO}} = 0.23 + 1.04 \cdot \frac{T_{TO}}{m_{MTO} \cdot g}$$

= 0.23 + 1.04 = 0.49

1.17) How is the mission of a civil aircraft defined with respect to its flight phases?



ES: Engine start
T: Taxi (out)
CLB: Climb
CR: Cruise
LOI: Loiter
DES: Descent
MA: Missed approach
L: Landing
T: Taxi (in)

1.18) What is a typical thrust specific fuel consumption of a turbo fan engine?
SFC_T = 16 mg/(Ns)

1.19) Give the equation to calculate the mission segment fuel fraction for the cruise phase! Hint: It is derived from the Breguet range equation.

$$B_s = \frac{L/D \cdot V}{SFC_T \cdot g} \qquad \frac{m_{LOI}}{m_{CR}} = e^{-\frac{s_{CR}}{B_s}}$$

1.20) An aircraft has a maximum take-off mass of 100 t and a wing loading of 1000 kg/m². Calculate the wing area!

$$S_W = m_{MTO} / \left(\frac{m_{MTO}}{S_W} \right)$$

= 100 t / (1 t/m²) = 100 m²

1.21) An aircraft has a maximum take-off mass of 100 t and a thrust to weight ratio of 0.25. Calculate the take-off thrust of the aircraft (all engines together)!

With g to be approximated to 10 N/kg (for hand calculation):

$$T_{TO} = m_{MTO} \cdot g \cdot \left(\frac{T_{TO}}{m_{MTO} \cdot g} \right)$$

= 100000 kg · 10 N/kg · 0.25 = 250 kN

1.22) A cabin is designed for 100 passengers. How many seats abreast do you propose? Explain your answer!

$$n_{SA} = 0.45 \cdot \sqrt{n_{PAX}}$$

= 4.5 => 5

1.23) A cabin is designed for 8-abreast seating. 4 benches with two seats each of 40 in width are used. How many aisles (of 20 in width) are required? What is the cabin width (including a gap to the side wall)?

Two aisles are needed because here we have more than 6 seats abreast.

This would be the cabin cross section: ∩∩_∩∩∩∩_∩∩

$d_{F,I}$ = width of all seats + width of all aisles + 2 · (gap between seat and side wall)

Cabin width: 4 · 40 in + 2 · 20 in + 2 · 1 in = 202 in = 5.13 m

(0,0254 m / in)

1.24) A cabin is designed for 240 passengers. The design follows the details given in the question above. What is (roughly) its length?

In the question above we deal with an aircraft with 8 seats abreast. This means that we need 30 rows for 240 seats. Each row needs on average (everything else included) 1 m of cabin length: 30 m.

1.25) An aircraft has a cabin length of 20 m and a fuselage diameter of 4 m. Calculate the fuselage length!

To the cabin length of 20 m we add 4 m for the cockpit and 1.6 times the fuselage outer diameter for the conical fuselage at the end (6.4 m). All together. The fuselage length will be approximately 30.4 m.

1.26) What is (aerodynamically) the optimum taper ratio for an unswept wing?

The optimum taper ratio (λ) for an unswept wing is approximately 0.45.

1.27) An aircraft has a high swept wing. What dihedral angle do you expect? (Give an approximate number).

Assuming the question refers to a typical aft swept wing. These aircraft are known to have a negative dihedral (anhedral). A typical value would be: -3°.

1.28) How does the tank volume change (increase or decrease) if …

a) the wing area is increased?

b) the relative thickness of the wing is increased?

c) the aspect ratio is increased?

a) the tank volume will increase
b) the tank volume will increase
c) the tank volume will decrease
This follows from common sense or from the equation for tank volume estimation.

1.29) Why do we need a higher maximum lift coefficient for the wing than for the whole aircraft?

The tail produces a down force for a longitudinally stable aircraft. The wing does not only need to carry the aircraft weight, but also this down force.

1.30) Consider a typical passenger aircraft with engines on the wing. Fuselage length is 60 m, mean aerodynamic chord is 3 m. Wing area is 70 m². Calculate the area of the horizontal tail!

$$S_H = \frac{C_H \ S_W \ c_{MAC}}{l_H}$$

$= 1 \cdot 70 \text{ m}^2 \cdot 3 \text{ m} / (0..5 \cdot 60 \text{ m}) = 7 \text{ m}^2$

1.31) A long range aircraft has a maximum take-off mass of 360 t. How many main wheels do you propose on the main landing gear? Explain your answer!

