HAW HAMBURG

DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Prof. Dr.-Ing. Dieter Scholz, MSME

Solution (in Part) of Flugzeugentwurf / Aircraft Design SS 2022

Date: 12.07.2022

1. Part

41 points, 60 minutes, closed books

1.5) An aircraft A is designed for a payload $m_{PL,A}$. Based on the same technology, an aircraft B has to be designed with $m_{PL,B} = 2\ m_{PL,A}$. Calculate $m_{MTO,B}\ /\ m_{MTO,A}$ or comment!

This follows directly from "First Law of Aircraft Design"

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

"Based on the same technology" means the denominator is the same for A and B. Hence MTOM is proportional to payload and $m_{MTO,B}$ / $m_{MTO,A}$ = 2.

1.6) An aircraft A is designed for a range R_A . Based on the same technology, an aircraft B has to be designed with $R_B = 2\ R_A$. Calculate $m_{MTO,B}\ /\ m_{MTO,A}$ or comment!

In this case it is not so easy to come to solution. Here payload for A and B is the same and $m_{MTO,B}$ / $m_{MTO,A}$ follows from the ratio of the denominator that need to be calculated. It may well be that there is no solution at all, if with increasing range the denominator gets zero or even negative.

1.7) What is the safety factor used to define the landing field length?

Lecture notes Section 5.1:
1/0.6 = 1.667 for jets and 1/0.7 = 1.429 for turboprops

1.8) What is the safety factor used to define the take-off field length, considering the case of all engines operative, AEO?

Lecture notes Section 5.2 (CS-25.133 (a)(2)): 1.15

1.9) A missed approach climb is pretty tough. Why? What are the two facts that help to make the missed approach climb bearable? *You may want to refer to the equation to calculate thrust-to-weight ratio for missed approach.*

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

sin γ is reduced by 0.3%-points compared to 2nd segment climb (i.e. from 2.4% to 2.1%, from 2.7% to 2.4%, from 3.0% to 2.7%). The aircraft is less heavy on landing. This means, the last term m_{ML} / m_{MTO} < 1 helps as well.

1.10) An aircraft has to be designed for 225 passengers. For the future a stretch is envisaged. Decide on the number of seats abreast in economy class. How many aisles does the aircraft need? How many flight attendants does the aircraft need?

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

Following this equation n_{SA} = 6.75, which is rounded up to 7.
Starting with 7 seats abreast, two aisles are necessary.
50 cabin crew for each new 50 passengers, means here: 5 cabin crew.

1.11) How many passengers (maximum number) can the "ZEROe" aircraft carry based on its door arrangement? *See picture!*

Assuming the largest door: a Type A door. A pair of Type A doors can evacuate 110 passengers (CS25.807).

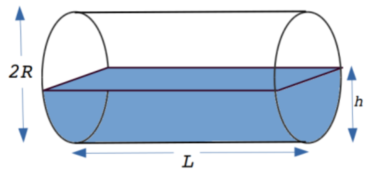
Remark:
1.) Airbus claims the aircraft will carry 200 passengers.
2.) Considering the proportions of the shown aircraft, not even 110 passengers, but more likely only about 20 will fit into the aircraft.

1.12) What are the ditching requirements with respect to sill (German: Schwelle) height?

The door sill has to be above the water line when the aircraft floats (CS 25.807 (e)(1)).

1.13) How do we calculate (in a first step), whether an aircraft is designed correctly to satisfy ditching requirements or not?

The maximum of the displaced volume, V_{disp} of the fuselage cylinder below the cabin floor is calculated.



Only as background and written reference:

The maximum buoyancy, B that can be achieved before the water flows into the cabin is

$B = \rho \, V_{disp} \, g$, ρ: density of water, g: earth acceleration

$V_{disp} = L \, (R^2 \cos^{-1}((R-h)/R) - (R-h)(2Rh-h^2)^{0.5})$

Aircraft weight, $W = m \, g$ must be less than buoyancy, B in order for the aircraft to float.

1.14) How is the tail volume coefficient defined for horizontal and vertical tails?

1.15) What is a (standard) dorsal fin? *Please add a little drawing to your answer!* What is the purpose of a dorsal fin?

1.16) What is a "round edge dorsal fin"? *Please add a little drawing to your answer!*

1.17) What are the design alternatives (*name two*) to a dorsal fin?

Find the answers in my paper "Empennage Sizing with the Tail Volume ..."
https://doi.org/10.13111/2066-8201.2021.13.3.13

1.18) A particular Airbus passenger aircraft may have a cruise Mach number of 0.82. What is its drag divergence Mach number? What is its wave drag coefficient at that Mach number? How is the Mach number called at which the wave drag is just reduced to zero?

$M_{DD} = M_{CR}$

Wave drag at M_{DD} is by definition 0,0020.

The Mach number at which wave drag just starts
is the critical Mach number, M_{crit}.

1.19) For what purpose is dihedral used in aircraft design?

Dihedral (the V-shape of the wing) is used to increase stability in roll and to achieve ground clearance of wing, engine, and/or propellers.

1.20) As a rule of thumb: How many kilogram maximum take-off mass can be carried by one main landing gear wheel?

30 t for large aircraft and 20 t for small aircraft.

1.21) What is meant by "rigid pavement" and "flexible pavement"?

"rigid pavement" has a concrete top and "flexible pavement" has an asphalt top surface.

1.22) What do we learn from Swedish crispbread (Swedish: knäckebröd / hårdbröd) when it comes to main landing gear design for rigid pavement?

Swedish crispbread is a good example to explain rigid pavement. A single wheel load (load on one spot) could lead to cracking of the rigid pavement, whereas the same load from one landing gear leg distributed over two, four, or even six wheels is less damaging for the rigid pavement.

1.23) An aircraft has a tire pressure of 200 psi. What is the pressure exerted on the ground?

200 psi.

1.24) Describe the minimum-effort path (from the lecture) to zero-lift drag coefficient estimation!

1.) Estimate maximum glide ratio, E_{max}.
2.) Estimate Oswald factor, e.
3.) Calculate zero-lift drag coefficient, C_{D0}.

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

1.25) Which parameter can be minimized in preliminary aircraft sizing to approximate minimization of Direct Operating Costs (DOC)? Explain why!

DOC

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

cannot be calculated in preliminary aircraft sizing due to missing input values. A good proxy (substitute, representative) for DOC to be minimized in aircraft design optimization is maximum take-off mass.

$$m_{MTO} = m_{PL} + m_F + m_{OE}$$

- Payload is given and constant. It does not change the minimum of the maximum take-off mass. Hence payload can be ignored here.
- Fuel mass is proportional to fuel costs and should be minimized.
- Operating empty mass drives production costs, aircraft price and depreciation. It should also be minimized.

Maximum take-off mass as a proxy for DOC in aircraft design optimization is better than fuel mass or operating empty mass alone, because it resembles two important DOC cost components instead of only one.

Questions from the Evening Lectures

1.26) We look at Effective Radiative Forcing, ERF from kerosene combustion. What is the share of a) CO2, b) contrails and resulting contrail cirrus, c) consequences of NOx emissions?

```
a) CO2:        1/3 = 2/6
b) Contrails:  1/2 = 3/6
c) NOx:        1/6
```

1.27) Less than 12% of the flights cause 80% of the contrail forcing! *Complete!*

1.28) Contrails are warming during the night, whereas contrails may be cooling during the day.

