DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

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Solution
Flugzeugentwurf / Aircraft Design SS 2023

Date: 14.07.2023

Duration of examination: 180 minutes

1. Part

45 points, 90 minutes, closed books

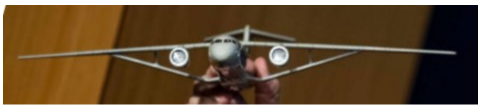
1.1) Please translate to German.

Please find the vocabulary given as part of the Lecture Notes.

1.2) Please translate to English.

Please find the vocabulary given as part of the Lecture Notes.

1.3) Shown is the X-66A. It is an experimental airliner under development by Boeing. It is part of the X-plane series and has been developed in collaboration with NASA.


https://www.nasa.gov/press-release/next-generation-experimental-aircraft-becomes-nasa-s-newest-x-plane
https://www.nasa.gov/press-release/nasa-issues-award-for-greener-more-fuel-efficient-airliner-of-future

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

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1. Large span (or aspect ratio):
   Advantage:      lower induced drag
   Disadvantage:   heavier wing
2. Braced wing:
   Advantage:      lighter wing
   Disadvantage:   due to struts more zero lift drag and interference drag
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3. High wing:
   Advantage:      braced wing configuration becomes possible,
                   installation space for high by-pass-ratio
                   engines available
   Disadvantage:   wing box goes through cabin or hump on fuselage,
                   difficult landing gear integration
4. T-Tail:
   Advantage: smaller horizontal tail
   Disadvantage:   heavier vertical tail, possibility of deep stall
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1.4) Please describe the preliminary sizing process for jets (based on Loftin 1980). A full answer requires maybe a diagram and a little more text. (This gives a maximum of 4 points!)

Please see Lecture Notes Chapter 5.

1.5) What is the ratio of the *maximum lift coefficient* and the *actual lift coefficient* at minimum approach speed of an aircraft certified by CS-25? (You may need to calculate!)

$1.3^2 = 1.69$

1.6) An unswept wing with high lift system has a *maximum lift coefficient* of 3.6. Estimate the maximum lift coefficient of a similar wing with 60° sweep!

Factor is cos(60°) = 0.5. Lift coefficient gets 1.8.

1.7) You are asked to design an ultra long range passenger aircraft. What is your proposal for the ratio of *maximum landing mass* to *maximum take-off mass*.

0.6

1.8) What is the defined end of the *2nd Segment*?

An altitude of 400 ft.

1.9) What *gradient of climb* may Airbus have used to calculate the *2nd Segment OEI* thrust-to-weight requirements for the ZEROe aircraft pictured? (This answer goes beyond a simple repetition of information from the Lecture Notes. Think!)

The aircraft has 8 engines. CS-25 defines the gradient of climb only up to 4 engines. The gradient is increasing with the number of engines. With many engines certification may require considering more than one engine inoperative. The chosen number of engines may have disadvantages based on certification rules, which however at this moment are not even given. This adds development risk.

1.10) Describe the influence of *thrust-to-weigh ratio* on the ratio of *operating empty mass* to *maximum take-off mass*! Please write down the equation if you can!

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

1.11) What is a typical value for the ratio of *operating empty mass* and *maximum take-off mass* for passenger aircraft?

0,5

1.12) Write down the equation known as *First Law of Aircraft Design* from which you can calculate the maximum take-off mass m_{MTO} from payload m_{PL} !

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

1.13) From which two aircraft mass values is the *mission segment mass fraction for the cruise phase* calculated? From which equation is the ratio of these two mass values calculated?

$$\frac{m_{LOI}}{m_{CR}} = e^{-\frac{s_{CR}}{B_s}}$$

1.14) What is *wetted aspect ratio*? Give the equation from which *maximum L/D in cruise* can be estimated from *wetted aspect ratio*!

maximum *L/D* =

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

wetted aspect ratio is the term

$$\frac{A}{S_{wet}/S_W}$$

1.15) Passenger jet aircraft may fly 3.5 times as fast in cruise compared to approach. This has consequences for the lift coefficient. Please name three measures (or effects) acting together to make this large speed range possible!

Without any measures, the lift coefficient in cruise (at high speed) would be too low and the drag would be very high, because the aircraft would fly far from the optimum lift coefficient (called $C_{L,minimum\ drag}$). Measures are taken to bridge the gap between approach speed and cruise speed:

a. Use the natural difference of an airfoil, wing, and aircraft between lift coefficient for minimum drag and lift coefficient for maximum lift.
b. Increase the lift coefficient at approach speed with high lift devices.
c. Increase the necessary lift coefficient by cruising at high altitude (low air density).

1.16) What is a typical value of the *equivalent skin friction coefficient* for passenger aircraft?

