DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

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Flugzeugentwurf / Aircraft Design SS 2023

Date: 14.07.2023

Duration of examination: 180 minutes

Last Name:	First Name:
Matrikelnummer:	
Points: of a maximum of 94 points.	Grade:

1. Part

45 points, 90 minutes, closed books

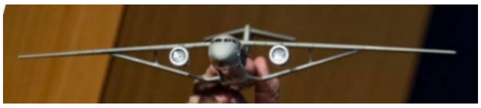
1.1) Please translate to German.
Please write clearly! Unreadable text causes subtraction of points!

1. aeroplane
2. aircraft
3. lift curve slope
4. thickness distribution
5. three-view drawing
6. empennage
7. canard (aircraft)
8. aviation
9. aileron
10. maneuverability
11. Breguet factor
12. fuselage

1.2) Please translate to English.
Please write clearly! Unreadable text causes subtraction of points!

1. Flugzeugentwurf
2. Machzahl
3. Phygoide
4. Reiseflug
5. Rückenflosse
6. Rumpfquerschnitt
7. Schränkung
8. Auftriebsverteilung
9. Profil
10. Profilsehne
11. Profiltiefe
12. Prandtl-Glauert-Regel

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!

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!)

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!)

1.6) 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!

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*.

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

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!)

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!

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

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} !

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?

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

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!

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

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!

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

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

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

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

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

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

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

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

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!

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"?

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?

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

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_xHy) like kerosine?

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?

Questions from the Evening Lectures

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

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?

1.35) 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!

Name:____________________

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 μ = 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!

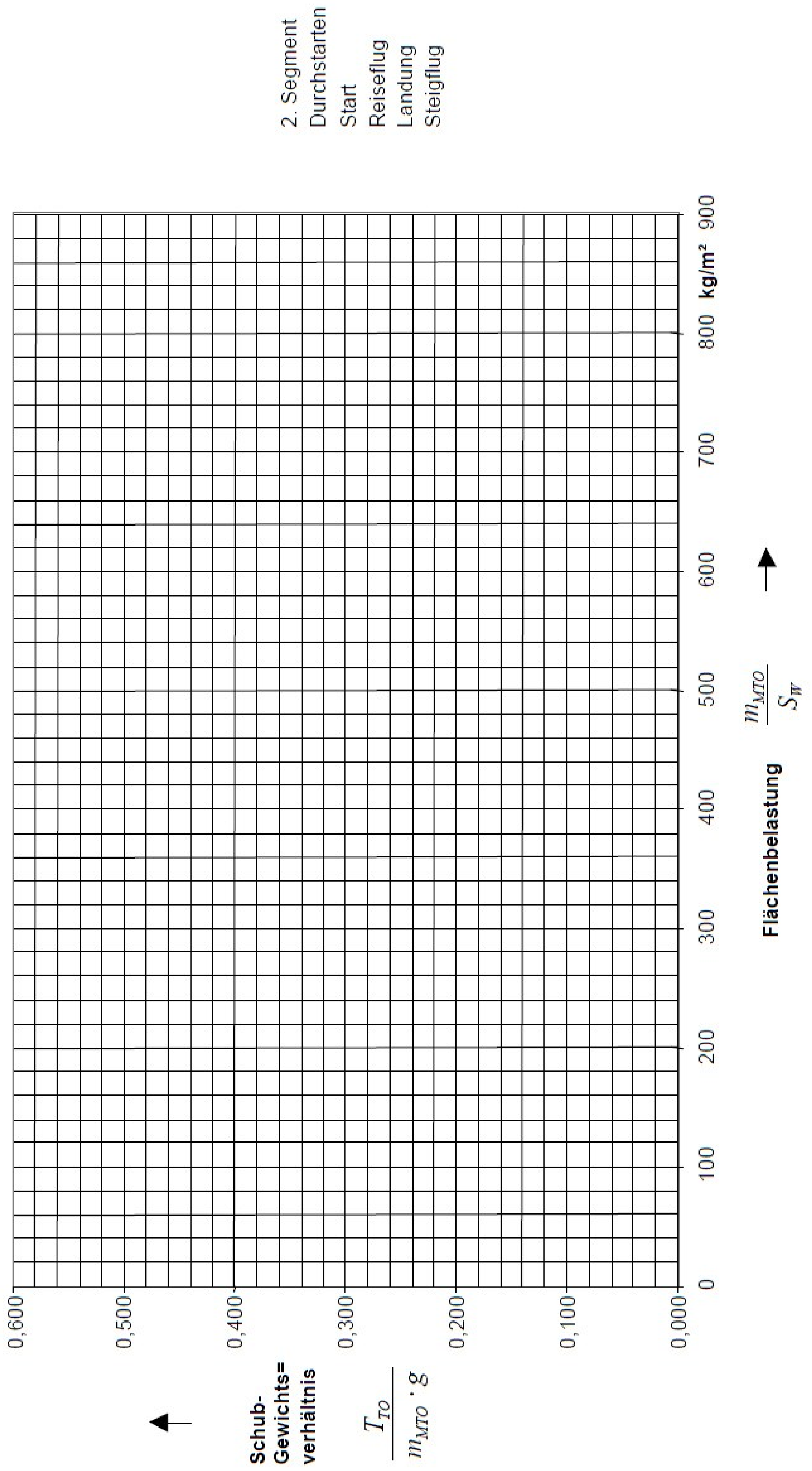
- wing loading from landing field length:
- thrust to weight ratio from take-off field length (at wing loading from landing):
- glide Ratio in 2. Segment:
- glide Ratio during missed approach maneuver:
- thrust to weight ratio from climb requirement in 2. Segment:
- thrust to weight ratio from climb requirement during missed approach maneuver:
- V_{CR}/V_{md}:
- design point
  - thrust to weight ratio :
  - wing loading:
- cruise altitude:
- maximum take-off mass:
- maximum landing mass:
- fuel mass, standard flight:
- wing area:
- thrust of one engine **in lb**:
- required tank volume **in m^3**:
- **wing span**: **Comment on the wing span !**

Calculate the change to A320 parameters:

- A320, maximum take-off mass: 73500 kg. Change in %:
- A320, fuel mass, standard flight: 13100 kg. Change in %:
- A320, wing span, without sharklets: 34,1 m. Change in %:

Draw the matching chart and indicate the <u>design point</u> 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)


2. Segment
Durchstarten
Start
Reiseflug
Landung
Steigflug
Schub-
Gewichts=
verhältnis
$\frac{T_{TO}}{m_{MTO} \cdot g}$
0,600
0,500
0,400
0,300
0,200
0,100
0,000
0
100
200
300
400
500
600
700
800
900
kg/m²
Flächenbelastung
$\frac{m_{MTO}}{S_W}$

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 2.6 (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!