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360 t / 30 t/wheel = 12 wheels
```

1.32) A typical passenger aircraft has an aspect ratio of 6. Estimate its maximum glide ratio E_{max}! Show your calculations!

$$E_{max} = k_E \sqrt{\frac{A}{S_{wet} / S_W}}$$

$= 14.9 \cdot (6/6)^{1/2} = 14.9$

1.33) Direct Operating Costs (DOC) are calculated from a maximum of 7 cost elements. Name at least 5 of them!

$$C_{DOC} = C_{DEP} + C_{INT} + C_{INS} + C_F + C_M + C_C + C_{FEE}$$

```
DEP: Depreciation
INT: Interest
INS: Insurance
F:   Fuel
M:   Maintenance
C:   Crew costs
FEE: Fees (landing, navigation, ground handling)
```

1.34) Give typical values for a jet transport for C_{D0}, e, E_{max}, and equivalent skin friction coefficient, C_{fe}!

C_{D0}, = 0.02
e = 0.85
E_{max} = 18
C_{fe} = 0.003

1.35) Give typical values for a jet transport for $C_{L,max,L}$, $C_{L,max,TO} / C_{L,max,L}$, A, and φ_{25} of the wing!

$C_{L,max,L}$ = 2.8
$C_{L,max,TO} / C_{L,max,L}$ = 0.8

A of the wing: 10
φ_{25} of the wing: 25° … 30°

1.) Peliminary Sizing I

Calculations for flight phases approach, landing, take-off, 2nd segment and missed approach

Bold blue values represent input data. Values based on experience are light blue. Usually you should not change these values! Results are marked **red**. Don't change these cells! Interim values, constants, ... are in black! "<<<<" marks special input or user action.	Author: **Prof. Dr.-Ing. Dieter Scholz, MSME** **HAW Hamburg** http://www.ProfScholz.de Example data: See Examination VelTech 2016

Approach

Factor	k_{APP}	1,70	$(m/s^2)^{0.5}$
Conversion factor		1,944	kt / m/s

Given: landing field length — **yes** <<<< **Choose according to task** (ja = yes; nein = no)

Landing field length	s_{LFL}	**1000**	**m**
Approach speed	V_{APP}	53,8	m/s
Approach speed	V_{APP}	**104,6**	**kt**

$$V_{APP} = k_{APP} \cdot \sqrt{s_{LFL}}$$

Given: approach speed — **no**

Approach speed	V_{APP}	**104,6**	**kt**
Approach speed	V_{APP}	53,8	m/s
Landing field length	s_{LFL}	**1000**	**m**

$$V_{APP} = \left(\frac{s_{LFL}}{k_{APP}} \right)^2$$

Landing

Landing field length	s_{LFL}	1000	m
Temperature above ISA (288,15K)	ΔT_L	**0**	**K**
Relative density	σ	1,000	
Factor	k_L	0,107	kg/m³
Max. lift coefficient, landing	$C_{L,max,L}$	**3,1**	
Mass ratio, landing - take-off	m_{ML} / m_{TO}	**0,90**	
Wing loading at max. landing mass	m_{ML} / S_W	**332**	**kg/m²**
