Hochschule für Angewandte Wissenschaften Hamburg
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DEPARTMENT FAHRZEUGTECHNIK UND FLUGZEUGBAU

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Lösung / Solution
Flugzeugentwurf / Aircraft Design SS 2015

Date: 11.07.2015

Duration of examination: 180 minutes

1. Part

35 points, 70 minutes, closed books

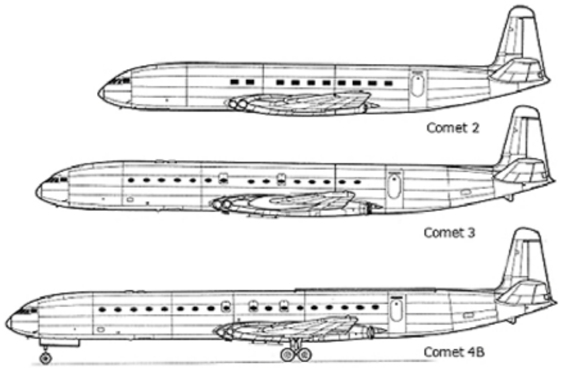
1.1) Please translate to German.
Please write clearly! Unreadable text will not harvest points!

1.	aeroplane	Flugzeug
2.	airplane	Flugzeug
3.	aircraft	Flugzeug
4.	flying wing	Nurflügelflugzeug
5.	aerodynamic center	Neutralpunkt
6.	payload	Nutzlast
7.	sweep	Pfeilung
8.	taper	Zuspitzung
9.	dihedral	V-Form
10.	twist	Schränkung
11.	camber	Wölbung
12.	bending	Biegung

1.2) Please translate to English.
Please write clearly! Unreadable text will not harvest points!

1.	Flugzeugentwurf	aircraft design
2.	Machzahl	Mach number
3.	Fahrwerk	landing gear
4.	Leitwerk	tail
5.	Höhenleitwerk	horizontal tail
6.	Seitenleitwerk	vertical tail (fin)
7.	Rückenflosse	dorsal fin
8.	Anstellwinkel	angle of attack
9.	Einstellwinkel	incidence angle
10.	Hängewinkel	bank angle
11.	Steigwinkel	climb angle
12.	V-Winkel	dihedral angle

1.3) Shown is a de Havilland DH 106 Comet. It was the first production commercial jet. Developed and manufactured by de Havilland at its Hatfield Aerodrome, Hertfordshire – the location of our long term ERASMUS partner university, the University of Hertfordshire.



Source: http://www.zoggavia.com

Please name 4 technical characteristics and for each characteristic at least one advantage and one disadvantage!

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1.) Engines buried in the wing:
      Advantage:        Less wetted area, less drag
      Disadvantage:     More complicated to handle during maintenance

2.) Horizontal tail with dihedral:
      Advantage:  Horizontal tail is for sure free of jet blast
      Disadvantage:     Less effective area

3.) Rectangular windows on Comet 2:
      Advantage:        Full use is made of the area formed by stringer and frame
      Disadvantage:     High stress in material in the corners of the window.
                        This lead to structural failures in the early days of this aircraft.