1.29) We look at Effective Radiative Forcing, ERF from hydrogen combustion. What is the share of a) CO2-emissions, b) none-CO2 emissions?

```
a)     0%
b)   100%
```

1.30) Which statement(s) is(are) correct? *Several (or even all) statements may be correct*.

a) Kerosene consists of hydrocarbons (CxHy), hydrogen is H2. This means that the combustion of hydrogen produces 2.56 times as much water and thus potentially more (sometimes warming) clouds could form (with the same amount of energy).

b) In principle, there are no contrails or cloud formation in an aircraft operated with LH2, because hydrogen aircraft are characterized by "zero emissions" (ZEROe).

c) Hydrogen burns without soot and thus without condensation nuclei. The water from the combustion condenses on the few condensation nuclei in the atmosphere. Assumption: If the radius of the ice crystals (imagined as a sphere) is 3.33 times as large as a result, then the volume is 3.33 . 3.33. 3.33 = 37 times as large and the cross-section of the sphere is 3.33. 3.33 = 11 times as large. Together, the sky is covered by only 11/37 · 2.56 = 76% compared to burning kerosene (with the same amount of energy).

1.31) Sustainable aviation fuel (SAF) differs chemically little from conventional kerosene. How should SAF become sustainable? What effects on global warming remain?

```
SAF should become sustainable with the "carbon cycle".
a) Biofuel: plants capture CO2, are converted to fuel, fuel is burned, CO2
   is released.
b) E-fuel: CO2 is caputured from the air (Direct Air Capture, DAC), CO2 is
   converted to fuel (with regenerative energy), fuel is burned, CO2 is re-
   leased.

Non-CO2 effects (contrails with contrail cirrus and NOx) remain.

Details of the carbon cycle and SAF (e-fuel) production in "Bild 8" (below)
from https://purl.org/aero/PR2021-07-03.
```

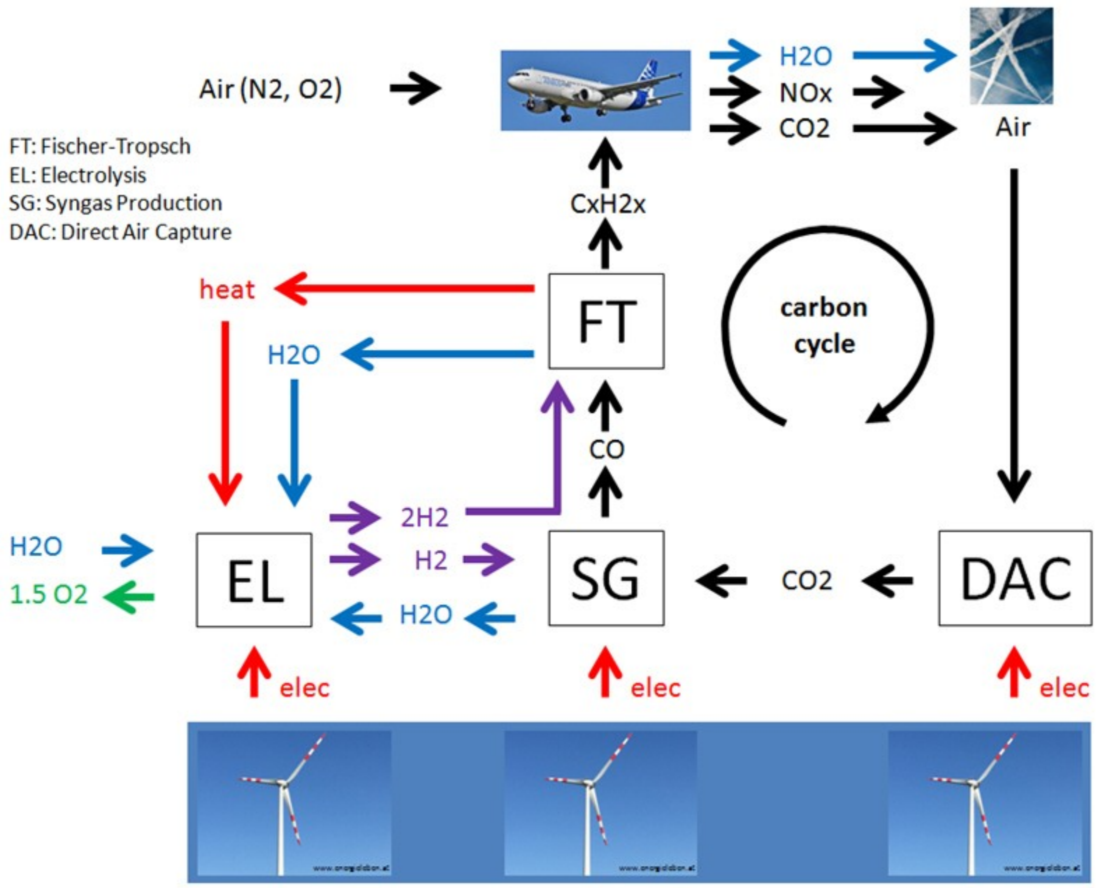


Bild 8: Herstellung von synthetischem Kerosin (E-Fuel) mit Power-to-Liquid (PtL). Durch die Entnahme von CO2 aus der Luft (Direct Air Capture, DAC) wird ein Kohlenstoffkreislauf (Carbon Cycle) ermöglicht. Gleichungen siehe Verdegaal 2015.

1.32) The aircraft recycling market matures. Publication of guidance material for best practices are published by associations like ....

Aircraft Fleet Recycling Association (AFRA) – founded by Boeing.

1.33) How can an aircraft or an aircraft component be given a second life? *Name six ways!*

In contrast to common disposal and recycling strategies, there are special reuse approaches.

1.) A general idea is to give an aircraft component a second life outside of aviation:

- raw parts for collectors or used for similar purpose (pump, electric motor, seat),
- art work from aircraft parts (wall decoration, sculpture),
- polished and extended parts for a new purpose (chair, table, lamp, clock).

2.) Give aircraft or fuselages with new or intact cabin interiors a second life as:

- apartment (home),
- hotel, café,
- registry office,
- eye-catcher, monument or aircraft in a museum.

1.34) Due to the requirements of flight mechanics, the mass of the aircraft and the center of gravity must be kept within specified limits. Why does the position of the center of gravity have to be constantly known during loading (on the ground)? What danger is there?

- The CG during loading could move behind the position of the main gears.
- The aircraft would then rotate and tip on its tail with possible damage.

1.35) Name the four cargo compartments, which are distinguished on the A330 Freighter!

- Lower deck forward cargo compartment.
- Lower deck aft cargo compartment.
- Bulk cargo compartment.
- Main deck cargo compartment.

1.36) An Airbus A330 can be equipped with 4 tanks. Outer wing tank, inner wing tank, center tank. What is the name of the fourth tank? Where is this tank located?

It is the trim tank in the horizontal stabilizer.

Name:____________________

2. Part

49 points, 120 minutes, open books

Task 2.1 (18 points)

Redesign of an *Airbus A320* !