Wing loading at max. take-off mass	m_{MTO} / S_W	**369**	**kg/m²**

$$k_L = 0{,}03694\, k_{APP}^2$$

$$m_{ML} / S_W = k_L \cdot \sigma \cdot C_{L,max,L} \cdot s_{LFL}$$

$$m_{MTO} / S_W = \frac{m_{ML} / S_W}{m_{ML} / m_{MTO}}$$

1.) Preliminary Sizing I

$$m_{MTO} / S_W = \frac{m_{ML} / S_W}{m_{ML} / m_{MTO}}$$

Take-off

Take-off field length	s_{TOFL}	**1000**	**m**
Temperatur above ISA (288,15K)	ΔT_{TO}	**0**	**K**
Relative density	σ	1,000	
Factor	k_{TO}	2,34	m³/kg
Exprience value for $C_{L,max,TO}$	0,8 * $C_{L,max,L}$	2,48	
Max. lift coefficient, take-off	$C_{L,max,TO}$	**3,1**	
Slope	a	**0,0007548**	**kg/m³**
Thrust-to-weight ratio	T_{TO}/m_{MTO}*g at m_{MTO}/S_W calculated from landing	**0,278**	

$$a = \frac{T_{TO} /(m_{MTO} \cdot g)}{m_{MTO} / S_W} = \frac{k_{TO}}{s_{TOFL} \cdot \sigma \cdot C_{L,max,TO}}$$

2nd Segment

Calculation of glide ratio

Aspect ratio	A	**10**
Lift coefficient, take-off	$C_{L,TO}$	2,15
Lift-independent drag coefficient, clean	$C_{D,0}$ (bei Berechnung: 2. Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,053
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,073
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E_{TO}	7,60

n_E	sin(γ)
2	0,024
3	0,027
4	0,030

Calculation of thrust-to-weight ratio

Number of engines	n_E	**4**
Climb gradient	sin(γ)	0,03
Thrust-to-weight ratio	T_{TO} / m_{MTO}*g	**0,216**

$$\frac{T_{TO}}{m_{MTO} \cdot g} = \left(\frac{n_E}{n_E - 1}\right) \cdot \left(\frac{1}{E_{TO}} + \sin\gamma\right)$$

Missed approach

Calculation of the glide ratio

Lift coefficient, landing	$C_{L,L}$	1,83
Lift-independent drag coefficient, clean	$C_{D,0}$ (bei Berechnung: Durchstarten)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,037
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 bzw. CS-25	**no**
	FAR Part 25	**yes**
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,072
Glide ratio in landing configuration	E_L	8,16

	JAR-25 bzw. CS-25	FAR Part 25
$\Delta C_{D,gear}$	0,000	0,015

<<<< Choose according to task

n_E	$\sin(\gamma)$
2	0,021
3	0,024
4	0,027

Calculation of thrust-to-weight ratio

Climb gradient	$\sin(\gamma)$	0,027
Thrust-to-weight ratio	$T_{TO} / m_{MTO}*g$	**0,179**

$$\frac{T_{TO}}{m_{MTO} \cdot g} = \left(\frac{n_E}{n_E - 1}\right) \cdot \left(\frac{1}{E_L} + \sin\gamma\right) \cdot \frac{m_{ML}}{m_{MTO}}$$

2.) Max. Glide Ratio in Curise

Estimation of k_E by means of 1.), 2.) or 3.)

1.) From theory				
