Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Safety Study on Air Sports Equipment

- Analysis of Accidents and Incidents with Air Sports Equipment in Germany, 2000-2019 -

This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (*Flugunfall-Untersuchungs-Gesetz - FlUUG*) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

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Abbreviations

ACAS	Airborne Collision Avoidance System
AMSL	Above Mean Sea Level
ATC	Air Traffic Control
BeauftrV	Regulations on the Delegation of Authority to Air Sports Associations
BFU	Bundesstelle für Flugunfalluntersuchung (German Federal Bureau of Aircraft Accident Investigation)
BMDV	Federal Ministry for Digital and Transport
BPRS	Ballistic Parachute Recovery System
CFIT	Controlled Flight Into or toward Terrain
CFRP	Carbon Fibre Reinforced Plastic
DAeC	German Aero Club
DESTATIS	Statistics of the Federal Statistical Office
DFV	German Skydiving Association
DHV	German Hang Gliding Association
DULV	German Ultralight Flight Association
EASA	European Aviation Safety Agency
ECCAIRS	European Coordination Centre for Accident and Incident Reporting Systems
EPAS	European Plan for Aviation Safety
FlUUG	Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft
FUS	Flugunfalluntersuchungsstelle beim Luftfahrt-Bundesamt
F-POST	Fire/Smoke (Post-Impact)
GA	General Aviation
GASP	Global Aviation Safety Plan
GPAS	German Plan for Aviation Safety

GPS	Global Positioning System
HFACS	Human Factors Analysis and Classification System
ICAO	International Civil Aviation Organization
IMC	Instrument Meteorological Conditions
LALT	Low Altitude Operation
LBA	Luftfahrt-Bundesamt (Federal Aviation Office)
LOC-I	Loss of Control-Inflight
LSG	Luftsportgerät (air sports equipment)
LSG-B	Luftsportgeräte-Büro (air sports equipment office)
LuftVO	Regulation on Aviation
MAC	Airprox/TCAS Alert/Loss of Separation/Near Midair Collisions/Midair Collisions
MTOM	Maximum Take-off Mass
SCF-NP	System/Component Failure or Malfunction (Non-Powerplant)
SCF-PP	System/Component Failure or Malfunction (Powerplant)
SD	Standard Deviation
SERA	Standardised European Rules of the Air
SMS	Safety Management System
SSP	State Safety Programme
VFR	Visual Flight Rules
V_{NE}	Never Exceed speed

Abstract

This safety study analysed accident and serious incident data involving air sports equipment in Germany which the German Federal Bureau of Aircraft Accident Investigation (BFU) investigated between 2000-2019. In this time period, the BFU investigated a total of 148 occurrences involving air sports equipment, 138 accidents and 10 serious incidents. These occurrences accounted for a total of 144 fatalities, while 44 persons suffered severe and 8 minor injuries.

The study is a complement to the published investigation reports. These reports and all data collected during the investigations were analysed in detail and key aspects and clusters identified. Each occurrence was analysed in regard to human, technological and environmental factors based on more than 200 different parameters.

The goal of this safety study was to analyse, classify and describe similarities, differences, causal and contributory factors and circumstances which resulted in the respective accident or serious incident.

As a result, the BFU issues four safety recommendations. These are addressed to the Federal Ministry for Digital and Transport (BMDV) and the Luftfahrt-Bundesamt (Federal Aviation Office, LBA) and aim at the development of an effective Safety Management System in the area of air sports equipment and actions to reduce the number of fatal accidents in this area.

1. Initial Situation

With the foundation of the German Federal Bureau of Aircraft Accident Investigation (BFU), 1998, as independent safety investigation authority for civil aviation, the requirements of Council Directive 94/56/EC were implemented. The obligations and focusses of the BFU were regulated by law. The investigation of accidents and serious incidents in commercial air traffic was determined as the main focus of the BFU. According to the law, the BFU should not investigate accidents involving air sports equipment, apart from some exceptions. The exceptions where the BFU can decide to investigate are defined in FlUUG § 3 (4) b: [...] *may be investigated, if the Federal Bureau expects significant results for the safety of aviation.* Over the years, the BFU formulated criteria to decide when to initiate an investigation into occurrences involving air sports equipment. In the last more than two decades, a number of accidents and serious incidents involving air sports equipment was and continues to be investigated and the findings are published in corresponding reports.