0.003

1.17) Based on this cabin design equation: $n_{SA} = 0.45 \cdot \sqrt{n_{PAX}}$, calculate the ratio of number of rows, n_R to the number of seats abreast, n_{SA} that is the underlying assumption for the equation!

1.18) Now, write the cabin design equation in a more general form and replace the "0.45" by k_{SA} which is a function of n_R and n_{SA}. Determine this function!

$$n_{SA} = 0.45 \sqrt{n_{pax}}$$

$$n_{SA}^2 = 0.45^2 \cdot n_{pax} = 0.45^2 \cdot n_R \cdot n_{SA}$$

$$\frac{n_{SA}}{n_R} = 0.45^2$$

$$\frac{n_R}{n_{SA}} = \frac{1}{0.45^2} = 4{,}938$$

$$\frac{1}{k_{SA}^2} = \frac{n_R}{n_{SA}}$$

$$k_{SA} = \sqrt{\frac{n_{SA}}{n_R}}$$

$$\boxed{n_{SA} = k_{SA} \cdot \sqrt{n_{pax}} \quad \text{with } k_{SA} = \sqrt{\frac{n_{SA}}{n_R}}}$$

1.19) How many passengers may at most be evacuated through a *Type A* door?

110

1.20) Please name the equation from which you can estimate the zero-lift drag coefficient, C_{D0} from maximum glide ratio E_{max} !

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

1.21) Which parameter has the strongest influence on the Oswald factor of a jet aircraft in cruise?

Most influence has the factor $k_{e,M}$, which takes care of the Mach effect on Oswald factor.

1.22) What is the non-planar wing system with the potential for the highest Oswald factor (lowest induced drag)?

It is the box wing also called Prandtl wing.

1.23) Please write down the equation to estimate the *horizontal tail area* from the *horizontal tail volume coefficient*!

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

1.24) What is the benefit of adding a (standard) dorsal fin compared to the same increase in vertical tail area?

The dorsal fin allows higher side slip angles. As such, it protects the vertical tail from a stall.

1.25) What is the wave drag coefficient a) at *critical Mach number*, b) at *drag divergence Mach number*?

a. 0
b. 0.002

1.26) Propose a dihedral angle for an aircraft with a 30° swept high wing!

Both (aft) seep and high wing stabilize the aircraft in roll. This gets already too much and needs to be compensated by anhedral (negative dihedral or V-shape). Select dihedral -5° to -2° (Lecture Notes), or -3.5° (calculated from the Nutshell).

1.27) An aircraft has these parameters: maximum take-off mass 73500 kg, maximum zero-fuel mass 62800 kg, range 3180 km, 150 passengers. Please calculate the fuel consumption per passenger!

The simple equation considers fuel reserves used. Fuel mass is 73500 kg – 62800 kg = 10700 kg. This divided by 3180 km and 150 passengers, multiplied by 100 gives a fuel consumption expressed as 2.24 kg per passenger and per 100 km.

1.28) Hamburg Airport claims that its airport operation is CO2-neutral since 2022 due to CO2 compensation. Even better, the airport now follows the strategy "Net Zero 2035", where by 2035 no CO2 compensation will be necessary anymore. a) How can this be achieved? b) What generates the most CO2 within the airport fence? Is the largest contributor to these CO2 addressed in "Net Zero 2035"?

a. Hamburg Airport intends to install wind and solar power plants.
b. The aircraft generate most CO2 within the airport fence.
c. The largest contributor to the CO2 within the fence of the airport is not considered in the airport environmental strategy.

1.29) 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. 2/6 = 1/3
b. 3/6 = 1/2
c. 1/6

1.30) What is the annual growth rate, if the number of aircraft is doubling from 2023 to 2040?

$2^{(1/17)}$ = 1.0416, the growth rate is 4.16%.

1.31) Airbus: "SAFs [Sustainable Aviation Fuels, from biological processes] are a good solution here as they produce around 80 percent less CO2". How can that be, if SAF are hydrocarbons (C_xH_y) like kerosine?

SAF from biological processes are made from plants that have absorbed CO2 during their life. This CO2 is put back into the atmosphere when the SAF (that does not differ much from kerosene) is burned in flight. SAF is sustainable, because it generates a carbon cycle. Due to inefficiencies in the cycle (trucks burning diesel fuel shipping goods, …) the carbon cycle does not safe 100% CO2, but only an estimated 80% (depending on the fuel production process).

1.32) The EU is calling for 70% Sustainable Aviation Fuel (SAF) by 2050 (a blend of 70% SAF and 30% kerosene). Let's assume SAFs "produce around 80 percent less CO2" (Airbus). a) To what percentage are CO2 emissions left? b) It is estimated that aviation will have grown by a factor of 2.9 by 2050. Based on this: How much more CO2 will be emitted in 2050 compared to today?

a. The 70% SAF are 35% from biofuel (CO2-efficiency 80%) hence as good as 0.8 · 35% = 28%. The other 35% are from e-fuel, which may be considered to have a CO2-efficiency of 100%. Together SAF is as good as 63%. The fuel in the tank is producing CO2 as 37% of the kerosene before.
b. Due to traffic growth, the 37% become 37% · 2.9 = 107%. This means CO2 emission in 2050 are increased(!) by about 7% compared to today (despite the ambitious introduction of SAF).