Oswald efficiency factor for k_E	e	**0,85**		
Equivalent surface friction coefficient	$C_{f,eqv}$	**0,003**		
Factor	k_E	14,9		
2.) Acc. to RAYMER				
Factor	k_E	15,8		
3.) From own statistics				
Factor	k_E	**???**		

Estimation of max. glide ratio in cruise, E_{max}

Factor	$k_{E\ chosen}$	**14,9**		**<<<< Choose according to task**
Relative wetted area	S_{wet} / S_w	**6,1**		S_{wet} / S_w = 6,0 ... 6,2
Aspect ratio	A	10	(from sheet 1)	
Max. glide ratio	E_{max}	**19,10**		
	or			
Max. glide ratio	$E_{max\ chosen}$	**19,10**		**<<<< Choose according to task**

3.) Preliminary Sizing II

Calculations for cruise, matching chart, fuel mass, operating empty mass and aircraft parameters m_{MTO}, m_L, m_{OE}, S_W, T_{TO}, ...

Parameter		Value	
By-pass ratio	BPR	**10**	
Max. glide ratio, cruise	E_{max}	19,10	(aus Teil 2)
Aspect ratio	A	10	(aus Teil 1)
Oswald eff. factor, clean	e	0,85	
Zero-lift drag coefficient	$C_{D,0}$	0,018	
Lift coefficient at E_{max}	$C_{L,m}$	0,70	
Mach number, cruise	M_{CR}	**0,66**	

$$C_{D,0} = \frac{\pi \cdot A \cdot e}{4 \cdot E_{max}^2}$$

$$C_{L,m} = \sqrt{C_{D,0} \cdot \pi \cdot A \cdot e}$$

Parameter	Value
V/V_m	**1,316074013**
$C_L/C_{L,m}$	0,577
C_L	0,404
E	16,541

Jet, Theory, Optimum: 1,316074013

$$C_L / C_{L,m} = 1/(V/V_m)^2$$

$$E = E_{max} \cdot \frac{2}{\frac{1}{\left(\frac{C_l}{C_{l,m}}\right)} + \left(\frac{C_l}{C_{l,m}}\right)}$$

Constants			
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81	m/s²
Air pressure, ISA, standard	p_0	101325	Pa
Euler number	e	2,718282	

$$\frac{T_{TO}}{m_{MTO} \cdot g} = \frac{1}{(T_{CR}/T_0) \cdot (L/D)_{max}}$$

$$\frac{m_{MTO}}{S_W} = \frac{C_L \cdot M^2}{g} \cdot \frac{\gamma}{2} \cdot p(h)$$

Altitude		Cruise				2nd Segment	Missed appr.	Take-off	Cruise	Landing
h [km]	h [ft]	T_{CR} / T_{TO}	T_{TO} / m_{MTO}*g	p(h) [Pa]	m_{MTO} / S_W [kg/m²]	T_{TO} / m_{MTO}*g	T_{TO} / m_{MTO}*g	T_{TO} / m_{MTO}*g	T_{TO} / m_{MTO}*g	T_{TO} / m_{MTO}*g
0	0	0,465	0,130	101325	1271	0,216	0,179	0,96	0,13	
1	3281	0,438	0,138	89873	1127	0,216	0,179	0,85	0,14	
2	6562	0,411	0,147	79493	997	0,216	0,179	0,75	0,15	
3	9843	0,384	0,157	70105	879	0,216	0,179	0,66	0,16	
4	13124	0,358	0,169	61636	773	0,216	0,179	0,58	0,17	
5	16405	0,331	0,183	54015	678	0,216	0,179	0,51	0,18	
6	19686	0,304	0,199	47176	592	0,216	0,179	0,45	0,20	
7	22967	0,278	0,218	41056	515	0,216	0,179	0,39	0,22	
8	26248	0,251	0,241	35595	447	0,216	0,179	0,34	0,24	
