Hochschule für Angewandte Wissenschaften Hamburg
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**DEPARTMENT FAHRZEUGTECHNIK UND FLUGZEUGBAU**

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# Solution:
# Flugzeugentwurf / Aircraft Design SS 2011

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## 1. Part

30 points, 60 minutes, closed books

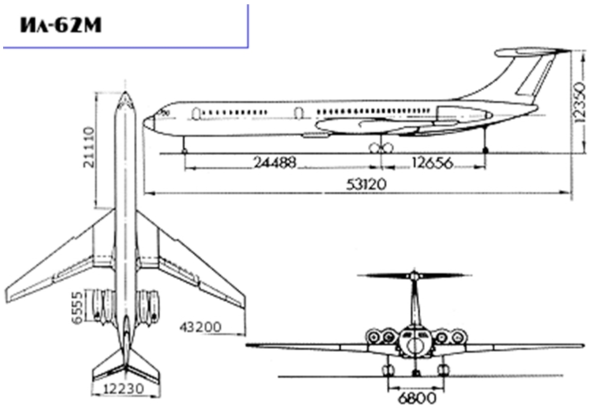
1.1) Please translate to German.
**Please write clearly! Unreadable text causes substraction of points!**

| | | |
|---|---|---|
| 1. | sweep | `Pfeilung` |
| 2. | wing root | `Flügelwurzel` |
| 3. | span | `Spannweite` |
| 4. | aisle | `Gang` |
| 5. | canard | `Entenflugzeug` *oder* `Entenleitwerk` |
| 6. | anhedral | `negative V-Form` |
| 7. | landing field length | `Sicherheitslandestrecke` |
| 8. | trolley | `Essenswagen` |
| 9. | landing gear | `Fahrwerk` |
| 10. | fuselage | `Rumpf` |
| 11. | empennage | `Leitwerk` |
| 12. | aileron | `Querruder` |

1.2) Please translate to English!
**Please write clearly! Unreadable text causes substraction of points!**

| | | |
|---|---|---|
| 1. | Dimensionierung | `preliminary sizing` |
| 2. | Leitwerk | `empennage` |
| 3. | Nutzlast | `payload` |
| 4. | Sitzschiene | `seat track` |
| 5. | Maximale Leertankmasse | `Maximum Zero Fuel Weight (`*or:*` Mass)` |
| 6. | Fracht | `cargo` |
| 7. | Reibungswiderstand | `friction` |
| 8. | Triebwerk | `engine` |
| 9. | Küche | `galley` |
| 10. | (Rumpf-)Querschnitt | `(fuselage) cross-section` |
| 11. | Masseverhältnis | `mass fraction` |
| 12. | Oswald Faktor | `Oswald's efficiency factor` |

1.3) Shown is the Iljuschin Il-62. Please name 4 Pros and Cons (Vor- und Nachteile) or name things that change flight operation!



Compare with old examination papers!

1.4) An aircraft for 225 passengers is planned. How many seats abreast do you plan for? Explain your reasoning!

$$n_{sa} = 0.45\sqrt{n_{Pax}} = 0.45 \cdot 15 = 6{,}75$$

Rounded: 7 seats abreast.
For practical reasons it is better to choose 6 or 8 seats abreast.

1.5) What is Maximum Zero Fuel Weight (Maximale Leertankmasse)? How can you calculate it?

The Maxium Zero Fuel Weight is the maximum weight of the aircraft without fuel.

$$m_{MZF} = m_{OE} + m_{MPL}$$

The Maxium Zero Fuel Weight is the sum of the Operating Empty Weight plus the Maximum Payload.

1.6) Please name 5 requirements for a civil passenger aircraft that determine the design point!

- Landing Field Length
- Take-Off Field Length
- 2nd Segment Climb Requirement, One Engine Inoperative
- Missed Approach Climb Requirement, One Engine Inoperative
- Cruise Mach Number Requirement

1.7) Please name the equation used to calculate $m_{MTO}$ from payload $m_{PL}$, operating weight empty ratio $\frac{m_{OE}}{m_{MTO}}$ and fuel mass ratio $\frac{m_F}{m_{MTO}}$ ! An aircraft proposal leads to $\frac{m_{OE}}{m_{MTO}}$ = 0,6 and $\frac{m_F}{m_{MTO}}$ = 0,4. Calculate $m_{MTO}$ of the proposed aircraft! Comment on this aircraft proposal!

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

The proposed aircraft would have a take-off mass of infinity.
The aircraft proposed is (as such) not feasible.

1.8) Based on CS-25 what is the required climb gradient (Steiggradient) in a one engine out situation (bei Triebwerksausfall) in the second segment (2. Segment)?

The climb gradient depends on the number of engines:

- 2 engines: 2.4 %
- 3 engines: 2.7 %
- 4 engines: 3.0 %

1.9) Please name the standardized aviation container that is mostly in use!

The aviation container mostly in use is called LD-3.

1.10) Given is a part of the certification rules:

**CS 25.771 Pilot compartment**

(b) The primary controls ... must be located with respect to the propellers so that no member of the minimum flight crew ... or part of the controls, lies in the region between the plane of rotation of any inboard propeller and the surface generated by a line passing through the centre of the propeller hub making an angle of 5º forward or aft of the plane of rotation of the propeller.

If in the event of a blade failure (ein Propeller bricht ab vom Antrieb) of a propeller driven aircraft a passenger is hit (Passagier wird getroffen) - which is certainly fatal (was tötlich sein wird) - would this be acceptable according to the part of the paragraph CS 25.771.

Yes, CS 25.771 only protects members of the (minimum) the flight crew.

1.11) For each sweep angle there is an optimum taper ratio that produces almost an elliptical lift distribution. Which sweep angle requires an optimum taper ratio $\lambda$ = 1? (Give the order of magnitude and the sign of the sweep angle)

The equation for estimating optimum taper ratio is

$\lambda_{opt} = 0.45\, e^{-0.036 \cdot \varphi_{25}}$ (sweep angle to be given in degrees)

Solved for the sweep angle

$$\varphi_{25} = -\frac{1}{0.036} \cdot \ln \frac{\lambda_{opt}}{0.45}$$

For an optimum taper ratio $\lambda$ = 1 a sweep angle of -22 ° would be required. For this closed book question without pocket calculator it is sufficient to state that the wing is swept forward.

1.12) Airbus and Boeing passenger airplanes experience in cruise a wave drag coefficient of about ... which is equal to ... drag counts.

Airbus and Boeing passenger airplanes experience in cruise a wave drag coefficient of about 0,0020 which is equal to 20 drag counts.

1.13) The chord of a swept wing is measured

**X** parallel to the x-z-plane (x-z-Ebene)
**X** in the direction of the undisturbed flow (in Richtung der freien Anströmung)
**O** perpendicular to the 25%-line (senkrecht zur 25%-Linie)
**O** perpendicular to the 50%-line (senkrecht zur 50%-Linie)

Mark every statement that is true! (Kennzeichnen Sie jede richtige Aussage)!

1.14) An aircraft shows a pitch attitude on approach (Nicklagewinkel im Landeanflug) with a certain nose down tendency (mit der Flugzeugnase zu weit unter dem Horizont). This could lead to a dangerous touch down with the nose gear first. Make 3 proposals how to change the aircraft design to solve that problem! (Machen Sie 3 Vorschläge um das Problem zu lösen!)

- Decrease the wing incidence angle
- Add slats (if not installed yet)
- Decrease the lift curve gradient (with many possible measures)

1.15) What are the pros and cons for the fin with the horizontal tail on top of the fin - i.e. in a T-tail configuration? (Nennen Sie die Vor- und Nachteile für das Seitenleitwerk, wenn das Höhenleitwerk sich auf dem Seitenleitwerk befindet!)

- The horizontal tail acts as end plate (winglet) for the vertical tail
- The horizontal tail is located in rather undisturbed flow

1.16) You want to increase the aspect ration of a wing at constant wing mass. Name 3 parameters that you could change (in which way?) or measures to achieve this! (Sie wollen die Flügelstreckung bei konstanter Flügelmasse erhöhen. Nennen Sie 3 Parameter, die Sie [in welcher Weise?] ändern können oder Maßnahmen dies zu erreichen!)

- Add a brace for the wing (example Cessna 172)
- Increase t/c the relative thickness of the wing
- Decrease wing sweep
- Decrease $\lambda$ the taper ratio
- Decrease the wing area and hence increase the wing loading

1.17) What is the difference between take-off field length and take-off distance? (Wie unterscheiden sich Sicherheitsstartstrecke und Startstrecke?)

Take-off distance is the actual distance needed. Take-off field length includes some measures of safety in normal operation (but does not show a safety margin in a one engine out situation).

1.18) You know that braking distance increases with the square of the approach speed. Proceeding from here. How do you find an equation including a constant based on statistical data to estimate landing distance from approach speed? (Sie wissen, dass die Bremsstrecke mit dem Quadrat der Anfluggeschwindigkeit steigt. Wie finden Sie daraus ein Gleichung mit einer Konstanten basierend auf statistischen Werten mit der Sie die Landestrecke aus der Anfluggeschwindigkeit abschätzen können?)

You start from this approach:

$$s_{LFL} = k_{LFL} \, v_{APP}^2$$

For many aircraft you now plot the landing field length over the square root of the approach speed. You plot a line from the origin of the diagram through the middle of the plotted data point. The slope of this line is the requested constant of proportionality $k_{LFL}$.