1.1 Objective and Methodology of the Safety Study

This safety study, based on Regulation (EU) No. 996/2010[1] of the European Parliament and of the Council on the investigation and prevention of accidents and incidents in civil aviation, shall combine and analyse notifications and results of occurrences investigated by the BFU. With the publication of this study the BFU serves to assist federal and regional aviation authorities, associations and organisations as well as interested parties to identify actions which will have the potential to increase aviation safety in the area of air sports equipment and therefore prevent future accidents. In addition to the published respective reports, this shall be achieved by an extensive statistical analysis of accidents and serious incidents involving air sports equipment.

This safety study used the following data sources:

- BFU data base (ECCAIRS)
- Final and interim reports of the BFU

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[1] Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, Current consolidated version: 11/09/2018, http://data.europa.eu/eli/reg/2010/996/oj

- BFU investigation files and interviews with the investigator in charge, where appropriate
- BFU notification diary
- Files of the air sports equipment office (LSG-B)
- Files of the German Ultralight Flight Association (DULV)
- Safety reports including statistics of the German Hang Gliding Association (DHV)
- Safety reports including statistics of the German Skydiving Association (DFV)
- Statistics of the Federal Statistical Office (DESTATIS)

This safety study analyses the occurrence data of air sports equipment in Germany between 2000 and 2019. The BFU chose this time span to consider an as large a data base as possible concerning air sports equipment accidents and serious incidents. For comparison and to give context to the development of accident numbers involving air sports equipment between 2000 and 2019, the BFU also listed the accident numbers between 1988 and 1997 recorded by the former accident investigation authority (FUS) at the Luftfahrt-Bundesamt.

A working group of accident investigators with extensive experience in accident investigation, flying, air sports equipment and statistical analysis as well as human factors expertise was formed to identify, define and compile important parameters concerning occurrences involving air sports equipment. For each data record of an accident or serious incident, a total of 206 parameters were identified and gathered. The data record of each occurrence (air sports equipment and occupants, respectively) encompassed 100 parameters from the three areas:

- Human factors (e.g. age, flying experience, licencing, body weight, injuries)
- Technology (e.g. construction, MTOM, damage, ballistic parachute recovery system)
- Environmental factors (e.g. weather, visibility, operating phase, fire)

In addition, 106 human factors parameters per data record were gathered to deeper analyse human factors (also systemic). The Human Factors Analysis and Classification System (HFACS) was applied accordingly.

The working group specifically discussed and assessed each individual case based on the final report and all BFU internal case files. Subsequently, based on the 206 parameters, these assessments were transferred to a general survey to quantify and compare them. The working group used a statistics and analysis software to analyse the data.

1.2 Duty and Operation of the BFU

The BFU is a higher federal authority in the area of responsibility of the Federal Ministry for Digital and Transport (BMDV). It is the duty of the BFU to investigate accidents and serious incidents of civil aircraft, to determine their possible causal factors, with the aim to prevent future accidents.

Legal bases are Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (Flugunfall-Untersuchungs-Gesetz, FlUUG) of 26 August 1998.

In accordance with Article 1 of Regulation (EU) No. 996/2010 and § 3 FlUUG[2], the sole purpose of the investigation is the prevention of future accidents and incidents. It is not the purpose of an investigation to assign blame or liability or to establish claims.

The legal bases in § 3 FlUUG include the following definitions, among other things:

> ***Accident***
>
> *means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:*
>
> *1. a person is fatally or seriously injured*
>
> - *on board an aircraft, or,*
> - *as a result of direct contact with any part of the aircraft including parts which have become detached from the aircraft, or,*
> - *as a result of direct exposure to jet or propeller blast,*

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[2] Law Relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft (Flugunfall-Untersuchungs-Gesetz – FlUUG), Last changed by Art. 153 G v. 20.11.2019, https://www.gesetze-im-internet.de/fluug/

except when these injuries are from causes other than the accident, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew members; or

2. the aircraft or the airframe sustains damage which:

- *which adversely affects the structural strength, performance or flight characteristics of the aircraft, and*
- *would normally require major repair or replacement of the affected aircraft component,*

except for engine failure or damage, when the damage to the aircraft is limited to the engine concerned, its cowlings or accessories; or for damage limited to propellers, wing tips, radio antennas, tyres, brakes, fairings or to small dents or puncture holes in the aircraft skin; or

3. the aircraft is missing or inaccessible.

Serious Incident

means an occurrence associated with the operation of an aircraft involving circumstances indicating that an accident nearly occurred […].

Incident

means an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

Fatal Injury

means an injury which is sustained by a person in an accident and which results in his/her death directly in the accident or within 30 days of the date of the accident.