4.) Fuselage converges at tail from top and from bottom.
      Advantage:        Less drag
      Disadvantage:     Requires longer main landing gear to avoid tail strike.
```

1.4) What is the value of a typical zero-lift drag coefficient for a passenger aircraft? Calculate its drag coefficient at minimum drag speed!

0.02

1.5) What is the value of a typical ratio between wetted area and wing area of a passenger aircraft? Estimate the maximum glide ratio $(L/D)_{max}$ for such an aircraft with an aspect ratio of 6!

A typical value for S_{wet}/S_W = 6.0 ... 6.2

$(L/D)_{max} = 14.9 \cdot (6/6)^{1/2} = 14.9$

1.6) What is the value of a typical equivalent skin friction coefficient for a passenger aircraft? And what is again the value of a typical ratio between wetted area and wing area of a passenger aircraft? Calculate the value for the zero lift drag coefficient of a passenger aircraft from these numbers!

0.003

1.7) What is the minimum speed (with respect to stall speed) at take-off of a business jet?

v_2/v_S = 1.2

1.8) What is the minimum speed (with respect to stall speed) at approach of a business jet?

v_{app}/v_S = 1.3

1.9) What is the ratio of the maximum lift coefficient and the actual lift coefficient at minimum approach speed of a business jet?

$(v_{app}/v_S)^2$ = 1.69

1.10) Please write down the „First Law of Aircraft Design“ from which you can calculate the maximum take-off mass m_{MTO} from payload m_{PL} ? Everything else equal: How much more is the maximum take-off mass m_{MTO} if the payload m_{PL} doubles?

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

If the payload m_{PL} doubles, also the maximum take-off mass m_{MTO} doubles.

1.11) How is the tail volume coefficient defined for a vertical tail? Explain how to obtain the vertical tail surface area from the vertical tail volume coefficient! Explain how to get each parameter needed!

Vertical tail volume coefficient: $C_V = \frac{S_V \cdot l_V}{S_W \cdot b}$

This is how to use it:

$$S_V = \frac{C_V \cdot S_W \cdot b}{l_V}$$

Get coefficient from given or own statistics. Take wing area and wing span from preliminary sizing. Get the vertical tail lever arm from a percentage (45 % ... 55 %) of the fuselage length.

1.12) Assume you investigated the one class seat layout of many passenger aircraft in order to find out the value of the ratio between the number of rows n_R and the number of seats abreast n_{SA}. Assume you found the ratio of $n_R/n_{SA} = 4$. Determine n_{SA} for an aircraft seating 169 passengers! Explain your choice in light of certification rules CS-25! Write the equation to determine n_{SA} for any ratio n_R/n_{SA} !

$$n_{SA} \cdot n_R = n_{pax}$$

$$n_{SA}^2 \cdot n_R = n_{pax} \cdot n_{SA}$$

$$n_{SA}^2 = \frac{n_{SA}}{n_R} \cdot n_{pax}$$

$$n_{SA} = \sqrt{\frac{n_{SA}}{n_R}} \cdot \sqrt{n_{pax}}$$

$$n_{SA} = \sqrt{\frac{1}{4}} \cdot \sqrt{n_{pax}}$$

$$= \frac{1}{2} \cdot \sqrt{169}$$

$$= \frac{1}{2} \cdot 13 = 6,5$$

This can be either 6 or 7 seats abreast. Since 7 seats require 2 aisles (CS-25) $n_{SA} = 6$ is the better choice.

1.13) You plan to design a fuselage with circular cross section for minimum zero lift drag. How do you set up your optimization? Select all correct options!

A The task is to minimize zero lift drag per cabin volume

X B The task is to minimize zero lift drag per cabin area

C The task is to minimize zero lift drag per frontal area

D The task is to minimize zero lift drag per total area of the passenger doors

E The task is to minimize zero lift drag per total area of the cargo doors

1.14) You want to design a cabin with 6 seats abreast. What are your options with respect to the number of aisles? Discuss!

```
6 seats abreast is the maximum number of seats allowed for one aisle
(CS-25). This does not preclude to have voluntarily more than one aisle for
a 6-abreast cabin.