Man geht aus von folgendem Ansatz:

$$s_{LFL} = k_{LFL} \, v_{APP}^2$$

Dann trägt man für möglichst viele Flugzeuge die Landestrecke auf über der Wurzel aus der Anfluggeschwindigkeit. Durch die Punkte im Diagramm wird eine Ausgleichsgrade gelegt, die durch den Ursprung des Diagramm verläuft. Die Steigung dieser Ausgleichsgraden ist der gesuchte Proportionalitätsfaktor $k_{LFL}$.

1.19) You have to make sure that the flow at the horizontal tail can cope with whatever situation it is faced with - even if the flow at the wing is already in a state where lift can hardly be generated any more. Name 2 parameters and how they have to be selected to achieve this!

- The horizontal tail should have 5° sweep more than the wing
- The horizontal tail should have a relative thickness 10% less the the wing

- The horizontal tail should be designed with a moderate lift coefficient (about 0.5)

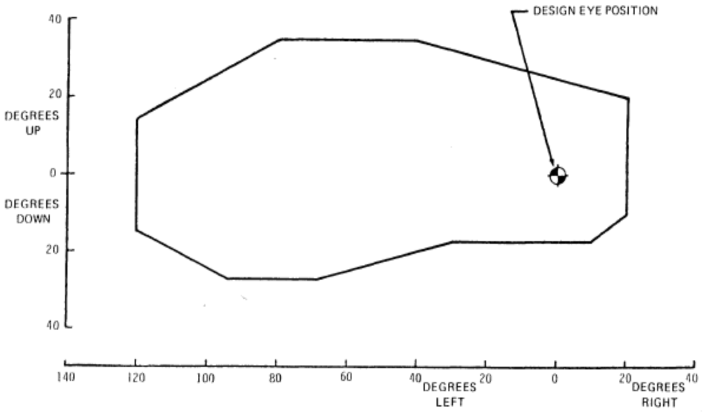
1.20) How can you ensure that a vertical tail is still operating at high side slip angles. Name the parameters and the direction of selected values to achieve this! Name measures! (Mit welchem Parameter und welchen Werten oder mit welcher Maßnahme können Sie sicherstellen, dass ein Seitenleitwerk auch bei großen Schiebewinkeln noch wirksam bleibt?)

- A dorsal fin (having a high sweep angle) can be added to the vertical tail
- The vertical tail can be designed with a high sweep angle

1.21) Define the tail volume coefficient for the horizontal tail! (Definieren Sie den Höhenleitwerkskoeffizienten!)

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

1.22) What is this graph used for? (Wofür wird dieses Diagramm genutzt?)



The diagram shows the required view for the captain out of the left cockpit windows in degrees up, down, left and right related to the design eye position.

1.23) An aircraft is sized (dimensioniert) with an overall maximum lift coefficient at landing $C_{L,max}$ = 2.4. What is (roughly) the required lift coefficient of the wing?

The maximum lift coefficient of the wing is roughly 1.1 times the overall maximum lift coefficent. This is $1.1 \cdot 2.4 = 2.64$

*Questions based on the evening lectures*

1.24) Describe why Air-to-Air Refueling (AAR) saves fuel in civil aircraft operations? What is the order of magnitude of its savings?

AAR saves fuel because less fuel is being carried. This saves induced drag. About 40 % of fuel can be saved depending on the stage length, number of AAR per trip and the efficiency of the tanker (compare with e.g. lecture notes Fig. 26).

1.25) Describe why Close Formation Flying (CFF) saves fuel in civil aircraft operations? What is the order of magnitude of its savings?

The trailing aircraft overlaps the wake of the lead aircraft by 10 % ... 15 % semi span and experiences an updraft from this wake. Induced drag may be reduced by 30 % this results in overall savings of 10 % ... 15 % for the trailing aircraft.

**Results to Task 2.1**

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

- Wing loading from landing field length: 600 kg/m²
- Thrust to weight ratio from take-off field length (at wing loading from landing): 0,275
- Glide Ratio in 2. Segment: 9,49
- Glide Ratio during missed approach maneuver: 8,3
- Thrust to weight ratio from climb requirement in 2. Segment: 0,259
- Thrust to weight ratio from climb requirement during missed approach maneuver: 0,244
- $V_{CR}/V_{md}$: 1,316 (Optimum)
- Design point
  - Thrust to weight ratio : 0,275
  - Wing loading: 600 kg/m²
- Cruise altitude: FL260 (26131 ft / 7965 m)
- maximum take-off mass: 77393 kg
- maximum landing mass: 66682 kg
- wing area: 129 m²
- span (NEW, NEW, NEW!): 35 m
- thrust of one engine **in N**: 104384 N
- required tank volume **in m³**: 22,9 m³

$m_{MPL}$ achievable while $m_{ML} > m_{MZF} + m_{F,res}$ ? Yes

66682 kg > 62679 kg + 3629 kg = 66308 kg
with
$m_{MZF} = m_{OE} + m_{MPL} = 42179$ kg + 20500 kg = 62679 kg

$m_{Cargo} = m_{MPL} - n_{PAX} * 102$ kg = 3364 kg

## 1.) Dimensionierung

**Berechnungen zu den Flugphasen Anflug, Landung, Start, 2. Segment und Durchstarten**

**Eingabewerte** sind **fett blau** gedruckte Werte.
**Erfahrungswerte** sind leicht blau gedruckte Werte. Felder normal NICHT ändern!
**Ergebnisse** sind **rot** gezeigt. Diese Felder NICHT verändern!
Zwischenwerte, Konstanten, ... sind schwarz gezeigt!
"**<<<<**" zeigt besondere Eingaben oder Eingriffe des Anwenders.

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### Anflug (Approach)

| | | | | |
|---|---|---|---|---|
| Faktor | $k_{APP}$ | 1,70 | $(m/s^2)^{0.5}$ | |
| Umrechnungsfaktor | m/s -> kt | 1,944 | kt / m/s | |
| | | | | |
| **Gegeben: Sicherheitslandestrecke** | | **nein** | | **<<<< Auswahl treffen gemäß Aufgabenstellung** |
| Sicherheitslandestrecke | $s_{LFL}$ | **1600** | m | |
| Anfluggeschwindigkeit | $V_{APP}$ | 68,1 | m/s | |
| Anfluggeschwindigkeit | $V_{APP}$ | **132,3** | **kt** | |
| | | | | |
| **Gegeben: Anfluggeschwindigkeit** | | **ja** | | |
| Anfluggeschwindigkeit | $V_{APP}$ | **135,0** | **kt** | Flight International 23-29 Novermber 2010 |
| Anfluggeschwindigkeit | $V_{APP}$ | 69,5 | m/s | |
| Sicherheitslandestrecke | $s_{LFL}$ | **1665** | **m** | |

**Quelle**

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

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

### Landung (Landing)

| | | | | |
|---|---|---|---|---|
| Sicherheitslandestrecke | $s_{LFL}$ | 1665 | m | |
| Starttemperatur über ISA (288,15K) | $\Delta T_L$ | **0** | K | |
| Dichteverhältnis | $\sigma$ | 1,000 | | |
| Faktor | $k_L$ | 0,107 | kg/m³ | |
| max. Auftriebsbeiwert, Landung | $C_{L,max,L}$ | **2,900** | | aus Entwurf berechnet |
| Massenverhältnis, Landung-Start | $m_{ML} / m_{TO}$ | **0,8616** | | Flight International 23-29 Novermber 2010 |
| Flächebelastung bei Landemasse | $m_{ML} / S_W$ | 517 | kg/m² | |
| Flächebelastung bei Startmasse | $m_{MTO} / S_W$ | **600** | **kg/m²** | |

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

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

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

### Start (Take-Off)

| | | | | |
|---|---|---|---|---|
| Sicherheitsstartstrecke | $s_{TOFL}$ | **2200** | m | Flight International 23-29 Novermber 2010 |
| Starttemperatur über ISA (288,15K) | $\Delta T_{TO}$ | **0** | K | |
| Dichteverhältnis | $\sigma$ | 1,000 | | |
| Faktor | $k_{TO}$ | 2,34 | m³/kg | |
| Erfahrungswert für $C_{L,max,TO}$ | 0,8 * $C_{L,max,L}$ | 2,32 | | |
| max. Auftriebsbeiwert, Start | $C_{L,max,TO}$ | **2,320** | | |
| Geradensteigung | a | **0,0004585** | **m²/kg** | |
| Schub-Gewichtsverhältnis | $T_{TO}/m_{MTO}$*g bei $m_{MTO}/S_W$ der Landung | **0,275** | | |

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

### 2. Segment

**Berechnung der Gleitzahl**

| | | | |
|---|---|---|---|
| Streckung | A | **9,5** | Annahme: wie A320 |
| Auftriebsbeiwert, Start | $C_{L,TO}$ | 1,61 | |
| Nullwiderstandsbeiwert, clean | $C_{D,0}$ (bei Berechnung: 2. Segment) | 0,020 | |
| Nullwiderstandsbeiwert, durch Flaps | $\Delta C_{D,flap}$ | 0,026 | |
| Nullwiderstandsbeiwert, durch Slats | $\Delta C_{D,slat}$ | 0,000 | |
| Profilwiderstandsbeiwert | $C_{D,P}$ | 0,046 | |
| Oswald-Faktor; mit Klappenausschlag | e | 0,7 | |
| Gleitzahl in Startkonfiguration | $E_{TO}$ | 9,49 | |