These are the requirements for the aircraft:

- Payload: 180 passengers with baggage (93 kg per passenger). Additional payload: 2516 kg.
- Range 1510 NM at a cruise Mach number $M_{CR} = 0.76$ (payload as above, with international reserves as given in FAR Part 121, with 5% extra fuel on distance flown, distance to alternate: 200 NM)
- Take-off field length $s_{TOFL} \leq$ 1768 m (ISA, MSL)
- Landing field length $s_{LFL} \leq 1448$ m (ISA, MSL)
- 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.
- Maximum lift coefficient of the aircraft in landing configuration $C_{L,max,L}= 3.41$
- Maximum lift coefficient of the aircraft in take-off configuration $C_{L,max,TO} = 2.58$
- The glide ratio is to be calculated for take-off and landing with $C_{D0} = 0.02$ and Oswald factor $e = 0.7$
- Oswald factor in cruise $e = 0.783$
- Aspect ratio $A = 9.5$
- Maximum glide ratio in cruise, $E_{max} = 17.48$
- The ratio of cruise speed and speed for minimum drag V_{CR}/V_{md} has to be found such that a favorable matching chart is obtained. Find V_{CR}/V_{md} with two digits after the decimal place
- The ratio of maximum landing mass and maximum take-off mass $m_{ML}/m_{MTO} = 0.878$
- The operating empty weight ratio is $m_{OE} / m_{MTO} = 0.56$
- The by-pass ratio (BPR) of the two CFM56 engines is $\mu = 6$; their thrust specific fuel consumption for cruise and loiter is $c = 16.5$ mg/(Ns).
- Use these values as Mission-Segment Fuel Fractions: Engine start: 0.997; Taxi: 0.993; Take-off: 0.993; Climb: 0.993; Descent: 0.993; Landing: 0.993.

Results for task 2.1

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

- Wing loading from landing field length: 602 kg/m²
- Thrust to weight ratio from take-off field length (at wing loading from landing): 0,309
- Glide Ratio in 2. Segment: 8,60
- Glide Ratio during missed approach maneuver: 7,32
- Thrust to weight ratio from climb requirement in 2. Segment: 0,280
- Thrust to weight ratio from climb requirement during missed approach maneuver: 0,277
- V_{CR}/V_{md}: 0,9484
- Design point
  - Thrust to weight ratio : 0,309
  - Wing loading: 602 kg/m²
- Cruise altitude: 38808 ft = 11829 m
- maximum take-off mass: 73538 kg
- maximum landing mass: 64567 kg
- wing area: 122,2 m²
- thrust of one engine **in lb**: 25031 lb
- required tank volume **in m³**: 17,1 m³

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

Label your line in the legend on the right of the matching chart. Here is your translation:

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

1.) Peliminary Sizing I

Calculations for flight phases approach, landing, tak-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: A320-200, see SAS

Approach

Factor	k_{APP}	1.70	$(m/s^2)^{0.5}$
Conversion factor	m/s -> kt	1.944	kt / m/s

Given: landing field length		**yes**	**<<<< Choose according to task**
Landing field length	s_{LFL}	**1448**	**m**
Approach speed	V_{APP}	64.8	m/s
Approach speed	V_{APP}	**125.9**	**kt**

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

Given: approach speed		**no**	
Approach speed	V_{APP}	**125.9**	**kt**
Approach speed	V_{APP}	64.8	m/s
Landing field length	s_{LFL}	**1448**	**m**

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

Landing

Landing field length	s_{LFL}	1448	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	$C_{L,max,L}$	**3.4100**		A320:
Mass ratio, landing - take-off	m_{ML} / m_{TO}	**0.878**		0.878
Wing loading at max. landing mass	m_{ML} / S_W	**528**	**kg/m²**	
Wing loading at max. take-off mass	m_{MTO} / S_W	**602**	**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}	1768	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 * $C_{L,max,L}$	2.728	
Max. lift coefficient, take-off	$C_{L,max,TO}$	2.58	
Slope	a	0.0005130	kg/m³
Thrust-to-weight ratio	T_{TO}/m_{MTO}*g at m_{MTO}/S_W calculated from landing	0.309	

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

2nd Segment

Calculation of glide ratio

Aspect ratio	A	9.5
Lift coefficient, take-off	$C_{L,TO}$	1.79
Lift-independent drag coefficient, clean	$C_{D,0}$ (bei Berechnung: 2. Segment)	0.020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0.035
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0.000
Profile drag coefficient	$C_{D,P}$	0.055
Oswald efficiency factor; landing configuration	e	0.7
Glide ratio in take-off configuration	E_{TO}	8.60

n_E	sin(γ)
2	0.024
3	0.027
4	0.030

Calculation of thrust-to-weight ratio

Number of engines	n_E	2
Climb gradient	sin(γ)	0.024
Thrust-to-weight ratio	T_{TO} / m_{MTO}*g	0.280

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

Missed approach

Calculation of the glide ratio

Lift coefficient, landing	$C_{L,L}$	2.02
Lift-independent drag coefficient, clean	$C_{D,0}$ (bei Berechnung: Durchstarten)	0.020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0.046
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	$C_{D,P}$	0.081
Glide ratio in landing configuration	E_L	7.32

<<<< Choose according to task

	JAR-25 bzw. CS-25	FAR Part 25
$\Delta C_{D,gear}$	0.000	0.015

Calculation of thrust-to-weight ratio

Climb gradient	$\sin(\gamma)$	0.021
Thrust-to-weight ratio	$T_{TO} / m_{MTO}*g$	**0.277**

n_E	$\sin(\gamma)$
2	0.021
3	0.024
4	0.027

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

2.) Max. Glide Ratio in Cruise

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

1.) From theory			
Oswald efficiency factor for k_E	e	**0.783**	**<<<< Choose according to task**
Equivalent surface friction coefficient	$C_{f,eqv}$	**0.003**	**<<<< Choose according to task**
Factor	k_E	14.3	
2.) Acc. to RAYMER			
Factor	k_E	15.8	
3.) From own statistics			
Factor	k_E	**14.2**	**<<<< Choose according to task**

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

Factor	$k_{E\ chosen}$	**14.2**	**<<<< Choose according to task**
Relative wetted area	S_{wet} / S_w	**6.27**	**<<<< Choose according to task**
Aspect ratio	A	9.5	(from sheet 1)
Max. glide ratio	E_{max}	**17.48**	
	or		
Max. glide ratio	$E_{max\ chosen}$	**17.480**	**<<<< 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	6	
Max. glide ratio, cruise	E_{max}	17.48	(aus Teil 2)
Aspect ratio	A	9.5	(aus Teil 1)
Oswald eff. factor, clean	e	0.783	
Zero-lift drag coefficient	$C_{D,0}$	0.019	
Lift coefficient at E_{max}	$C_{L,m}$	0.67	
Mach number, cruise	M_{CR}	0.76	

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

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

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	

Parameter	Value
Estimated V/V_m	0.9484
$C_L/C_{L,m}$	1.112
C_L	0.743
E	17.383
Density	0.319162675
Vm	235.1236257
Vcr	224.2886598
Real Vcr/Vm	0.953918005

Jet, Theory, Optimum: 1.316074013

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

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

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

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

Altitude		Cruise				2nd Segment	Missed appr.	Take-off	Cruise
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
0	0	0.564	0.102	101325	3103	0.280	0.277	1.59	0.10
1	3281	0.532	0.108	89873	2752	0.280	0.277	1.41	0.11
2	6562	0.500	0.115	79493	2435	0.280	0.277	1.25	0.12
3	9843	0.468	0.123	70105	2147	0.280	0.277	1.10	0.12
4	13124	0.436	0.132	61636	1888	0.280	0.277	0.97	0.13
5	16405	0.404	0.142	54015	1654	0.280	0.277	0.85	0.14
6	19686	0.372	0.155	47176	1445	0.280	0.277	0.74	0.15
7	22967	0.340	0.169	41056	1257	0.280	0.277	0.65	0.17
8	26248	0.309	0.186	35595	1090	0.280	0.277	0.56	0.19
9	29529	0.277	0.208	30737	941	0.280	0.277	0.48	0.21
10	32810	0.245	0.235	26431	809	0.280	0.277	0.42	0.24
11	36091	0.213	0.270	22627	693	0.280	0.277	0.36	0.27
12	39372	0.181	0.318	19316	592	0.280	0.277	0.30	0.32
13	42653	0.149	0.386	16498	505	0.280	0.277	0.26	0.39
14	45934	0.117	0.491	14091	432	0.280	0.277	0.22	0.49
15	49215	0.085	0.675	12035	369	0.280	0.277	0.19	0.68
					602				
					602				
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

3.) Preliminary Sizing II

<<<< Read design point from matching chart!