Advantage:    Two aisles facilitate boarding and deboarding and could lead
              to a little shorter turn around time, because boarding and
              deboarding are usually on the "critical path".
Disadvantage: Two aisles cause a larger fuselage diameter and hence more
              wetted area and zero-lift drag. On the other hand the fuse-
              lage could turn out to be lighter.
Together:     Only a more detailed design of the two versions of this air-
              craft and a comparison can tell what would be the better so-
              lution. From experience I can tell (and aircraft statistics
              clearly show) that the 6-abreast two aisle version will not
              be able to demonstrate advantages after all.
```

1.15) In which sequence is it best to allocate wing parameters in a hand calculation? Input parameter is the cruise Mach number. Select all correct options!

A First: wing vertical position, sweep, dihedral angle. Then: taper ratio, thickness ratio.

X B First: wing vertical position, sweep. Then: taper ratio, dihedral angle, thickness ratio.

C First: sweep. Then: wing vertical position, taper ratio, dihedral angle, thickness ratio.

D First: dihedral angle, sweep. Then: taper ratio, wing vertical position, thickness ratio.

1.16) Please order these Mach numbers with respect to increasing flight speed: (typical) cruise Mach number, MMO, critical Mach number, MD, M_{DD}! Discuss your sequence if necessary!

critical Mach number (typical) cruise Mach number = M_{DD} MMO MD

1.17) Name three parameters that you would change, if asked to reduce wing drag in transonic flight at given cruise Mach number! Would you increase or decrease each of these parameters?

- increase wing sweep
- reduce relative thickness of the wing (of the airfoil)
- reduce lift coefficient for less supervelocities
- select efficient transonic airfoil

1.18) You need to carry much fuel for your long range aircraft. How would you change (increase or decrease) each parameter listed (if you are still free to decide): Wing area, wing aspect ratio, wing sweep, taper ratio, relative thickness of the wing? Discuss your selection if necessary!

- increase wing area
- decrease wing aspect ratio
- wing sweep has no/little influence on wing fuel tank volume and should be set for other reasons
- taper ratio: $\lambda = 0$ (decrease if higher)
- increase relative thickness of the wing

1.19) Many wings have a kink and are hence formed by two trapezia. Why is this necessary? State aerodynamic benefits (if any)!

This is necessary to integrate the main landing gear on the wing. The wing is roughly were the CG is, but the main landing gear needs to be a little aft of the CG. With an inner wing with unswept trailing edge, room is made for an additional inboard rear spar used to mount the main landing gear. There are not really aerodynamic advantages from the double trapezoidal wing – with the exception of maybe one advantage: It becomes possible to use an inner wing trailing edge flap without sweep which shows a higher maximum lift coefficient than a swept flap.

1.20) Explain why wing twist may help to optimize the lift distribution in the design point, but causes more drag in off-design situations!