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

**Berechnung des Schub-Gewichts-Verhältnis**

| | | | |
|---|---|---|---|
| Anzahl der Triebwerke | $n_E$ | **2** | http://de.wikipedia.org/wiki/Comac_C919 |
| Steiggradient | $\sin(\gamma)$ | 0,024 | |
| Schub-Gewichtsverhältnis | $T_{TO} / m_{MTO}$*g | **0,259** | |

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

### Durchstarten (Missed Approach)

**Berechnung der Gleitzahl**

| | | | |
|---|---|---|---|
| Auftriebsbeiwert, Landung | $C_{L,L}$ | 1,72 | |
| Nullwiderstandsbeiwert, clean | $C_{D,0}$ (bei Berechnung: Durchstarten) | 0,020 | |
| Nullwiderstandsbeiwert, durch Flaps | $\Delta C_{D,flap}$ | 0,031 | |
| Nullwiderstandsbeiwert, durch Slats | $\Delta C_{D,slat}$ | 0,000 | |
| **Abfrage**: Zulassungsbasis | JAR-25 bzw. CS-25 | **nein** | **<<<< Auswahl treffen gemäß Aufgabenstellung** |
| | FAR Part 25 | **ja** | |
| Nullwiderstandsbeiwert, durch Fahrwerk | $\Delta C_{D,gear}$ | 0,015 | |
| Profilwiderstandsbeiwert | $C_{D,P}$ | 0,066 | |
| Gleitzahl in Landekonfiguration | $E_L$ | 8,30 | |

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

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

**Berechnung des Schub-Gewichts-Verhältnis**

| | | |
|---|---|---|
| Steiggradient | $\sin(\gamma)$ | 0,021 |
| Schub-Gewichtsverhältnis | $T_{TO} / m_{MTO}$*g | **0,244** |

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

## 2.) max. Gleitzahl im Reiseflug

**Abschätzung des Parameters $k_E$ mit 1.), 2.) oder 3.)**

| 1.) Aus der Theorie | | | Quelle |
|---|---|---|---|
| Oswald-Faktor für $k_E$ | e | **0,78** | angenommen (wie A320) |
| äquivalenter Oberflächenwiderstandbeiwert | $C_f$ quer | **0,003** | geschätzt |
| Faktor | $k_E$ | 14,3 | |

| 2.) Nach RAYMER | | |
|---|---|---|
| Faktor | $k_E$ | 15,8 |

| 3.) Aus eigener Statistik | | |
|---|---|---|
| Faktor | $k_E$ | **???** |

**Abschätzung der maximalen Gleitzahl im Reiseflug, $E_{max}$**

| | | | | |
|---|---|---|---|---|
| Faktor | $k_E$ gewählt | **14,3** | **<<<< Auswahl treffen gemäß Aufgabenstellung** | |
| Oberflächenverhältnis | $S_{wet}$ / $S_w$ | **6,2** | $S_{wet}$ / $S_w$ = 6,0 ... 6,2 | geschätzt |
| Streckung | A | 9,5 (aus Teil 1) | | |
| max. Gleitzahl | $E_{max}$ | **17,69** | | |
| | oder | | | |
| max. Gleitzahl | $E_{max}$ gewählt | **17,69** | **<<<< Auswahl treffen gemäß Aufgabenstellung** | angenommen (etwas schlechter als A320) |

# 3.) Dimensionierung

**Berechnungen zu Reiseflug, Entwurfsdiagramm, Kraftstoffmasse, Betriebsleermasse**
**und den Flugzeugparametern: $m_{MTO}$, $m_L$, $m_{OE}$, $S_W$, $T_{TO}$, ...**

| Parameter | | Wert | Quellen |
|---|---|---|---|
| Nebenstromverhältnis | BPR | **11** | BPR: http://de.wikipedia.org/wiki/CFM_International_LEAP-X |
| max. Gleitzahl, Reiseflug | $E_{max}$ | 17,69 (aus Teil 2) | |
| Streckung | A | 9,5 (aus Teil 1) | |
| Oswald-Faktor, clean | e | 0,78 | angenommen in Anlehnung an A320 |
| Nullwiderstandsbeiwert | $C_{D,0}$ | 0,019 | |
| Auftriebsbeiw. bei $E_{max}$ | $C_{L,m}$ | 0,66 | |
| Machzahl, Reiseflug | $M_{CR}$ | **0,785** | http://de.wikipedia.org/wiki/Comac_C919 |

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

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

| Parameter | Wert | |
|---|---|---|
| $V/V_m$ | **1,31607401** | Jet, Theorie, Optimum: 1,316074013 |
| $C_L/C_{L,m}$ | 0,577 | |
| $C_L$ | 0,380 | |
| E | 15,319 | |

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

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

| Konstanten | | |
|---|---|---|
| Isentropenexponent, Luft | $\gamma$ | 1,4 |
| Erdbeschleunigung | g | 9,81 m/s² |
| Luftdruck, ISA, Standard | $p_0$ | 101325 Pa |
| Eulersche Zahl | e | 2,718282 |

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

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

| **Flughöhe** | | **Reiseflug** | | | | **2. Segment** | **Durchstarten** | **Start** | Reiseflug | **Landung** |
|---|---|---|---|---|---|---|---|---|---|---|
| h [km] | h [ft] | $T_{CR}/T_{TO}$ | $T_{TO}/m_{MTO}$*g | p(h) [Pa] | $m_{MTO}/S_W$ [kg/m²] | $T_{TO}/m_{MTO}$*g | $T_{TO}/m_{MTO}$*g | $T_{TO}/m_{MTO}$*g | $T_{TO}/m_{MTO}$*g | $T_{TO}/m_{MTO}$*g |
| 0 | 0 | 0,440 | 0,148 | 101325 | 1693 | 0,259 | 0,244 | 0,78 | 0,15 | |
| 1 | 3281 | 0,414 | 0,158 | 89873 | 1501 | 0,259 | 0,244 | 0,69 | 0,16 | |
| 2 | 6562 | 0,389 | 0,168 | 79493 | 1328 | 0,259 | 0,244 | 0,61 | 0,17 | |
| 3 | 9843 | 0,364 | 0,180 | 70105 | 1171 | 0,259 | 0,244 | 0,54 | 0,18 | |
| 4 | 13124 | 0,338 | 0,193 | 61636 | 1030 | 0,259 | 0,244 | 0,47 | 0,19 | |
| 5 | 16405 | 0,313 | 0,209 | 54015 | 902 | 0,259 | 0,244 | 0,41 | 0,21 | |
| 6 | 19686 | 0,287 | 0,227 | 47176 | 788 | 0,259 | 0,244 | 0,36 | 0,23 | |
| 7 | 22967 | 0,262 | 0,249 | 41056 | 686 | 0,259 | 0,244 | 0,31 | 0,25 | |
| 8 | 26248 | 0,237 | 0,276 | 35595 | 595 | 0,259 | 0,244 | 0,27 | 0,28 | |
| 9 | 29529 | 0,211 | 0,309 | 30737 | 513 | 0,259 | 0,244 | 0,24 | 0,31 | |
| 10 | 32810 | 0,186 | 0,352 | 26431 | 442 | 0,259 | 0,244 | 0,20 | 0,35 | |
| 11 | 36091 | 0,160 | 0,407 | 22627 | 378 | 0,259 | 0,244 | 0,17 | 0,41 | |
| 12 | 39372 | 0,135 | 0,484 | 19316 | 323 | 0,259 | 0,244 | 0,15 | 0,48 | |
| 13 | 42653 | 0,110 | 0,596 | 16498 | 276 | 0,259 | 0,244 | 0,13 | 0,60 | |
| 14 | 45934 | 0,084 | 0,776 | 14091 | 235 | 0,259 | 0,244 | 0,11 | 0,78 | |
| 15 | 49215 | 0,059 | 1,112 | 12035 | 201 | 0,259 | 0,244 | 0,09 | 1,11 | |
| | | | | | 600 | | | | | 0 |
| | | | | | 600 | | | | | 0,5 |
| Hinweise: | 1m=3,281 ft | $T_{CR}/T_{TO}$= f(BPR,h) | Gl.(5.27) | Gl. (5.32/5.33) | Gl. (5.34) | aus Teil 1 | aus Teil 1 | aus Teil 1 | Wiederholung für den Plot | aus Teil 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Flächenbelastung | $m_{MTO}/S_W$ | **600 kg/m²** | **<<<< Entwurfspunkt aus Entwurfsdiagramm ablesen.** | | | |
| Schub-Gewichtsverhältnis | $T_{TO}/(m_{MTO}$*g) | **0,275** | **<<<<** Die angegebenen Daten sind dann richtig, wenn Start und Landung gleichzeitig dimensionierend sind. | | | |
| Schubverhältnis | $(T_{CR}/T_{TO})_{CR}$ | 0,237 | | | | |
| Umrechnungsfaktor | m -> ft | 0,305 m/ft | | | | |
| Reiseflughöhe | $h_{CR}$ | **7965 m** | Dienstgipfelhöhe | 12100 | -34,18% | http://de.wikipedia.org/wiki/Comac_C919 |
| Reiseflughöhe | $h_{CR}$ | **26131 ft** | | | | |
| Temperatur, Troposphäre | $T_{Troposphäre}$ | 236,38 K | $T_{Stratosphäre}$ | 216,65 K | | |
| Temperatur, $h_{CR}$ | $T(h_{CR})$ | 236,38 | | | | |
| Schallgeschwindigkeit, $h_{CR}$ | a | 308 m/s | | | | |
| Reisefluggeschwindigkeit | $V_{CR}$ | **242 m/s** | | | | |
| Umrechnungsfaktor | NM -> m | 1852 m/NM | | | | http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/COMAC090809.xml long range version |
| Auslegungsreichweite | R | **3000 NM** | Long Range Flight | | | http://www.flightglobal.com/articles/2009/09/09/332070/comac-outlines-details-of-c919-twinjet-family.html long range version |
| Auslegungsreichweite | R | 5556000 m | | | | http://www.flightglobal.com/articles/2009/09/09/331993/aa09-chinas-comac-discloses-more-details-on-c919.html long range version |
| Flugstrecke zum Ausweichplatz | $s_{to\_alternate}$ | 200 NM | | | | |
| Flugstrecke zum Ausweichplatz | $s_{to\_alternate}$ | 370400 m | | | | |
| **Abfrage**: FAR Part121-Reserves? | domestic | **nein** | | | | |
| | international | **ja** | | | | |
| Kraftstoffreserve auf Langstrecke | | 5% | | | | |
| Reserveflugstrecke | $s_{res}$ | 648200 m | | | | |
| Spez.Kraftstoffverbrauch, Reise | $SFC_{CR}$ | **1,36E-05 kg/N/s** | typischer Wert: | 1,60E-05 kg/N/s | | http://de.wikipedia.org/wiki/CFM_International_LEAP-X (15% weniger Verbrauch) |
| Breguet-Faktor, Reichweite | $B_s$ | 27784962 m | | | | |
| Fuel-Fraction, Reiseflug | $M_{ff,CR}$ | 0,819 | | | | |
| Fuel-Fraction, Reserveflugstr. | $M_{ff,RES}$ | 0,977 | | | | |
| Flugzeit im Warteflug | $t_{loiter}$ | 1800 s | | | | |
| Spez.Kraftstoffverbr., Warteflug | $SFC_{loiter}$ | **1,36E-05 kg/N/s** | | | | |
| Breguet-Faktor, Flugzeit | $B_t$ | 114821 s | | | | |
| Fuel-Fraction, Warteflug | $M_{ff,loiter}$ | 0,984 | | | | |

