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Project

Requirements from National Regulations for Microlight Aircraft and Statistical Parameters for Preliminary Sizing

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Abstract

The purpose of this project is to examine and describe the regulations of microlight aircraft. The national rules of mostly European countries are described in more detail and are compared to the German rules. Most important among the regulations is the maximum take-off mass. In some countries, the limit of 472.5 kg has been raised recently to 600 kg. The report leads from microlight regulations to preliminary sizing of microlight aircraft. Preliminary sizing is based on statistical parameters, which are evaluated for typical microlight aircraft. The parameter k_{APP} relates landing field length to approach speed. From microlight statistics it was determined an average value k_{APP} = 2.149 $m^{0.5}/s$. The parameter k_{TO} helps to determine the ratio of power-to-mass and wing loading. An average value k_{TO} = 1.915 m^3/kg was determined. The glide ratio can be estimated from "wetted aspect ratio" with an average k_E = 12.12. The average operating empty mass ratio was determined to 0.578. This means that a microlight aircraft with a maximum take-off mass of 600 kg might have an operating empty mass of about 347 kg. This work does not provide a spreadsheet tool for microlight sizing. But at least the project provides the input parameters for preliminary sizing from microlight regulations together with necessary statistical parameters. As such, a preliminary microlight aircraft sizing by a hand calcuation becomes possible. The report also helps pilots and microlight owners to understand why certain values appear in the operating manual and on which regulations they are based.

HAW HAMBURG

DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Requirements from National Regualtions for Microlight Aircraft and Statistical Parameters for Preliminary Sizing

Task for the Project

Background

Microlight aircraft are sold all over the world with different maximum take-off mass. Which aircraft can be flown with which license in which country is often unclear as it falls under the national law of the respective country. As a microlight pilot or as a microlight manufacturer the actual country information is very important for developing, manufacturing, flying, selling and reselling microlights of different types. To perform a successful design of a microlight aircraft, requirements as well as some statistical parameters must be known.

Task

The purpose of this project is to provide a clear overview of various national regulations of microlight aircraft. Furthermore, average statitical values for preliminary sizing of microlight aircraft have to be evaluated. The report should follow these steps:

- Determine requirements for microlight aircraft (maximum take-off mass, minimum speed, maximum seating capacity, load factor, ...)
- Determine statistical parameter for microlight preliminary sizing (k_{APP}, k_L, k_{TO}, and k_E) as defined in the lecture notes.

The report has to be written in English based on German or international standards on report writing.

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List of Symbols

A	Aspect ratio
b	Span
C_D	Drag coefficient
$C_{L,max,L}$	Maximum lift coefficient, landing
$C_{L,max,TO}$	Maximum lift coefficient, take-off
C_{m0}	Pitching moment coefficient at zero lift
c_h	Factor for the power decrease
E	Lift-to-drag ratio
E_{max}	Maximum lift-to-drag ratio
g	Acceleration due to gravity
k_{App}	Approach parameter
k_E	Landing parameter
k_L	Landing parameter
k_{TO}	Take-off parameter
m	Mass/weight
m_F	Fuel weight
m_L	Landing weight
m_{MTO}	Maximum take-off weight
m_{OE}	Operation empty weight
n_{PAX}	Numper of persons
P_S	Shaft power
R	Range
R^2	Coefficient of determination
ROC	Rate of climb
S	Surface
S_W	Wing area
S_{Wet}	Wetted area
S_{LFL}	Landing field length
S_{TOG}	Take-off ground roll
T	Temperature
T_{TO}	Thrust at take-off
u	Useful load
V	Speed
V_2	Take-off speed
V_A	Rated maneuvering speed
V_{APP}	Approach speed
V_B	Rated speed for strong gusts
V_{CR}	Cruise speed

V_D	Rated maximum speed
V_F	Rated speed with extended flaps
V_{FE}	Maximum allowable speed with flaps extended
V_H	The highest horizontal speed at maximum continuous engine power
V_{NE}	Speed never to exceed
V_{RA}	Maximum permissible speed in strong turbulence
$V_{S,0}$	Minimum speed in landing configuration
$V_{S,1}$	Minimum speed in start configuration
y_i	Values from the given statistic
$\hat{y}_i$	Calculated values (of the residues)
$\bar{y}_i$	Calculated values (of y)

Greek Symbols

γ	Climbing angle
ρ	Density
ρ_0	Density at sea level
σ	Density ratio
η	Efficiency
η_p	Propeller efficiency

Indices

CL	Climb
CR	Cruise
F	Flaps
H	Horizontal
LD	Landing
MTO	Maximum-take-off
NE	Never exceed
P	Propeller
TO	Take-off
W	Wing
Wet	Wetted (surface)

List of Abbreviations

CFD	Computational Fluid Dynamics
CS	Certification Specification
DAeC	Deutscher Aero Club e.V.
DULSV	Deutsche Ultraleicht-Segelflugverband | German Ultralight Sailplane Association
DULV	Deutscher Ultraleichtflugverband | German Microlight Association
EAS	Equivalent airspeed
EASA	European Aviation Safety Agency
EMF	European Microlight Federation
FAA	Federal Aviation Administration
FAI	Fédération Aéronautique Internationale
FAR	Federal Aviation Regulation
FFPLUM	Fédération Française de Planeur Ultra-Léger Motorisé
FOCA	Federal Office of Civil Aviation
ICAO	International Civil Aviation Organization
JAA	Joint Aviation Authorities
LAA	Letecká Amatérská Asociace
LAPL(A)	Light Aircraft Pilot License (Aeroplane)
LBA	Luftfahrt-Bundesamt
LTF-L	Luftüchtigkeitsforderungen für aerodynamisch gesteuerte Luftsportgeräte | Airworthiness requirements for aerodynamically controlled air sports equipment
LTF-UL	Luftüchtigkeitsforderungen an ein aerodynamisch gesteuertes Ultraleichtflugzeug | Airworthiness requirements for an aerodynamically controlled ultralight aircraft
LuftVO	Luftverkehrs-Ordnung | Air Traffic Regulation
MTOW	Maximum Take-Off Weight
OUV	Oskar-Ursinus-Vereinigung
UL	Ultralight
USA	United States of America
PDF	Portable document format
ROC	Rate-Of-Climb
SERA	Standardised European Rules of the Air
SPL	Sportpilotenlizenz | Sport Pilot License
VFR	Visual Flight Rules
VLA	Very Light Airplanes
VMLL	Verband zur Förderung motorisierter Leichter Luftsportgeräte | Association for the Promotion of Powered Light Air Sports Equipment

List of Definitions

Coefficient of determination

In order to read off the quality of the statistical regression, the coefficient of determination R^2 can be calculated with

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2} = 1 - \frac{\text{Variation of residues}}{\text{Variation of y}}$$

which is defined in the interval between 0 and 1. It indicates what percentage of the variance of the dependent variable is explained. A higher value is better. $R^2 = 1$ would mean that all values are exactly described by the regression. (**Lehnert 2018**, based on **Fahrmeir 2010**)

OpenFoam

Open-Source Field Operation and Manipulation is a numerical computer program written in C++ for solving airflow problems.

Safety Factor

According to JAR-23 *Loads* and *Factor of safety*, the safety factor is generally set to **1.5** unless otherwise provided. All limit loads of the strength requirement are multiplied by the safety factor to become ultimate loads, which can then be used for further work.

1 Introduction

1.1 Motivation

Microlight airplanes are light, mostly simple airplanes for 1-2 persons. In recent years, microlight aircraft are enjoying great popularity. In Germany, there have never been so many registered aircraft as in 2019. In 2014, there were 3987 registered aircraft, while in 2019 there were already 4210 (**DAeC 2019** - *Jahresvergleich* page 11). In the future, this industry will grow even more with efficient and innovative aircraft. Flying cars for the masses as seen in science fiction movies may also be more likely to become a reality in the microlight market, as pilot training is much faster and less expensive than with a higher class of aircraft. The restrictions and definitions that apply to microlight aircraft are described in the next chapters.

1.2 Objectives

The purpose of this paper is to describe the framework and regulations for microlight aircraft. The national regulations of different countries are examined and described in more detail based on the German regulations. This work goes in the direction of preliminary sizing by understanding and defining statistical parameters for ultralight aircraft. The aim of the work is to provide an overview of regulations of the microlight aircraft market and to provide a basis on which a design of microlight aircraft can be performed.

1.3 Literature Review

For the overview of the different national regulations for microlight aircraft, the publications of the different countries were used, such as the German regulations published by the LBA which is based on the international exemption according to EASA. Flight mechanical calculations and the determination of statistical parameters are based on the lecture notes by **Scholz 2015**. For the statistical parameter determination of microlight aircraft, the aircraft data comes from **Jane's 1992**.

1.4 Structure

The content of this project is structured as follows:

Chapter 2 describes how microlight aircraft are defined and gives an overview of different classes. It describes why the rules are national law and shows the rules for microlight aircraft of different countries summarized in a clear table. Then, using the rules of Germany, it goes into detail about the requirements.

Chapter 3 discusses the preliminary sizing of microlight aircraft with many subchapters where statistical design parameters are calculated shuch as parameters for approach speed, take-off field length, lift-to-drag ratio and the calculation of the relative operation empty mass.

Chapter 4 represents a final summary and conclusion of the project and provides further recommendations for future research.

2 Definitions and Regulation

2.1 Overview of International Microlight Requirements

Microlight aircraft types are light air vehicles of different classes such as microlight and ultralight multi-axle aircraft with or without floats, helicopters, gyroplanes, powered hang gliders (paramotor and motor kite) and airships (Classes from **FFPLUM 2021**)

Normally, all rules of flying are international matters regulated by "International Civil Aviation Organization" ICAO or the "Joint Aviation Authorities" JAA (which is now transferred with most of the tasks to the "European Aviation Safety Agency" EASA). The rules for microlights is a national matter as they are explicitly excluded from the international regulations.

In the Basic Regulations (EC) No 2016/2008 of EASA, Annex II specifies which flying objects are excluded from international regulation (**EASA 2008**):

(a) historic aircraft meeting the criteria below:

(i) non-complex aircraft whose:
- initial design was established before 1 January 1955, and
- production has been stopped before 1 January 1975;
or

(ii) aircraft having a clear historical relevance, related to:
- a participation in a noteworthy historical event, or
- a major step in the development of aviation, or
- a major role played into the armed forces of a Member State;

(b) aircraft specifically designed or modified for research, experimental or scientific purposes, and likely to be produced in very limited numbers;

(c) aircraft of which at least 51 % is built by an amateur, or a non-profit making association of amateurs, for their own purposes and without any commercial objective;

(d) aircraft that have been in the service of military forces, unless the aircraft is of a type for which a design standard has been adopted by the Agency;

(e) aeroplanes, helicopters and powered parachutes having no more than two seats, a maximum take-off mass (MTOM), as recorded by the Member States, of no more than:

(i) 300 kg for a land plane/helicopter, single-seater; or

(ii) 450 kg for a land plane/helicopter, two-seater; or

(iii) 330 kg for an amphibian or floatplane/helicopter single-seater; or

(iv) 495 kg for an amphibian or floatplane/helicopter two-seater, provided that, where operating both as a floatplane/helicopter and as a land plane/helicopter, it falls below both MTOM limits, as appropriate;

(v) 472,5 kg for a land plane, two-seater equipped with an airframe mounted total recovery parachute system;

(vi) 315 kg for a land plane single-seater equipped with an airframe mounted total recovery parachute system;
and, for aeroplanes, having the stall speed or the minimum steady flight speed in landing configuration not exceeding 35 knots calibrated air speed (CAS);

(f) single and two-seater gyroplanes with a maximum take off mass not exceeding 560 kg;

(g) gliders with a maximum empty mass, of no more than 80 kg when single-seater or 100 kg when two-seater, including those which are foot launched;

(h) replicas of aircraft meeting the criteria of (a) or (d) above, for which the structural design is similar to the original aircraft;

(i) unmanned aircraft with an operating mass of no more than 150 kg;

(j) any other aircraft which has a maximum empty mass, including fuel, of no more than 70 kg.

In the shown quote you can see in point (e) and (f) that an aircraft with a maximum take-off weight $\boldsymbol{m_{MTO}} = \mathbf{472.5\ kg}$ is exempt from national regulations.

10 years later, EASA has finally made it possible to **increase the weights** and stall speed for Europe in **Regulation (EU) 2018/1139**. This means that European countries can implement a takeoff weight increase in their national requirements (**EASA 2018 a**, Article 2, 8):

8. A Member State may decide to exempt from this Regulation the design, production, maintenance and operation activities in respect of one or more of the following categories of aircraft:

(a) aeroplanes, other than unmanned aeroplanes, which have no more than two seats, measurable stall speed or minimum steady flight speed in landing configuration not exceeding 45 knots calibrated air speed and a maximum take-off mass (MTOM), as recorded by the Member State, of no more than 600 kg for aeroplanes not intended to be operated on water or 650 kg for aeroplanes intended to be operated on water;

(b) helicopters, other than unmanned helicopters, which have no more than two seats and a MTOM, as recorded by the Member State, of no more than 600 kg for helicopters not intended to be operated on water or 650 kg for helicopters intended to be operated on water;

(c) sailplanes, other than unmanned sailplanes, and powered sailplanes, other than unmanned powered sailplanes, which have no more than two seats and a MTOM, as recorded by the Member State, of no more than 600 kg.