With wing twist, the local angle of attack can be increased or decreased and as such the wing loading may be adapted to an elliptical one (or a triangle one – whatever is the goal) in the design point of the flight envelope. However consider the case where the wing produces no lift. With twist (often washout) it would e.g. show negative lift outboard and positive lift inboard (in contrast to an untwisted wing that would show no lift along the whole span). Lift is followed by drag (even if it cancels out over the whole wing).

1.21) For a quick design of a main landing gear: How many tons from the maximum take-off mass do you allocate to each of the main wheels? Or in other words: How many wheels do we need on the main gear?

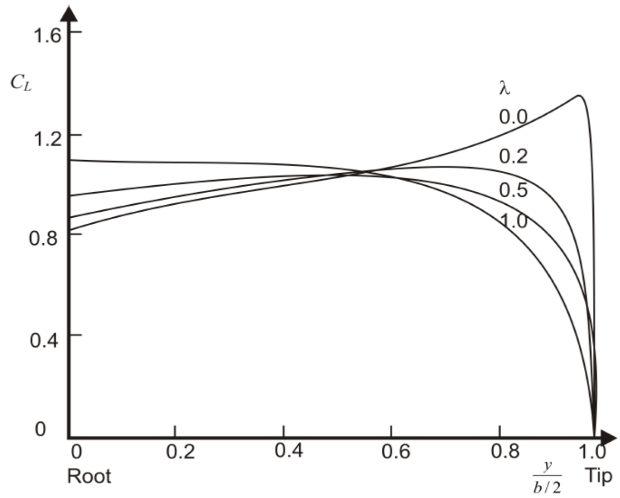
Each main wheel can carry: 20 t ... 30 t

The minimum number of main wheels is: $n_{MW} = m_{MTO}$ / 30 t

1.22) How is the concrete of a runway more likely to fail due to a certain large aircraft with given mass: if each main landing gear leg has two wheels or if each main landing gear leg has four wheels?

The load should always be distributed over a larger area. Four wheels (especially if they are spaced far apart) are better that two. In a formal calculation this is shown with a smaller "equivalent single wheel load" and a smaller Aircraft Classification Number, ACN.

1.23) At a certain angle of attack, a wing would "theoretically" show the distribution of the lift coefficient as given in the diagram that gives actually the behavior of four wings with different taper ratios. Here "theoretically" means that the diagram was produced with an aerodynamic code that can not predict stall. You plan to use an airfoil with a maximum lift coefficient of 1.2. Which of the wings stalls at the given angle of attack and where does it stall? Which wing(s) will produce most lift? Discuss!



The wing with the taper ratio λ = 0 will stall, because it "tries to achieve" a local lift coefficients lager than 1.2 on the wing tip i.e. outboard of 80 % halfspan.

The two wings with λ = 0.2 and λ = 0.5 will produce most lift, because they have quite an even distribution of the local lift coefficient and are wasting only very little. The wing with λ = 1.0 will stall inboard first and will waste lift their.

1.24) What is the ultimate design goal (objective function) for commercial aircraft?

The ultimate goal in commercial aviation is to make money. This means revenues should be as high as possible and costs should be as low as possible. Every unit of transport (expressed as passenger mile) should be generated at lowest costs!

Questions from the Lecture Series

1.25) Has metal a chance in aircraft design in the future, or will aircraft continue to be dominated by composite materials? Explain your answer!

Metal has a chance if production costs can be reduced. This means that metal cutting processes (milling, turning, and drilling) have to be fast, so that an expensive machine can produce more in a given amount of time.

1.26) ICAO puts aircraft in various classes. What are the span limitations (at airports) for aircraft in Class C and D respectively?

Class C: 36 m
Class D: 52 m

1.27) What is the advantage of a propeller driven aircraft compared to a propfan with respect to engine integration certification?

`With respect to engine integration and certification, it is important to note that propfans are considered to disintegrate. The fuselage structure in the vicinity of the engine needs to be reinforced. Propellers are not considered to disintegrate and save the mass for structure reinforcement.`