Questions from the Evening Lectures

1.33) What suggestion does Prof. Poll make to eliminate aviation's contribution to climate change?

In aviation, "contrail management" is a major weapon in the fight against climate change. Avoid warming contrails and produce cooling contrails. As such aviation could become net cooling.

1.34) The carbon footprint varies in size. We look at the 1% of the world's population who fly the most. What percentage of CO2 from aviation is caused by this 1% of the world's population?

1% of the population produces 50% of the CO2 from aviation. Source: https://doi.org/10.1016/j.gloenvcha.2020.102194 and many others.

1.35) If you have 1 MWh of renewable energy in the form of electricity, what should you do with it to save as much CO2 as possible? Here are some initial suggestions: production of SAF for aviation, production of LH2 for aviation, powering a CO2 capture system, powering a heat pump, ... Choose one option or name an even better option that is not mentioned here!

`The best option would be to reduce the output of a coal power plant (and with more MWh to close the coal power plant). It is not wise to spend the limited renewable energy on aviation. See here: http://PTL.ProfScholz.de.`

2. Part

49 points, 90 minutes, open books

Task 2.1 (22 points)

Redesign of an *Airbus A320*: neo engines, high wing, large span

In 2008, NASA awarded research contracts (each worth about $2 million) to six industry teams to study advanced concepts for commercial transport aircraft. The Subsonic Ultra-Green Aircraft Research (SUGAR) project led by the Boeing Company resulted in the NASA N+3 initiative (entry into service in 2030 to 2035) of high wing, large span, strut braced aircraft with different propulsion technologies. Phase 1 results were presented in early 2011 (picture). Time flies! Boeing received more contracts over the years. Work has started now on a full scale design with flight test: the Boeing X-66A, which is part of the famous X-plane series of experimental US aircraft. Check out what Airbus could do in a similar way!

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 calculated for take-off and landing with $C_{D0} = 0.02$ and Oswald factor $e = 0.7$

- Oswald factor in cruise $e = 0.75$ (lower due to larger aspect ratio)
- Aspect ratio $A = 25.0$!
- Maximum glide ratio in cruise, E_{max} calculated from theory with equivalent surface friction coefficient, $C_{fe} = 0.003$ and relative wetted area, $S_{wet}/S_W = 6.8$ (higher due to smaller wing).
- 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 to maximum take-off mass, m_{ML}/m_{MTO} has to be determined to fulfill final checks on aircraft mass.
- The operating empty weight ratio is $m_{OE} / m_{MTO} = 0.56$
- The by-pass ratio (BPR) of the two CFM LEAP 1-A engines is $\mu = 11$; their thrust specific fuel consumption for cruise and loiter is $c = 14.0$ mg/(Ns).
- Use these values as Mission-Segment Fuel Fractions: Taxi: 0.992; Take-off: 0.992; Climb: 0.992; Descent: 0.992; Landing: 0.992.

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

- wing loading from landing field length: 577,4 Kg/m²
- thrust to weight ratio from take-off field length (at wing loading from landing): 0,296
- glide Ratio in 2. Segment: 15,86
- glide Ratio during missed approach maneuver: 13,02
- thrust to weight ratio from climb requirement in 2. Segment: 0,174
- thrust to weight ratio from climb requirement during missed approach maneuver: 0,179
- V_{CR}/V_{md}: 1,24
- design point
  - thrust to weight ratio : 577,4 Kg/m² ↕
  - wing loading: 0,296
- cruise altitude: 39040 ft = 11899 m
- maximum take-off mass: 62371 kg
- maximum landing mass: 56945 kg
- fuel mass, standard flight: 8187 kg
- wing area: 108,0 m²
- thrust of one engine **in lb**: 20372 Lb
- required tank volume **in m³**: 10,6 m³
- **wing span:** 51,96 m **Comment on the wing span !** Just fits in ICAO Class D (52 m)

Calculate the change to A320 parameters:

- A320, maximum take-off mass: 73500 kg. Change in %: – 15,14 %
- A320, fuel mass, standard flight: 13100 kg. Change in %: – 37,5 %
- A320, wing span, without sharklets: 34,1 m. Change in %: + 52,4 %

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.