The German "Luftüchtigkeitsforderungen an ein aerodynamisch gesteuertes Ultraleichtflugzeug" **LTF-UL** were finally changed at the beginning of 2019. Now microlight aircraft can be certified in Germany that no longer have a m_{MTO} of 472.5 kg as before, but microlight aircraft can have a weight of $\boldsymbol{m_{MTO}} = \mathbf{600\ kg}$ (with floats: $m_{MTO} = 650\ \text{kg}$) (**LTF-UL 2019**).

In Germany the LTF-UL are published by the "Luftfahrt-Bundesamt" LBA. The comissioned organizations of all microlight German air sports associations is the "Deutscher Ultraleichtflugverband e.V." DULV next to the "Deutsche Aero Club" DAeC which is a member of the "Fédération Aéronautique Internationale" FAI.

FAI was founded in October 1905 in Paris and is a non-governmental and non-profit organization that organizes rules for control and certification of world records and rules for air sports events around the world. With over 100 member countries, they provide a international platform and help countries with rules and recommendations for their respective national law. "FAI - the global organisation for the promotion of air sports and recreational flying" (**FAI 2021**)

The DAeC and the DULV are important for microlight flying in Germany. They share the tasks of the different ultralight types and regulate certifications, authorizations, supervision for operation at airfields, collection of costs and pilot education.

The "Oskar-Ursinus-Vereinigung" **OUV** promotes the self-building of aircraft, **provides assistance** and refers to the LBA. The **DVLL** (which consists of "Deutsche Ultraleicht-Segelflugverband" DULSV and "Verband zur Förderung motorisierter Leichter Luftsportgeräte" VMLL) takes care of the very light **120 kg - class** (empty mass incl. rescue parachute) whose airworthiness requirement **LTF-L** is also published by the **LBA**. In 2010, the 120 kg microlight class was published, which has the advantage of not requiring an airworthiness certificate or annual inspection. In this project, I will not go into more detail about this class. (**LTF-L 2012**)

The German **air traffic** is regulated by the "Luftverkehrs-Ordnung" **LuftVO**. For the European area, there are now the "Standardised European Rules of the Air" **SERA** which replace the air traffic rules of the LuftVO. (**Luftrecht 2015**)

The “European Microlight Federation” **EMF** is an **association for microlight aircraft** founded in 2004 with members from various national aero clubs and microlight federations from Europe (including Switzerland and San Marino). The aim of the EMF is to **promote microlight flying in Europe** also by helping countries to draft national regulations. If you want to make international flights with a microlight or you want to charter a microlight in a foreign country, it is difficult with all the national regulations, because for each country there are different regulations. The EMF describes in a handy dokument some regulations and contacts for many European countries. (**EMF 2019**)

In **France**, the "Fédération Française de Planeur Ultra-Léger Motorisé" **FFPLUM is responsible for microlight aircraft**. They are the head of the EMF and a major support of the European microlight flying. This association stands under the national aeroclub Aero-Club de France, founded in 1895 which is the first aeronautical institution in the world. The requirements for a microlight aircraft are described in “**La règlementation ULM de 2019**” Class 3 (see Table 2.1). (**FFPLUM 2021**)

Table 2.1 French microlight requirements, masses and power (**ULM 2019**, page 6)

3 Classe	Configuration	Masses max. (en kg)	Masse à vide max avec nouvelles masses max (en kg)*	Masses d'emport forfaitaires (en kg)				Cumul total de masse para+ flot+ carb+pil/pax	Puissance (en kW et (en CV)) Puisssances max.	VSO (VC)
				Crédit masse forfaitaire parachute	Crédit masse forfaitaire flotteurs	Masse forfaitaire pilote/ passager	Masse forfaitaire carburant (essence)**			
Multiaxe monoplace	**Basique**	330	223	-	-	86	21	107	65 (88)	38Kts (70km/h)
	+ parachute	345	238	15	-	86	21	122	65 (88)	38Kts (70km/h)
	+ flotteurs	360	253	-	30	86	21	137	65 (88)	38Kts (70km/h)
	+ parachute + flotteurs	375	268	15	30	86	21	152	65 (88)	38Kts (70km/h)
Multiaxe biplace	**Basique**	500	312,5	-	-	156	31,5	187,5	80 (109)	38Kts (70km/h)
	+ parachute	525	337,5	25	-	156	31,5	212,5	80 (109)	38Kts (70km/h)
	+ flotteurs	545	357,5	-	45	156	31,5	232,5	80 (109)	38Kts (70km/h)
	+ parachute + flotteurs	570	382,5	25	45	156	31,5	257,5	80 (109)	38Kts (70km/h)

* Nouvel arrêté ULM

** 30 litres x 0,7 (monoplace)
** 45 litres x 0,7 (biplace)

You can see that the new rules of 2019 allow a maximum takeoff weight of $\boldsymbol{m_{MTO} = 525}$ **kg** (**two seater** with 25 kg parachute). For a floatable aircraft there is 45 kg more for the floats. The minimum passenger weight is 156 kg with at least 45 l (31.5 kg) of fuel. The engine must not exceed the power of 80 kW. The minimum airspeed $\boldsymbol{V_{S,0}}$ must not exceed **70 km/h**.

A **single-seat** aircraft is allowed to have a $\boldsymbol{m_{MTO} = 345}$ **kg** (15 kg parachute), with floats 30 kg more. The minimum passenger weight is 86 kg with at least 30 l (21 kg) of fuel. The engine must not exceed the power of 65 kW. The minimum flying speed $\boldsymbol{V_{S,0}}$ must also not exceed **70 km/h**.

As a logical consequence, the operation empty weight (without parachute) cannot exceed $\boldsymbol{m_{OE} = 223}$ **kg** for a **single-seater** and $\boldsymbol{m_{OE} = 312.5}$ **kg** for a **two-seater**.

In the **Czech Republic**, the microlight association "Letecká Amatérská Asociace" **LAA** is responsible for microlight aircraft. The **Czech Republic** and **Germany** have set the maximum take-off mass to $\boldsymbol{m_{MTO} = 600}$ **kg**. The Czech Ministry of Transport and Communications describes the requirements for a microlight aircraft in Regulation 108/1997 Sb., vyhlášky č. 66/2019 (**Czech 2019**, page 21):

§ 24

Charakteristika jednotlivých druhů sportovních létajících zařízení

(K § 81 odst. 8 zákona)

(1) ltralehký kluzák je maximálně dvoumístnébezmotorové letadlo řízené aerodynamickými prostředky,jehož maximální vzletová hmotnost nepřevyšuje 600 kg.

(2) Motorový ultralehký kluzák je maximálně dvoumístné ultralehké letadlo vybavené pohonnou jednotkou, jehož maximální vzletová hmotnost nepřevyšuje 600 kg.

(3) ltralehký letoun je maximálně dvoumístné motorové letadlo řízené aerodynamickými prostředky,jehož pádová rychlost nepřevyšuje 83 km/h a maximální vzletová hmotnost nepřevyšuje 600 kg nebo650 kg v případě ultralehkých letounů, které jsouurčeny k použití na vodě.

The Czech regulations of 2019 are very similar to the German LTF-UL of 2019. In Chapter 2.2 the regulations are discussed in more detail.

Most other European countries have not yet adapted their national regulations and are still at a $\boldsymbol{m_{MTO}} = \mathbf{472.5\ kg}$ (with parachute). In the near future, more countries will probably renew their national regulations.

In the **USA** the "Federal Aviation Administration" FAA has as a comparable category to the European microlight aircraft, the "Very Light Airplanes" which is regulated by FAR 21.17 (b) and published by EASA under **CS-VLA**. The CS-23 - Amendments 5 replaces the CS-VLA. This is explained in more detail in the liability disclaimer from **EASA 2018 b**:

> *This version is issued by the European Aviation Safety Agency (EASA) in order to provide its stakeholders with an updated and easy-to-read publication. It has been prepared by putting together the certification specifications with the related acceptable means of compliance. However, this is not an official publication and EASA accepts no liability for damage of any kind resulting from the risks inherent in the use of this document. EASA has determined that future changes due to developments in the state-of-the-art and introduction of future technologies in the scope of CS-VLA will only be incorporated in CS-23. CS-VLA will not be amended and remain at the current amendment level (CS-VLA — Amendment 1). CS-23 — Amendment 5 replaces CS-VLA as the applicable certification specifications.*

The most important data about the CS-VLA class are (**EASA 2018 b**, P. 18 based on **EASA 2003**, P. 1-A-1):

- Maximum take-off weight $\boldsymbol{m_{MTO}}$ of **750 kg**
- Maximum seating capacity $\boldsymbol{n_{PAX}}$ of **2**
- Landing configuration stall speed $\boldsymbol{V_{S,0}}$ not more than **83 km/h** (45 kt)
- Only "visual flight rules" **VFR**

Other classes in the USA are listed in Table 2.2. To find out which class has which requirements and authorization, the **FAA** offers in the **Federal Register - Part III** clear tables (starting on page 44778), where the various classes can be compared. (**FAA 2004**)

In Table 2.2 is a summary of **Microlight aircraft** in different countries and their definitions as **land plane with VFR, two passengers and a parachute**.

Table 2.2 Overview and Requirements of microlight aircraft in different countries

Countries	Type	m_{MTO} kg	$V_{S,0}$ km/h	Others	Source
Australia	Microlight aircraft	600	-	-	**CAA 2012**
Austria	Ultraleichtflugzeug[a]	475	65	-	**Austro 2019**
Belgium	Ultra-léger	472.5	65	-	**Belgique 2020**
Canada	Basic ultra-light	544	72	-	**Canada 2019**
	Advanced ultra-light	560	72	-	**Canada 2004**
China	超轻型飞机	480	72		**CAA.CN 1997**
Czech	Light aircraft	600	83	-	**Czech 2019**
Denmark	Ultralight aeroplane	472.5	65	-	**SLV 2008**
France	Microlight multiaxis	525	70	-	**ULM 2019**
Germany	Ultraleichtflugzeug[b]	600	83	-	**LTF-UL 2019**
	120 kg Klasse	260	55	Empty mass $\leq$ 120 kg	**LTF-L 2012**
India	Microlight aircraft[c]	450	-	-	**India 2018**
Italy	Aero sportivo	600	-	-	**ULM.IT 2010**
Japan	超軽量動力機 [d]	236	65	$V_{NE} \leq 185\ \mathrm{km/h}$	**Japan 2015**
New Zealand	Microlight aircraft	600	-	-	**CAA.NZ 2012**
Norway	Small light aeroplane	472.5	65	-	**Norge 2007**
Slovenia	Ultralahkih letalnih	600	83	-	**RS 2019**
Switzerland	Ecolight aircraft[e]	600	83	-	**Swiss 2019**
United Kingdom	Microlight aircraft[f]	472.5	-	-	**CAA.CO 2018**
United States	Part 103 ultralight[g]	115	45	$V_{NE} \leq 102\ \mathrm{km/h}$	**FAA 2004**
	Light-sport aircraft[h]	600	83	-	**FAA 2004**
	Very light airplane	750	83	-	**EASA 2018 b**

[a] validation according german standard LTF-UL, the m_{MTO} should be increased to 600 kg quite soon, but Austria still needs time to implement its changes in the aviation law and regulation.
[b] can be flown with a national SPL licence
[c] wing area not less than 10 m², weight without parachute
[d] empty weight with parachute, wing area not less than 10 m²
[e] validation according German standard LTF-UL, but with at least a LAPL(A), (international) EASA licence. Validation by "Federal Office of Civil Aviation" FOCA
[f] The UK CAA has confirmed that in 2021, the microlight definition will be expanded to $m_{MTO} = 600\ \mathrm{kg}$ and $V_{S,0} = 83\ \mathrm{km/h}$
[g] one seat, no license required
[h] fixed landing gear, fixed pitch propeller

2.2 Microlight Requirements in Germany

The LTF-UL construction regulations define the minimum requirements for a microlight aircraft. It should be ensured that the order and safety of air traffic and public safety are not endangered. The use of the microlight aircraft should be safe for the intended purpose. Important regulations from the LTF-UL are discussed as well as more regulations that are important for further aircraft design.

According to LTF-UL 1 *Anwendbarkeit*, the maximum permissible takeoff mass $\boldsymbol{m_{MTO}}$ is specified as **600 kg** (without floats, including rescue equipment) or **650 kg** (with floats, including rescue equipment). The stall speed in landing configuration $\boldsymbol{V_{S,0}}$ shall not exceed **83 km/h** (45 kt) (**LTF-UL 2019**).