Serious Injury

means an injury which is sustained by a person in an accident and which:

1. requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received; or

2. results in a fracture of any bone (except simple fractures of fingers, toes or nose); or

3. involves lacerations which cause severe haemorrhage or nerve, muscle or tendon damage; or

4. involves injury to any internal organ; or

5. involves second or third degree burns, or any burns affecting more than 5% of the body surface; or

6. involves verified exposure to infectious substances or harmful radiation.

Purpose and Subject of the investigation is stipulated in § 3 FlUUG:

(1) Accidents and incidents are subject to investigations with the sole purpose of determining the causes as far as possible with the intention of preventing future accidents and incidents. § 18 subparas 4 and 5 shall remain unaffected.

(2) The investigation shall not serve the purpose of establishing blame, liability or claims.

(3) Subject to an investigation is any accident and serious incident associated with the operation of:

- any aeroplane when operated by a commercial operator,

- aeroplanes not operated by a commercial operator if they have a maximum mass of more than 2.000 kg,

- rotorcraft,

- airships,

- balloons.

(4) Accidents and incidents to

a) aeroplanes with a maximum mass up to 2.000 kg, if the accident or incident did not occur during operations for a commercial operator, and

gliders and motorgliders

will be investigated only if the Federal Bureau expects new insight into the safety aspects of aviation from such an investigation;

b) aircraft other than those indicated under subpara 3 and under part a) may be investigated, if the Federal Bureau expects significant results for the safety of aviation.

(5) Para 4 subpara b) shall be applied accordingly to incidents associated with the operation of aircraft.

1.3 State of Aviation Safety in Germany

Similar to other states the Federal Republic of Germany has, for decades, made efforts to ensure and improve aviation safety. On the proactive side, before an accident occurs, registration and oversight authorities, aviation sport associations, special interest groups and unions, flying schools, clubs, etc. are involved. On the other side, when an accident or serious incident has occurred, it is an important task of the state to publish, process and use the insights gained from the investigations to improve the aviation system.

The International Civil Aviation Organisation (ICAO) published Annex 19 Safety Management, among other things, to continue to improve aviation safety worldwide in spite of the progress already made. Based on ICAO Annex 19 the member states are required to compile national safety management programs and plans. The European Union and its member states also implemented these regulations.

In 2020, Germany published a State Safety Program[3] for the first time. This national State Safety Program is defined as "Set of rules and measures to guarantee the steady improvement of aviation safety at the national level." In the State Safety Program, air sports is named as a significant part of aviation in Germany and thus plays an important role when setting the priorities in the German State Safety Program. Therefore, the Air Sports Associations are included in the process and a possible extension of the duties of representatives in regard to the stipulations of ICAO Annex 19 and the report of safety-relevant occurrences shall be subject to the German Plan for Aviation Safety (GPAS)[4].

In the GPAS, the BMDV published in January 2022, the chapter Safety Objectives identifies the steady improvement of aviation safety as planned objective. The five subsequent subobjectives list identification, assessment and minimisation of aviation risks and the exchange of information on safety-relevant occurrences in all aviation areas and the promotion of the safety culture and the implementation of corresponding actions in air sports, among other things. The promotion of safety management

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[3] https://www.bmvi.de/SharedDocs/DE/Artikel/LF/state-safety-programm-deutschland.html

[4] https://www.bmvi.de/SharedDocs/DE/Anlage/LF/deutscher-plan-fuer-luftverkehrssicherheit-pdf.pdf?__blob=publicationFile

systems, the safety culture in General Aviation and a common understanding of “Human Factors” are among the measures the GPAS describes, which result from the duty of being an EU member state.

The GPAS chapter Organisational Issues lists six occurrence categories which are mostly based on the ICAO high risk categories listed in the Global Aviation Safety Plan (GASP[5]) and thus are primarily relevant for commercial air traffic:

1. Airprox/TCAS Alert/Loss of Separation/Near Midair Collisions/Midair Collisions (MAC)
2. Ground Collision (GCOL)
3. Loss of Control-Inflight (LOC-I)
4. Runway Excursion (RE)
5. Runway Incursion (RI)
6. Controlled Flight Into or toward Terrain (CFIT)

1.4 Occurrence Notifications

1.4.1 Notifications of Accidents and Serious Incidents

Referring to Regulation (EU) No. 996/2010 and the FlUUG, the German Regulation on Aviation (LuftVO)[6] regulates the reporting of accidents and serious incidents as follows:

> *§ 7 Reports of Accidents and Incidents*
>
> *(1) The pilot in command shall promptly report accidents involving civil aircraft, which occur in the sovereign territory of the Federal Republic of Germany, in terms of Regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and repealing Directive 94/56/EC, in the respective current version, Article 2 Number 1, to the Federal Bureau of Aircraft Accident Investigation. If the pilot is not able to, another crew member must report in accordance with Number 1 or if no crew member is able to, the operator of the aircraft. The obligation to report in accordance with Number 1 is also valid for accidents of German aircraft outside the sovereign territory of the Federal*