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Example data: See Klausur SS05

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}	**1448**	**m**	
Approach speed	V_{APP}	64,7	m/s	
Approach speed	V_{APP}	**125,746**	**kt**	$V_{APP} = k_{APP} \cdot \sqrt{s_{LFL}}$

Given: approach speed		**no**		
Approach speed	V_{APP}	**134,5**	**kt**	$V_{APP} = \left(\frac{s_{LFL}}{k_{APP}} \right)^2$
Approach speed	V_{APP}	69,2	m/s	
Landing field length	s_{LFL}	**1448**	**m**	

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	$k_L = 0{,}03694\, k_{APP}^2$
Max. lift coefficient, landing	$C_{L,max,L}$	**3,41**		
Mass ratio, landing - take-off	m_{ML} / m_{TO}	**0,913**		$m_{ML} / S_W = k_L \cdot \sigma \cdot C_{L,max,L} \cdot s_{LFL}$
Wing loading at max. landing mass	m_{ML} / S_W	**527,19486**	**kg/m²**	
Wing loading at max. take-off mass	m_{MTO} / S_W	**577,43139**	**kg/m²**	$m_{MTO} / S_W = \frac{m_{ML} / S_W}{m_{ML} / m_{MTO}}$

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	**0,296**	

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

2nd Segment

Calculation of glide ratio

Aspect ratio	A	**25**
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}	15,86

n_E	$\sin(\gamma)$
2	0,024
3	0,027
4	0,030

Calculation of thrust-to-weight ratio

Number of engines	n_E	**2**
Climb gradient	$\sin(\gamma)$	0,024
Thrust-to-weight ratio	$T_{TO} / m_{MTO}*g$	**0,174**

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

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	13,02

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

<<<< Choose according to task

Calculation of thrust-to-weight ratio

Climb gradient	$\sin(\gamma)$	0,021
Thrust-to-weight ratio	T_{TO} / m_{MTO}*g	**0,179**

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 Curise

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

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

$$k_E = \frac{1}{2}\sqrt{\frac{\pi \cdot e}{\overline{c_f}}}$$

1.) From theory		
Oswald efficiency factor for k_E	e	**0,75**
Equivalent surface friction coefficient	$C_{f,eqv}$	**0,003**
Factor	k_E	14,0
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	**14,0**	**<<<< Choose according to task**
Relative wetted area	S_{wet} / S_w	**6,8**	S_{wet} / S_w = 6,0 ... 6,2
Aspect ratio	A	25	(from sheet 1)
Max. glide ratio	E_{max}	**26,87**	
	or		
Max. glide ratio	$E_{max\ chosen}$	**26,87**	**<<<< 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	**11**	
Max. glide ratio, cruise	E_{max}	26,87	(aus Teil 2)
Aspect ratio	A	25	(aus Teil 1)
Oswald eff. factor, clean	e	0,75	
Zero-lift drag coefficient	$C_{D,0}$	0,020	
Lift coefficient at E_{max}	$C_{L,m}$	1,10	
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
V/V_m	**1,24**
$C_L/C_{L,m}$	0,650
C_L	0,713
E	24,560

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	
	R	287,053	m^2/s^2 K

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

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

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	0,440	0,093	101325	2977	0,174	0,179	1,53	0,09
1	3281	0,414	0,098	89873	2641	0,174	0,179	1,35	0,10
2	6562	0,389	0,105	79493	2336	0,174	0,179	1,20	0,10
3	9843	0,364	0,112	70105	2060	0,174	0,179	1,06	0,11
4	13124	0,338	0,120	61636	1811	0,174	0,179	0,93	0,12
5	16405	0,313	0,130	54015	1587	0,174	0,179	0,81	0,13
6	19686	0,287	0,142	47176	1386	0,174	0,179	0,71	0,14
7	22967	0,262	0,155	41056	1206	0,174	0,179	0,62	0,16
8	26248	0,237	0,172	35595	1046	0,174	0,179	0,54	0,17
9	29529	0,211	0,193	30737	903	0,174	0,179	0,46	0,19
10	32810	0,186	0,219	26431	777	0,174	0,179	0,40	0,22
11	36091	0,160	0,254	22627	665	0,174	0,179	0,34	0,25
12	39372	0,135	0,302	19316	568	0,174	0,179	0,29	0,30
13	42653	0,110	0,372	16498	485	0,174	0,179	0,25	0,37
14	45934	0,084	0,484	14091	414	0,174	0,179	0,21	0,48
15	49215	0,059	0,694	12035	354	0,174	0,179	0,18	0,69
					577				
					578				
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