**Reserveflugstrecke:**

| FAR Part 121 | $s_{res}$ |
|---|---|
| domestic | 370400 m |
| international | 648200 m |

**Reservezeit:**

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

| | | **Scholz:** | |
|---|---|---|---|
| Fuel-Fraction, Triebwerksstart | $M_{ff,engine}$ | **0,999** | **<<<< Werte** |
| Fuel-Fraction, Rollen | $M_{ff,taxi}$ | **0,997** | **<<<< kopieren** |
| Fuel-Fraction, Start | $M_{ff,TO}$ | **0,996** | **<<<< aus** |
| Fuel-Fraction, Steigflug | $M_{ff,CLB}$ | **0,996** | **<<<< Tabelle** |
| Fuel-Fraction, Sinkflug | $M_{ff,DES}$ | **0,995** | **<<<< rechts** |
| Fuel-Fraction, Landung | $M_{ff,L}$ | **0,995** | **<<<<** |

| Phase | $M_{ff}$ nach Flugphase [Roskam] | |
|---|---|---|
| | transport jet | business jet |
| engine start | 0,990 | 0,990 |
| taxi | 0,990 | **0,995** |
| take-off | 0,995 | 0,995 |
| climb | 0,980 | 0,980 |
| descent | 0,990 | 0,990 |
| landing | 0,992 | 0,992 |

http://www.airliners.net/aviation-forums/general_aviation/print.main?id=5000477

Flight International 23-29 Novermber 2010:
COMAC C919:
Capacity: 156 two-class, 168 all-economy
Range: 2200nm, 3000nm*
Cruise speed: Mach 0.785
MTOW: 72500kg, 77300kg*
MLW: 66600kg
Max Fuel: 19560kg
OEW: 42100kg
Standard payload: 15920kg
Max payload: 20500
Length: 38,9m
Wingspan: 35.8m
Fuselage width: 3.96 [external]
Take-off performance: 2000m, 2200m*
Landing performance: 1600m
Approach speed: 135 kt

http://atwonline.com/aircraft-engines-components/news/singapore-airshow-news-0201

The aircraft built by COMAC will be a three-model program with the larger C929 and C939 to follow.
COMAC, which is expected to have a significant presence at this week's show, claims the C919 will have
3% lower weight, 12%-15% lower fuel burn and 5% better lift-to-drag ratio than the A320.
First flight is slated for September 2014 with first delivery expected in June 2016.
Initial production rates are expected to be 5-10 annually. [Singapore Airshow, Feb. 2010]

| | | | | | | |
|---|---|---|---|---|---|---|
| Fuel-Fraction, Standardflug | $M_{ff,std}$ | 0,804 | | | | |
| Fuel-Fraction, alle Reserven | $M_{ff,res}$ | 0,953 | | | | |
| Fuel-Fraction, gesamt | $M_{ff}$ | 0,766 | | | | |
| Kraftstoffmassenanteil | $m_F/m_{MTO}$ | 0,234 | | | | |
| Betriebsleermasenverhältnis | $m_{OE}/m_{MTO}$ | 0,516 | nach Loftin | | | |
| Betriebsleermasenverhältnis | $m_{OE}/m_{MTO}$ | **xxx** | nach Statistik (falls gegeben) | | | |
| Betriebsleermasenverhältnis | $m_{OE}/m_{MTO}$ | **0,545** | **<<<< Auswahl treffen gemäß Aufgabenstellung** | | | |
| | | | aus Nachrechnung | | | |
| **Abfrage**: Flugzeugtyp | Kurz- / Mittelstr. | **ja** | **<<<< Auswahl treffen gemäß Aufgabenstellung** | | | |
| | Langstrecke | **nein** | | | | |
| Masse: Passagier mit Gepäck | $m_{PAX}$ | 102,0 kg | | | | |
| Anzahl der Passagiere | $n_{PAX}$ | **168** | | | | http://www.flightglobal.com/articles/2009/09/24/332664/safran-and-ge-make-move-for-c919-engine-supply.html |
| Frachtmasse | $m_{cargo}$ | **0 kg** | | | | |
| Nutzlast | $m_{PL}$ | **17136 kg** | 17136 kg | 0,00% | | aus Nachentwurf ermittelt |
| maximale Abflugmasse | $m_{MTO}$ | **77393 kg** | 77300 kg | 0,12% | | Flight International 23-29 Novermber 2010 |
| maximale Landemasse | $m_{ML}$ | **66682 kg** | 66600 kg | 0,12% | | Flight International 23-29 Novermber 2010 |
| Betriebsleermasse | $m_{OE}$ | **42179 kg** | 42100 kg | 0,19% | | Flight International 23-29 Novermber 2010 |
| Kraftstoffmasse für Standardflug | $m_F$ | **18078 kg** | | | | |
| Flügelfläche | $S_w$ | **129 m²** | 122 m² | 5,42% | Vergleich nur mit A320, C919-Wert ist unbekannt | A320-200 |
| Spannweite | b | **35,0 m** | 35,8 m | -2,20% | | http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/COMAC090809.xml |
| Startschub | $T_{TO}$ | 208768 N | **alle** Triebwerke zusammen | | | |
| Startschub EINES Triebwerks | $T_{TO}/n_E$ | **104384 N** | **ein** Triebwerk 133000 | -21,52% | | http://de.wikipedia.org/wiki/CFM_International_LEAP-X |
| Startschub EINES Triebwerks | $T_{TO}/n_E$ | 23466 lb | **ein** Triebwerk | | | |
| Kraftstoffmasse, erforderlich | $m_{F,erf}$ | 18315 kg | 19560 kg | -6,37% | Max Fuel | Flight International 23-29 Novermber 2010 |
| Kraftstoffdichte | $\rho_F$ | 800 kg/m³ | | | | |
| Kraftstoffvolumen, erforderlich | $V_{F,erf}$ | **22,9 m³** | (später zu vergleichen mit der Tankgeometrie) | | | |
| max. Nutzlast | $m_{MPL}$ | **20500 kg** | → | | 168 Pax (à 102 kg) für Range at max. Pax | |
| max. Leertankmasse | $m_{MZF}$ | 62679 kg | | | 3364 kg zusätzliche Fracht | ermittelt (vereinfacht) |
| Leertankmasse | $m_{ZF}$ | 59315 kg | | | | |
| Kraftstoffmasse, alle Reserven | $m_{F,res}$ | 3629 kg | | | | |