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[5] https://www.icao.int/safety/GASP/Pages/GASP-Doc.-10004.aspx

[6] German Regulation on Aviation (Luftverkehrs-Ordnung (LuftVO)) from 29.10.2015, https://www.gesetze-im-internet.de/luftvo_2015/BJNR189410015.html

Republic of Germany, and for accidents involving foreign aircraft which were operated by a German operator at the time. Air sports equipment is not covered by this obligation to report.

(2) The pilot in command shall promptly report serious incident in terms of Regulation (EU) No. 996/2010 Article 2 which occurred during operation of civil aeroplanes, rotorcraft, balloons and airships in the sovereign territory of the Federal Republic of Germany, to the German Federal Bureau of Aircraft Accident Investigation. The obligation to report in accordance with Number 1 is also valid for serious incidents outside the sovereign territory of the Federal Republic of Germany during operation of German aircraft, involving foreign aircraft which were operated by a German operator at the time.

(3) If the Aviation Supervision Offices, the Flugleitungen at aerodromes, air navigation services or other persons involved receive knowledge about an accident or serious incident in accordance with Regulation (EU) No. 996/2010 Article 2 Number 11, they are obligated to promptly report the accident or serious incident to the Federal Bureau of Aircraft Accident Investigation, notwithstanding para 1 and 2.

(4) Reports in accordance with para 1 to 3 shall include:

1. *Name and location of the reporting person,*
2. *Location and time of the accident or serious incident,*
3. *Type, registration and call sign of the aircraft,*
4. *The name of the operator,*
5. *Purpose of the flight, aerodrome of departure and arrival,*
6. *The name of the pilot in command,*
7. *Number of crew members and passengers,*
8. *Extend of personal injury and property damage,*
9. *Information regarding transported hazardous goods,*
10. *Description of the sequence of the accident or serious incident.*

To complete the report, on request of the Federal Bureau of Aircraft Accident Investigation, the operator of the aircraft is obligated to present a detailed report using the mailed format within 14 days.

(5) The Federal Bureau of Aircraft Accident Investigation is authorised to gather, store and use data in accordance with subpara 4 if required in particular cases of accident and incident investigation in civil aviation. The data in accordance with subpara 4 has to be deleted promptly if they are no longer needed for the completion of duties in accordance with number 1.

(6) Obligations to transfer reports to the Luftfahrt-Bundesamt and other aviation authorities on the basis of other regulations or stipulations remain unaffected.

(7) Accidents and incidents during operation of air sports equipment have to be promptly reported in writing or electronically by the pilot to the delegations authorised in accordance with § 31c of the Federal Aviation Act. Subpara 1 number 2 and subparas 4 and 5 apply accordingly.

1.4.2 Regulation for Occurrence Reporting in Civil Aviation

In addition to the national reporting obligations to the BFU regarding accidents and serious incidents and in regard to air sports equipment to the Air Sports Associations, respectively, that have been in place for decades, a few years ago the European Union established another reporting system. In accordance with Regulation (EU) No. 376/2014 on the reporting, analysis and follow-up of occurrences in civil aviation, relevant safety information relating to civil aviation is reported, collected, stored, protected, exchanged, disseminated and analysed. This regulation applies for occurrences and other safety information which concern civil aircraft covered by Regulation (EU) No. 2018/1139.

This regulation does not apply to occurrences and other safety information which concern unmanned aerial vehicles for which no registration/no certificate or explanation is required, in accordance with Regulation (EU) No. 2018/1139 article 56 subparas 1 and 5, provided that the occurrence or other safety information applying to these aircraft do not affect severely or fatally injured persons or aircraft other than unmanned aerial vehicles. Member States may apply this regulation for occurrences and other safety information which concern aircraft not covered by Regulation (EU) No. 2018/1139. In Germany, air sports equipment is exempt from notifications in accordance with Regulation (EU) No. 376/2014.

1.5 BFU Activities between 2000 and 2019

Once the BFU has received an occurrence notification, generally the attempt is made to gather as much information as possible so that a sound decision can be made whether an investigation is initiated. At the end of an investigation, the BFU publishes the findings in form of a Final Report. If a safety deficit is determined during an investigation, safety recommendations will be published. Findings derived from investigations are a part of flight safety work hence distributed in form of lectures or publications.