Wing loading	m_{MTO} / S_W	**577**	**kg/m²**	**<<<< Press START button to automatically adjust cruise line**
Thrust-to-weight ratio	T / (m_{MTO}*g)	**0,296**		
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0,137		
Conversion factor	m -> ft	0,305	m/ft	
Cruise altitude	h_{CR}	**11899**	**m**	A320:
Cruise altitude	h_{CR}	**39040**	**ft**	39100 ft -0,15%
Temperature, troposphere	$T_{Troposphäre}$	210,80	K	$T_{Stratosphäre}$ 216,65 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}	**1,40E-05**	**kg/N/s**	typical value 1,60E-05 kg/N/s
Breguet-Factor, cruise	B_s	40101557	m	
Fuel-Fraction, cruise	$M_{ff,CR}$	0,933		
Fuel-Fraction, extra fliht distance	$M_{ff,RES}$	0,987		
Loiter time	t_{loiter}	1800	s	
Spec.fuel consumption, loiter	SFC_{loiter}	**1,40E-05**	**kg/N/s**	
Breguet-Factor, flight time	B_t	178823	s	
Fuel-Fraction, loiter	$M_{ff,loiter}$	0,990		
Fuel-Fraction, taxi	$M_{ff,taxi}$	**0,997**	**<<<< Copy values**	
Fuel-Fraction, take-off	$M_{ff,TO}$	**0,992**	**<<<< from**	
Fuel-Fraction, climb	$M_{ff,CLB}$	**0,992**	**<<<< table**	
Fuel-Fraction, descent	$M_{ff,DES}$	**0,992**	**<<<< on the**	
Fuel-Fraction, landing	$M_{ff,L}$	**0,992**	**<<<< right !**	

Reserve flight distance:

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

Extra time:

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

Phase	M_{ff} per flight phases		
	transport jet	business jet	transport jet
taxi	0,997	0,995	0,990
take-off	0,992	0,995	0,995
climb	0,992	0,980	0,980
descent	0,992	0,990	0,990
landing	0,992	0,992	0,992
	[Scholz, Nita]	[Roskam]	[Roskam]

3.) Preliminary Sizing II

Fuel-Fraction, standard flight	$M_{ff,std}$	0,903	
Fuel-Fraction, all reserves	$M_{ff,res}$	0,962	
Fuel-Fraction, total	M_{ff}	0,868734	
Mission fuel fraction	m_F/m_{MTO}	0,131266	
Realtive operating empty mass	m_{OE}/m_{MTO}	0,538	acc. to Loftin
Realtive operating empty mass	m_{OE}/m_{MTO}	**0,561**	from statistics (if given)
Realtive operating empty mass	m_{OE}/m_{MTO}	**0,560**	**<<<< Choose according to task**
Choose: type of a/c	short / medium range	**yes**	**<<<< Choose according to task**
	long range	**no**	