According to LTF-UL 25 *Massegrenzen – Höchstmasse*, the maximum mass of the aircraft cannot be less than the empty mass including the minimum equipment of the aircraft plus the **passenger** mass of at least **110 kg for a single-seat aircraft** and the passengers mass of at least **200 kg for a two-seat aircraft** plus a fuel supply for at least one hour of cruise flight at maximum power of the engine. (**LTF-UL 2019**)

According to LTF-UL 51 *Start*, the takeoff distance with maximum mass and no wind from standstill to an altitude of 15 m (for a takeoff on dry, level, short mown grass) shall not exceed **450 m**. In Annex III *Schwimmfähige Ultraleichtflugzeuge* (floatable microlight aircraft), the start distance for floatable microlight aircraft from standstill to an altitude of 15 m is maximum **900 m**. (**LTF-UL 2019**)

According to LTF-UL 65 *Steigflug*, the climb must be more than **1.5 m/s** with engine takeoff power, landing gear retracted, max. flight mass, flaps in the position intended for climbing, and without exceeding any specified temperature limits. (**LTF-UL 2019**)

According to LTF-UL 331 *Symmetrische Flugzustände*, the maximum negative lift coefficient in the normal condition can be assumed to be -0.8 if no more precise data are available. The determined zero moment coefficient C_{m0} must be assumed to be at least ± 0.025. (**LTF-UL 2019**)

The UL aircraft must remain controllable and maneuverable in any flight situation (LTF-UL 143). It must also have sufficient feeling of stability and control (LTF-UL 171). (**LTF-UL 2019**)

According to LTF-UL 303 *Sicherheitszahl*, the safety factor of at least 1.5 must be selected for a more accurate design of the aircraft, which is multiplied by the respective load multiple (see definition of the safety factor on page 11). Higher load multiples are required for inaccurate strength data and for certain components. For example, the rudder joints have a load multiple of 4.44, which gives with the safety factor of 1.5 a safety of 6.67 against fracture. (**LTF-UL 2019**)

According to LTF-UL 333 *Allgemeines*, the microlight aircraft must withstand gusts of 15 m/s upwards (positive) and downwards (negative) (perpendicular to the flight path) at the rated speed for strong gusts $\boldsymbol{V_B}$ (see Figure 2.1). At the rated maximum speed $\boldsymbol{V_D}$, the ultraight aircraft must withstand gusts of 7.5 m/s upwards and downwards (perpendicular to the flight path). (**LTF-UL 2019**)

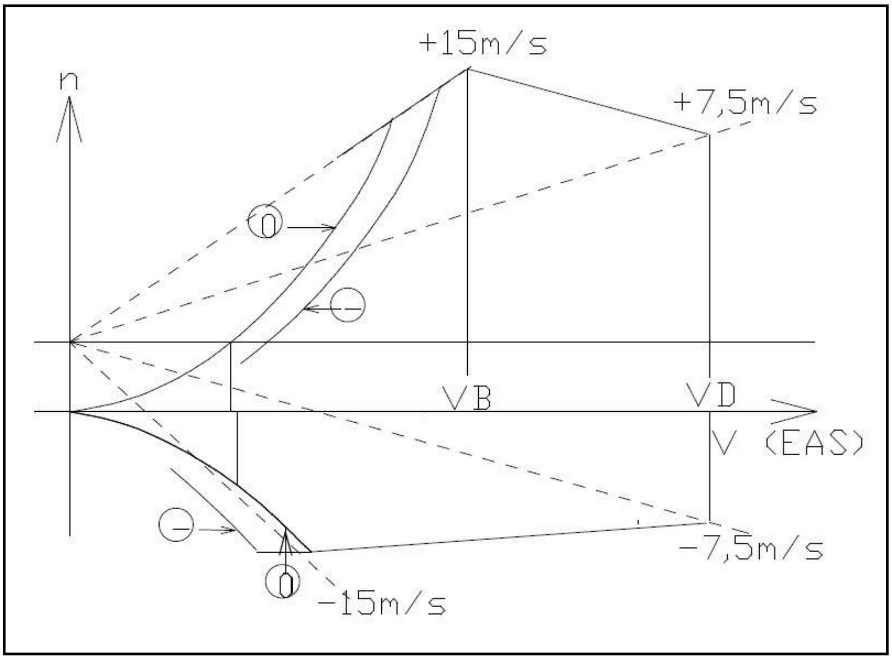

Figure 2.1 V-n diagram for gusts load (**LTF-UL 2019**, page 19)

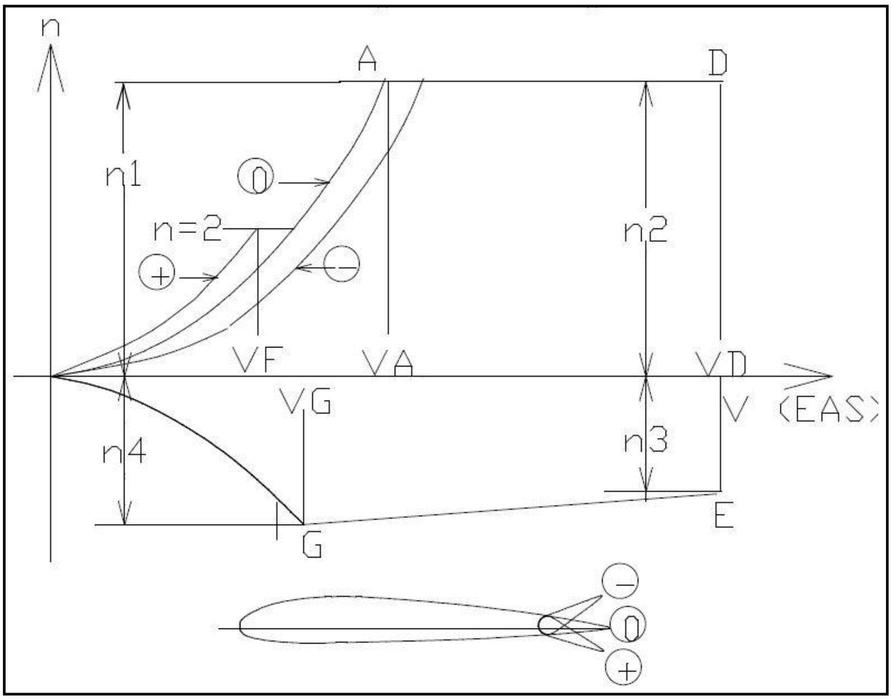

Figure 2.2 V-n diagram for interception load (**LTF-UL 2019**, Page 19)

According to LTF-UL 337 *Abfang-Lastvielfache*, the safe interception load multiples (in the V-n diagram in Figure 2.2) must have at least the following values:

$$n_1 = +4.0$$
$$n_2 = +4.0$$
$$n_3 = -1.5$$
$$n_4 = -2.0$$

The minimum interception load factors are important for the structural design.

The rated maneuvering speed $\boldsymbol{V_A}$ is given by Formula 2.1 where the $\boldsymbol{V_{S1}}$ is the stall speed at maximum mass with flaps retracted and engine at idle.

$$V_A = V_{S1} \cdot \sqrt{n_1} \tag{2.1}$$

The maximum rated speed $\boldsymbol{V_D}$ cannot be less than $\boldsymbol{1.2 \cdot V_H}$ (the highest horizontal speed at the highest engine continuous power) and it must be less than $\boldsymbol{1.5 \cdot V_A}$ (higher value applies). The design speed for strong gusts $\boldsymbol{V_B}$ cannot be less than $\boldsymbol{0.9 \cdot V_H}$ or $\boldsymbol{V_B = V_A}$ (higher value applies). Speed $\boldsymbol{V_F}$ is the design speed for extended wing flaps. (**LTF-UL 2019**, LTF-UL 335 *Bemessungs-Fluggeschwindigkeiten*)

According to LTF-UL 1545 *Geschwindigkeitsmesser*, the different airspeeds must be color coded on the airspeed indicator. The **white arc** is the airworthy speed range with fully extended flaps and goes from $\boldsymbol{1.1 \cdot V_{S0}}$ (stall speed at maximum mass with flaps extended) to $\boldsymbol{V_{FE}}$ (maximum allowable speed with flaps extended). The **yellow radial triangle** marks the maneuvering speed $\boldsymbol{V_A}$ which is the maximum allowable speed for full, even abrupt, rudder deflection. The **green arc** represents the normal operating range and goes from $\boldsymbol{1.1 \cdot V_{S1}}$ **to** $\boldsymbol{V_{RA}}$ (maximum allowable speed in strong turbulence). The **yellow arc** is the speed that only can be flown in calm weather and goes from $\boldsymbol{V_{RA}}$ **to** $\boldsymbol{V_{NE}}$ (maximum permissible speed which must never be exceeded). The **red radial line** at the end represents $\boldsymbol{V_{NE}}$ (see Figure 2.3). (**LTF-UL 2019**)

Figure 2.3 Cockpit of a C-42, speed indicator

3 Preliminary Sizing of Microlight Aircraft

The regulations, which are important for the preliminary sizing of microlight aircraft, are collected from the LTF-UL.

Parameters for the preliminary sizing are searched for and evaluated with the help of statistical data, mainly from aircraft data from **Jane's 1992**. For the following preliminary sizing of microlight, only one propeller drive is used for the calculation. Turboprops and turbofans make not much sense in today's microlight class with respect to fuel consumption, noise pollution, price and efficiency. For smaller engines in general, the efficiency of the compressor quickly becomes low as the ratio between the gap and the blade height becomes large. To counteract this, a radial compressor could be used instead of an axial compressor, which generally have smaller air mass flows for the same engine outer diameter. This means that the compressor pressure ratio is already lower, the specific fuel consumption higher and therefore the efficiency lower. (**Bräunling 2009**, page 37)

In order to understand why statistical parameters are necessary for preliminary sizing, the process of this phase must be understood.

In preliminary sizing, a selected aircraft configuration (consisting of a rough wing and fuselage configuration and a propulsion system) is graphically optimized using a matching chart. The calculations for aircraft with jet engines are based on the thrust-to-weight ratio and the wing loading, so these two ratios are the basis of the preliminary sizing. In order to optimize the parameters in the different flight phases, the design diagram shows the ratio of $T_{TO}/m_{MTO} \cdot g$ on the y-axis and m_{MTO}/S_W on the x-axis for jets (see Figure 3.1).

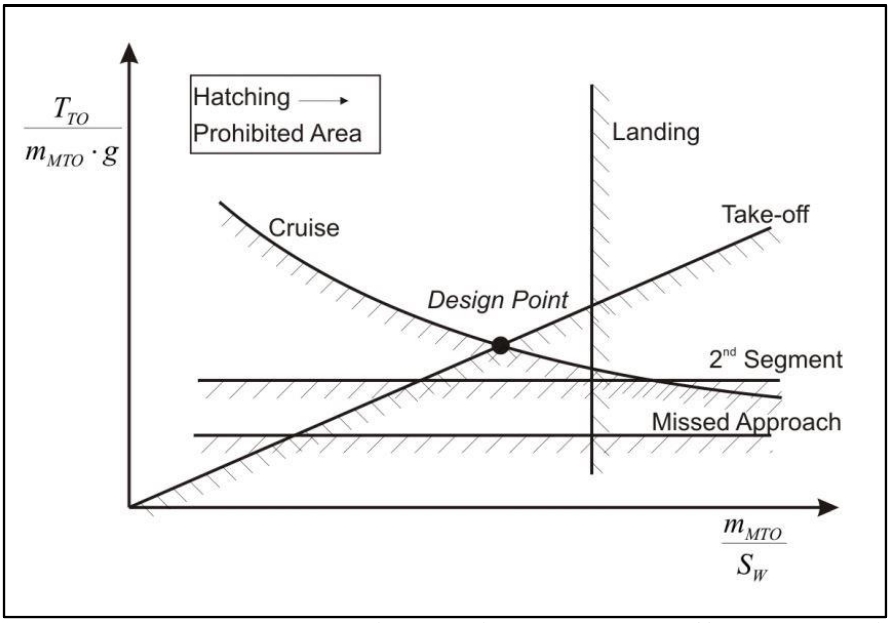

Figure 3.1 Matching chart for aircraft with jet engines (**Scholz 2015**, Chapter 5)

For **propeller driven aircraft**, the calculation is not based on thrust T_{TO} but on power P_{TO}. This gives $\boldsymbol{P_{TO}/m_{MTO}}$ on the y-axis and the wing loading m_{MTO}/S_W on the x-axis.

Usally the first optimization priority is to achieve the **lowest possible** thrust-to-weight or **power-to-weight ratio**, as this leads to lower fuel consumption. The second priority is to achieve the **highest possible wing loading**, which leads to the utilization of the structure that ensure lightweight construction. The optimized design point is the intersection between cruise and take-off as shown in Figure 3.1. The hatching represents the prohibited design area. After the design point has been selected, the realtive operating empty mass m_{OE}/m_{MTO} and the relative fuel mass m_F/m_{MTO} are calculated which leads to the maximum take-off mass m_{MTO}. More about this in Chapter 3.4 *Relative Operation Empty Mass*.

A more detailed description about the use of the matching chart can be found in the paper from **Scholz 2008**.

More information about the whole process can be found in a project by **Nita 2008** who has done a good and very detailed aircraft design of an ATR 72 with turboprop engine (CS-25).

Matalla 2006 does a preliminary sizing of a propeller driven aircraft according to CS-25, CS-23 and CS-VLA.