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

Wing loading	m_{MTO} / S_W	**602**	**kg/m²**
Thrust-to-weight ratio	$T_{TO} / (m_{MTO}*g)$	**0.309**	
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0.186	
Conversion factor	m -> ft	0.305	m/ft
Cruise altitude	h_{CR}	**11829**	**m**
Cruise altitude	h_{CR}	**38808**	**ft**
Temperature, troposphere	$T_{Troposphäre}$	211.26	K
Temperature, h_{CR}	$T(h_{CR})$	216.65	
Speed of sound, h_{CR}	a	295	m/s
Cruise speed	V_{CR}	**224**	**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	**no**	
	international	**yes**	
Extra-fuel for long range		5%	
Extra flight distance	s_{res}	510226	m
Spec.fuel consumption, cruise	SFC_{CR}	**1.65E-05**	**kg/N/s**
Breguet-Factor, cruise	B_s	24086131	m
Fuel-Fraction, cruise	$M_{ff,CR}$	0.890	
Fuel-Fraction, extra fliht distance	$M_{ff,RES}$	0.979	
Loiter time	t_{loiter}	1800	s
Spec.fuel consumption, loiter	SFC_{loiter}	**1.65E-05**	**kg/N/s**
Breguet-Factor, flight time	B_t	107389	s
Fuel-Fraction, loiter	$M_{ff,loiter}$	0.983	
Fuel-Fraction, engine start	$M_{ff,engine}$	**0.997**	**<<<< Copy**
Fuel-Fraction, taxi	$M_{ff,taxi}$	**0.993**	**<<<< values**
Fuel-Fraction, take-off	$M_{ff,TO}$	**0.993**	**<<<< from**
Fuel-Fraction, climb	$M_{ff,CLB}$	**0.993**	**<<<< table**
Fuel-Fraction, descent	$M_{ff,DES}$	**0.993**	**<<<< on the**
Fuel-Fraction, landing	$M_{ff,L}$	**0.993**	**<<<< right !**

11900 m		-0.60%
39100 ft		-0.75%
$T_{Stratosphäre}$	216.65	K

Reserve flight distance:

FAR Part 121	s_{res}	
domestic	370400	m
international	510226	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	0.998	0.998
descent	0.990	0.990
landing	0.992	0.992

Fuel-Fraction, standard flight	$M_{ff,std}$	0.866				
Fuel-Fraction, all reserves	$M_{ff,res}$	0.949				
Fuel-Fraction, total	M_{ff}	0.822				
Mission fuel fraction	m_F/m_{MTO}	0.178				
Realtive operating empty mass	m_{OE}/m_{MTO}	0.551		acc. to Loftin		
Realtive operating empty mass	m_{OE}/m_{MTO}	**0.573**	A320:	from statistics (if given)		
Realtive operating empty mass	m_{OE}/m_{MTO}	**0.560**	0.560	**<<<< 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**				

in kg	Short- and Medium Range	Long Range
m_{PAX}	93.0	97.5

			A320:	Änderung:	A320, relative:
Payload	m_{PL}	**19256 kg**	19256 kg	0.00%	
Max. Take-off mass	m_{MTO}	**73538 kg**	73500 kg	0.05%	
Max. landing mass	m_{ML}	**64567 kg**	64500 kg	0.10%	0.878
Operating empty mass	m_{OE}	**41181 kg**	41244 kg	-0.15%	0.561
Mission fuel fraction, standard flight	m_F	**13101 kg**			
Wing area	S_w	**122.2 m²**	122.4 m³	-0.16%	600 kg/m²
Take-off thrust	T_{TO}	222694 N	**all engines together**		
T-O thrust of ONE engine	T_{TO} / n_E	**111347 N**	111200 N	0.13%	0.308
T-O thrust of ONE engine	T_{TO} / n_E	25031 lb	**one engine**		
Fuel mass, needed	$m_{F,erf}$	13704 kg			
Fuel density	ρ_F	800 kg/m³			
Fuel volume, needed	$V_{F,erf}$	**17.1 m³**	(check with tank geometry later on)		
Max. Payload	m_{MPL}	**19256 kg**	19256 kg	0.00%	
Max. zero-fuel mass	m_{MZF}	60437 kg	60500 kg	-0.10%	
Fuel mass, all reserves	$m_{F,res}$	3726 kg			
Fuel mass, flight + reserves		16827			

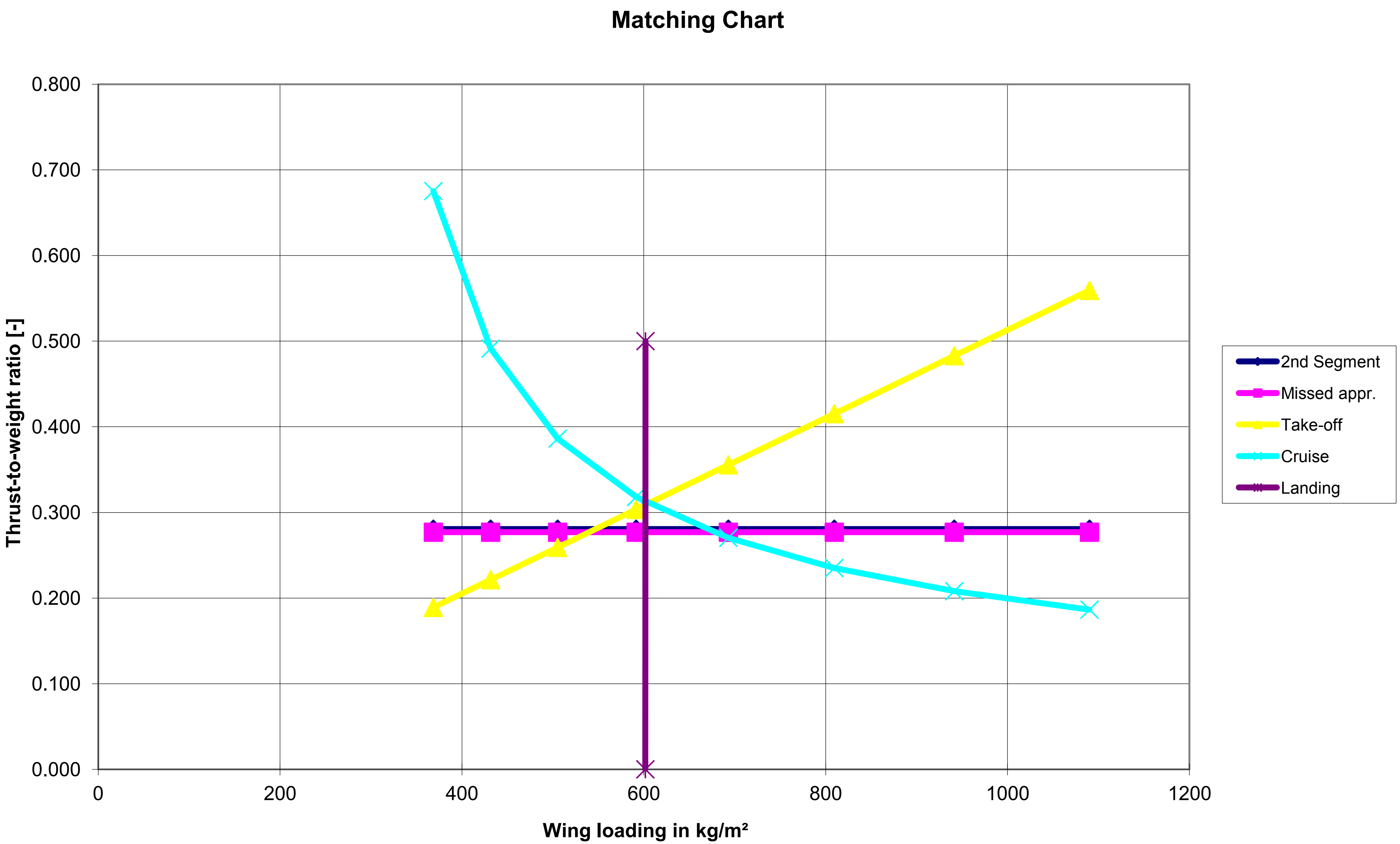
Check of assumptions check: m_{ML} > $m_{MZF} + m_{F,res}$ **?**