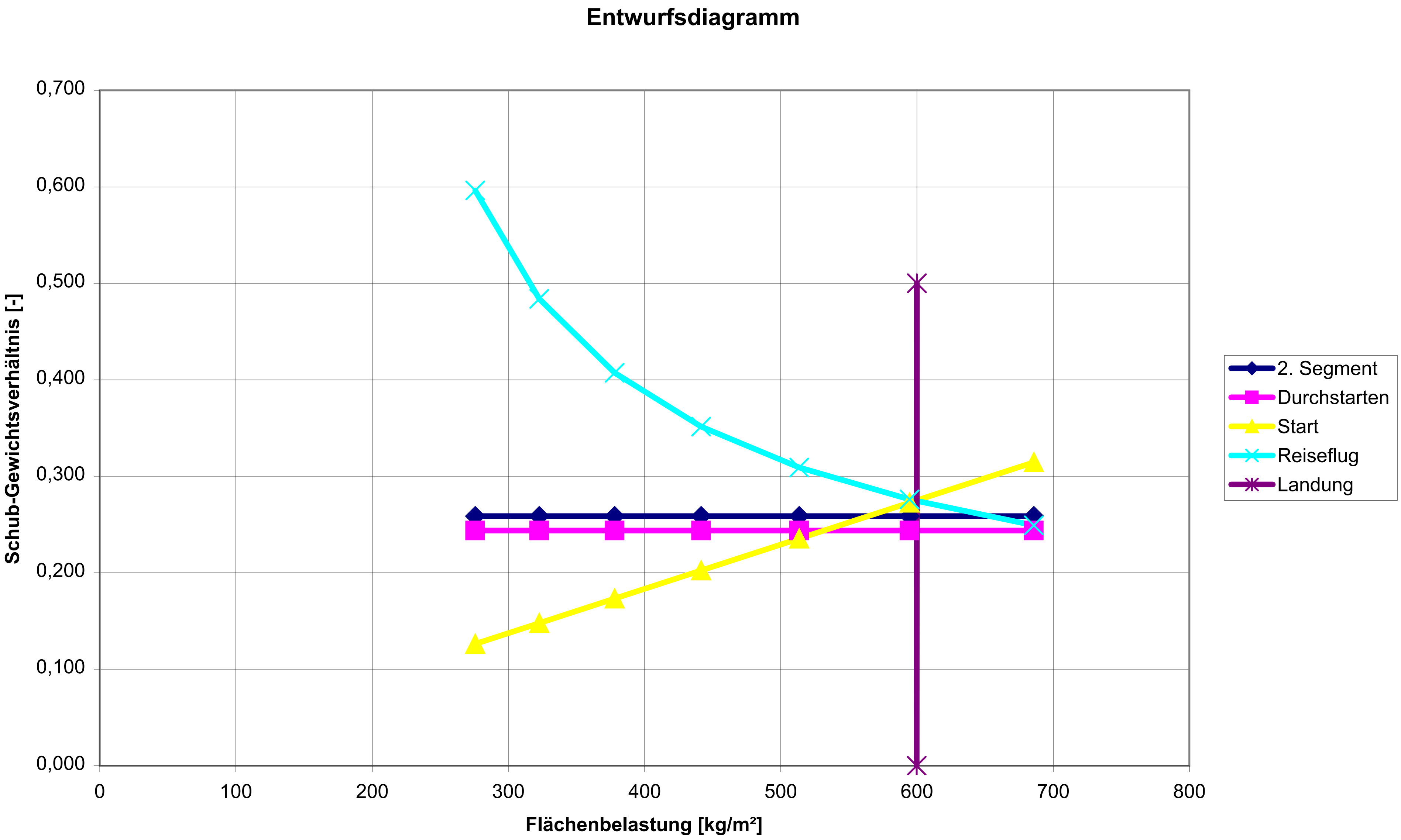
| | | |
|---|---|---|
| $m_{MPL}$ | 20500 kg | http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/COMAC090809.xml |
| $m_{PL,maxPax}$ | 17136 kg | http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=comm&id=news/COMAC090809.xml |
| $m_{PL,maxRange}$ | 13772 kg | geschätzt |

| in kg | Kurz- und Mittelstrecke | Langstrecke |
|---|---|---|
| $m_{PAX}$ | 102,0 | 97,5 |

| | | | | |
|---|---|---|---|---|
| Überprüfung der Annahmen: | check: | $m_{ML}$ | > | $m_{MZF} + m_{F,res}$ **?** |
| | | 66682 kg | > | 66308 kg |
| | | | **ja** | |

Dimensionierung erfolgreich beendet!

weitere Quelle:
http://www.flightglobal.com/articles/2010/11/05/349329/china-special-c919-update.html


Entwurfsdiagramm
Schub-Gewichtsverhältnis [-]
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
Flächenbelastung [kg/m²]
2. Segment
Durchstarten
Start
Reiseflug
Landung

# 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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**HAW Hamburg**
http://www.ProfScholz.de
See Klausur SS11

## Approach

| | | | |
|---|---|---|---|
| Factor | $k_{APP}$ | 1,70 | $(m/s^2)^{0.5}$ |
| Conversion factor | | 1,944 | kt / m/s |
| **Given: landing field length** | | **no** | **<<<< Choose according to task** |
| Landing field length | $s_{LFL}$ | **1665** | **m** |
| Approach speed | $V_{APP}$ | 69,4 | m/s |
| Approach speed | $V_{APP}$ | **135,0** | **kt** |
| **Given: approach speed** | | **yes** | |
| Approach speed | $V_{APP}$ | **135,0** | **kt** |
| Approach speed | $V_{APP}$ | 69,5 | m/s |
| Landing field length | $s_{LFL}$ | **1665** | **m** |

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

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

## Landing

| | | | |
|---|---|---|---|
| Landing field length | $s_{LFL}$ | 1665 | m |
| Temperature above ISA (288,15K) | $\Delta T_L$ | **0** | **K** |
| Relative density | $\sigma$ | 1,000 | |
| Factor | $k_L$ | 0,107 | kg/m³ |
| Max. lift coefficient, landing | $C_{L,max,L}$ | **2,9** | |
| Mass ratio, landing - take-off | $m_{ML} / m_{TO}$ | **0,8616** | |
| Wing loading at max. landing mass | $m_{ML} / S_W$ | **517** | **kg/m²** |
| Wing loading at max. take-off mass | $m_{MTO} / S_W$ | **600** | **kg/m²** |

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

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

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

$m_{ML} / m_{MTO}$

## Take-off

| | | | |
|---|---|---|---|
| Take-off field length | $s_{TOFL}$ | **2200** | **m** |
| Temperatur above ISA (288,15K) | $\Delta T_{TO}$ | **0** | **K** |
| Relative density | $\sigma$ | 1,000 | |
| Factor | $k_{TO}$ | 2,34 | m³/kg |
| Exprience value for $C_{L,max,TO}$ | 0,8 * $C_{L,max,L}$ | 2,32 | |
| Max. lift coefficient, take-off | $C_{L,max,TO}$ | **2,320** | |
| Slope | a | **0,0004585** | **kg/m³** |
| Thrust-to-weight ratio | $T_{TO}/m_{MTO}$*g at $m_{MTO}/S_W$ calculated from landing | **0,275** | |

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

## 2nd Segment

### Calculation of glide ratio

| | | | |
|---|---|---|---|
| Aspect ratio | A | **9,5** | |
| Lift coefficient, take-off | $C_{L,TO}$ | 1,61 | |
| Lift-independent drag coefficient, clean | $C_{D,0}$ (bei Berechnung: 2. Segment) | 0,020 | |
| Lift-independent drag coefficient, flaps | $\Delta C_{D,flap}$ | 0,026 | |
| Lift-independent drag coefficient, slats | $\Delta C_{D,slat}$ | 0,000 | |
| Profile drag coefficient | $C_{D,P}$ | 0,046 | |
| Oswald efficiency factor; landing configuration | e | 0,7 | |
| Glide ratio in take-off configuration | $E_{TO}$ | 9,49 | |

| $n_E$ | 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 | **0,259** | |

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

## Missed approach

### Calculation of the glide ratio

| | | |
|---|---|---|
| Lift coefficient, landing | $C_{L,L}$ | 1,72 |
| Lift-independent drag coefficient, clean | $C_{D,0}$ (bei Berechnung: Durchstarten) | 0,020 |
| Lift-independent drag coefficient, flaps | $\Delta C_{D,flap}$ | 0,031 |
| 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 | $C_{D,P}$ | 0,066 |
| Glide ratio in landing configuration | $E_L$ | 8,30 |

| | 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 | $T_{TO} / m_{MTO}*g$ | **0,244** |

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

# 2.) Max. Glide Ratio in Curise

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

1.) From theory

| | | |
|---|---|---|
| Oswald efficiency factor for $k_E$ | $e$ | **0,78** |
| Equivalent surface friction coefficient | $C_{f,eqv}$ | **0,003** |
| Factor | $k_E$ | 14,3 |

2.) Acc. to RAYMER

| | | |
|---|---|---|
| Factor | $k_E$ | 15,8 |

3.) From own statistics

| | | |
|---|---|---|
| Factor | $k_E$ | **???** |

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

| | | | |
|---|---|---|---|
| Factor | $k_E$ chosen | **14,3** | **<<<< Choose according to task** |
| Relative wetted area | $S_{wet} / S_w$ | **6,2** | $S_{wet} / S_w = 6{,}0 \dots 6{,}2$ |
| Aspect ratio | $A$ | 9,5 | (from sheet 1) |
| Max. glide ratio | $E_{max}$ | **17,69** | |

or

| | | | |
|---|---|---|---|
| Max. glide ratio | $E_{max\ chosen}$ | **17,69** | **<<<< 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 | $E_{max}$ | 17,69 | (aus Teil 2) |
| Aspect ratio | A | 9,5 | (aus Teil 1) |
| Oswald eff. factor, clean | e | 0,78 | |
| Zero-lift drag coefficient | $C_{D,0}$ | 0,019 | |
| Lift coefficient at $E_{max}$ | $C_{L,m}$ | 0,66 | |
| Mach number, cruise | $M_{CR}$ | **0,785** | |