3.1 Statistical Parameter k_L and k_{App}

The statistical parameter k_{App} in the following formula is used to give a correlation between landing field length s_{LFL} and approach speed V_{APP}. This value is set to $k_{App} = 1.70\ \sqrt{m/s^2}$ for aircraft with jet engines according to **Loftin 1980** (**Scholz 2015**, Chapter 5).

$$V_{APP} = k_{App} \cdot \sqrt{s_{LFL}} \tag{3.1}$$

$$k_{App} = \sqrt{\frac{k_L \cdot 2g \cdot 1.3^2}{\rho_0}} \tag{3.2}$$

$$k_L = \frac{\frac{m_{ML}}{S_W}}{C_{L,max,L} \cdot s_{LFL}} \tag{3.3}$$

The landing field length is calculated according to CS/FAR from the landing distance and a safety factor. The safety factor is 1.667 for jets and 1.429 for turboprops. (**Scholz 2015**, Chapter 5)

Microlight aircraft, which is dimensioned according to LTF-UL, does not need these parameters for preliminary sizing, because no landing distance is required. Nevertheless it is interesting to evaluate a statistical k_{App} for microlight aircraft for comparison with the parameters for jets and turboprops (see Table 3.1).

Table 3.1 Statistical estimation of the parameter k_{APP} and k_L with aircraft from **Jane's 1992**

Aircraft	m_L kg	S_W m^2	Flap type	$C_{L,max,L}$	S_{LFL} m	k_L	k_{APP}
Australite	295	4.9	plain flap	1.80	153	0.220	2.437
Aerocar Mini-Imp	385	9.3	plain flap	1.80	183	0.126	1.844
Aviasud Mistral 532	400	17.9	no flap	1.55	80	0.180	2.209
Aero Designs Pulsar	435	7.4	plain flap	1.80	244	0.133	1.900
Pober Super Ace	467	11.0	no flap	1.55	168	0.164	2.105
Taylor TA-2 Bird	526	10.1	no flap	1.55	122	0.276	2.734
Brändli BX-2	550	8.5	plain flap	1.80	150	0.240	2.547
Anglin Spacewalker II	567	11.7	no flap	1.55	183	0.171	2.150
Acro Sport Cougar M1	567	7.6	plain flap	1.80	213	0.194	2.292
Zenair Zenith CH 2000	630	11.0	slotted flap	2.20	183	0.142	1.962
Jurca M.J.5 Sirocco	680	10.0	plain flap	1.80	200	0.189	2.261
VAN'S RV-4	680	10.2	plain flap	1.80	130	0.284	2.774
Piel C.P.750	760	11.0	plain flap	1.80	280	0.137	1.926
Arctic S1B2	862	17.3	plain flap	1.80	153	0.181	2.213

The values for the maximum lift coefficient $C_{L,max,L}$ were taken from the diagram of Raymer 1989 (see Figure 3.2). **Roskam 1989** also gives values for $C_{L,max,L}$ for homebuilts and single engine propeller driven aircraft between 1.2 and 2.3 where the selected values from Table 3.1 also seem to fit well (**Scholz 2015**, Chapter 5, page 5).

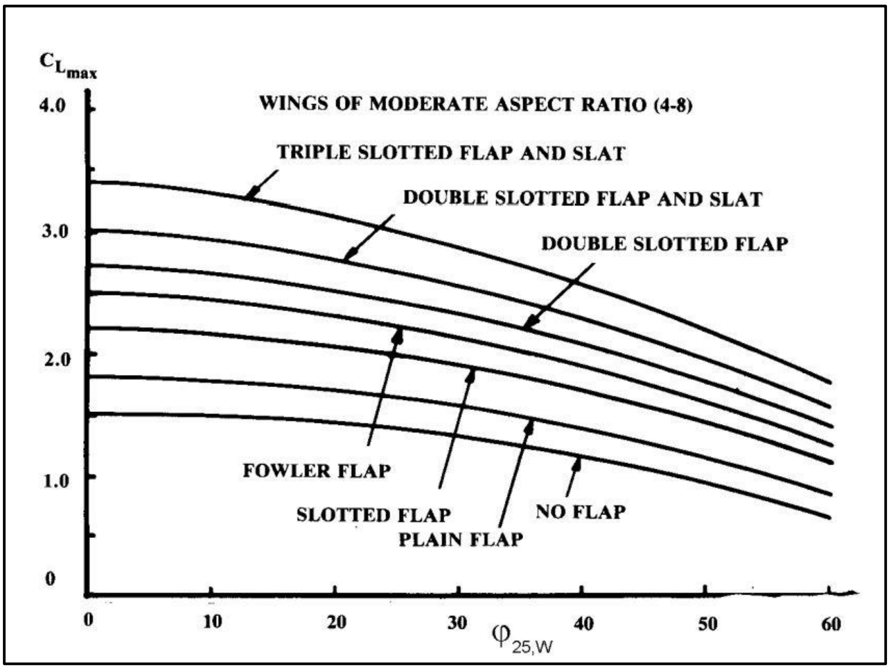

Figure 3.2 Maximum lift coefficient of aircraft with different high-lift devices as a function of wing sweep based on **Raymer 1989** (**Scholz 2015**, Chapter 5)

For the graphical average evaluation of k_L the m_L/S_W is calculated for the y-axis and the $C_{L,max,L} \cdot S_{LFL}$ for the x-axis. Now all flights can be represented as a point. The slope of the regression line through the point cloud represents the statistical factor k_L (Figure 3.3).

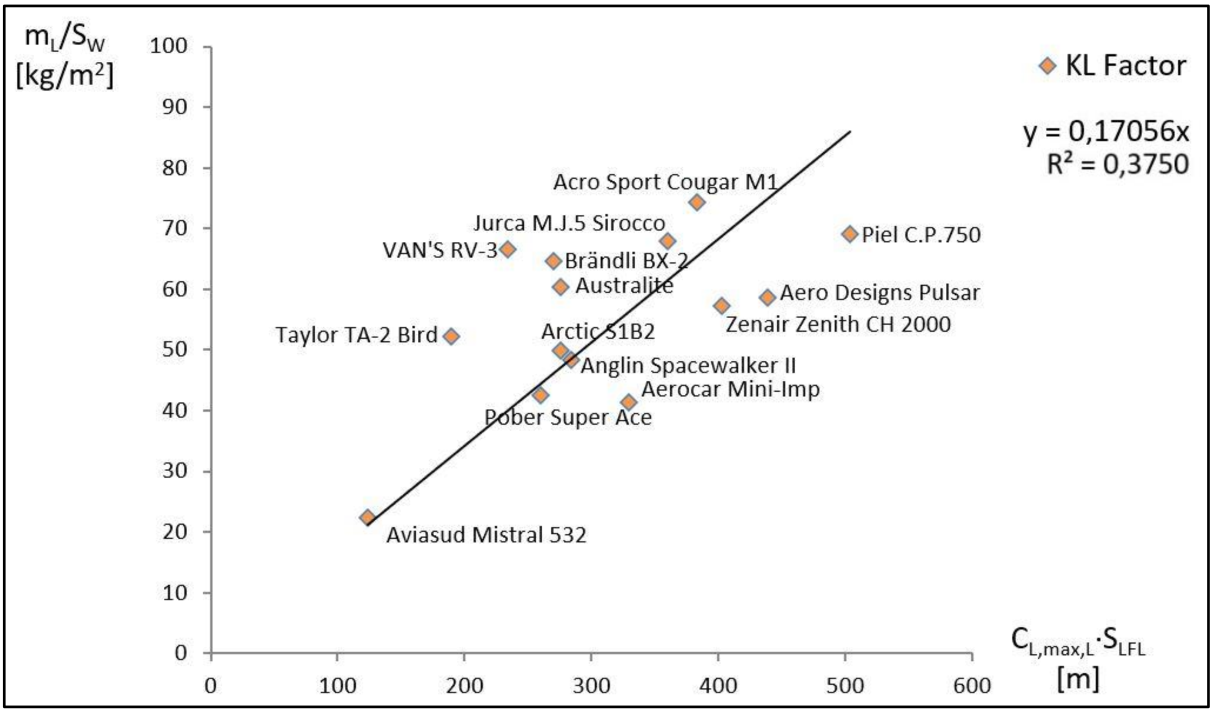

Figure 3.3 Parameter k_L as the slope of a regression line

We now obtain from Figure 3.3 an averaged $k_L = 0.1706\ \mathrm{kg/m^3}$ and can calculate a k_{App} using formula (3.2).

$$k_{App} = \sqrt{\frac{0.1706\ \frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 2 \cdot 9.81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 1{,}3^2}{1.225\ \frac{\mathrm{kg}}{\mathrm{m}^3}}} = 2.149\sqrt{\frac{\mathrm{m}}{\mathrm{s}^2}}$$

In order to read off the quality of the statistical regression, the coefficient of determination R^2 can be calculated (in my case with the Excel data analysis). The quality of the result of the regression line from the parameter k_L from Figure 3.3 is $R^2 = 37\ \%$ which is not really good as can be seen already from the distributed point cloud. (A definition of R^2 is given on page 11)

To optain a better statistical result, more aircraft data can be examined or it could be helpful to divide the aircraft types again into types with similar aerodynamic performance, for example by including the lift-to-drag coeffiecent of aircraft with similar takeoff weight.

3.2 Statistical Parameter k_{TO}

From Chapter 2.2 *Microlight Requirements in Germany*, we can see that the take-off field length S_{TOFL} with maximum mass and without wind from standstill to an altitude of 15 m must not exceed 450 m. The takeoff distance is therefore a design parameter.

The take-off ground roll S_{TOG} can be calculated with

$$S_{TOG} = \frac{g \cdot m_{MTO}^2}{\rho \cdot C_{L,LOF} \cdot S_W \cdot T} = \frac{g}{\rho \cdot C_{L,LOF}} \cdot \frac{\frac{m_{MTO}}{S_W}}{\frac{T_{TO}}{m_{MTO} \cdot g}} \tag{3.4}$$

which can be transformed to the following design ratio (see matching chart in Figure 3.1).

$$\frac{\frac{T_{TO}}{m_{MTO} \cdot g}}{\frac{m_{MTO}}{S_W}} = \frac{1}{\rho \cdot S_{TOG} \cdot \sigma \cdot C_{L,max,L}} \tag{3.5}$$

Assuming that the takeoff ground roll S_{TOG} is proportional to the take-off field length S_{TOFL}, the following equation is obtained.

$$\frac{\frac{T_{TO}}{m_{MTO} \cdot g}}{\frac{m_{MTO}}{S_W}} = \frac{k_{TO}}{S_{TOFL} \cdot \sigma \cdot C_{L,max,TO}} \tag{3.6}$$

For propeller driven microlight aircraft, the engine thrust T_{TO} can be replaced with the shaft power P_S where the propeller efficiency η_p with speed V has to be considered.

$$\frac{\frac{P_S}{m_{MTO}}}{\frac{m_{MTO}}{S_W}} = \frac{k_{TO} \cdot g \cdot V}{S_{TOFL} \cdot \sigma \cdot C_{L,max,TO} \cdot \eta_p} \tag{3.7}$$

After rearranging the equation to k_{TO} we get

$$k_{TO} = \frac{\left(\frac{P_S}{m_{MTO}}\right) \cdot S_{TOFL} \cdot \sigma \cdot C_{L,max,TO} \cdot \eta_p}{\left(\frac{m_{MTO}}{S_W}\right) \cdot g \cdot V} \tag{3.8}$$

where we can now estimate the k_{TO} using aircraft data from **Jane's 1992** (see Table 3.2), resulting in the following calculation for the Taylor TA-2 Bird aircraft with Equation (3.8).

$$k_{TO} = \frac{160.3 \frac{W}{kg} \cdot 122\ m \cdot \sigma \cdot C_{L,max,TO} \cdot \eta_p}{52.2 \frac{kg}{m^2} \cdot 9.81 \frac{m}{s^2} \cdot 17.2 \frac{m}{s}}$$

With a density ratio $\sigma = 1$ (sea level) and a lift coefficient in take-off configuration

$$\begin{aligned} C_{L,max,TO} &= 0.8 \cdot C_{L,max,L} \\ &= 0.8 \cdot 1.55 = 1.24 \end{aligned} \tag{3.9}$$

($C_{L,max,L}$ from Table 3.2). The propeller efficiency in take-off configuration for all aircraft is estimated here to $\eta_p = 0.65$ which is a good value and normal for a variable pitch propeller (see Figure 3.4). With these values we get k_{TO}.