64567 kg > 64163 kg

yes

Aircraft sizing finished!

ramp weight	74280 kg	73900 kg	0.51%	



Matching Chart
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Thrust-to-weight ratio [-]
0
200
400
600
800
1000
1200
Wing loading in kg/m²
2nd Segment
Missed appr.
Take-off
Cruise
Landing

Task 2.2 (~~19~~ 17 points) 17

Design of a *Hydrogen (LH2) Airbus A320* !

- Maximum glide ratio in cruise is now: $E_{max} = 16.92$ (reduced by 3.2%).
- Relative operating empty mass is increased by 14%.
- The specific fuel consumption for cruise and loiter is based on the original one of $c = 16.5$ mg/(Ns). Calculate the specific fuel consumption of the hydrogen engine from the explanation below.

Hydrogen has 2.87 times more energy per mass (kg) than kerosene (Jet A-1). The inverse means that its mass is 1/2.87 = 0.35 or only 35% for the same energy. This also means that the Specific Fuel Consumption, c (SFC) of a hydrogen jet engine is only 35% of that known from a kerosene jet engine. This has nothing to do with the propulsive or thermodynamic efficiency of the engine. It is just a result from the gravimetric energy of the fuel in use.

Hints for your design:

- Mass ratio, landing - take-off: 0.95
- Max. lift coefficient, take-off: 2.45
- The ratio of cruise speed and speed for minimum drag V_{CR}/V_{md} has to be found such that a favorable matching chart is obtained. Find V_{CR}/V_{md} with two digits after the decimal place.

Results to task 2.2

- Specific fuel consumption for cruise and loiter of the hydrogen engine: $5{,}78 \cdot 10^{-6}\ \frac{kg}{Ns}$
- *Standard results from preliminary sizing (see next page "More results for task 2.2")*
- Change of parameters in % compared to the standard A320 (Task 2.1)
  - Change of max. take-off mass: − 2,49 %
  - Change of max. landing mass: + 5,50%
  - Change of operating empty mass: + 11,16 %
  - Change of fuel mass: − 49,07%
  - **Change of energy used or change of energy-equivalent kerosene fuel mass:** + 45,52%
  - Change of wing area: + 5,57%
  - Change of take-off thrust: − 5,17%

8

More results for task 2.2

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

- Wing loading from landing field length: 556 kg/m²
- Thrust to weight ratio from take-off field length (at wing loading from landing): 0,300
- Glide Ratio in 2. Segment: 9.02
- Glide Ratio during missed approach maneuver: 7,32
- Thrust to weight ratio from climb requirement in 2. Segment: 0,270
- Thrust to weight ratio from climb requirement during missed approach maneuver: 0,299
- V_{CR}/V_{md}: 1,0350
- Design point
  - Thrust to weight ratio : 0,300
  - Wing loading: 556 kg/m²
- Cruise altitude: 11485m, 37681 ft
- maximum take-off mass: 71704 kg
- maximum landing mass: 68119 kg
- wing area: 129 m²
- thrust of one engine **in lb**: 23738 Lb
- required tank volume **in m³**: 9,2 m³

Draw the matching chart and **indicate the design point in the matching chart**! 1,5

7,5

Half of the points compared to 2.1

1.) Peliminary Sizing I

Calculations for flight phases approach, landing, tak-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: A320-200, see SAS

Approach

Factor	k_{APP}	1.70	$(m/s^2)^{0.5}$
Conversion factor	m/s -> kt	1.944	kt / m/s
Given: landing field length		**yes**	**<<<< Choose according to task**
Landing field length	s_{LFL}	**1448**	**m**
Approach speed	V_{APP}	64.8	m/s
Approach speed	V_{APP}	**125.9**	**kt**
Given: approach speed		**no**	
Approach speed	V_{APP}	**125.9**	**kt**
Approach speed	V_{APP}	64.8	m/s
Landing field length	s_{LFL}	**1448**	**m**

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

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

Landing

Landing field length	s_{LFL}	1448	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	$C_{L,max,L}$	**3.4077**	
Mass ratio, landing - take-off	m_{ML} / m_{TO}	**0.950**	
Wing loading at max. landing mass	m_{ML} / S_W	**528**	**kg/m²**
Wing loading at max. take-off mass	m_{MTO} / S_W	**556**	**kg/m²**

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

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

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

A320:
0.878

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}	1768	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 * $C_{L,max,L}$	2.72616	
Max. lift coefficient, take-off	$C_{L,max,TO}$	2.45	
Slope	a	0.0005402	kg/m³
Thrust-to-weight ratio	T_{TO}/m_{MTO}*g at m_{MTO}/S_W calculated from landing	0.300	

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

2nd Segment

Calculation of glide ratio

Aspect ratio	A	9.5
Lift coefficient, take-off	$C_{L,TO}$	1.70
Lift-independent drag coefficient, clean	$C_{D,0}$ (bei Berechnung: 2. Segment)	0.020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0.030
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0.000
Profile drag coefficient	$C_{D,P}$	0.050
Oswald efficiency factor; landing configuration	e	0.7
Glide ratio in take-off configuration	E_{TO}	9.02

n_E	sin(γ)
2	0.024
3	0.027
4	0.030

Calculation of thrust-to-weight ratio

Number of engines	n_E	2
Climb gradient	sin(γ)	0.024
Thrust-to-weight ratio	T_{TO} / m_{MTO}*g	0.270

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

Missed approach

Calculation of the glide ratio

Lift coefficient, landing	$C_{L,L}$	2.02
Lift-independent drag coefficient, clean	$C_{D,0}$ (bei Berechnung: Durchstarten)	0.020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0.046
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	$C_{D,P}$	0.081
Glide ratio in landing configuration	E_L	7.32