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

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

| Parameter | Value | |
|---|---|---|
| $V/V_m$ | **1,316074013** | Jet, Theory, Optimum: 1,316074013 |
| $C_L/C_{L,m}$ | 0,577 | |
| $C_L$ | 0,380 | |
| E | 15,319 | |

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

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

| 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 | 0,440 | 0,148 | 101325 | 1693 | 0,259 | 0,244 | 0,78 | 0,15 |
| 1 | 3281 | 0,414 | 0,158 | 89873 | 1501 | 0,259 | 0,244 | 0,69 | 0,16 |
| 2 | 6562 | 0,389 | 0,168 | 79493 | 1328 | 0,259 | 0,244 | 0,61 | 0,17 |
| 3 | 9843 | 0,364 | 0,180 | 70105 | 1171 | 0,259 | 0,244 | 0,54 | 0,18 |
| 4 | 13124 | 0,338 | 0,193 | 61636 | 1030 | 0,259 | 0,244 | 0,47 | 0,19 |
| 5 | 16405 | 0,313 | 0,209 | 54015 | 902 | 0,259 | 0,244 | 0,41 | 0,21 |
| 6 | 19686 | 0,287 | 0,227 | 47176 | 788 | 0,259 | 0,244 | 0,36 | 0,23 |
| 7 | 22967 | 0,262 | 0,249 | 41056 | 686 | 0,259 | 0,244 | 0,31 | 0,25 |
| 8 | 26248 | 0,237 | 0,276 | 35595 | 595 | 0,259 | 0,244 | 0,27 | 0,28 |
| 9 | 29529 | 0,211 | 0,309 | 30737 | 513 | 0,259 | 0,244 | 0,24 | 0,31 |
| 10 | 32810 | 0,186 | 0,352 | 26431 | 442 | 0,259 | 0,244 | 0,20 | 0,35 |
| 11 | 36091 | 0,160 | 0,407 | 22627 | 378 | 0,259 | 0,244 | 0,17 | 0,41 |
| 12 | 39372 | 0,135 | 0,484 | 19316 | 323 | 0,259 | 0,244 | 0,15 | 0,48 |
| 13 | 42653 | 0,110 | 0,596 | 16498 | 276 | 0,259 | 0,244 | 0,13 | 0,60 |
| 14 | 45934 | 0,084 | 0,776 | 14091 | 235 | 0,259 | 0,244 | 0,11 | 0,78 |
| 15 | 49215 | 0,059 | 1,112 | 12035 | 201 | 0,259 | 0,244 | 0,09 | 1,11 |
| | | | | | 600 | | | | |
| | | | | | 600 | | | | |
| 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 | $m_{MTO} / S_W$ | **600** | **kg/m²** | <<<< **Read design point from matching chart!** |
| Thrust-to-weight ratio | $T_{TO} / (m_{MTO}*g)$ | **0,275** | | <<<< Given data is correct when take-off and landing is sizing the aircraft at the same time. |
| Thrust ratio | $(T_{CR}/T_{TO})_{CR}$ | 0,237 | | |
| Conversion factor | m -> ft | 0,305 | m/ft | |
| Cruise altitude | $h_{CR}$ | **7965** | **m** | |
| Cruise altitude | $h_{CR}$ | **26131** | **ft** | |
| Temperature, troposphere | $T_{\text{Troposphäre}}$ | 236,38 | K | $T_{\text{Stratosphäre}}$ 216,65 K |
| Temperature, $h_{CR}$ | $T(h_{CR})$ | 236,38 | | |
| Speed of sound, $h_{CR}$ | $a$ | 308 | m/s | |
| Cruise speed | $V_{CR}$ | **242** | **m/s** | |
| | | | | |
| Conversion factor | NM -> m | 1852 | m/NM | |
| Design range | R | **3000** | **NM** | |
| Design range | R | 5556000 | 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 | $s_{res}$ | 648200 | m | |
| Spec.fuel consumption, cruise | $SFC_{CR}$ | **1,36E-05** | **kg/N/s** | typical value 1,60E-05 kg/N/s |
| | | | | |
| Breguet-Factor, cruise | $B_s$ | 27784962 | m | |
| Fuel-Fraction, cruise | $M_{ff,CR}$ | 0,819 | | |
| Fuel-Fraction, extra fliht distance | $M_{ff,RES}$ | 0,977 | | |
| | | | | |
| Loiter time | $t_{loiter}$ | 1800 | s | |
| Spec.fuel consumption, loiter | $SFC_{loiter}$ | **1,36E-05** | **kg/N/s** | |
| Breguet-Factor, flight time | $B_t$ | 114821 | s | |
| Fuel-Fraction, loiter | $M_{ff,loiter}$ | 0,984 | | |
| | | | | |
| Fuel-Fraction, engine start | $M_{ff,engine}$ | **0,999** | **<<<< Copy** | |
| Fuel-Fraction, taxi | $M_{ff,taxi}$ | **0,997** | **<<<< values** | |
| Fuel-Fraction, take-off | $M_{ff,TO}$ | **0,996** | **<<<< from** | |
| Fuel-Fraction, climb | $M_{ff,CLB}$ | **0,996** | **<<<< table** | |
| Fuel-Fraction, descent | $M_{ff,DES}$ | **0,995** | **<<<< on the** | |
| Fuel-Fraction, landing | $M_{ff,L}$ | **0,995** | **<<<< right !** | |

**Reserve flight distance:**

| FAR Part 121 | $s_{res}$ |
|---|---|
| domestic | 370400 m |
| international | 648200 m |

**Extra time:**

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

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

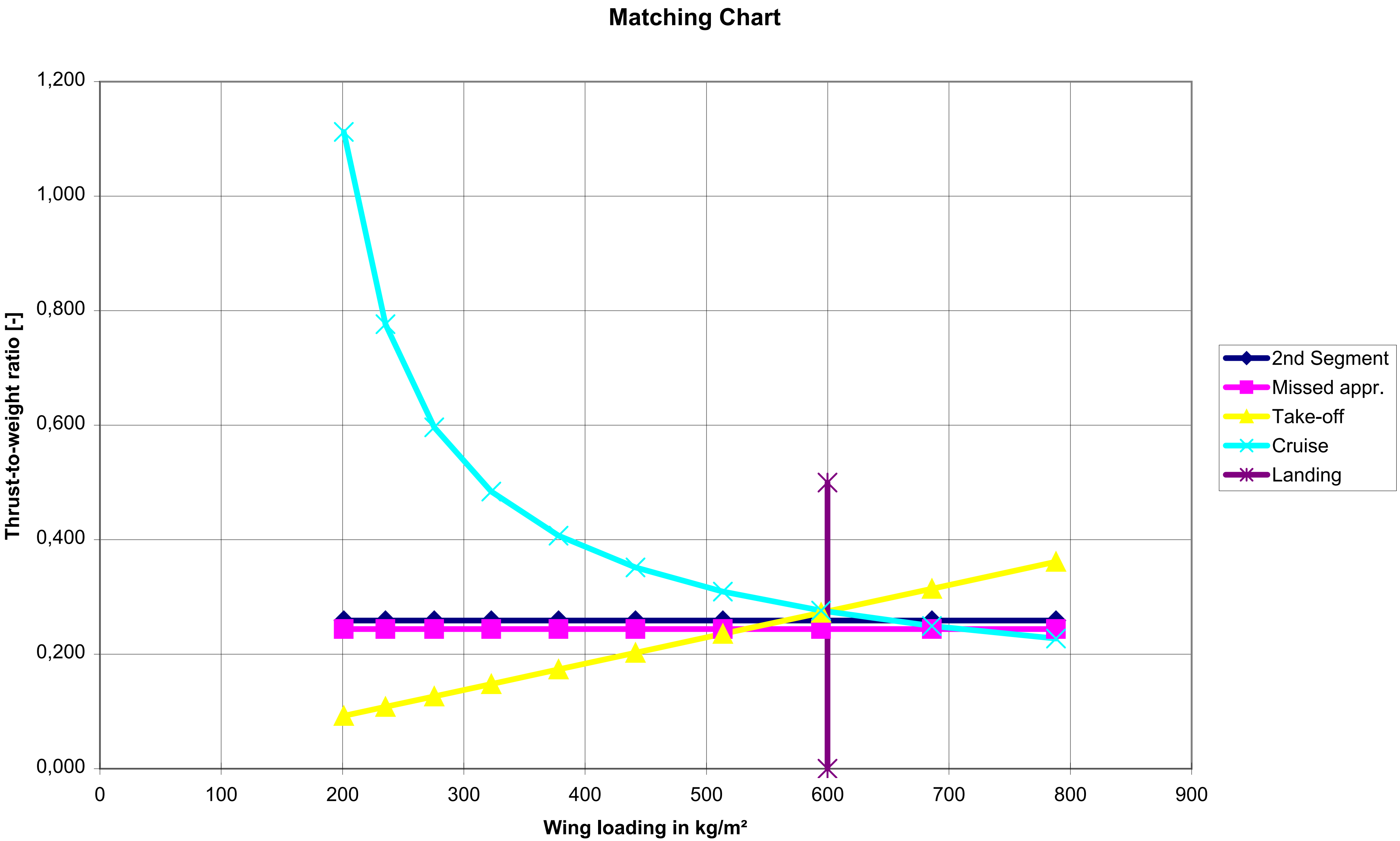
| | | | | |
|---|---|---|---|---|
| Fuel-Fraction, standard flight | $M_{ff,std}$ | 0,804 | | |
| Fuel-Fraction, all reserves | $M_{ff,res}$ | 0,953 | | |
| Fuel-Fraction, total | $M_{ff}$ | 0,766 | | |
| Mission fuel fraction | $m_F/m_{MTO}$ | 0,234 | | |
| | | | | |
| Realtive operating empty mass | $m_{OE}/m_{MTO}$ | 0,516 | | acc. to Loftin |
| Realtive operating empty mass | $m_{OE}/m_{MTO}$ | **xxx** | | from statistics (if given) |
| Realtive operating empty mass | $m_{OE}/m_{MTO}$ | **0,545** | | **<<<< Choose according to task** |
| | | | | |
| **Choose**: type of a/c | short / medium range | **yes** | | **<<<< Choose according to task** |
| | long range | **no** | | |
| Mass: Passengers, including baggage | $m_{PAX}$ | 102,0 | kg | |
| Number of passengers | $n_{PAX}$ | **168** | | |
| Cargo mass | $m_{cargo}$ | **0** | **kg** | |
| Payload | $m_{PL}$ | **17136** | **kg** | |
| | | | | |
| Max. Take-off mass | $m_{MTO}$ | **77393** | **kg** | |
| Max. landing mass | $m_{ML}$ | **66682** | **kg** | |
| Operating empty mass | $m_{OE}$ | **42179** | **kg** | |
| Mission fuel fraction, standard flight | $m_F$ | **18078** | **kg** | |
| Wing area | $S_w$ | **129** | **m²** | |
| Span | b | 35,01 | m | |
| Take-off thrust | $T_{TO}$ | 208768 | N | **all engines together** |
| T-O thrust of ONE engine | $T_{TO} / n_E$ | **104384** | **N** | **one engine** |
| T-O thrust of ONE engine | $T_{TO} / n_E$ | 23466 | lb | **one engine** |
| | | | | |
| Fuel mass, needed | $m_{F,erf}$ | 18315 | kg | |
| Fuel density | $\rho_F$ | 800 | kg/m³ | |
| Fuel volume, needed | $V_{F,erf}$ | **22,9** | **m³** | (check with tank geometry later on) |
| | | | | |
| Max. Payload | $m_{MPL}$ | **20500** | **kg** | |
| Max. zero-fuel mass | $m_{MZF}$ | 62679 | kg | |
| Zero-fuel mass | $m_{ZF}$ | 59315 | kg | |
| | | | | |
| Fuel mass, all reserves | $m_{F,res}$ | 3629 | kg | |