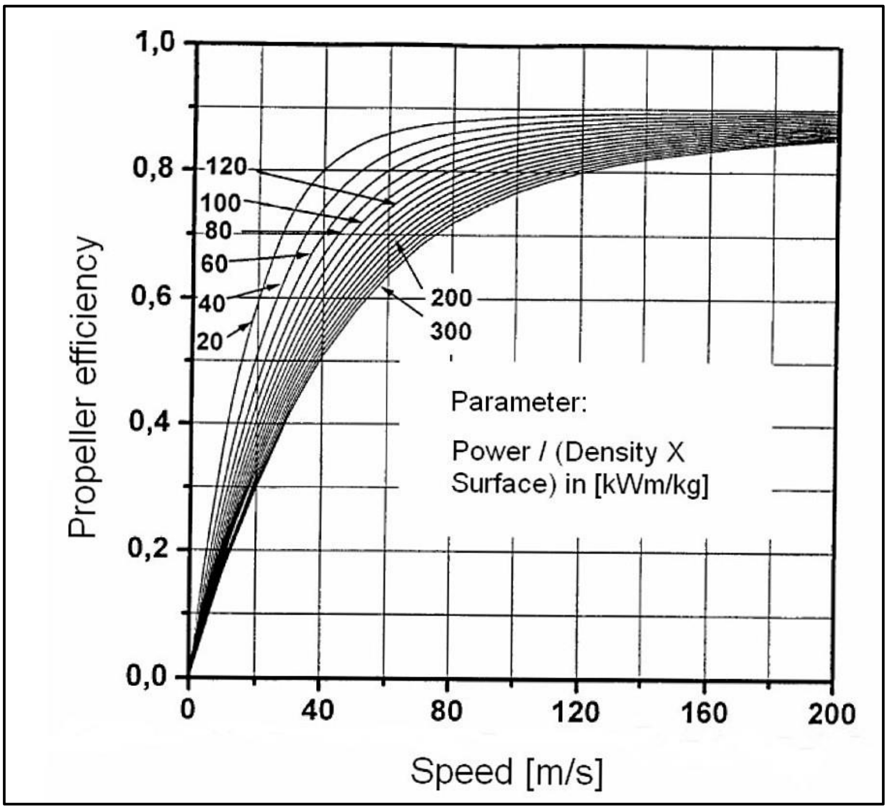

Figure 3.4 Propeller efficiency η_p for variable pitch propellers as a function of aircraft speed and disc loading (**Scholz 2008**, based on **Markwardt 1998**)

$$k_{TO} = \frac{160.3\ \frac{\mathrm{W}}{\mathrm{kg}} \cdot 122\ \mathrm{m} \cdot 1 \cdot 1.24 \cdot 0.65}{52.2\ \frac{\mathrm{kg}}{\mathrm{m}^2} \cdot 9.81\ \frac{\mathrm{m}}{\mathrm{s}^2} \cdot 17.2\ \frac{\mathrm{m}}{\mathrm{s}}} = 1.79\ \frac{\mathrm{m}^3}{\mathrm{kg}}$$

Table 3.2 Statistical estimation of the parameter k_{TO} with aircraft from **Jane's 1992**

Aircraft	P_S/m_{MTO} W/kg	S_{TOFL} m	$C_{L,max,TO}$	Wing loading kg/m^2	V m/s	k_{TO} m^3/kg
Brändli BX-2 [b]	88.2	300	1.44	64.7	19.8	1.97
Acro Sport Cougar M1[b]	105.8	244	1.44	74.4	20.3	1.63
Aero Designs Pulsar [b]	113.1	244	1.44	58.6	17.2	2.61
Aerocar Mini-Imp [c]	122.1	183	1.44	41.4	19.1	2.70
Arctic S1B2 [a]	129.9	153	1.44	49.8	13.0	2.94
Pober Super Ace [c]	135.8	107	1.44	42.6	14.8	2.19
Taylor TA-2 Bird [a]	**160.3**	**122**	**1.24**	**52.2**	**17.2**	**1.79**
Australite [c]	161.7	153	1.44	60.4	19.3	2.02
VAN'S RV-4 [a]	164.7	137	1.44	66.5	20.5	1.58
Piel C.P.750 [a]	176.3	190	1.24	69.1	23.6	1.69

[a] tandem two seats
[b] side-by-side two seats
[c] one seat

To obtain a average k_{TO} factor for microlight aircraft, we enter the $(P_S/m_{MTO}) \cdot S_{TOFL} \cdot \sigma \cdot C_{L,max,TO} \cdot \eta_p$ for the y-axis and the $(m_{MTO}/S_W) \cdot g \cdot V$ for the x-axis, calculated with the values from Table 3.2 (same procedure as with the parameter k_{APP} in Chapter 3.1). The factor represents the slope of the regression line through the point cloud which gives $\boldsymbol{k_{TO} = 1.915\ \mathrm{m^3/kg}}$ (Figure 3.5).

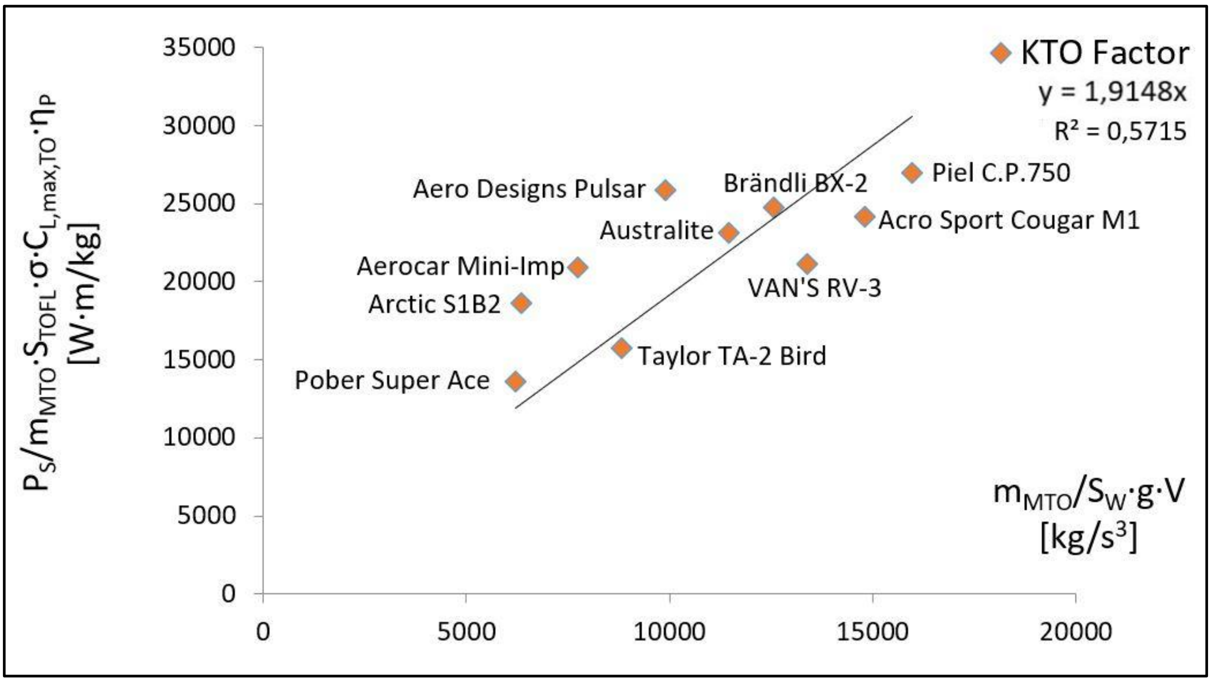

Figure 3.5 Parameter k_{TO} as the slope of a regression line

The **quality of this result** (and so the quality of the regression line) from the parameter k_{TO} in Figure 3.5 is $\boldsymbol{R^2 = 57\ \%}$ which is a good result (definition of R^2 is given on page 11). As already mentioned in Chapter 3.1, a better statistical result can be achieved with more aircraft data or it could be helpful to divide the aircraft types again into types with similar aerodynamic performance.

3.3 Statistical Parameter k_E

The parameter k_E for microlight aircraft is important to estimate the maximum lift-to-drag ratio. It can be found by using statistical values from aircraft (Equation 3.10). The difficulty is to find microlight aircraft data for the wetted area S_W in the literature.

$$k_E = \frac{E_{max}}{\sqrt{\frac{A}{S_{Wet}/S_W}}} \tag{3.10}$$

Raymer 1989 and **Torenbeek 1988** describe a way to estimate S_{Wet}, but it leads not to simplification in my case, which is why they are not mentioned further here.

Based on geometry data of a three side view (**Blueprint 2021**), the wetted area of fuselage, wing, vertical stabiliser, rudder and landing gear can be estimated (see measurements in Figure 3.6). The aircraft geometry is described mathematically with trapezoidal area, cone surface area and truncated cone surface area.

$$S_{Wet,fus} = 13.3\ m^2$$
$$S_{Wet,wing} = 16.55\ m^2$$
$$S_{Wer,hor.T} = 3.1\ m^2$$
$$S_{Wet,ver.T} = 1.7\ m^2$$
$$S_{Wet,gear} = 1.24\ m^2$$
$$\sum S_{Wet} \approx 36\ m^2$$

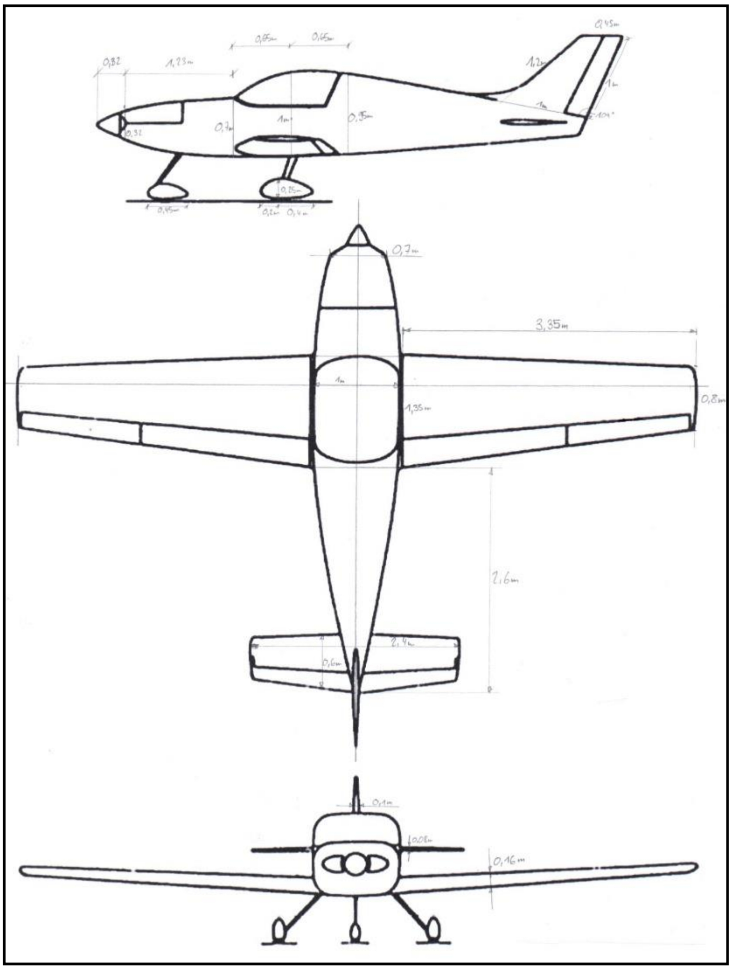

Figure 3.6 Three side view from the Pulsar aircraft (**Blueprint 2021**)

The aspect ratio A in Equation (3.10) can be calculated with the following Formula.

$$A = \frac{b^2}{S_W} = \frac{(7.62\ \text{m})^2}{7.43\ \text{m}^2} = 7.815 \tag{3.11}$$

Now only the maximum lift-to-drag ratio is missing, which is unfortunately not given in the literature for the Aero Design Pulsar Airplane, so this value must be estimated approximately for this aircraft. I set $E_{max} = 14$, which is already a good value for microlight airplanes. With the geometrically determined result $S_{Wet} = 36\ \text{m}^2$, the aspect ratio $A = 7.815$, the determined $E_{max} = 14$ and the $S_W = 7.43\ \text{m}^2$ from **Jane's 1992** we get with Equation (3.10) a k_E of 11.02.

$$k_E = \frac{14}{\sqrt{\frac{7.815}{\frac{36\ \text{m}^2}{7.43\ \text{m}^2}}}} = 11.02$$

A second method to get a S_{Wet} for a UL aircraft is with **OpenVSP 2021**. The UL aircraft model Van's Aircraft RV-7 is from the **OVSP Hangar 2021** and opened in **OpenVSP 2021** (see Figure 3.7). Using the "Parasite Drag" tool, the wetted areas can now be calculated. First convert the values from ft to m and then multiply the values by a scale factor which can be set for example by the known span $b = 25 \text{ ft} = 7.62 \text{ m}$ (**Van's 2019**).