	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	$\sin(\gamma)$	0.021
Thrust-to-weight ratio	$T_{TO} / m_{MTO}*g$	**0.299**

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

2.) Max. Glide Ratio in Cruise

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

1.) From theory			
Oswald efficiency factor for k_E	e	**0.783**	**<<<< Choose according to task**
Equivalent surface friction coefficient	$C_{f,eqv}$	**0.003**	**<<<< Choose according to task**
Factor	k_E	14.3	
2.) Acc. to RAYMER			
Factor	k_E	15.8	
3.) From own statistics			
Factor	k_E	**14.2**	**<<<< Choose according to task**

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

Factor	k_E chosen	**13.7456**	**<<<< Choose according to task**
Relative wetted area	S_{wet} / S_w	**6.27**	**<<<< Choose according to task**
Aspect ratio	A	9.5	(from sheet 1)
Max. glide ratio	E_{max}	**16.92**	
	or		
Max. glide ratio	$E_{max\ chosen}$	**16.92**	**<<<< 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	6	
Max. glide ratio, cruise	E_{max}	16.92	(aus Teil 2)
Aspect ratio	A	9.5	(aus Teil 1)
Oswald eff. factor, clean	e	0.783	
Zero-lift drag coefficient	$C_{D,0}$	0.020	
Lift coefficient at E_{max}	$C_{L,m}$	0.69	
Mach number, cruise	M_{CR}	0.76	

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

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

Parameter	Value
Estimated V/V_m	1.0350
$C_L/C_{L,m}$	0.934
C_L	0.645
E	16.880
Density	0.336931423
Vm	216.369308
Vcr	224.2886598
Real Vcr/Vm	1.036601087

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
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
0	0	0.564	0.105	101325	2692	0.270	0.299	1.45	0.11
1	3281	0.532	0.111	89873	2388	0.270	0.299	1.29	0.11
2	6562	0.500	0.119	79493	2112	0.270	0.299	1.14	0.12
3	9843	0.468	0.127	70105	1863	0.270	0.299	1.01	0.13
4	13124	0.436	0.136	61636	1638	0.270	0.299	0.88	0.14
5	16405	0.404	0.147	54015	1435	0.270	0.299	0.78	0.15
6	19686	0.372	0.159	47176	1253	0.270	0.299	0.68	0.16
7	22967	0.340	0.174	41056	1091	0.270	0.299	0.59	0.17
8	26248	0.309	0.192	35595	946	0.270	0.299	0.51	0.19
9	29529	0.277	0.214	30737	817	0.270	0.299	0.44	0.21
10	32810	0.245	0.242	26431	702	0.270	0.299	0.38	0.24
11	36091	0.213	0.278	22627	601	0.270	0.299	0.32	0.28
12	39372	0.181	0.327	19316	513	0.270	0.299	0.28	0.33
13	42653	0.149	0.398	16498	438	0.270	0.299	0.24	0.40
14	45934	0.117	0.506	14091	374	0.270	0.299	0.20	0.51
15	49215	0.085	0.695	12035	320	0.270	0.299	0.17	0.70
					556				
					556				
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

3.) Preliminary Sizing II

Wing loading	m_{MTO} / S_W	556	kg/m²
Thrust-to-weight ratio	T_{TO} / (m_{MTO}*g)	0.300	
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0.197	
Conversion factor	m -> ft	0.305	m/ft
Cruise altitude	h_{CR}	11485	m
Cruise altitude	h_{CR}	37681	ft
Temperature, troposphere	$T_{Troposphäre}$	213.50	K
Temperature, h_{CR}	$T(h_{CR})$	216.65	
Speed of sound, h_{CR}	a	295	m/s
Cruise speed	V_{CR}	224	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	no	
	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	s_{res}	510226	m
Spec.fuel consumption, cruise	SFC_{CR}	5.78E-06	kg/N/s
Breguet-Factor, cruise	B_s	66826840	m
Fuel-Fraction, cruise	$M_{ff,CR}$	0.959	
Fuel-Fraction, extra fliht distance	$M_{ff,RES}$	0.992	
Loiter time	t_{loiter}	1800	s
Spec.fuel consumption, loiter	SFC_{loiter}	5.78E-06	kg/N/s
Breguet-Factor, flight time	B_t	297950	s
Fuel-Fraction, loiter	$M_{ff,loiter}$	0.994	
Fuel-Fraction, engine start	$M_{ff,engine}$	0.997	**<<<< Copy**
Fuel-Fraction, taxi	$M_{ff,taxi}$	0.993	**<<<< values**
Fuel-Fraction, take-off	$M_{ff,TO}$	0.993	**<<<< from**
Fuel-Fraction, climb	$M_{ff,CLB}$	0.993	**<<<< table**
Fuel-Fraction, descent	$M_{ff,DES}$	0.993	**<<<< on the**
Fuel-Fraction, landing	$M_{ff,L}$	0.993	**<<<< right !**

<<<< Read design point from matching chart!

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

11900	m	-3.49%
39100	ft	-3.63%

$T_{Stratosphäre}$ 216.65 K

Reserve flight distance:

FAR Part 121	s_{res}	
domestic	370400	m
international	510226	m

typical value 1.60E-05 kg/N/s

k_SFC	0.35

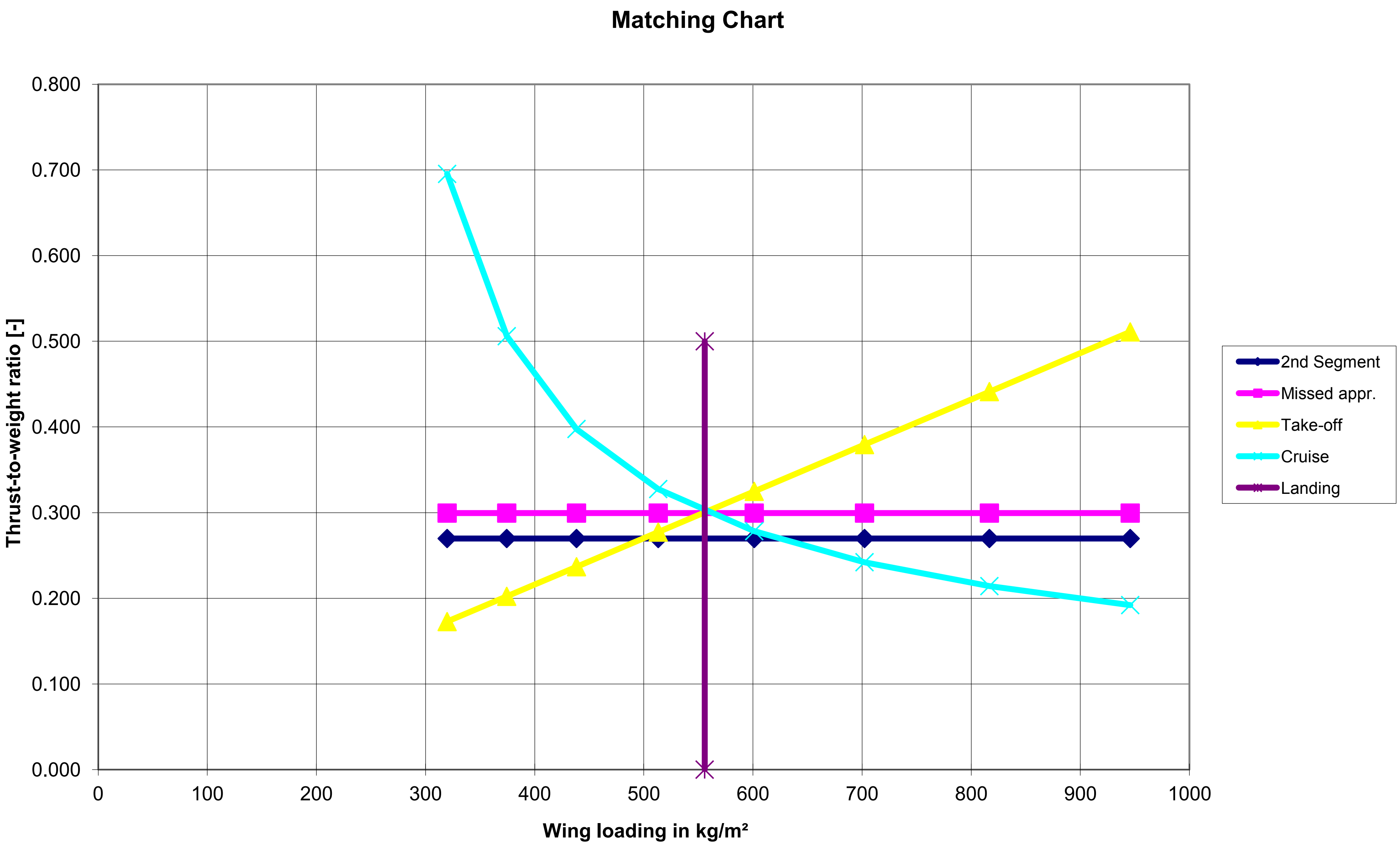
Extra time:

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	0.998	0.998
descent	0.990	0.990
landing	0.992	0.992

3.) Preliminary Sizing II

Fuel-Fraction, standard flight	$M_{ff,std}$	0.932					
Fuel-Fraction, all reserves	$M_{ff,res}$	0.973					
Fuel-Fraction, total	M_{ff}	0.907					
Mission fuel fraction	m_F/m_{MTO}	0.093					
Realtive operating empty mass	m_{OE}/m_{MTO}	0.542		acc. to Loftin			
Realtive operating empty mass	m_{OE}/m_{MTO}	**0.573**	A320:	from statistics (if given)			
Realtive operating empty mass	m_{OE}/m_{MTO}	**0.638**	0.560	**<<<< Choose according to task**		k_MOE	1.14
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		in kg	Short- and Medium Range	Long Range	
Number of passengers	n_{PAX}	**180**		m_{PAX}	93.0	97.5	
Cargo mass	m_{cargo}	**2516 kg**		A320-Nachentwurf:	Änderung:		
Payload	m_{PL}	**19256 kg**		19256 kg	0.00%		
Max. Take-off mass	m_{MTO}	**71704 kg**		73538 kg	-2.49%	A320, relative:	
Max. landing mass	m_{ML}	**68119 kg**		64567 kg	5.50%	0.878	
Operating empty mass	m_{OE}	**45776 kg**		41181 kg	11.16%	0.560	
Fuel mass, standard flight, LH2	m_F	**6672 kg**		13101 kg	-49.07%		
Energy-equivalent fuel mass, kerosene		**19064 kg**		13101 kg	45.52%	This gives an idea of the fuel costs!	
Wing area	S_w	**129.0 m²**		122.2 m³	5.57%	602 kg/m²	
Take-off thrust	T_{TO}	211190 N		**all engines together**			
T-O thrust of ONE engine	T_{TO} / n_E	**105595 N**		111347 N	-5.17%	0.309	
T-O thrust of ONE engine	T_{TO} / n_E	23738 lb		**one engine**			
Fuel mass, needed	$m_{F,erf}$	7321 kg					
Fuel density	ρ_F	800 kg/m³					
Fuel volume, needed	$V_{F,erf}$	**9.2 m³**		(check with tank geometry later on)			
Max. Payload	m_{MPL}	**19256 kg**		19256 kg	0.00%		
Max. zero-fuel mass	m_{MZF}	65032 kg		60500 kg	7.49%		
Fuel mass, all reserves	$m_{F,res}$	1961 kg					
Fuel mass, flight + reserves		8633					
Check of assumptions	check:	m_{ML}		>	$m_{MZF} + m_{F,res}$ **?**		
		68119 kg		>	66993 kg		
				yes			
				Aircraft sizing finished!			
ramp weight		72427 kg		73900 kg	-1.99%		



Matching Chart
Thrust-to-weight ratio [-]
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
800
900
1000
Wing loading in kg/m²
2nd Segment
Missed appr.
Take-off
Cruise
Landing

Task 2.3 (2 points)

Airbus claimes (https://perma.cc/FP8M-JYPD)

"The widest single-aisle cabin in the sky"

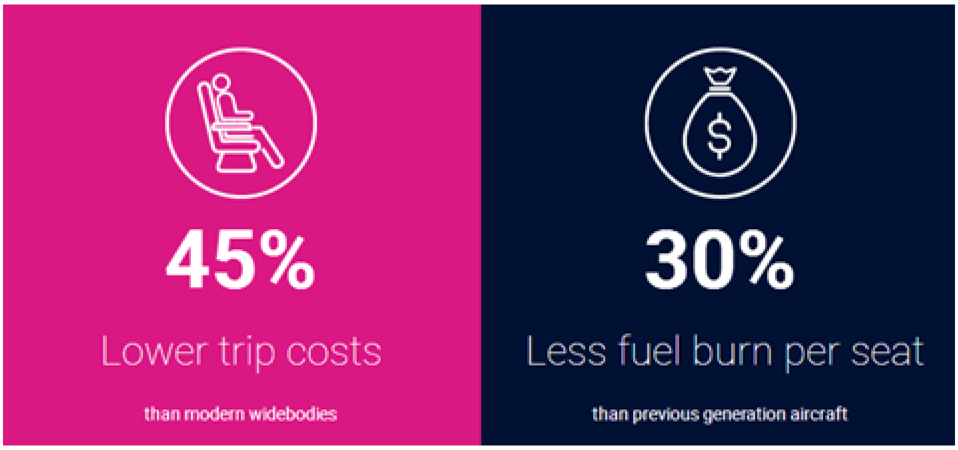
Some data:

	fuselage width	fuselage height
Boeing sing aisle (707, 727, 737, 757):	3760 mm	4010 mm
Airbus single aisle (A319, A320, A321):	3950 mm	4141 mm
Comac C919:	3960 mm	4166 mm
Irkut MC 21:	4060 mm	4060 mm

Please comment carefully!

Task 2.4 (4 points)

Airbus claimes with respect to the A321XLR (https://perma.cc/JGR6-X64C):



a) Comment on the "45%-Claim"! To what extend does it make sense?

b) Comment on the "30%-Claim"! To what extend does it make sense?

As the "previous generation aircraft" the Boeing 757 is discussed.
Calculate fuel burn from the simple approach as given below

A/C	MTOM	MZFM	range, R	passenger, Pax
B757	122500 kg	95250 kg	4445 km	279
A321XLR	101000 kg	74374 kg	6750 km	244

Fuel Consumption = (MTOM – MZFM) / (R · Pax) · 100 in kg per 100 km per passenger

(from https://doi.org/10.48441/4427.225)

Task 2.3

The Airbus claim is <u>not</u> justified, because C919 and MC 21 have a wider cabin.

It may be questioned, why Airbus uses the addition "in the sky" in its claim?