1.28) How efficient are winglets?

A Winglets have no effect on the aerodynamic efficiency of an aircraft.

X B Winglets 1 m high have roughly the same effect as a horizontal wing span increase of 0.5 m on each wing tip.

C Vertical winglets have the same aerodynamic effect as a horizontal wing span extension of the same size.

1.29) What amount of fuel saving can be achieved with a "Smart Turboprop" (as described in the evening lecture) against the jet powered A320?

`Fuel saving is given as 36 %.`

1.30) Explain how it is possible to achieve "double digit" (%) savings in fuel consumption of passenger aircraft just based on parameter choice in aircraft design without any introduction of new technologies!

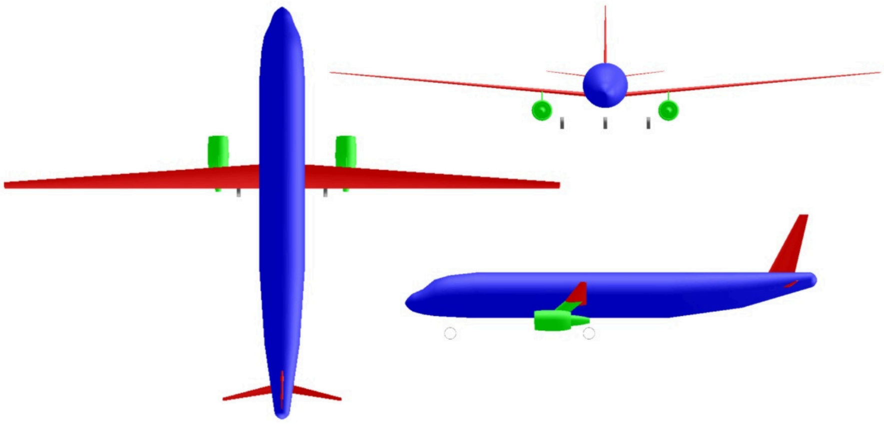
`This is possible by violating values of commonly selected parameters:`

- `Higher value of the wing span violating ICAO classes.`
- `Higher value of take-off and landing distance.`
- `Slower cruise flight leading to lower flight.`
- `Changing the objective function from DOC to fuel consumption.`

2. Part

Task 2.1

Design "The Rebel"!



These are the requirements for the aircraft:

- Payload: 180 people on board with baggage. 93 kg per person. Additional cargo: 2516 kg.
- Range 1510 NM at a cruise Mach number $M_{CR} = 0.55$ (payload as above, with reserves as given in FAR Part 121, domestic reserves, distance to alternate: 200 NM)
- Take-off field length $s_{TOFL} \leq$ 2700 m (ISA, MSL at maximum take-off mass)
- Landing field length $s_{LFL} \leq 2700$ m (ISA, MSL at maximum landing mass)
- Furthermore the requirements from FAR Part 25 §121(b) (2. Segment) and FAR Part 25 §121(d) (missed approach) shall be met

For your calculation

- The factor k_{APP} for approach, k_L for landing and k_{TO} for take off should be selected according to the spread sheet and to the lecture notes.
- The ratio of maximum landing mass and maximum take-off mass $m_{ML}/m_{MTO} = 0{,}92$
- Maximum lift coefficient of the aircraft in landing configuration $C_{L,max,L}= 3{,}1$
- Maximum lift coefficient of the aircraft in take-off configuration $C_{L,max,TO} = 3{,}1$
- The glide ratio is to be calculated for take-off and landing with $C_{D0} = 0.02$ and Oswald factor $e = 0.5$
- Oswald factor in cruise $e = 0.68$
- Aspect ratio $A = 34.8$
- Calculate the maximum glide ratio in cruise, E_{max} with $e = 0.68$ und $S_{wet} / S_W = 9.1$
- The ratio of cruise speed and speed for minimum drag is set to the optimum value:

  $V_{CR} / V_{md} = \sqrt[4]{3}$. **Design point is the intersection from take-off and landing line!!!**

- The operating empty mass ratio is $m_{OE} / m_{MTO} = 0.59$.
- The by-pass ratio (BPR) of this generic engine is close to $\mu = 15.5$; their thrust specific fuel consumption for cruise and loiter is assumed to be $c = 10{,}3$ mg/(Ns).
- Use these values as Mission-Segment Fuel Fractions: Engine start: 1.00; Taxi: 0.997; Take-off: 0.994; Climb: 0.994; Descent: 0.994; Landing: 0.994.

Results to task 2.1

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

- Wing loading from landing field length: **973 kg/m²**
- Thrust to weight ratio from take-off field length (at wing loading from landing): **0.272**
- Glide Ratio in 2. Segment: **13.68**