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

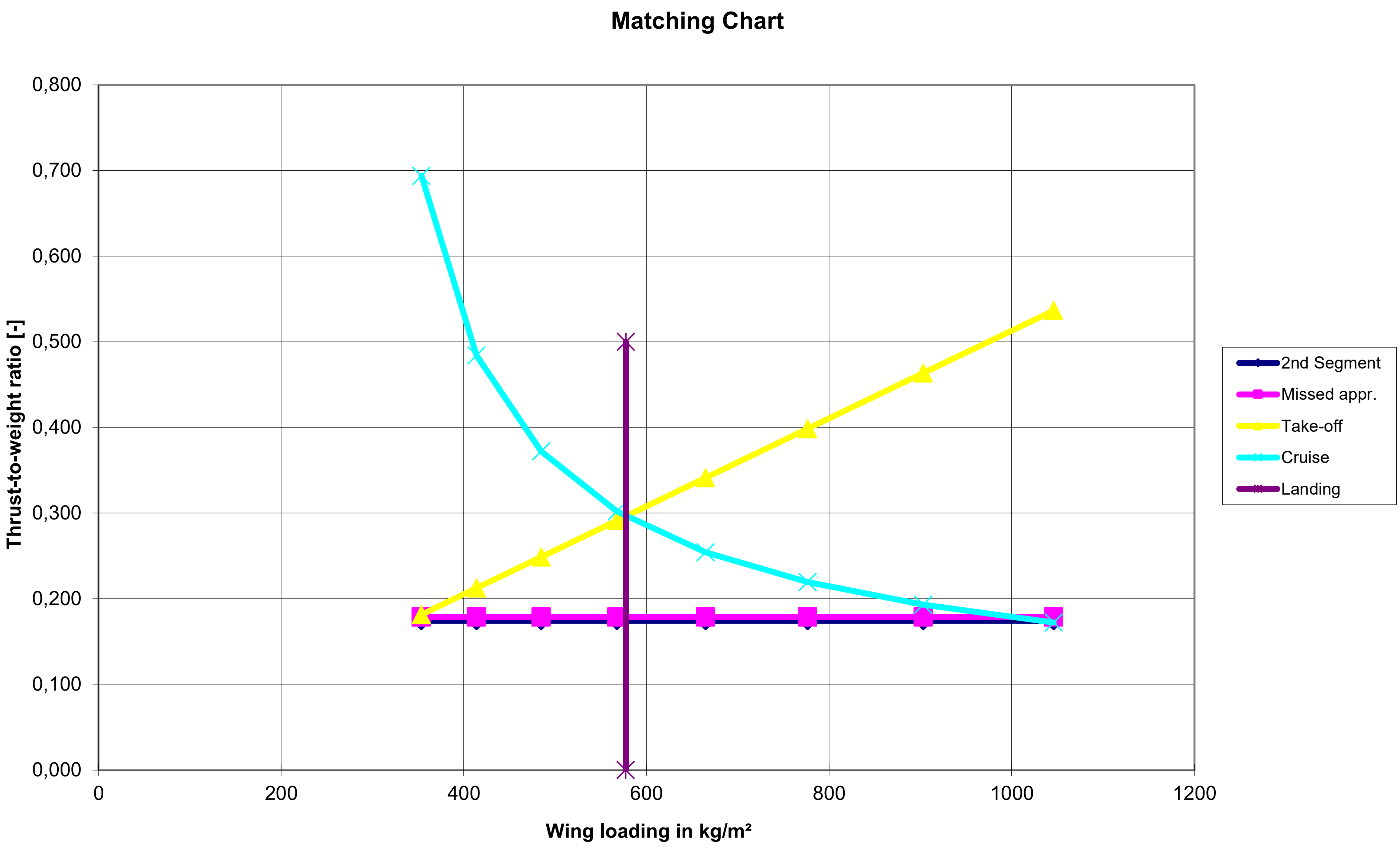
			A320:	Change:	A320, relative:
Mass: Passengers, including baggage	m_{PAX}	93,0 kg			
Number of passengers	n_{PAX}	**180**			
Cargo mass	m_{cargo}	**2516 kg**			
Payload	m_{PL}	**19256 kg**	19256 kg	0,00%	
Max. Take-off mass	m_{MTO}	**62371 kg**	73500 kg	-15,14%	
Max. landing mass	m_{ML}	**56945 kg**	64500 kg	-11,71%	0,878
Operating empty mass	m_{OE}	**34928 kg**	41244 kg	-15,31%	0,561
Mission fuel fraction, standard flight	m_F	**8187 kg**	13102 kg	-37,51%	
Wing area	S_w	**108,0 m²**	122,4 m²	-11,75%	
Take-off thrust	T_{TO}	181244 N	**all engines together**		
T-O thrust of ONE engine	T_{TO} / n_E	**90622 N**	111150 N	-18,47%	
T-O thrust of ONE engine	T_{TO} / n_E	20372 lb	**one engine**		
Span	b	**51,96 m**	34,1 m	52,39%	
Fuel mass, needed	$m_{F,erf}$	8350 kg			
Fuel density	ρ_F	785 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}	54184 kg			
Zero-fuel mass	m_{ZF}	54184 kg			
Fuel mass, all reserves	$m_{F,res}$	2377 kg			

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

56945 kg > 56561 kg

yes

Aircraft sizing finished!



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 (5 points)

We use the Excel-Tool for the **Diederich-Method** given on http://Diederich.ProfScholz.de

Use the parameters as given in the Excel-Sheet, but set

- quarter chord sweep, φ_{25} : 0°
- twist, ε_t : 0°

1. Look only at the distribution of the lift coefficient, c_L (hide all the other lines) .
2. Change the taper ratio, λ from 0.1 via 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, to 1.0 and read for each λ the relative span position, η from the chart where c_L has a maximum (i.e. where the wing is likely to stall first).
3. Compare η from 2. with the approximation for η from the Lecture Notes (7.38) by calculating the difference in η for each λ resulting from the two methods.
4. Comment on your findings.

Task 2.3 (6 points)

At higher cruise Mach numbers the **Oswald factor**, e depends mostly on the Mach-sensitive parameter, $k_{e,M}$ as given in the lecture notes (Method 1). Calculate $k_{e,M}$! Your long range passenger jet aircraft has a cruise Mach number of 0.85. Note: You have to determine also the parameter a_e ! Now, produce a quick estimate of the Oswald factor, e for your jet, using the statistical data given in Method 1. Assume the theoretical Oswald factor, e_{theo} is 1.

Task 2.4 (5 points)