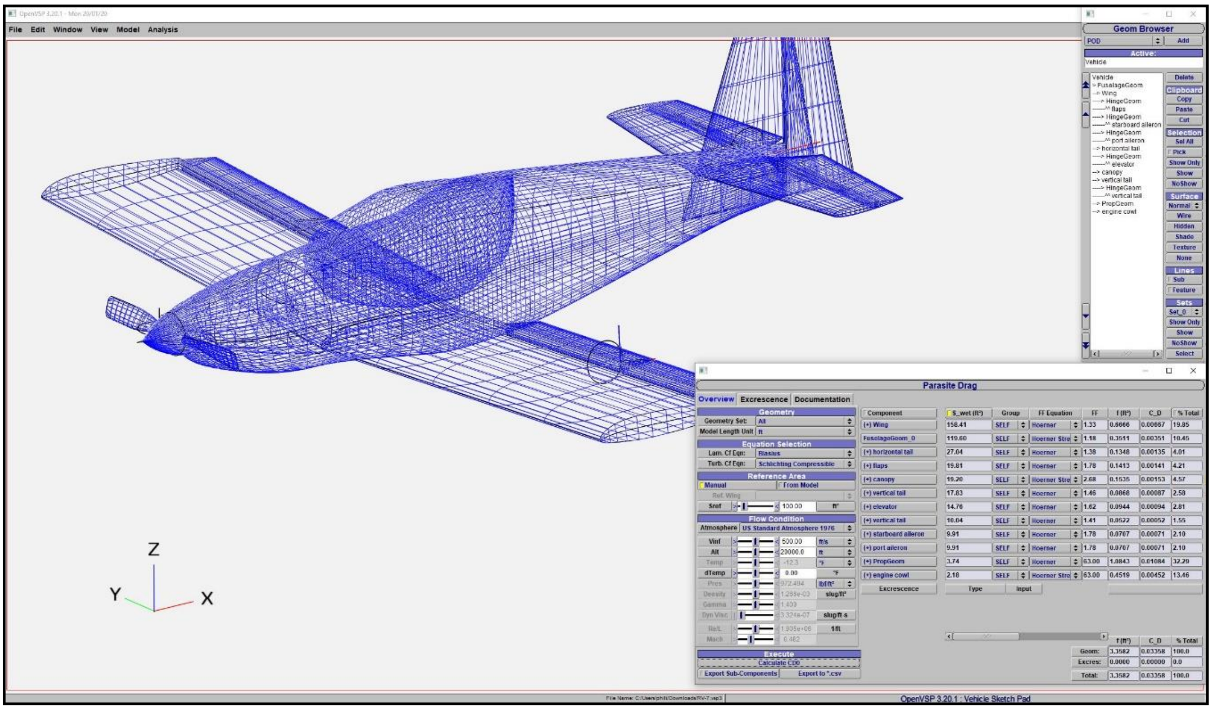

Figure 3.7 Van's Aircraft RV-7 in **OpenVSP 2021**

This gives us the following values:

$$S_{Wet,fus} = 16.5 \text{ m}^2$$
$$S_{Wet,wing} = 23.7 \text{ m}^2$$
$$S_{Wer,hor.T} = 5.5 \text{ m}^2$$
$$S_{Wet,ver.T} = 3.3 \text{ m}^2$$
$$S_{Wet,gear} = 2.5 \text{ m}^2$$
$$\sum S_{Wet} \approx 51.5 \text{ m}^2$$

With the aspect ratio

$$A = \frac{(7.62 \text{ m})^2}{11.2 \text{ m}^2} = 5.18$$

from Equation (3.11), we can calculate the k_E parameter.

$$k_E = \frac{12}{\sqrt{\frac{5.18}{\frac{51.5\ \mathrm{m}^2}{11.2\ \mathrm{m}^2}}}} = 11.3$$

In a paper "Design of Microlight Aircraft" from **Christos 2018**, the design and development of a two-seat microlight aircraft in relation to the European UL regulations was described using CFD programs like **OpenFoam** (description on page 11). The analysis reveals the wetted area of the aircraft as $S_{Wet} = 44.89\ \mathrm{m}^2$ with a wing area $S_W = 9.9\ \mathrm{m}^2$. The aspect ratio A is calculated as follows.

$$A = \frac{(9.0\ \mathrm{m})^2}{9.9\ \mathrm{m}^2} = 8.18$$

The E_{max} can be read from Figure 3.8 and calculated using Equation (3.12). (**Christos 2018**)

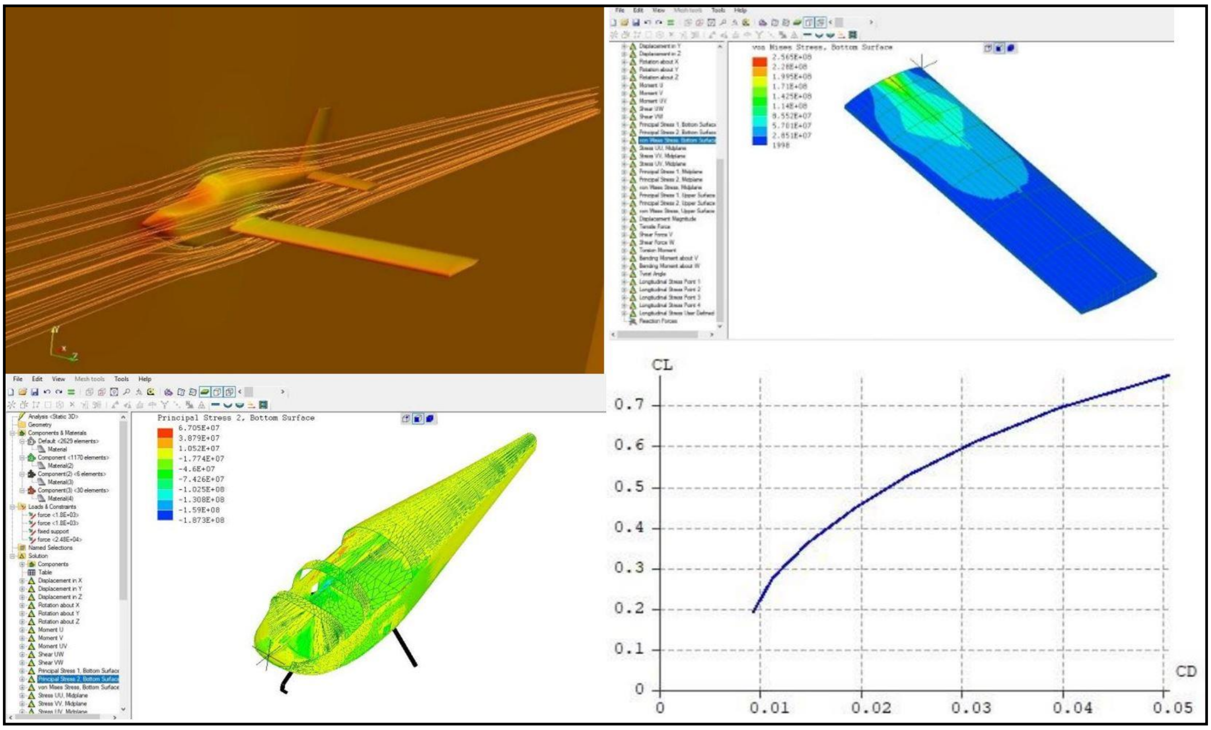

Figure 3.8 UL-Design by **Christos 2018**

$$E_{max} = \frac{L}{D} = \frac{C_L}{C_D} = \frac{0.45}{0.02} = 22.5 \tag{3.12}$$

With Formula (3.10) we can now calculate a third

$$k_E = \frac{22.5}{\sqrt{\frac{8.18}{\frac{44.89\ \mathrm{m}^2}{9.9\ \mathrm{m}^2}}}} = 16.75$$

which is a very high value that stems from the fact that the aircraft has a very high lift-to-drag ratio. The microlight aircraft is very well designed in that regard because it has so little drag. (The real measured value would be certainly lower than in the simulation.)

In the paper *Design and Analysis of Wing of an Microlight Aircraft* from **Yuvaraj 2015** on page 7462 values of 3 to 4 are given for a S_{Wet}/S_W which stems from investigations of microlight aircraft. For further aircraft design they use a $S_{Wet}/S_W = 3.5$. The aspect ratio can also be calculated from their data.

$$A = \frac{(9.144\ \mathrm{m})^2}{13.935\ \mathrm{m}^2} = 6$$

Further, they give a $C_{L,max} = 1.231$ and a $C_D = 0.107$ resulting in a

$$E_{max} = \frac{1.231}{0.107} = 11.5$$

with Formula (3.12) based on **Yuvaraj 2015**. Now the resulting k_E can be calculated.

$$k_E = \frac{11.5}{\sqrt{\frac{6}{3.5}}} = 8.78$$

All four variants are shown in Table 3.3.

Table 3.3 Statistical estimation of the parameter k_E

Aircraft source	E_{max}	A	S_{Wet}/S_W	k_E
Pulsar **Blueprint 2021**	14	7.82	4.84	11.02
RV-7 **OpenVSP 2021**	12	5.16	4.60	11.32
Christos 2018	22.5	8.18	4.53	16.75
Yuvaraj 2015	11.5	6	3.5	8.78

The k_E parameter of **Yuvaraj 2015** is quite small, because first the glide ratio is not very good and also the ratio of S_{Wet}/S_W is quite small. For comparison, the other three values for S_{Wet}/S_W are all above 4.5.

In Figure 3.9 the four aircraft are shown where the slope of the regression line represents the factor k_E. The y-axis represents the E_{max} and the x-axis represents the

$$\sqrt{\left(\frac{A}{S_{Wet}/S_W}\right)} \quad .$$

We get a result of $k_E = 12.12$ which is a smaller value than the $k_E = 14.9$ for jet powered aircraft according to **Loftin 1980** (**Scholz 2015**, Chapter 5).

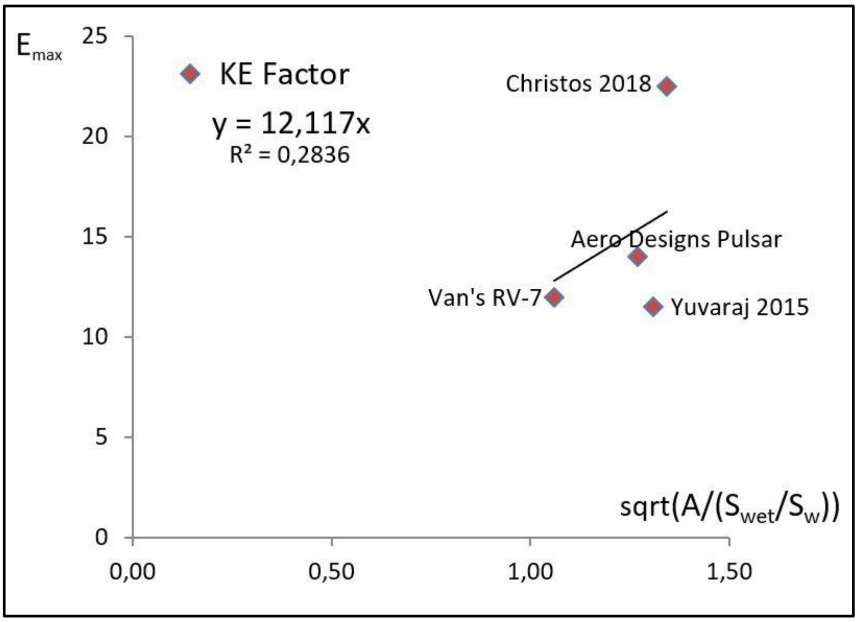

Figure 3.9 Parameter k_E as the slope of a regression line

Within the frame of this project, only a few aircraft were analyzed for the parameter k_E. The quality of the result is therefore only $K^2 = 28\ \%$. In order to be able to make a statistically reliable statement, significantly more aircraft should be examined for this parameter.

3.4 Relative Operation Empty Mass

The **relative operating empty mass** is the ratio of the operating empty weight to the maximum take-off weight $\boldsymbol{m_{OE}/m_{MTO}}$. The **useful load** $\boldsymbol{u}$ is defined in equation (3.13). The relative operating empty mass shows at the end of the aircraft sizing if the aircraft has been designed light or if the aircraft structure has been designed heavy.

$$u = \frac{m_F + m_{PL}}{m_{MTO}} = 1 - \frac{m_{OE}}{m_{MTO}} \tag{3.13}$$

The relative operation empty mass m_{OE}/m_{MTO} of microlight aircraft is estimated from statistics. For the following statements and charts in the figures, the statistical data in Table 3.4 are based on **Janes's 1992**.

Table 3.4 Aircraft data for statistical m_{OE}/m_{MTO} based on **Jane's 1992**

Aircraft	m_{MTO} kg	m_{OE} kg	m_{OE}/m_{MTO}	P_S/m_{MTO} W/kg	V_{CR} m/s	R km
Australite [c]	295	159	0.539	161.7	56.6	284
Aerocar Mini-Imp [c]	385	227	0.590	122.1	66.9	804
Aviasud Mistral 532 [b]	400	174	0.435	117.5	27.7	500
Aero Designs Pulsar [b]	435	231	0.531	113.1	62.5	804
Pober Super Ace [c]	467	311	0.666	135.8	33.6	386
Taylor TA-2 Bird [a]	526	277	0.527	160.3	42.5	547
Acro Sport Cougar M1 [b]	567	283	0.499	105.8	53.6	965
Anglin Spacewalker II [a]	567	331	0.584	164.0	50.0	.
Brändli BX-2 [b]	550	315	0.573	88.2	64.4	926
Jurca M.J.5 Sirocco [a]	680	430	0.632	156.6	59.7	932
VAN'S RV-4 [a]	680	404	0.594	164.7	73.3	1287
Piel C.P.750 [a]	760	480	0.632	176.3	69.4	1100
Arctic S1B2 [a]	862	487	0.565	129.9	49.4	1049

[a] tandem two seats
[b] side-by-side two seats
[c] one seat
. Numerical value unknown

Normally, the operation empty weight includes the crew, but for smaller aircraft with less than about six seats, the crew (the pilot(s)) is included as part of the payload. In our case, the payload consists of baggage and persons on board $m_{PL} = \text{Baggage} + \text{Crew}$.