1.5.1 Investigations

Between 2000 and 2019, the BFU investigated a total of 5,667 accidents and serious incidents, of which 148 (2.6%) involved air sports equipment (Fig. 1). Of the 707 fatal accidents, 101 (14.2%) were attributable to air sports equipment.

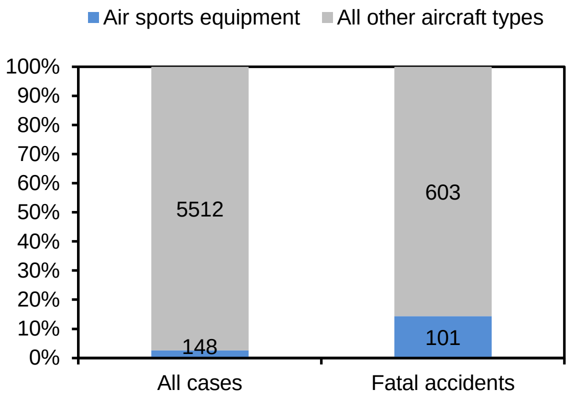

Fig. 1: Investigated accidents and serious incidents, all cases and fatal accidents Source: BFU

1.5.2 Reports

In the period under consideration, the BFU published a total of 1,004 Final Reports, of which 125 (12.4%) involved air sports equipment. In addition, a total of 1,036 Interim Reports were published as part of the monthly Bulletin, of which 88 (8.5%) occurrences involved air sports equipment.

1.5.3 Safety Recommendations

Regulation (EU) No. 996/2010 and the FlUUG define the term Safety Recommendation.

Regulation (EU) No. 996/2010

> *Article 2 Definitions*
>
> *For the purposes of this Regulation, the following definitions shall apply:*
>
> *[…]*
>
> *15. 'safety recommendation' means a proposal of a safety investigation authority, based on information derived from a safety investigation or other sources such as safety studies, made with the intention of preventing accidents and incidents;*
>
> *[…]*

FlUUG

> *§ 2 Definitions*
>
> *For the purpose of this Law:*
>
> *[…]*
>
> *Safety Recommendation*
>
> *means a proposal made by the Federal Bureau of Aircraft Accidents Investigation for the purpose of preventing accidents or incidents, based on facts and information derived from the investigation.*
>
> *[…]*

Between 2000 and 2019, the BFU issued a total of 284 safety recommendations, of which 33 (12%) specifically in regard to air sports equipment (Fig. 2).

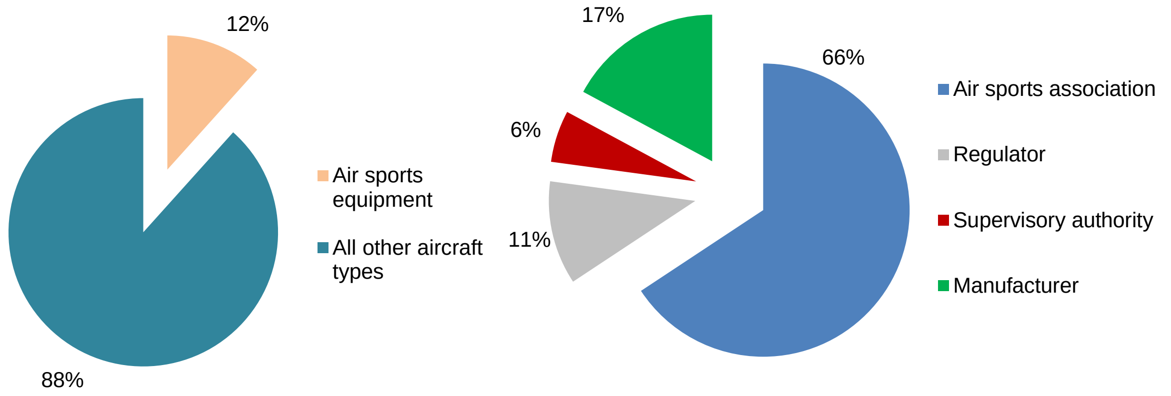

Fig. 2: Safety recommendations in regard to air sports equipment (left) and their addressees (right) Source: BFU

1.5.3.1 Addressees of Safety Recommendations

The identification of an addressee of a safety recommendation, who can ensure the elimination of a safety deficit, is an essential task in connection with issuing a safety recommendation. Figure 2 (right) shows that two thirds of all safety recommendations issued in the considered time period concerning air sports equipment addressed the authorised Air Sports Associations, another 17% the respective air sports equipment manufacturer.