9	29529	0,224	0,270	30737	386	0,216	0,179	0,29	0,27	
10	32810	0,198	0,306	26431	332	0,216	0,179	0,25	0,31	
11	36091	0,171	0,354	22627	284	0,216	0,179	0,21	0,35	
12	39372	0,144	0,420	19316	242	0,216	0,179	0,18	0,42	
13	42653	0,117	0,515	16498	207	0,216	0,179	0,16	0,51	
14	45934	0,091	0,667	14091	177	0,216	0,179	0,13	0,67	
15	49215	0,064	0,945	12035	151	0,216	0,179	0,11	0,94	
					369					0
					369					0,5
Remarks:	1m=3,281 ft	T_{CR}/T_{TO}= f(BPR,h)	Gl.(5.27)	Gl. (5.32/5.33)	Gl. (5.34)	from sheet 1.)	from sheet 1.)	from sheet 1.)	Repeat for plot	from sheet 1.)

Wing loading	m_{MTO} / S_W	**369**	**kg/m²**
Thrust-to-weight ratio	T_{TO} / (m_{MTO}*g)	**0,278**	
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0,217	
Conversion factor	m -> ft	0,305	m/ft
Cruise altitude	h_{CR}	**9258**	**m**
Cruise altitude	h_{CR}	**30374**	**ft**
Temperature, troposphere	$T_{Troposphäre}$	227,97	K
Temperature, h_{CR}	$T(h_{CR})$	227,97	
Speed of sound, h_{CR}	a	303	m/s
Cruise speed	V_{CR}	**200**	**m/s**
Conversion factor	NM -> m	1852	m/NM
Design range	R	**1510**	**NM**
Design range	R	2796520	m
Distance to alternate	$s_{to\_alternate}$	200	NM
Distance to alternate	$s_{to\_alternate}$	370400	m
Chose: FAR Part121-Reserves?	domestic	**yes**	
	international	**no**	
Extra-fuel for long range		10%	
Extra flight distance	s_{res}	370400	m
Spec.fuel consumption, cruise	SFC_{CR}	**1,40E-05**	**kg/N/s**
Breguet-Factor, cruise	B_s	24063708	m
Fuel-Fraction, cruise	$M_{ff,CR}$	0,890	
Fuel-Fraction, extra fliht distance	$M_{ff,RES}$	0,985	
Loiter time	t_{loiter}	2700	s
Spec.fuel consumption, loiter	SFC_{loiter}	**1,40E-05**	**kg/N/s**
Breguet-Factor, flight time	B_t	120438	s
Fuel-Fraction, loiter	$M_{ff,loiter}$	0,978	
Fuel-Fraction, engine start	$M_{ff,engine}$	**1,000**	**<<<< Copy**
Fuel-Fraction, taxi	$M_{ff,taxi}$	**0,997**	**<<<< values**
Fuel-Fraction, take-off	$M_{ff,TO}$	**0,994**	**<<<< from**
Fuel-Fraction, climb	$M_{ff,CLB}$	**0,994**	**<<<< table**
Fuel-Fraction, descent	$M_{ff,DES}$	**0,994**	**<<<< on the**
Fuel-Fraction, landing	$M_{ff,L}$	**0,994**	**<<<< right !**

<<<< Read design point from matching chart!

<<<< Given data is correct when take-off and landing is sizing the aircraft at the same time.

$T_{Stratosphäre}$ 216,65 K

Reserve flight distance:

FAR Part 121	s_{res}
domestic	370400 m
international	650052 m

typical value 1,60E-05 kg/N/s

Extra time:

FAR Part 121	t_{loiter}
domestic	2700 s