| in kg | Short- and Medium Range | Long Range |
|---|---|---|
| $m_{PAX}$ | 102,0 | 97,5 |

| | | | | | |
|---|---|---|---|---|---|
| Check of assumptions | check: | $m_{ML}$ | | > | $m_{MZF} + m_{F,res}$ **?** |
| | | 66682 | kg | > | 62944 kg |
| | | | | **yes** | |

Aircraft sizing finished!

| | | | |
|---|---|---|---|
| Cargo mass | $m_{cargo}$ | 3364 | kg |


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

# Task 2.2

**The task can be solved with the Excel table using the section for 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

| | | |
|---|---|---|
| Number of engines | $n_E$ | **4** |
| Mass ratio, landing - take-off | m ML / m TO | **0,8616** |

**Missed approach**

| $n_E$ | sin(γ) |
|---|---|
| 2 | 0,021 |
| 3 | 0,024 |
| 4 | 0,027 |

| | | |
|---|---|---|
| Glide ratio in landing configuration | $E_L$ | **11,00** |
| **Calculation of thrust-to-weight ratio** | | |
| Climb gradient | sin(γ) | 0,027 |
| Thrust-to-weight ratio | $T_{TO} / m_{MTO} * g$ | **0,135** |

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

# Task 2.3

a) According to the lecture notes

$$\underset{\uparrow \text{wing}}{C_{L,max}} = 1.1 \cdot C_{L,max,\text{INITIAL SIZING}}$$

Hence, the wing should produce

$$1.1 \cdot 2.9 = \underline{\underline{3.19}} \qquad = C_{L,max}$$

b) According to the lecture notes the high lift system should produce at least

$$0{,}95 \cdot \Delta C_{L,max,f} + \Delta C_{L,max,s} = C_{L,max} - C_{L,max,clean}$$

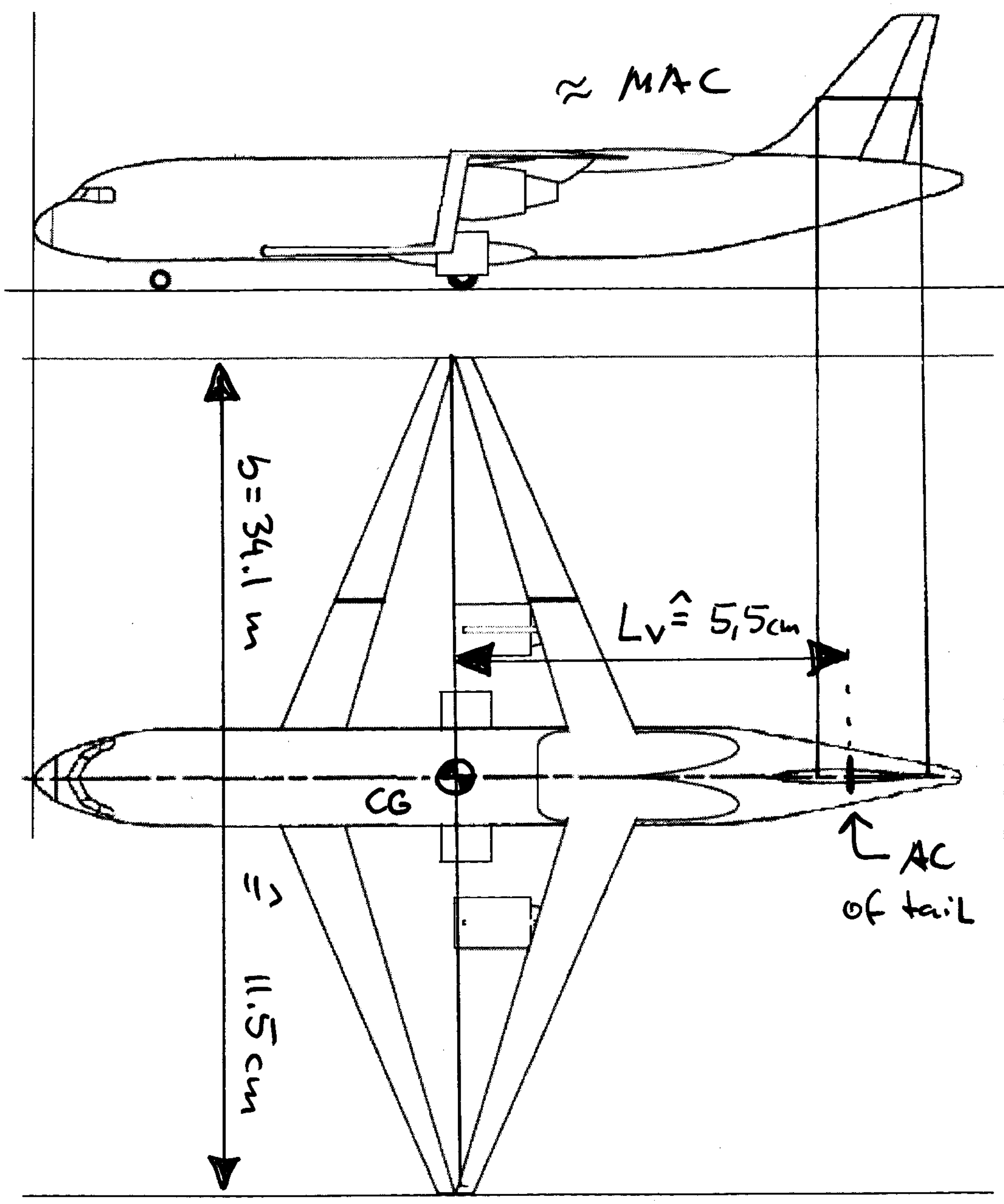
$$\Delta C_{L,\text{High Lift}} = C_{L,max} - C_{L,max,clean} \overset{!}{=} 3.19 - 1.7 = 1.49$$