We remember from Chapter 2.2 *Microlight Requirements in Germany*, that the passenger weight for a single seat aircraft is 110 kg and for a two seats aircraft 200 kg (LTF-UL 25). With a statistically evaluated m_{OE} it is possible to determine how much baggage and fuel can be carried on board in addition to the passengers, for example, according to LTF-UL.

Using the same procedure as in the previous chapters, in Figure 3.10 the statistical value of **relative operation empty mass** is determined with the slope of a regression. The parameter relative operation empty mass is $\boldsymbol{m_{OE}/m_{MTO} = 0.5781}$, which is a very good statistical result with a coefficient of determination $\boldsymbol{R^2 = 93}$ %.

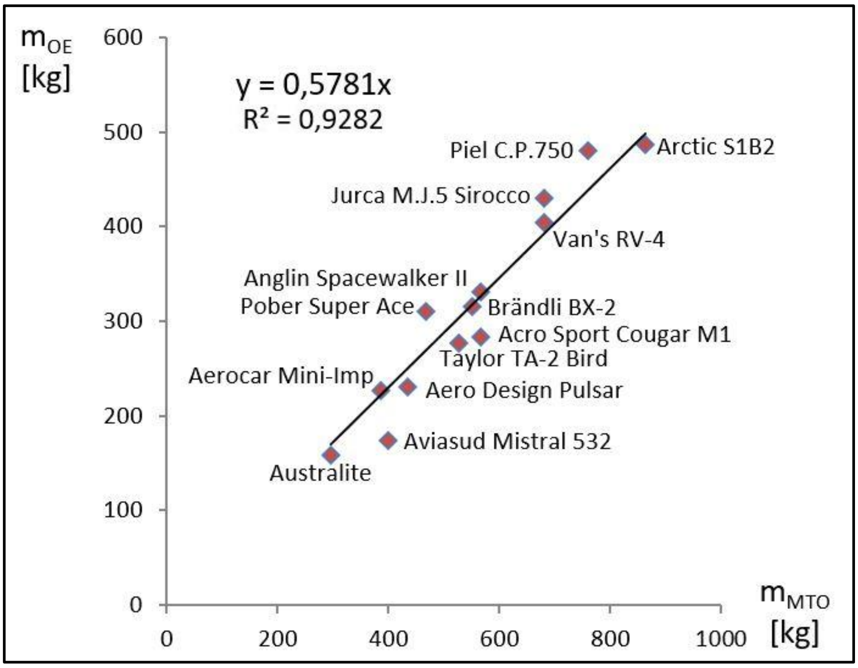

Figure 3.10 Relative operation empty mass m_{OE}/m_{MTO} as the slope of a regression line

In the following figures, the relative operation empty mass m_{OE}/m_{MTO} is set as a function of cruising speed V_{CR}, power-to-weight ratio P_S/m_{MTO}, takeoff mass m_{MTO} and range R. Unfortunately, all these statements are statistically below a coefficient of determination $\boldsymbol{R^2 < 20}$ % which is why they do not have much significance. However, they have been included in this project to give a rough direction of the parameter.

In Figure 3.11, the relative operation empty mass $\boldsymbol{m_{OE}/m_{MTO}}$ can be read as a function of cruising speed $\boldsymbol{V_{CR}}$ as a linear regression, which leads to Equation 3.14.

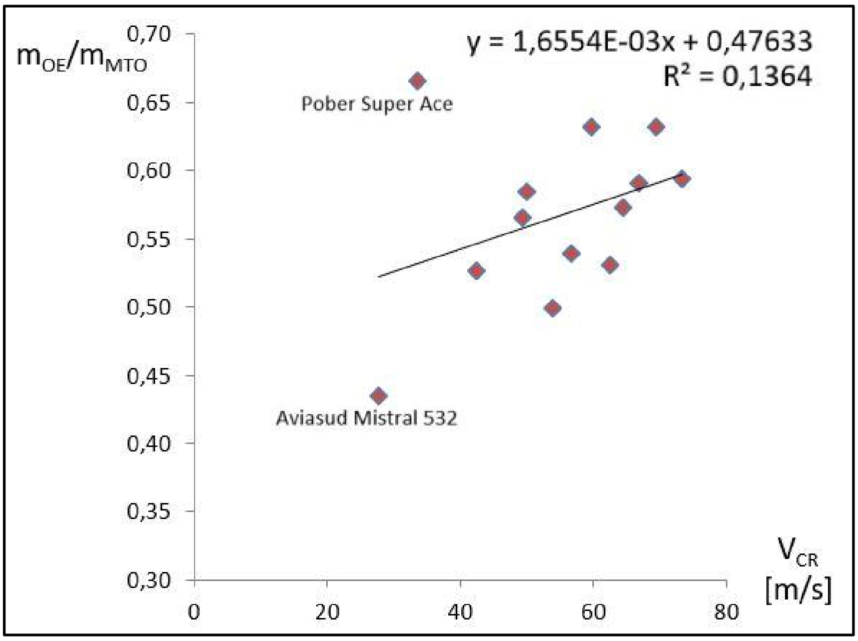

Figure 3.11 m_{OE}/m_{MTO} as a function of V_{CR}

$$\frac{m_{OE}}{m_{MTO}} = 0.4765 + 0.0017 \cdot V_{CR} \tag{3.14}$$

In Figure 3.12, the relative operation empty mass $\boldsymbol{m_{OE}/m_{MTO}}$ can be read as a function of power-to-weigth ratio $\boldsymbol{P_S/m_{MTO}}$ as a linear regression, which leads to Equation 3.15.

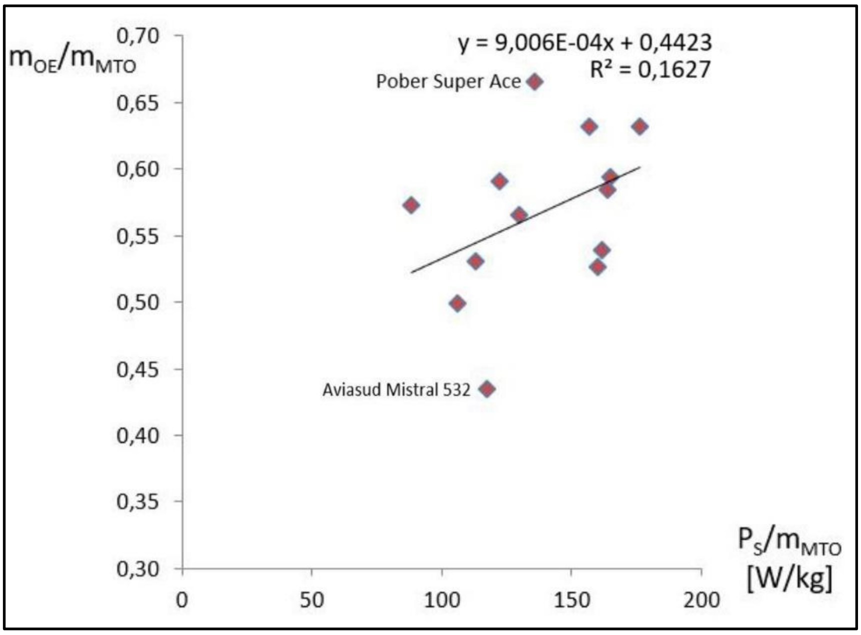

Figure 3.12 m_{OE}/m_{MTO} as a function of P_S/m_{MTO}

$$\frac{m_{OE}}{m_{MTO}} = 0.4423 + 9.006 \cdot 10^{-4} \cdot \frac{P_S}{m_{MTO}} \tag{3.15}$$

In Figure 3.13, the relative operation empty mass $\boldsymbol{m_{OE}/m_{MTO}}$ can be read as a function of the maximum take-off weigth $\boldsymbol{m_{MTO}}$ as a linear regression, which leads to Equation 3.16.

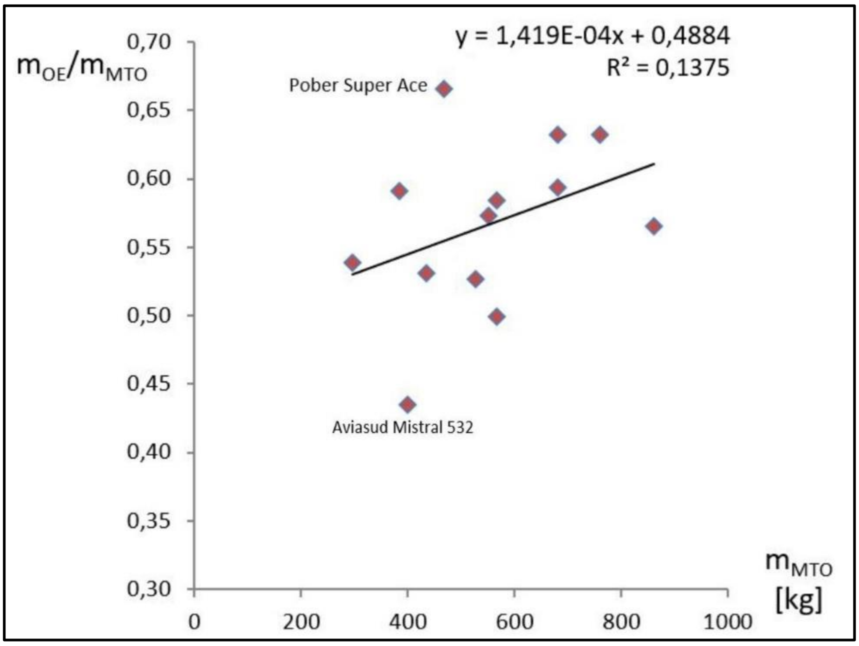

Figure 3.13 m_{OE}/m_{MTO} as a function of m_{MTO}

$$\frac{m_{OE}}{m_{MTO}} = 0.4884 + 1.419 \cdot 10^{-4} \cdot m_{MTO} \tag{3.16}$$

In Figure 3.14, the relative operating empty mass $\boldsymbol{m_{OE}/m_{MTO}}$ can be read as a function of the range $\boldsymbol{R}$ as a linear regression, which leads to Equation 3.17.

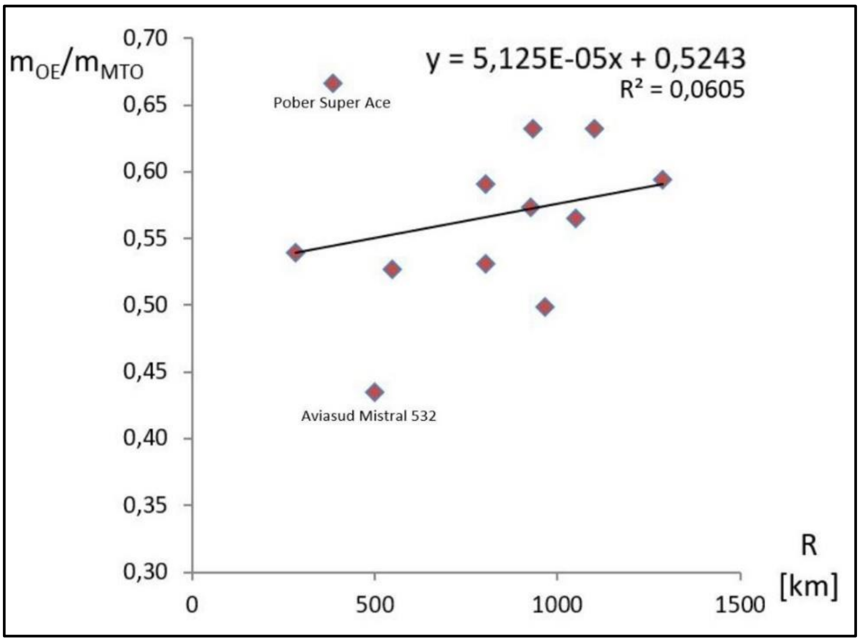

Figure 3.14 m_{OE}/m_{MTO} as a function of R

$$\frac{m_{OE}}{m_{MTO}} = 0.5243 + 5.125 \cdot 10^{-5} \cdot R \tag{3.17}$$

The table values for the range are also not so meaningful because some manufacturers specify the maximum range with and without reserve (45 min). Some manufacturers use extra tanks and some only the standard tank. Also flying at different cruising speeds (0.55 to 0.8 times engine power) leads to different ranges which adds the difficulty of finding a useful statistical relationship.

As already mentioned, the baggage and fuel weight can now be statistically calculated. For microlight aircraft, the baggage weight is very small, which is why it can be neglected for simplification. Therefore the crew weight becomes the payload m_{PL}. The $m_{OE} + m_{PL}$ is calculated according to LTF-UL. This results in the example calculation for the VAN'S RV-4

$$m_{OE} + m_{PL} = 404 \text{ kg} + 200 \text{ kg} = 604 \text{ kg}$$

which leads to 0.888 realtive to the maximum take-off weight.