international	1800 s

Phase	M_{ff} per flight phases [Roskam]	
	transport jet	business jet
engine start	0,990	0,990
taxi	0,990	**0,995**
take-off	0,995	0,995
climb	0,980	0,980
descent	0,990	0,990
landing	0,992	0,992

Fuel-Fraction, standard flight	$M_{ff,std}$	0,869	
Fuel-Fraction, all reserves	$M_{ff,res}$	0,951	
Fuel-Fraction, total	M_{ff}	0,827	
Mission fuel fraction	m_F/m_{MTO}	0,173	
Realtive operating empty mass	m_{OE}/m_{MTO}	0,519	acc. to Loftin
Realtive operating empty mass	m_{OE}/m_{MTO}	**xxx**	from statistics (if given)
Realtive operating empty mass	m_{OE}/m_{MTO}	**0,500**	**<<<< Choose according to task**
Choose: type of a/c	short / medium range	**yes**	**<<<< Choose according to task**
	long range	**no**	
Mass: Passengers, including baggage	m_{PAX}	93,0 kg	
Number of passengers	n_{PAX}	**180**	
Cargo mass	m_{cargo}	**2516 kg**	
Payload	m_{PL}	**19256 kg**	
Max. Take-off mass	m_{MTO}	**58914 kg**	
Max. landing mass	m_{ML}	**53023 kg**	
Operating empty mass	m_{OE}	**29457 kg**	
Mission fuel fraction, standard flight	m_F	**10201 kg**	
Wing area	S_w	**160 m²**	
Take-off thrust	T_{TO}	160785 N	**all engines together**
T-O thrust of ONE engine	T_{TO} / n_E	**40196 N**	**one engine**
T-O thrust of ONE engine	T_{TO} / n_E	9036 lb	**one engine**
Fuel mass, needed	$m_{F,erf}$	10347 kg	
Fuel density	ρ_F	800 kg/m³	
Fuel volume, needed	$V_{F,erf}$	**12,9 m³**	(check with tank geometry later on)
Max. Payload	m_{MPL}	**19256 kg**	
Max. zero-fuel mass	m_{MZF}	48713 kg	
Zero-fuel mass	m_{ZF}	48713 kg	
Fuel mass, all reserves	$m_{F,res}$	2865 kg	

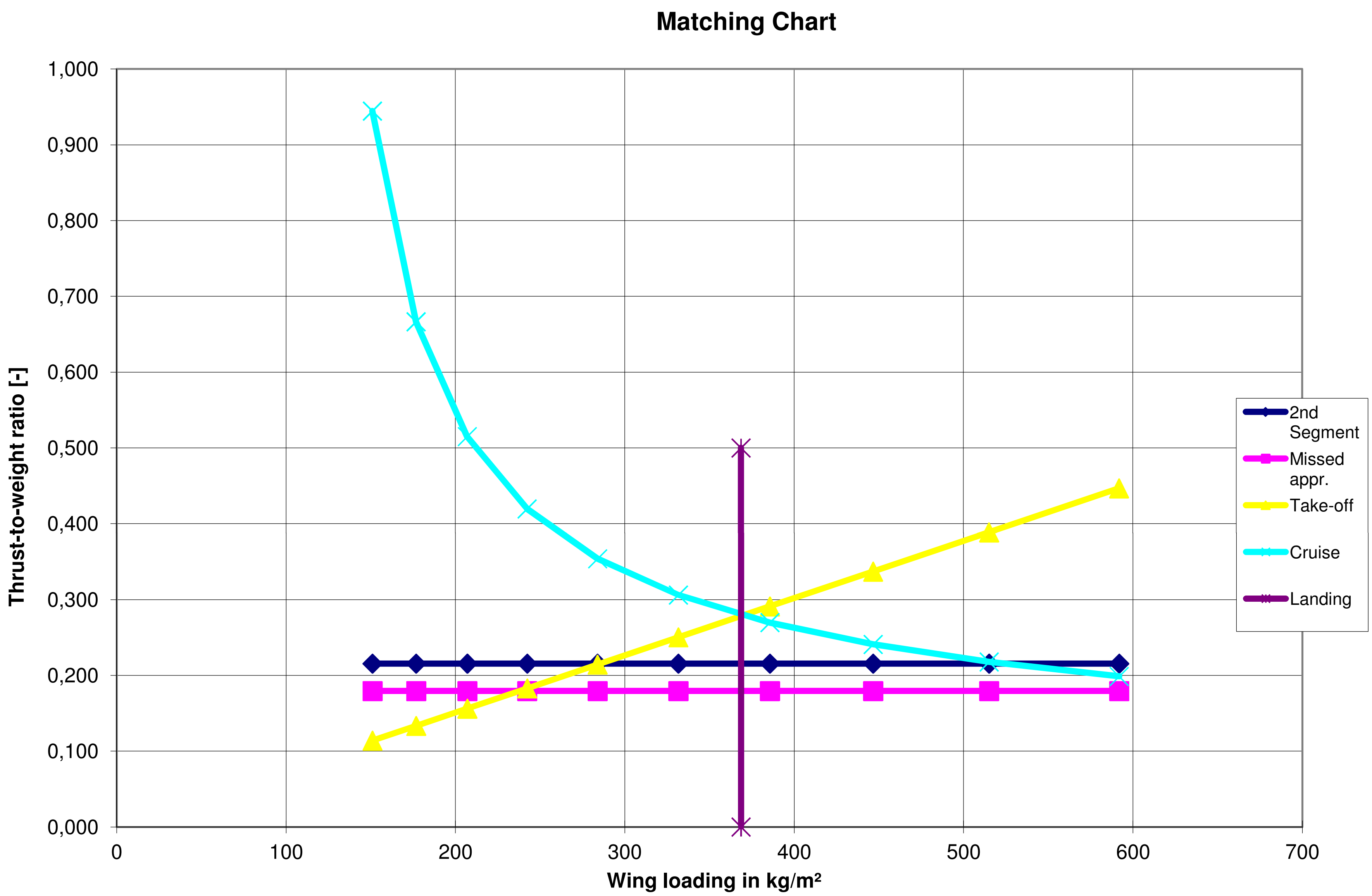
in kg	Short- and Medium Range	Long Range
m_{PAX}	93,0	97,5

Check of assumptions check: m_{ML} > $m_{ZF} + m_{F,res}$ **?**

53023 kg > 51578 kg

yes

Aircraft sizing finished!


Matching Chart
Thrust-to-weight ratio [-]
1,000
0,900
0,800
0,700
0,600
0,500
0,400
0,300
0,200
0,100
0,000
0
100
200
300
400
500
600
700
Wing loading in kg/m²
2nd Segment
Missed appr.
Take-off
Cruise
Landing

Results to task 2.1

Please insert your results here! Do not forget the units!

- Wing loading from landing field length: **369 kg/m²**
- Thrust to weight ratio from take-off field length (at wing loading from landing): **0,278**
- Glide Ratio in 2. Segment: **7,60**
- Glide Ratio during missed approach maneuver: **8,16**
- Thrust to weight ratio from climb requirement in 2. Segment: **0,216**