1.5.3.2 Safety Recommendation Subject Areas

By far the largest part of BFU Safety Recommendations requested the airworthiness review of the type concerned (37%). Together with recommendations in regard to technical changes (18%) and special airworthiness inspection (3%), these type and aircraft related recommendations comprised more than half (58%) of all published safety recommendations concerning air sports equipment. The improvement of procedures for the performance of technical validations also accounted for a large part of safety recommendations (18%, Fig. 3).

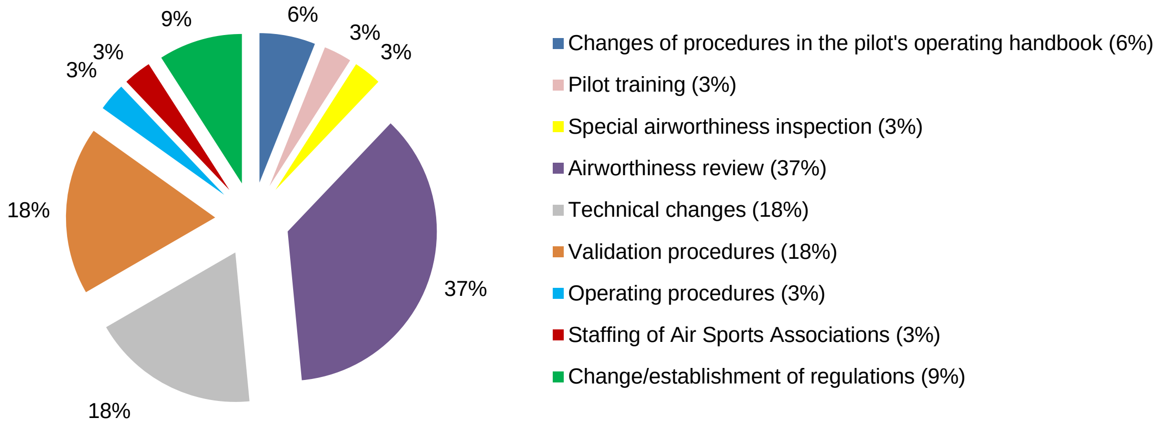

Fig. 3: Subject areas of BFU Safety Recommendations concerning air sports equipment Source: BFU

1.5.3.3 Timing of Issuing a Safety Recommendation

During the investigation of an accident or serious incident, there are basically two options to issue a safety recommendation. At the end of an investigation together with the Final Report or during an on-going investigation as a so-called immediate action. Critical for the decision as to when to issue a safety recommendation are the time of identification of a certain safety deficit, the severity of the resulting consequences should the safety deficit continue and the urgency of the actions required to minimise the risk.

Of the 33 safety recommendations the BFU issued concerning air sports equipment, 27 (82%) were issued at the end and 6 (18%) during the on-going investigation. Five of these six safety recommendations regarded the suspension of the involved aircraft type and one operational limitations.

1.5.3.4 Implementation of Safety Recommendations

Out of the 33 safety recommendations concerning air sports equipment issued between 2000 and 2019, 28 (85%) were implemented. Three safety recommendations (9%) were partially implemented and 2 (6%) not at all (Fig. 4).

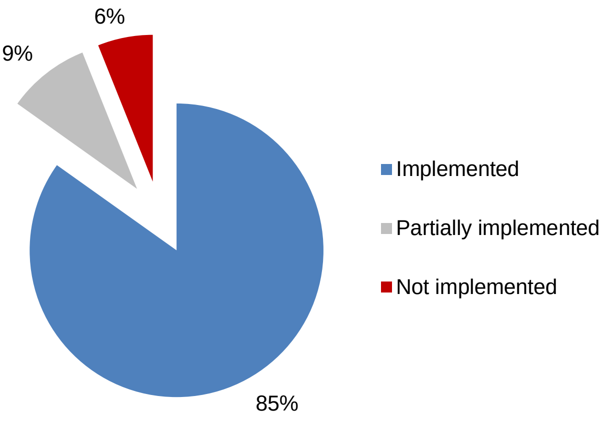

Fig. 4: Implementation of safety recommendations concerning air sports equipment, 2000-2019 Source: BFU

1.5.4 Safety Actions

The term safety action means actions which are implemented, e.g. by Air Sports Associations or manufacturers, even before or without the BFU issuing a corresponding safety recommendation. These could be Airworthiness Directives (AD), Service Bulletins (SB), or safety information. During the relevant time period, Air Sports Associations and manufacturers arranged and implemented a number of safety actions without involving the BFU. The BFU does not have exact figures in this regard. In connection with the BFU investigations, the Air Sports Associations and manufacturers arranged or implemented at least one safety action in 21 cases (14.2%).