C919 and MC21 are flying, but not yet with any airline (in operation).

This could be the "excuse":
C919 and MC 21 <u>are</u> wider, but <u>not in airline operation</u> in the sky.

The addition "in the sky" does not turn an invalid statement into a valid statement.

Task 2.4

a) Airbus compares the trip costs of a small aircraft (A321XLR, single aisle) with a big aircraft ("wide body").
No wonder, the small aircraft has lower (absolute) trip costs !

b) Calculated fuel consumption with given data and given equation.

B757 : 2.20 Kg/100km/pax
A321XLR : 1.62 Kg/100km/pax

$$\frac{2.2-1.62}{2.2} = 26{,}5\% \text{ reduction}$$

This may well be rounded up to 30%. In addition, more precise data may show : 30%
This claim may be justified, BUT:

How much sense does it make to compare with "previous generation A/C" ?

Task 2.5 (3 points)

With the Airbus A321LR and A321XLR several parameters where changed:

- Fuel volume increased
- Max. take-off mass increased
- Payload reduced

Please draw a generic paylaod-range diagram and show in the diagram, how these changes individually and combined lead to more range!

Task 2.6 (5 points)

Qantas intends to fly Sydney to NewYork and Sydney to London nonstop (https://perma.cc/K4T6-E4QP).

SYD – JFK: 16000 km
SYD – LHR: 17000 km

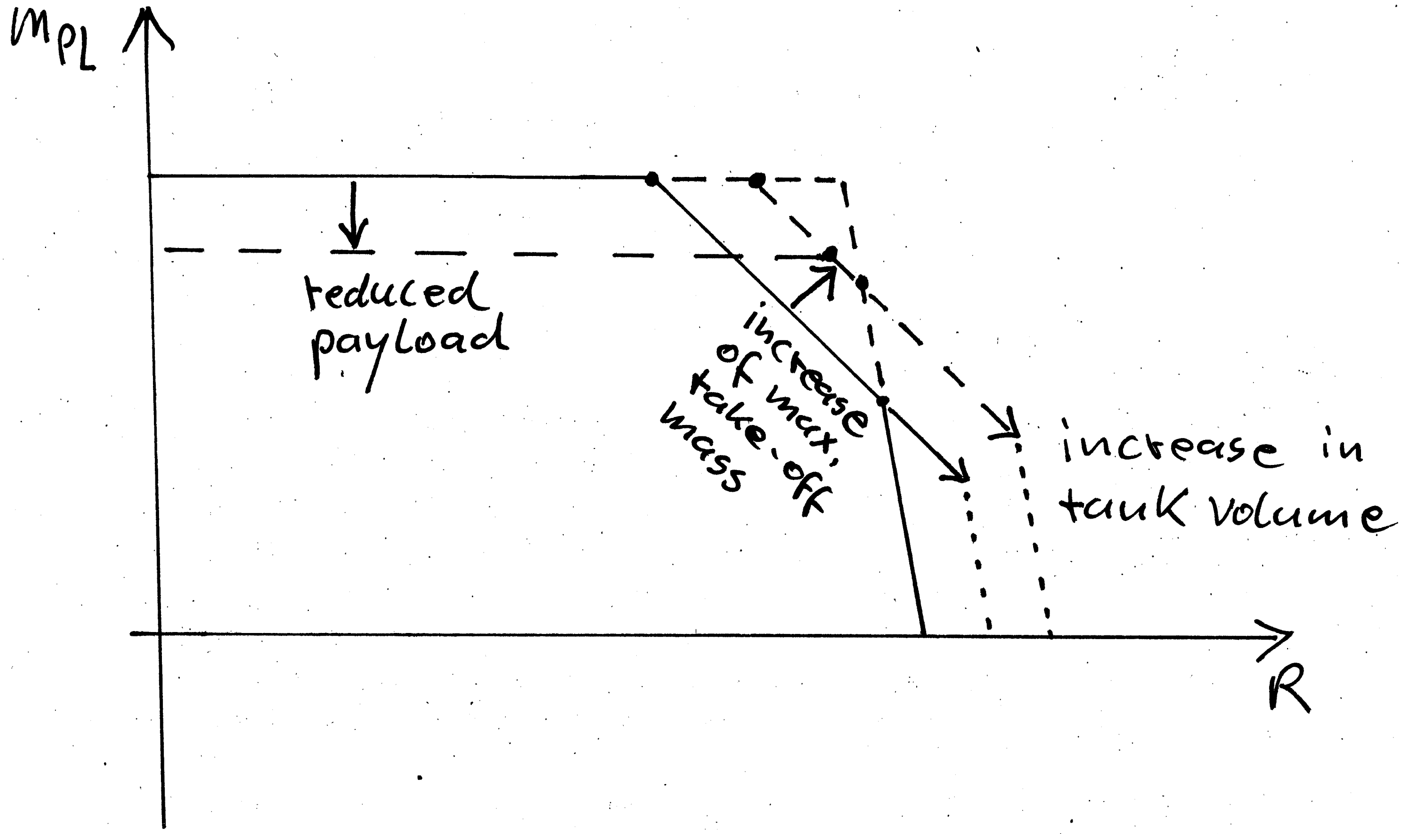
Critics say, much fuel could be saved if a fuel stop would be used.
Consider SYD – LHR, Glide ratio: 18, SFC: 16 mg/(Ns),
Speed is calculated from a cruise Mach number 0.8 in the stratosphere.
Consider only cruise flight.
Consider a direct flight as cruise (without mission segment mass fractions) as reference (100%).

a) Assume an intermediate fuel stop in the middle of SYD – LHR.
Calculate the fuel burn relative to the reference (still no mass fractions)!

b) Assume mission segment mass fractions (only) for the intermediate stop for descent, landing, taxi, take-off, climb (from the lecture notes). Calculate the fuel burn relative to the reference!

c) Comment on your findings in a) and b).

Task 2.5



m_{PL}
reduced payload
increase of max. take-off mass
increase in tank volume
R

Task 2.6

$R = 17000$ km $\qquad E = 18$

$c = 16 \frac{mg}{Ns}$ $\qquad g = 9.81$ m/s²

$M = 0.8$

$a = 295{,}07$ m/s $\qquad V = M \cdot a = 236{,}06$ m/s

$$B = \frac{V \cdot E}{c \cdot g} = 27070{,}6 \text{ km}$$

$$R = B \cdot \ln \frac{m_1}{m_2} = B \ln \frac{m_2 + m_F}{m_2} = B \ln\left(1 + \frac{m_F}{m_2}\right)$$

$$e^{R/B} = 1 + \frac{m_F}{m_2} \qquad \boxed{\frac{m_F}{m_2} = e^{R/B} - 1}$$

Direct: $e^{0{,}628} - 1 = 0{,}8738 = \frac{m_F}{m_2}$

1-Stop: $2 \cdot e^{0{,}628/2} - 1 = 0{,}7378 = \frac{m_F}{m_2}$

a) 1-Stop fuel burn: 0,844 of direct flight

b) All named mission segment mass fractions multiplied:
$0{,}993 \cdot 0{,}993 \cdot 0{,}993 \cdot 0{,}993 \cdot 0{,}993 = 0{,}993^5$
$= 0{,}9655$

1-Stop fuel burn: 0,874 of direct flight

c) Even considering extra fuel burn from an additional take-off and landing, a 1-stop operation can safe fuel: ≈ 12%. This advantage may not be enough considering additional landing fees and reduced utilization!