Table 3.5 Aircraft data for statistical $(m_{OE} + m_{PL})/m_{MTO}$ based on **Jane's 1992**

Aircraft	m_{MTO} kg	$m_{OE} + m_{PL}$ kg	$(m_{OE} + m_{PL})/m_{MTO}$
Australite [c]	295	269	0.912
Aerocar Mini-Imp [c]	385	337	0.875
Aviasud Mistral 532 [b]	400	374	0.935
Aero Designs Pulsar [b]	435	431	0.991
Pober Super Ace [c]	467	421	0.901
Taylor TA-2 Bird [a]	526	477	0.907
Acro Sport Cougar M1 [b]	567	483	0.851
Anglin Spacewalker II [a]	567	531	0.936
Brändli BX-2 [b]	550	515	0.936
Jurca M.J.5 Sirocco [a]	680	630	0.926
VAN'S RV-4 [a]	680	604	0.888
Piel C.P.750 [a]	760	680	0.895
Arctic S1B2 [a]	862	687	0.797

[a] tandem two seats
[b] side-by-side two seats
[c] one seat
. Numerical value unknown

Using the data from Table 3.5, we calculate with Figure 3.15 a statistical $\boldsymbol{(m_{OE} + m_{PL})/ m_{MTO} = 0.890}$ with a coefficient of determination of $\boldsymbol{R^2 = 96}$ % (see defintion on page 11).

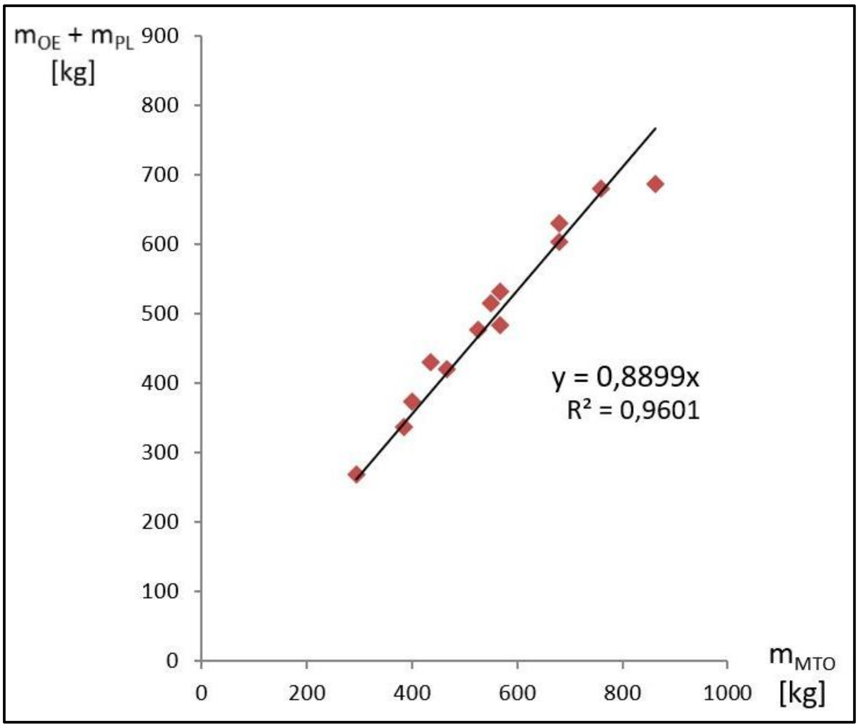

Figure 3.15 $m_{OE} + m_{PL}$ as a function of m_{MTO}

The **average fuel weight** for microlight (after LTF-UL) designed with a $m_{MTO} = 600$ kg would result in a $\boldsymbol{m_F} = 600\text{ kg} - (0.890 \cdot 600\text{ kg}) = \mathbf{66\ kg}$. This corresponds to about **89 l** of gasoline.

According to LTF-UL, the largest possible operation empty weight is $m_{OE} = 600\text{ kg} - 200\text{ kg} \leq 400\text{ kg}$ (parachute is part of m_{OE}). The worst relative operation empty weight is therefore $m_{OE}/m_{MTO} \leq 400/600 = 0.667$. As briefly described at the beginning of the chapter, the m_{OE}/m_{MTO} ratio shows whether an aircraft has been designed light or not. A large value means a heavy structure and a small value means a light structure and therefore it is desired.

In an exemplary consideration of **how much weight** is available for the **aircraft structure** of a two-seater microlight aircraft with a range of **1000 km**, the following can be roughly calculated.

$$m_{MTO} - m_{PL} - \text{parachute} - m_F$$
$$600\text{ kg} - 200\text{ kg} - 25\text{ kg} - 94\text{ l} \cdot 0.74\ \frac{\text{kg}}{\text{l}} \approx 300\text{ kg}$$

This means that for the aircraft structure with engine, instruments, hoses, electric cables, pull cables, landing gear (wheels and brakes), possibly landing gear retraction mechanism, seats and other material covers in the interior **300 kg** remain. In this calculation, the fuel fraction is approximately $m_F/m_{MTO} = 11.6\ \%$.

3.5 Dimensioning for the Required Climb

For microlight aircraft, no minimum angle of climb $\boldsymbol{\gamma}$ is required but a minimum rate of climb $\boldsymbol{ROC}$ of $\mathbf{1.5\ m/s}$ (Chapter 2.2).

$$\frac{P_{S,TO}}{m_{MTO}} = \frac{\left(ROC + \frac{V_2}{E}\right) \cdot g}{\eta_{CL} \cdot (\sigma(h) \cdot (1 + c_h) - c_h)} \tag{3.18}$$

$$ROC = \frac{\eta_{P,CR} \cdot P_S}{m_{MTO} \cdot g} - \frac{V_{CR}}{E} \tag{3.19}$$

Equation 3.18 can be used to dimension according to the rate of climb. Another statistical parameter is not required here.

For an aircraft design with a given minimum ROC, a selected aerodynamic requirement E and a chosen speed at which the aircraft should still reach $ROC = 1.5\ \mathrm{m/s}$, it is easy to calculate with Equation 3.18 **how much engine power** the aircraft must have.

3.6 Dimensioning for the Minimum Speed

As mentioned in Chapter 2.2 *Microlight Requirements in Germany*, the minimum speed must not exceed 83 km/h. The following equation can be used to dimension according to the minimum speed.

$$V_{S,0} \leq 83\ \frac{\mathrm{km}}{\mathrm{h}} = \sqrt{\frac{m_{MTO} \cdot 2 \cdot g}{S_W \cdot C_{L,max,L} \cdot \rho_0 \cdot \sigma}} \tag{3.20}$$

For the design of the flaps for a microlight aircraft, the required $C_{L,max,L}$ plays a major role. For an average microlight with $m_{MTO} = 600\ \mathrm{kg}$, $S_W = 8\ \mathrm{m}^2$ and compliance with $V_{S,0} \leq 83\ \mathrm{km/h}$, the calculation can be made as follows

$$23.056\ \frac{\mathrm{m}}{\mathrm{s}} = \sqrt{\frac{600\ \mathrm{kg} \cdot 2 \cdot 9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}}{8\ \mathrm{m}^2 \cdot C_{L,max,L} \cdot 1.225\ \frac{\mathrm{kg}}{\mathrm{m}^3} \cdot 1}}$$

$$\rightarrow C_{L,max,L} = 2.26$$

which results in a required $C_{L,max,L} \geq 2.26$. From Figure 3.2 it can be seen that at least a very good slotted flap or even a fowler flap is needed.

Before you have to consider a more complicated flap like the fowler flap, you should first consider increasing the wing area or reduce the maximum takeoff weight, because this will reduce the required $C_{L,max,L}$. For example, the same aircraft with a wing area of $S_W = 10\ \mathrm{m}^2$ would only have a required $C_{L,max,L} = 1.81$, where a plain flap can be enough.

For fast flying aircraft, large wings are aerodynamically disadvantageous because they require more thrust and thus more fuel. For a fast flying, aerodynamically efficient aircraft, a more mechanically complex flap mechanism is necessary to produce a landing configuration that delivers the required $C_{L,max}$. These relationships can also be read very well from the matching chart (Chapter 3, Figure 3.1). In the end, it is a question of economics as how the microlight aircraft is designed.

Additional formulas for preliminary sizing are also well presented in the work of **Matalla 2006**.

4 Summary and Conclusion

The microlight industry is currently in a major transition, as the maximum take-off weight increase from 472.5 kg to 600 kg in the respective countries has only recently taken place. Manufacturers have new opportunities to design microlight aircraft, but also customers expect the rapid weight increase of the aircraft. Therefore, we are currently in a race of manufacturers to bring new aircraft on the market to have a short term competitive advantage. Furthermore, many national countries are behind with the regulations, but in the next few years, most countries should have adapted the new rule and thus the load increase.

Outside Europe there are also similar microlight classes like the basic ultra-light class in Canada or the light-sport aircraft class from the USA which can be flown with more or less effort for the pilot license. Also the very light classes are represented in other countries like the 120 kg class in germany. Although the rules of the various countries are so similar, it is not easy to make a trip to other countries which is why a unification of the rules could be an advantage. The **EMF 2019** is already trying to collect the respective rules or rather national contacts together. However, an official international page with clear rules of all countries does not yet exist. It is therefore a dichotomy that on the one hand you would like to have unified rules that could be published by ICAO, but on the other hand it makes microlight flying much simpler and cheaper just by being exempt from ICAO rules.

The matching chart is an important and powerful tool in preliminary sizing to compare different design strategies and to find a design point. This includes, for example, deeper considerations for the flap mechanism (high-lift devices), as this affects the $C_{L,max}$ and thus the wing area can be designed in different sizes. The required parameters for the preliminary sizing of an microlight aircraft were determined statistically. The aircraft considered in this project are chosen very differently in their configuration and weight class so that it is easy to see at which value a more specific case difference is worthwhile and which parameters provide a good generally valid result. To evaluate whether a statistical statement is good or bad, the result quality rating R^2 is calculated for each statistic. Why some statistical parameters have so little significance is due the fact that microlight aircraft have very different configurations with partly two seats in a row, side by side or only one seat. Aerodynamics, efficiency are as different as the different selling costs of microlights (development and manufacturing costs).

For preliminary sizing of microlight aircraft, similar aircraft types should be chosen as reference. Attention should be paid to the configuration (type of aircraft and seating arrangement) and the take-off weight. Each aircraft design requires its own simplified market analysis on similar aircraft in order to proceed with statistically good values into further design. For exotic configurations, common parameters should be used.

If a statistical safety landing distance compared to the approach speed for microlight aircraft is to be calculated, a $\boldsymbol{k_{APP} = 2.149}$ $\sqrt{\mathbf{m/s^2}}$ was determined which is higher than the $k_{APP} = 1.7$ $\sqrt{\mathrm{m/s^2}}$ of jets (according to **Loftin 1980**). Here, however, a more exact case differentiation of the microlight would have to be made in order to obtain a statistically better value.

The statistical parameter k_{TO} is important to calculate the take-off field length as a function of power to weight ratio and weight to wing area ratio (matching chart). For microlight aircraft this results in $\boldsymbol{k_{TO} = 1.915\ \mathrm{m^3/kg}}$ which is below the value for jets $k_{TO} = 2.34\ \mathrm{m^3/kg}$ (according to **Loftin 1980**). This value is already quite generally valid and may only need slight corrections for the aircraft to be designed.

The parameter k_E is important to estimate the maximum lift-to-drag ratio E_{max}. Four different approaches were used to calculate the parameter for microlight aircraft. The result is $\boldsymbol{k_E = 12.12}$ which is a smaller value than the $k_E = 14.9$ for jets according to **Loftin 1980**. Since the parameter is very different depending on the flight performance E to be designed, a case distinction must be made here. Aircraft with high glide ratio have a larger k_E value than aircraft with smaller E.

The statistical examination of various aircraft for the relative operation empty mass gives very important information, for example, about how much weight is needed for the structure. With a very good general statement, we can now say that a new microlight aircraft certified in Germany with a $\boldsymbol{m_{MTO} \leq 600\ \mathrm{kg}}$ should statistically have a maximum operation empty weight of $\boldsymbol{m_{OE}} = 0.578 \cdot 600\ \mathrm{kg} = \boldsymbol{346.8\ \mathrm{kg}}$. This weight includes all important aircraft internals such as seats, instruments, displays and parachute.

With relatively simple formulas, further microlight preliminary sizing questions can be answered, such as which climb rate can still be flown with which engine power. The minimum required airspeed of $V_{S,0} \leq 83\ \mathrm{km/h}$ must also not be exceeded, which is why attention must be paid to the correct sizing of the high-lift systems. However, the real aircraft values and airspeeds will only be determined during final test flights, which will show how well the respective parameters were predicted. In order to be able to guarantee a safe test flight, the microlight aircraft design must be calculated with sufficient certainty.

Further research could be done to provide all necessary calculation steps for the preliminary sizing of a microlight aircraft in an Excel spreadsheet. On **PreSTo 2020** you can see what has already been done and what can be used. It is also interesting to make a strict case distinction of microlight types and maximum weights in a future project. However, it probably makes more sense to examine each aircraft design individually to obtain the best possible parameters.

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On 2021-04-04 all links were tested and access was possible.