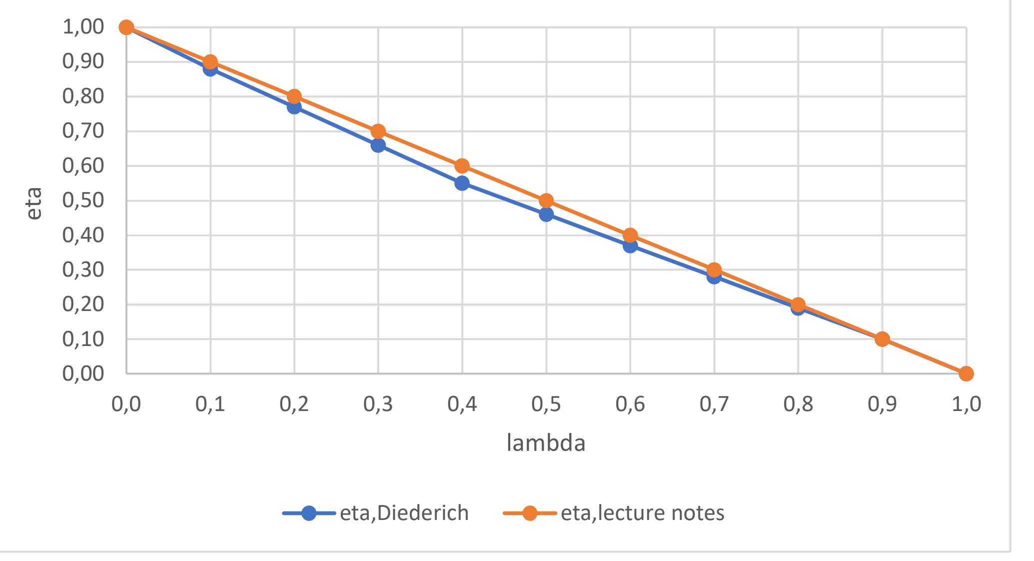
a) An aircraft has 180 seats and 30 rows. Estimate the cabin length!
b) How many aisles are needed for this aircraft?
c) Estimate the volume of the overhead stowage!
d) Estimate the mass of the carry-on baggage this aircraft can accommodate in the cabin, i.e. in the overhead stowage!

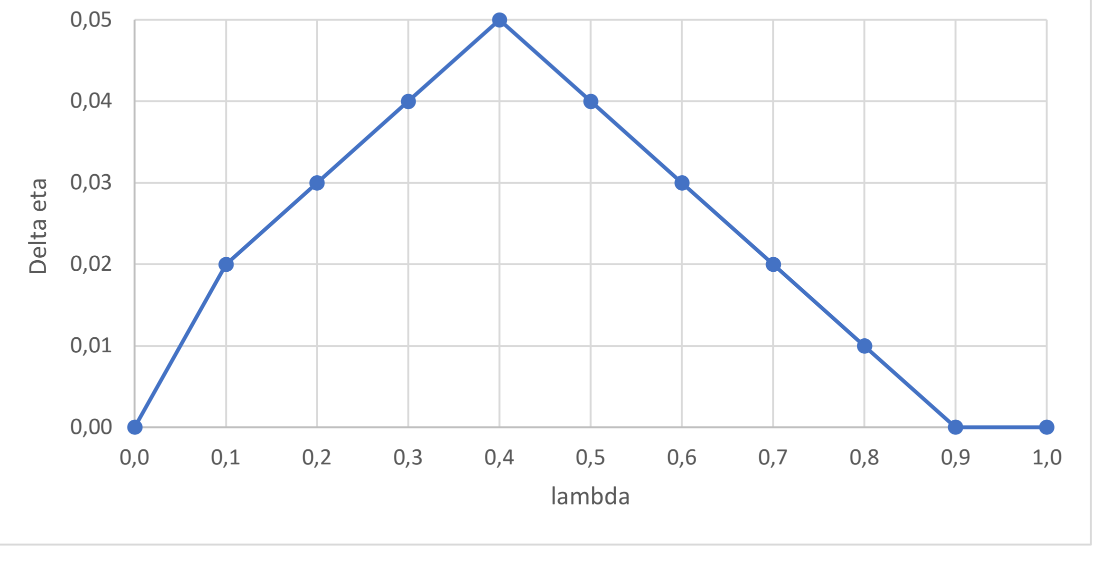
Task 2.5 (5 points)

A passenger aircraft has a cruise Mach number of 0.8. Estimate wing sweep at quarter chord, average thickness ratio of the wing, thickness ratio at wing tip and wing root, and optimum taper ratio. Note: Make use of the simple equation(s) in the "Nutshell" from the Lecture Notes!

Task 2.2

lambda	eta,Diederich	eta,lecture notes	Delta eta
0,0	1,00	1,00	0,00
0,1	0,88	0,90	0,02
0,2	0,77	0,80	0,03
0,3	0,66	0,70	0,04
0,4	0,55	0,60	0,05
0,5	0,46	0,50	0,04
0,6	0,37	0,40	0,03
0,7	0,28	0,30	0,02
0,8	0,19	0,20	0,01
0,9	0,10	0,10	0,00
1,0	0,00	0,00	0,00





Task 2.3

$$M_0 = M_{CR} + 0.08 = 0.93$$

$$M_{comp} = 0.3 \qquad b_e = 10.8$$

$$a_e = \frac{-1}{\left(\frac{M_0}{M_{comp}} - 1\right)^{b_e}} = -0.00033155$$

$$k_{e,M} = a_e \left(\frac{M}{M_{comp}} - 1\right)^{b_e} + 1 = 0{,}766$$

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

$$= 1 \cdot 0.973 \cdot 0.873 \cdot 0.766$$

$$\underline{\underline{e = 0.65}}$$

Task 2.4

a) 180 seats, 30 rows

Cabin length : **30 m**

b) 180/30 = 6 seats abreast

=> **one aisle**

c) Lecture Notes:

"On modern planes $0{,}05\,m^3$ to $0{,}065\,m^3$" overhead stowage per passenger.