1.5.5 Flight Safety Work

As a matter of routine, the BFU compiled and published yearly statistics for civil aviation during the time span under consideration. On request by politics, aviation and other authorities, Air Sports Associations, professional journals, educational organizations, the media, etc., the BFU compiled and provided special data analyses in regard to different aircraft types, operating modes, occurrence categories or operating phases. Internally, the BFU regularly performed data analyses to determine accident black spots and to compare them with, for example, a five-year-annual average. BFU speakers used this information during flight safety lectures and other events. The BFU regularly provides information and speakers for the education and training of flight instructors, general aviation airworthiness inspectors, fire brigades, police and other organisations.

In 2009, the Flight Safety Office of the German Aero Club was disbanded; up until then the BFU worked together with the seven Flight Safety Inspectors (FSI). For more than five decades the Flight Safety Office had been active in all areas of General Aviation. During their cooperation, the BFU regularly informed the FSI about investigation results, findings from current accidents and serious incidents and discussed flight safety developments also in regard to air sports equipment. According to the last annual report of the Flight Safety Office published in 2008, the FSI performed 314 flight safety lectures for General Aviation with a total of 10,200 pilots. In the years since, BFU employees increased the number of flight safety lectures for General Aviation (Fig. 5) but could not nearly cover as great a range as the FSI.

Fig. 5: Example flight safety lecture (left) and BFU exhibition booth (right) Source: BFU

The BFU regularly participates in aviation fairs with an exhibition booth in order to ensure the information exchange with interested parties, to answer questions and to communicate flight safety findings.

1.6 Inventory

The term air sports equipment includes hang gliders, paragliders and parachutes, ultralight gyrocopters, ultralight helicopters as well as aerodynamically or weight-shift controlled ultralights. According to the Regulations on the Delegation of Authority to Air Sports Associations (BeauftrV), the German Aero Club (DAeC), the German Ultralight Flight Association (DULV), the German Hang Gliding Association (DHV) and the German Skydiving Association (DFV) are responsible for different areas of air sports equipment. These include type certification and registration of ultralights, ultralight helicopters and gyrocopters (only DAeC and DULV), issuing of permits and ratings for aviation personnel, for training and supervision during air sports equipment operation. The following illustrates the different types of air sports equipment and their respective accident statistics.

1.6.1 Hang Gliders

A hang glider is a foot-launched, single or two-seated, non-motorised, mostly weight-shift controlled air sports equipment. It consists of a control frame, sail spars and a sailcloth covering. According to the DHV, hang gliders are flown in Germany since the mid-70s. The BFU does not have any information from the DHV about the number of certified hang glider types, registered hang gliders and licence holders.

The BFU analysed the respective DHV publications of the years 2000 to 2019 concerning the number of accidents (Fig. 6). The statistical data of the DHV show a total number of 564 accidents with hang gliders in the 20-year time period; of which 58 were fatal accidents. The annual average of hang glider accidents was 28 (SD[7] = 7); on average three fatal accidents per year.

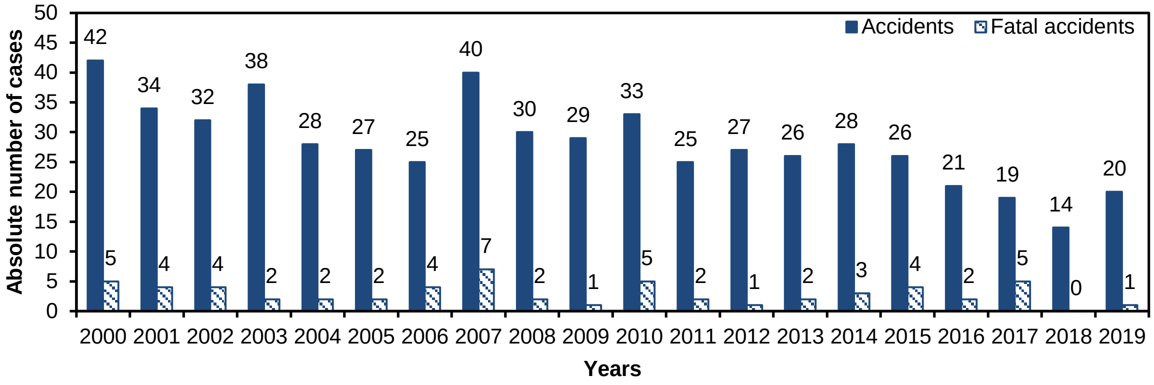

Fig. 6: Number of hang glider accidents 2000-2019 (national and international) Source: DHV, adaptation BFU

Accident statistics for the 10-year period 1988-1997 were used to better contextualise the current accident figures. At the time, the same notification obligations and addressees for accidents involving air sports equipment applied as for any other civil aircraft. The air accident investigation authority at the LBA (FUS, predecessor of the BFU before the founding in 1998) recorded a total of 401 accidents involving hang gliders between 1988 and 1997; of which 54 were fatal accidents (Fig. 7). This equals

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[7] Standard Deviation (SD) measures how far a set of numbers is spread out from their average value.

an average of 40 accidents (SD = 11) per year for this time period, on average 5 fatal accidents per year.