- Glide Ratio during missed approach maneuver: **13.76**
- Thrust to weight ratio from climb requirement in 2. Segment: **0.194**
- Thrust to weight ratio from climb requirement during missed approach maneuver: **0.172**
- $V_{CR} / V_{md} = \sqrt[4]{3}$ = **1.316**
- Design point
  - Thrust to weight ratio : **0.272**
  - Wing loading: **973 kg/m²**
- Cruise altitude: **8465 m = 27772 ft**
- maximum take-off mass: **67308 kg**
- maximum landing mass: **61923 kg**
- wing area: **69.1 m²**
- thrust of one engine **in N**: **89850 N**
- required tank volume **in m^3**: **10.6 m³**

Draw the matching chart (you need to change the scale of the axis for the wing loading!) and **indicate the design point in the matching chart**!

1.) Peliminary Sizing I

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

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 actio.

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Example data: See Klausur SS15

Approach				
Factor	k_{APP}	1,70	$(m/s^2)^{0.5}$	
Conversion factor		1,944	kt / m/s	
Given: landing field lengtl		**yes**		**<<<< Choose according to tasl** (ja = yes; nein = no)
Landing field length	s_{LFL}	**2700**	**m**	
Approach speed	V_{APP}	88,4	m/s	
Approach speed	V_{APP}	**171,9**	**kt**	$V_{APP} = k_{APP} \cdot \sqrt{s_{LFL}}$
Given: approach speed		**no**		
Approach speed	V_{APP}	**152,0**	**kt**	$s_{LFL} = \left(\frac{V_{APP}}{k_{APP}} \right)^2$
Approach speed	V_{APP}	78,2	m/s	
Landing field length	s_{LFL}	**2111**	**m**	
Landing				
Landing field length	s_{LFL}	2700	m	
Temperature above ISA (288,15K)	ΔT_L	**0**	**K**	
Relative density	σ	1,000		$k_L = 0{,}03694\, k_{APP}^2$
Factor	k_L	0,107	kg/m³	
Max. lift coefficient, landing	$C_{L,max,L}$	**3,1**		$m_{ML} / S_W = k_L \cdot \sigma \cdot C_{L,max,L} \cdot s_{LFL}$
Mass ratio, landing - take-off	m_{ML} / m_{TO}	**0,92**		
Wing loading at max. landing mass	m_{ML} / S_W	**896**	**kg/m²**	$m_{MTO} / S_W = \frac{m_{ML} / S_W}{m_{ML} / m_{MTO}}$
Wing loading at max. take-off mass	m_{MTO} / S_W	**973**	**kg/m²**	

Take-off

Take-off field length	s_{TOFL}	**2700**	**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	**0,0002796**	**kg/m³**
Thrust-to-weight ratio	T_{TO}/m_{MTO}*g at m_{MTO}/S_W calculated from landing	**0,272**	

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

2nd Segment

Calculation of glide ratic

Aspect ratio	A	**34,8**
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	0,5
Glide ratio in take-off configuration	E_{TO}	13,68

n_E	sin(γ)
2	0,024
3	0,027
4	0,030

Calculation of thrust-to-weight ratic

Number of engines	n_E	**2**
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	T_{TO} / m_{MTO}*g	**0,194**

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

Missed approach

Calculation of the glide ratic

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	13,76

	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 ratic

Climb gradient	$\sin(\gamma)$	0,021
Thrust-to-weight ratio	T_{TO} / m_{MTO}*g	**0,172**

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

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	**0,68**	
Equivalent surface friction coefficient	$C_{f,eqv}$	**0,003**	
Factor	k_E	13,3	
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	$k_{E\ chosen}$	**13,3**	**<<<< Choose according to task**
Relative wetted area	S_{wet} / S_w	**9,1**	S_{wet} / S_w = 6,0 ... 6,2