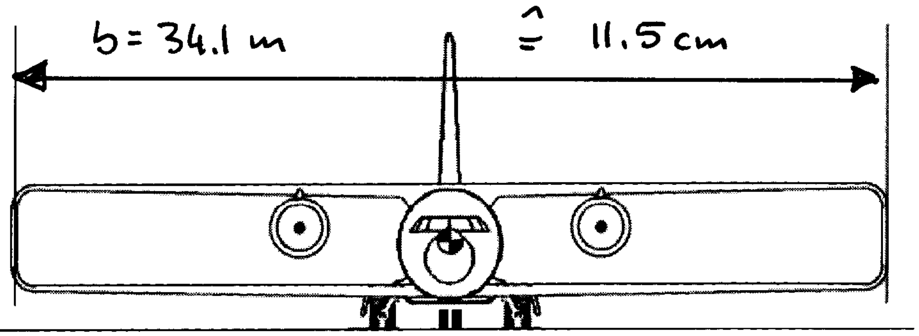
$$\Delta C_{L,max,s} = \underset{\uparrow 40\%}{0{,}4} \cdot 1.49 = 0{,}596$$

$$\Delta C_{L,max,f} = \frac{1}{0{,}95} \cdot (1{,}49 - 0{,}596) = \underline{\underline{0{,}941}}$$

## Task 2.4

Task 2.4





a) scale : $\frac{11.5}{3410} = \underline{\underline{1:297}}$

**A320 fuselage**

**engines**
CFM56-5

**wings**
simple trapezes
symmetric to y-axis
total ref. area: 122 m² $S_W$
root chord: 2,9 m
taper ratio: 0,24
h/b = 0.12 (h = 4.14 m ; $\underline{\underline{b = 34.1 \text{ m}}}$)

front wing sweep (25% of chord): 22,1°
aft wing sweep (25% of chord): -18,4°

**landing gear**
integration similar to Avro RJ
limits maximum pitch angle for takeoff (8°)
tilt angle of 55° (max. allowable value)

b) $L_V \hat{=} 5{,}5\text{cm}$

$L_V = \underline{\underline{16{,}3\text{ m}}}$

c) $C_V = \frac{S_V \cdot L_V}{S_W \cdot b}$ mit $C_V = 0{,}09$

$$S_V = \frac{C_V \cdot S_W \cdot b}{L_V} = \frac{0.09 \cdot 122 \cdot 34.1}{16.3} \text{ m}$$

$$= 22.96 \text{ m}^2 \approx \underline{\underline{23 \text{ m}^2}}$$

# Task 2.5

Wave drag (Wellenwiderstand)

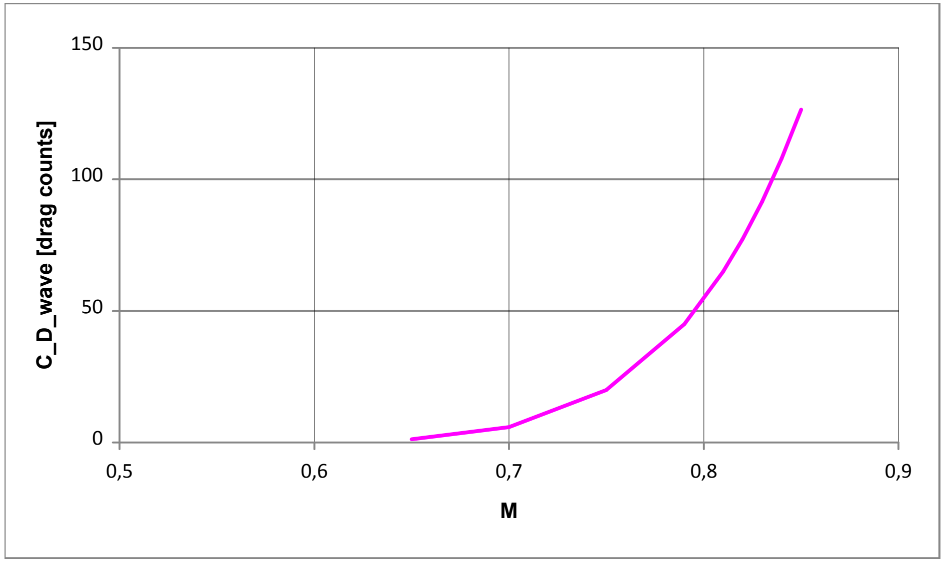
Mcrit = 0,5

a = 0,09

b= 5,5

$$\Delta C_{D,wave} = a \cdot \left( \frac{M}{M_{crit}} - 1 \right)^b$$

| Mach | Calculation<br>ΔC_D,wave | in CTS |
|---|---|---|
| 0,65 | 0,0001 | 1 |
| 0,7 | 0,0006 | 6 |
| 0,75 | 0,0020 | 20 |
| 0,79 | 0,0045 | 45 |
| 0,81 | 0,0065 | 65 |
| 0,82 | 0,0077 | 77 |
| 0,83 | 0,0092 | 92 |
| 0,84 | 0,0108 | 108 |
| 0,85 | 0,0127 | 127 |



**a)** **The wave drag coefficient is 0,002 or 20 drag counts.**

**b)** **The Mach number of 0,75 is hence the Drag Divergence Mach number (M_DD).**

**c)** **If the aircraft follows common layout principles applied at Airbus or Boeing M = 0,75 is the Cruise Mach Number.**

# Task 2.6 COMAC Total Price

| | | | relative price | | |
|---|---|---|---|---|---|
| n_seats | 168 | | | | |
| price per seat | 265000 | USD | | | |
| P_deliver | 4,45E+07 | USD | | 88% | aircraft |
| k_PE | 293 | USD | | | |
| T_TO | 133000 | N | | | |
| P_E | 4,14E+06 | USD | | | |
| n_E | 2 | | | | |
| n_E * P_E | 8,28E+06 | USD | 16% | | engines |
| P_AF | 3,62E+07 | USD | 72% | | airframe |
| k_S,AF | 0,1 | | | | |
| K_S,E | 0,3 | | | | |
| P_S,AF | 3,62E+06 | USD | 7% | | spares for the airframe |
| P_S,E | 2,49E+06 | USD | 5% | | spares for the engines |
| P_S | 6,11E+06 | USD | | 12% | spares |
| **P_tot** | **5,06E+07** | **USD** | | 100% | |

**Compare with:**

http://www.msnbc.msn.com/id/11582772/ns/business-us_business/t/airbus-outshines-boeings/

Both the A320 and 737 have a list price of around $60-70 Million

http://de.wikipedia.org/wiki/Airbus-A320-Familie

Listenpreis: 73,2 bis 80,6 Million USD

# Task 2.7

**all measures in mm**

1 in = 25,4 mm

| | C919 | A320 | lecture notes * |
|---|---|---|---|
| fuselage width | 3960 | 3950 | --- |
| fuselage height | 4166 | 4141 | --- |
| aisle width | 500 | 483 | 457 |
| aisle height | 2250 | 2220 | 1930 |
| seat width | 457 | 457 | 432 |
| cargo hold height | 1250 | 1295 | --- |
| cargo hold floor width | 1578 | 1575 | --- |

* Minimum values according to RAYMER

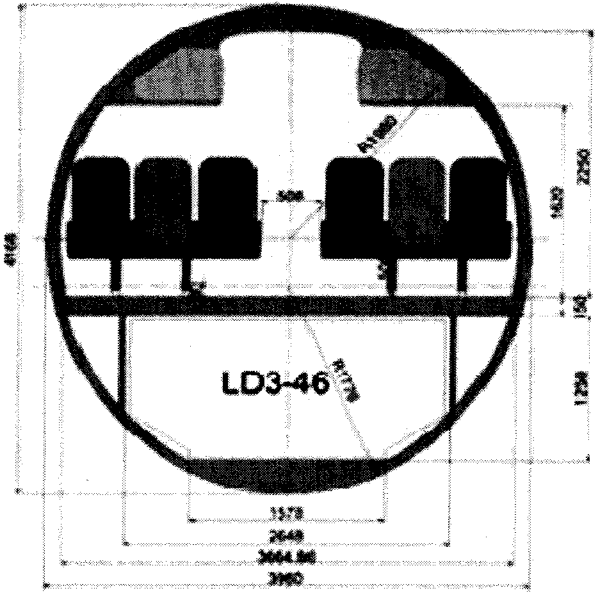
**Comments**

a) Airbus and COMAC's values are above recommended minimum values from literature

b) With the exception of the cargo hold height, COMAC's values are slightly higher
The enlargement of the C919 compared with the A320 is minimal
**The COMAC's values show a high similarity with Airbus values. Have they been copied?**

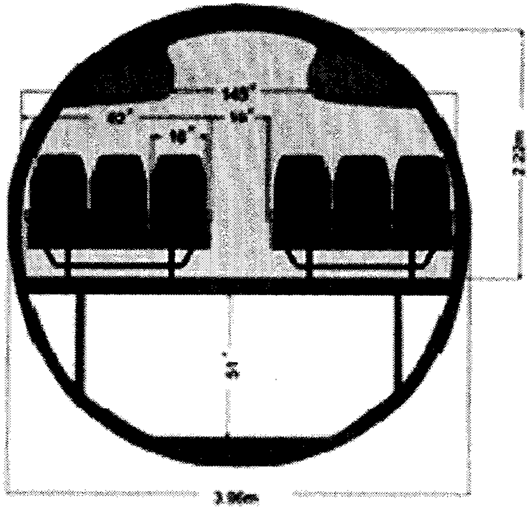
c) COMAC draws it's fuselage by a factor of 6.4/6.1 = 1,05 larger
In reality however the fuselage is only by a factor of 3960/3950 = 1,003 larger
**COMAC tries to give a faulty impression that it's fuselage cross section is substantially larger compared to the A320**
However, in reality the values are practically identical.

## COMAC Cross Section Comparison:



6,4 cm

6,4 cm



6,1 cm

6,1 cm