- Thrust to weight ratio from climb requirement during missed approach maneuver: **0,179**
- Design point (Glide Ratio during cruise: **19,1**)
  - Thrust to weight ratio : **0,278**
  - Wing loading: **369 kg/m²**
- Cruise altitude: **9258 m = 30374 ft**
- Maximum take-off mass: **58914 kg**
- Maximum landing mass: **53023 kg**
- Wing area: **160 m²**
- Thrust of one engine **in N**: **40196 N**
- Required tank volume **in m³**: **12,9 m³** **14 points**

Draw the matching chart and also **indicate the design point in the matching chart**!

½ point for each of the 5 lines, ½ point for the design point indicated in the diagram **3 points**

Label your lines in the legend on the right of the page of the chart. Here is your translation:

2. Segment	=	2. Segment
Durchstarten	=	missed approach
Start	=	take-off
Reiseflug	=	cruise
Landing	=	landing
Steigflug	=	climb (not required here)

Part 2

Task2.2

a)

Sweep angle of the wing:

$$\varphi_{25} = 39{,}3° \, (M_{CR})^2$$

M_CR	0,66
phi_25	**17,1 °**

b)

Relative thickness of the wing, *t/c* from cruise Mach number only:

$$\left(\frac{t}{c}\right) = -0{,}0439 \cdot \tan^{-1}(3.3450 \cdot M_{CR} + -3.0231) \;\; +0{,}0986$$

t/c	**0,129**

d)

r	1,3

$$(t/c)_t \;= 4/(3+\mathrm{r}) \; t/c$$

t/c_t	**0,120**

c)

$$(t/c)_r \;= r \; (t/c)_t$$

t/c_r	**0,156**

e)

$$\lambda_{opt} = 0.45 \cdot e^{-0.036 \varphi_{25}}$$

φ_{25} in degree

λ should not be smaller than 0.2

lamda_opt	**0,243**

f)

$$\Gamma = \frac{\partial \Gamma}{\partial k_{Z,W}} \cdot k_{Z,W} + \frac{\partial \Gamma}{\partial \varphi_{25}} \cdot \varphi_{25} + \Gamma_0$$

$k_{Z,W} = 0.0$, for low wing aircraft
$k_{Z,W} = 0.5$, for mid-wing aircraft
$k_{Z,W} = 1.0$ for high-wing aircraft

$\frac{\partial \Gamma}{\partial k_{Z,W}}$	- 7.46°
$\frac{\partial \Gamma}{\partial \varphi_{25}}$	- 0.115
Γ_0	6.91°

dgdz	-7,46
dgdphi	-0,115
gamma_0	6,91
k_zw	0
gamma	**4,9**

Task2.3

$$d = \sqrt{\frac{m_{MTO}}{n_W \ \ p * w / d}}$$

$$w = w/d \cdot d$$

m_MTO	360	t
n_W	12	
p_star	30	t/m²
wd	0,4	
d	**1,58**	
w	**0,632**	

Task2.4

a)

$$C_{DEP} = \frac{P_{total} - P_{residual}}{n_{DEP}} = \frac{P_{total}\left(1 - \frac{P_{residual}}{P_{total}}\right)}{n_{DEP}}$$

P_total	1,00E+08	USD	
residual	0,1		
n_DEP	14		
C_DEP	6428571	USD	(per A/C and per year)

b)

n_t,a = $\frac{k_{U1}}{t_f + k_{U2}}$

k_U1	3750	h
k_U2	0,75	h
t_f	1	h
n_t,a	**2143**	

c)

C_DEP,s,t = C_DEP / n_t,a / n_PAX

n_PAX	150	
C_DEP,s,t	**20,00**	**USD**