Aspect ratio	A	34,8	(from sheet 1)
Max. glide ratio	E_{max}	**26,09**	
	or		
Max. glide ratio	$E_{max\ chosen}$	**26,09**	**<<<< 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	**15,5**
Max. glide ratio, cruise	E_{max}	26,09 (aus Teil 2)
Aspect ratio	A	34,8 (aus Teil 1)
Oswald eff. factor, clean	e	0,68
Zero-lift drag coefficient	$C_{D,0}$	0,0273
Lift coefficient at E_{max}	$C_{L,m}$	1,42
Mach number, cruise	M_{CR}	**0,55**

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

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

Parameter	Value
V/V_m	1,316074013
$C_L/C_{L,m}$	0,577
C_L	0,823
E	22,596

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	0,328	0,135	101325	1799	0,194	0,172	0,50	0,13	
1	3281	0,309	0,143	89873	1596	0,194	0,172	0,45	0,14	
2	6562	0,289	0,153	79493	1411	0,194	0,172	0,39	0,15	
3	9843	0,269	0,164	70105	1245	0,194	0,172	0,35	0,16	
4	13124	0,250	0,177	61636	1094	0,194	0,172	0,31	0,18	
5	16405	0,230	0,192	54015	959	0,194	0,172	0,27	0,19	
6	19686	0,211	0,210	47176	838	0,194	0,172	0,23	0,21	
7	22967	0,191	0,231	41056	729	0,194	0,172	0,20	0,23	
8	26248	0,172	0,258	35595	632	0,194	0,172	0,18	0,26	
9	29529	0,152	0,291	30737	546	0,194	0,172	0,15	0,29	
10	32810	0,133	0,334	26431	469	0,194	0,172	0,13	0,33	
11	36091	0,113	0,391	22627	402	0,194	0,172	0,11	0,39	
12	39372	0,094	0,473	19316	343	0,194	0,172	0,10	0,47	
13	42653	0,074	0,598	16498	293	0,194	0,172	0,08	0,60	
14	45934	0,054	0,814	14091	250	0,194	0,172	0,07	0,81	
15	49215	0,035	1,270	12035	214	0,194	0,172	0,06	1,27	
					973					0
					974					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	**973 kg/m²**	**<<<< Read design point from matching chart!**
Thrust-to-weight ratio	T_{TO} / (m_{MTO}*g)	**0,272**	**<<<<** Given data is correct when take-off and landing is sizing the aircraft at the same time.
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0,163	
Conversion factor	m -> ft	0,305 m/ft	
Cruise altitude	h_{CR}	**8465 m**	
Cruise altitude	h_{CR}	**27772 ft**	
Temperature, troposphere	$T_{Troposphäre}$	233,13 K	$T_{Stratosphäre}$ 216,65 K
Temperature, h_{CR}	$T(h_{CR})$	233,13	
Speed of sound, h_{CR}	a	306 m/s	
Cruise speed	V_{CR}	**168 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}	**1,03E-05 kg/N/s**	typical value 1,60E-05 kg/N/s
Breguet-Factor, cruise	B_s	37653593 m	
Fuel-Fraction, cruise	$M_{ff,CR}$	0,928	
Fuel-Fraction, extra fliht distance	$M_{ff,RES}$	0,990	
Loiter time	t_{loiter}	2700 s	
Spec.fuel consumption, loiter	SFC_{loiter}	**1,03E-05 kg/N/s**	
Breguet-Factor, flight time	B_t	223631 s	
Fuel-Fraction, loiter	$M_{ff,loiter}$	0,988	
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 !**

Reserve flight distance:

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

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	$M_{ff,std}$	0,906	
Fuel-Fraction, all reserves	$M_{ff,res}$	0,967	
Fuel-Fraction, total	M_{ff}	0,876	
Mission fuel fraction	m_F/m_{MTO}	0,124	
Realtive operating empty mass	m_{OE}/m_{MTO}	0,513	acc. to Loftin
Realtive operating empty mass	m_{OE}/m_{MTO}	**xxx**	from statistics (if given)
Realtive operating empty mass	m_{OE}/m_{MTO}	**0,590**	**<<<< Choose according to task**
Choose: type of a/c	short / medium range	**yes**	**<<<< Choose according to tasl**
	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**	

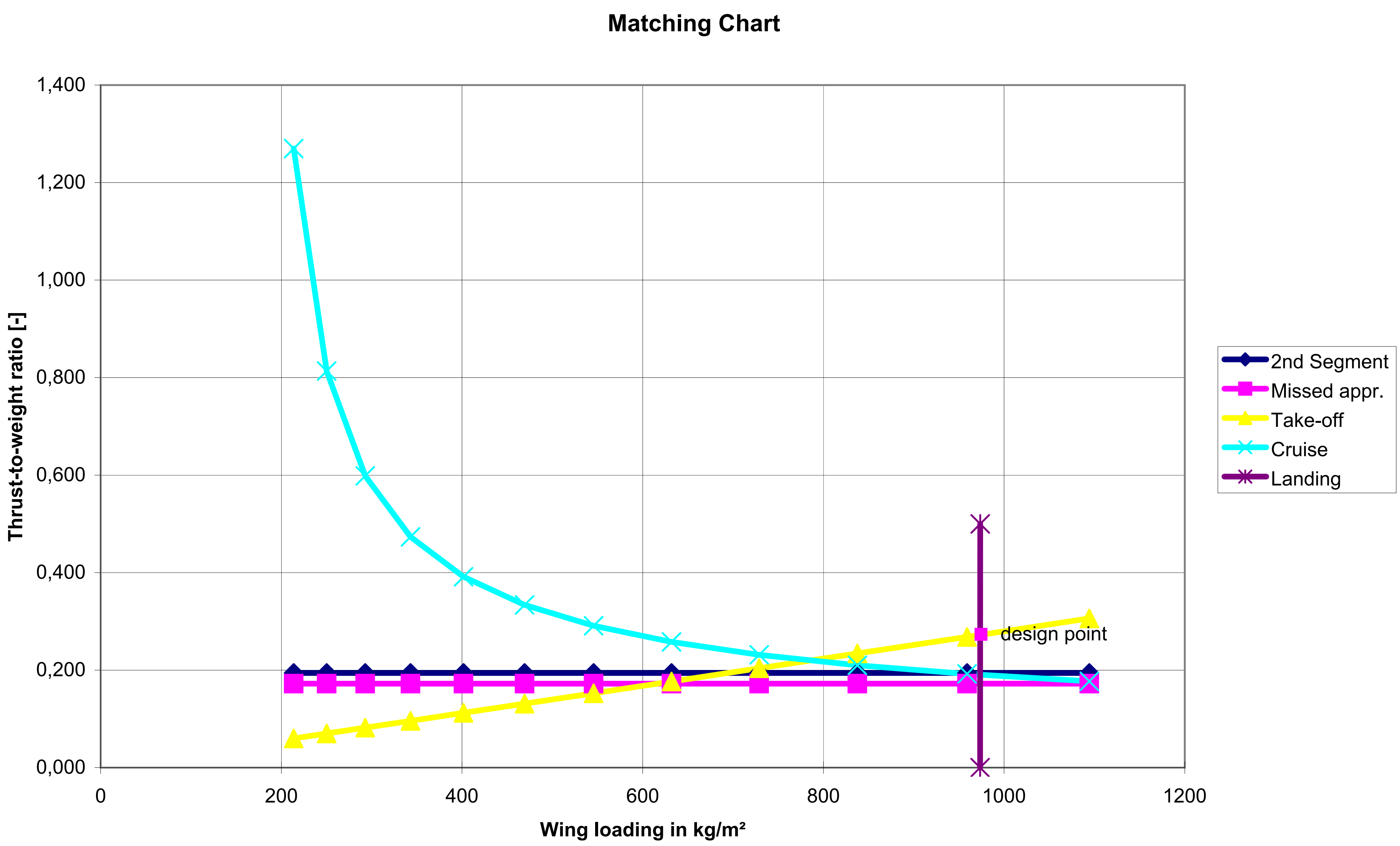