Average: $0.0575\,m^3$

$V = 180 \cdot 0.0575\,m^3 = \underline{\underline{10{,}35\,m^3}}$

d) $m = V \cdot \rho = 10.35\,m^3 \cdot 170\,kg/m^3 = \underline{\underline{1760\,kg}}$

Alternative (better) solution:

c) Nutshell:

$V_{OS} = S_{OS,tot} \cdot L_{OS}$ $\qquad L_{OS} = K_{OS} \cdot L_{cabin}$ ($K_{OS} = 0{,}723$)

$S_{OS,tot} = n_{OS,lat} \cdot S_{OS,lat} + n_{OS,ce} \cdot S_{OS,ce}$ ($n_{OS,lat} = 2$, $n_{OS,ce} = 0$)

$= 2 \cdot 0{,}201\,m^2 = 0{,}402\,m^2$

$V_{OS} = 0{,}402\,m^2 \cdot 0{,}723 \cdot 30\,m = 8{,}72\,m^3$

d) $m_{OS} = V_{OS} \cdot \rho_B = 8{,}72\,m^3 \cdot 180{,}13\,kg/m^3$

$= \underline{\underline{1571\,kg}}$

Task 2.5

$M_{CR} = 0.8$

$\varphi_{25} = 39.3° \cdot M_{CR}^2 = \underline{\underline{25.15°}}$

$t/c = -0.0439 \cdot \tan^{-1}(3.345\, M_{CR} - 3.0231) + 0.0986$

$= 0.113 = \underline{\underline{11.3\%}}$ Note: $\tan^{-1}$ requires input in rad !

$(t/c)_t = 4/(3+r) \cdot t/c = \underline{\underline{10.5\%}}$

(r = 1.3)

$(t/c)_r = r \cdot (t/c)_t = \underline{\underline{13.7\%}}$

$\lambda_{opt} = 0.45 \cdot e^{-0.036 \cdot \varphi_{25}}$ (φ_{25} in deg)

$= 0.182$

$\Rightarrow \underline{\underline{0.2}}$ for aileron integration

Task 2.6 (6 points)

The German Business Aviation Association (GBAA) argues in a press release that business jets drive innovation in aviation. As such, other types of aircraft benefit from the business jets. In particular: business jets have "improved propulsion systems and aerodynamic structures". "General aviation stands for 90% of global aviation". Please comment on the text and check the statements!

I had argued these statements in a document (and discussed with you). The document is called:

"Comment on:
Last generation: 'Business jet marked with color at Sylt Airport' "

Mundsinger [GBAA] admits that operators only use SAF "in very small quantities". According to GBAA: "Business aircraft manufacturers [are] driving innovation." "Business aviation is a direct innovation and technology incubator for the broader aviation industry, including commercial aviation." "Technologies [are] being developed that are generally transferred to commercial aviation and often enable drastic performance improvements and fuel and therefore emissions savings." Mundsinger says business jets "were the first to incorporate winglets, glass cockpits, lighter composite materials, improved propulsion systems and more aerodynamic structures into their products." These statements are not proven and are probably false. One thing is certain: The specific fuel consumption (SFC) of the jet engines of business jets is on average around 30% higher than that of passenger jets (own calculation). This is due to the low bypass ratio (BPR) and the smaller size of the engines on business jets. With a low BPR, far from being used is what is currently the technical standard. A glass cockpit provides a different form of display and therefore saves nothing. In some cases, the old profiles from the 1960s continued to be used as aerodynamic wing profiles for decades, although new, more fuel-efficient profiles had long been standard on passenger jets. This is simply because business aviation is less exposed to commercial pressure than commercial aviation, which must exist with a small percentage profit margin. A business jet is often bought simply based on its appearance and top speed. Mundsinger is quoted as saying: "Today, general aviation represents 90% of global air traffic, which accounts for 2% of global CO_2 emissions." He explains: General Aviation "...includes not only business traffic but also sport aviation, school and training flights as well as ambulance and government flights". The statistical statement has little to do with "factual discussion": 1.) The activists criticize business jets and not general aviation / general aviation in general. 2.) Presumably the "90%" refers to the number of starts. This also includes the starts of the gliding clubs. 3.) Why are the CO_2 from general aviation compared to global CO_2 emissions (including industry, heating, the entire transport sector, ...)?

Source: https://purl.org/aero/M2023-06-07

Your answer in the examination could have been much shorter.