in kg	Short- and Medium Range	Long Range
m_{PAX}	93,0	97,5

			From DGLR Presentation	Delta		
Max. Take-off mass	m_{MTO}	**67308 kg**	66000 kg	2,0%		
Max. landing mass	m_{ML}	**61923 kg**				
Operating empty mass	m_{OE}	**39712 kg**	39200 kg	1,3%		
Mission fuel fraction, standard flight	m_F	**8340 kg**	7500 kg	11,2%		
Wing area	S_w	**69,1 m²**	68,0 m²	1,7%	span, b_W	49,1 m
Take-off thrust	T_{TO}	179700 N	**all engines together**			
T-O thrust of ONE engine	T_{TO} / n_E	**89850 N**	**one engine**			
T-O thrust of ONE engine	T_{TO} / n_E	20198 lb	**one engine**			

Fuel mass, needed	$m_{F,erf}$	8517 kg	
Fuel density	ρ_F	800 kg/m³	
Fuel volume, needed	$V_{F,erf}$	**10,6 m³**	(check with tank geometry later on)
Max. Payload	m_{MPL}	**19256 kg**	
Max. zero-fuel mass	m_{MZF}	58968 kg	
Zero-fuel mass	m_{ZF}	58968 kg	
Fuel mass, all reserves	$m_{F,res}$	2247 kg	

Check of assumptions	check:	m_{ML}	>	m_{ZF} + $m_{F,res}$	**?**
		61923 kg	>	61214 kg	
			yes		

Aircraft sizing finished!


Matching Chart
Thrust-to-weight ratio [-]
0,000
0,200
0,400
0,600
0,800
1,000
1,200
1,400
0
200
400
600
800
1000
1200
Wing loading in kg/m²
design point
2nd Segment
Missed appr.
Take-off
Cruise
Landing

Task 2.2

phi_25 = LN(1/0,45)*(-1/0,037) = **-21,6 °** $\lambda_{opt} = 0.45 \cdot e^{-0.0375\varphi_{25}}$

GAMMA = -7,46*1 + 0,115*21,58+6,91 = **1,9 °** $\Gamma = \frac{\partial \Gamma}{\partial k_{Z,W}} \cdot k_{Z,W} + \frac{\partial \Gamma}{\partial \varphi_{25}} \cdot \varphi_{25} + \Gamma_0$

Table 2.20 Values for the derivatives in Equation (2.80)

	Own	Raymer
$\frac{\partial \Gamma}{\partial k_{Z,W}}$	- 7.46°	- 7°
$\frac{\partial \Gamma}{\partial \varphi_{25}}$	- 0.115	- 0.1
Γ_0	6.91°	6°

Task 2.3

e = **0,747**

$$e = e_{theo} \cdot k_{e,F} \cdot k_{e,D_0} \cdot k_{e,M}$$

e_theo = **0,868**

$$e_{theo} = \frac{1}{1 + f(\lambda - \Delta\lambda) \cdot A}$$

$$f(\lambda) = 0.0524\,\lambda^4 - 0.15\lambda^3 + 0.1659\lambda^2 - 0.0706\lambda + 0.0119$$

f(lam - DEL_lam) = 0,004356422

lam - DEL_lam = 0,157

DELTA_lambda = 0,093

$$\Delta\lambda = -0.357 + 0.45 \cdot e^{0.0375\varphi_{25}}$$

k_e,F = 1 - 2*(4/49)^2 = **0,987**

$$k_{e,F} = 1 - 2\left(\frac{d_F}{b}\right)^2$$

Table 2.4 $k_{e,F}$ and k_{e,D_0} factors for each aircraft category

d_F = 4 m and M = 0.55 =>

Aircraft category	d_F / b	$k_{e,F}$	k_{e,D_0}
All	0.115	0.974	-
Jet	0.116	0.973	0.873

$$k_{e,M} = \begin{cases} a_e\left(\dfrac{M}{M_{comp}} - 1\right)^{b_e} + 1, & M > M_{comp} \\ 1, & M \le M_{comp} \end{cases}$$

$$\boxed{\begin{aligned} a_e &= -0.001521 \\ b_e &= 10.82 \end{aligned}}$$

M_{comp} stands for compressibility Mach number and has the constant value of 0.3.

k_e,M = -0,001521*(0,55/0,3 - 1)^10,82 + 1 = **0,99979**

Task 2.4

$$C_{D0} = \sum_{c=1}^{n} C_{f,c} \cdot FF_c \cdot Q_c \cdot \frac{S_{wet,c}}{S_{ref}}$$

C_D,0_F / (l_F*d_F) is proportional to FF_F * Swet_F / (l_F*d_F) => minimum

$$FF_F = 1 + \frac{60}{(l_F / d_F)^3} + \frac{(l_F / d_F)}{400}$$

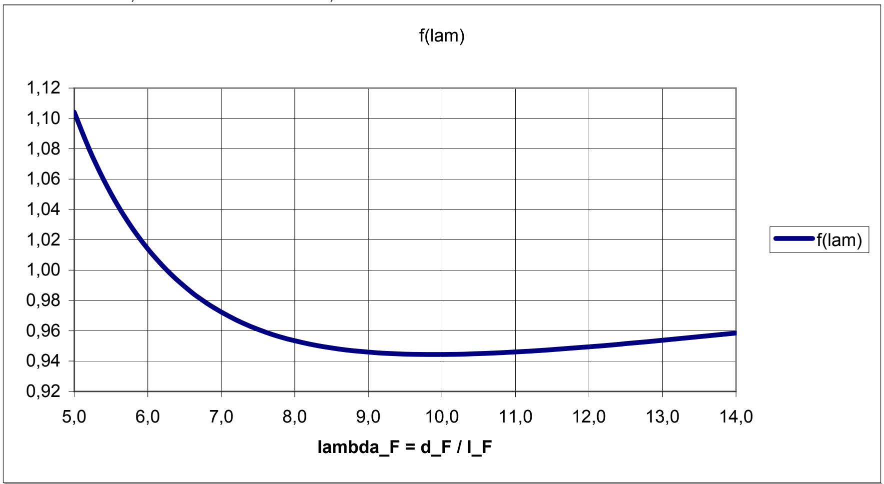
$$S_{wet,F} = \pi \cdot d_F \cdot l_F \cdot \left(1 - \frac{2}{\lambda_F}\right)^{2/3} \left(1 + \frac{1}{\lambda_F^{\,2}}\right)$$

f(lam) = (1 + 60/lam^3+lam/400) * (1 - 2/lam)^(2/3)*(1 + 1/lam^2) => min

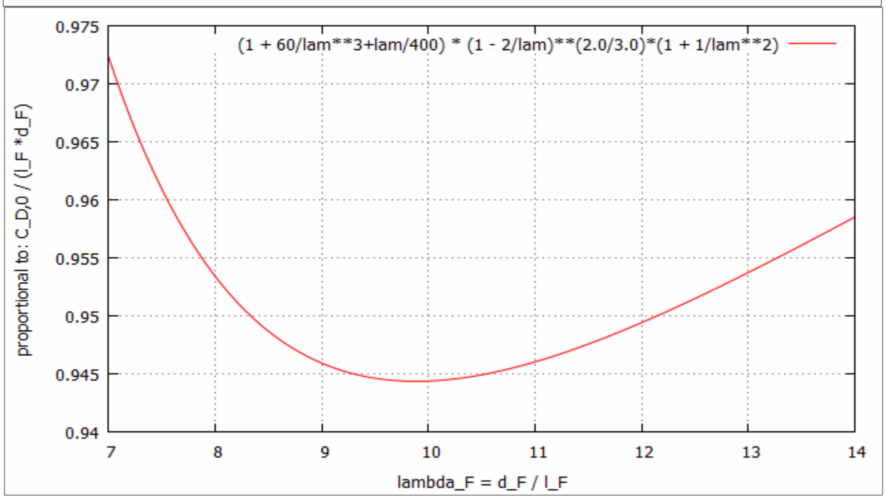
lam = 9,88 with Solver
f(lam) = 0,94435 => minimum

lam	f(lam)
5,0	1,1042
5,2	1,0801
5,4	1,0596

Plots:



with Excel



with gnuplot