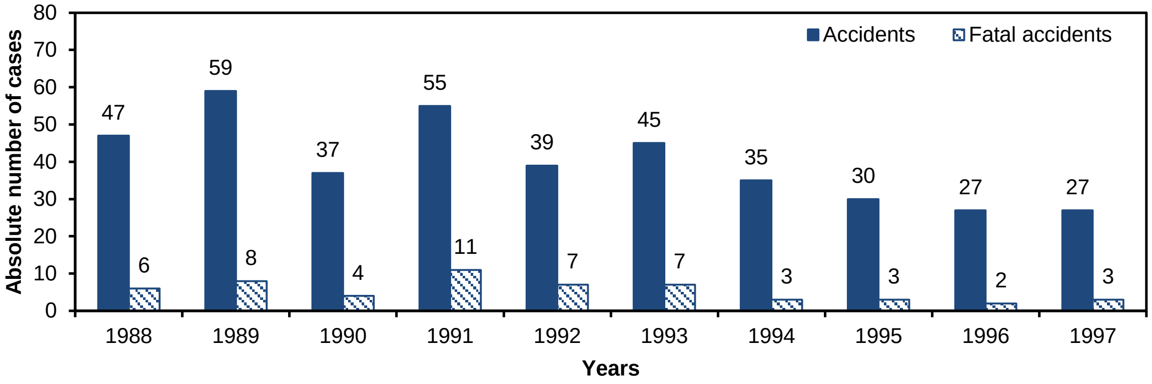

Fig. 7: Number of hang glider accidents 1988-1997 (national and international) Source: FUS, adaptation BFU

1.6.2 Paraglider

A paraglider is a foot-launched, single or two-seated, non-motorised air sports equipment with a textile ram air-filled wing. According to the DHV, paragliders are flown in Germany since 1987. The BFU does not have any information about the number of DHV certified paraglider types, registered paragliders or licence holders.

Concerning the accident numbers of paragliders, the BFU analysed the respective DHV publications of the years 2000 to 2019 (Fig. 8). The DHV statistics showed that 4,006 paraglider accidents occurred in the regarded time period, of which 182 were fatal accidents. This equals an average of 200 accidents (SD = 34) and 9 fatal accidents per year, respectively.

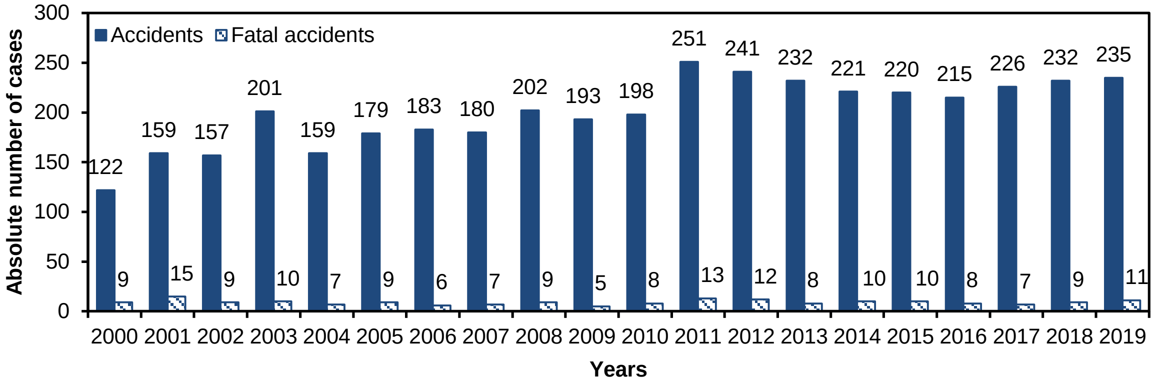

Fig. 8: Paraglider accident numbers 2000-2019 (national and international) Source: DHV, adaptation BFU

Between 1988 and 1997, FUS recorded a total of 545 accidents, of which 30 were fatal (Fig. 9). This equals an average of 55 accidents (SD = 12) and 3 fatal accidents per year.

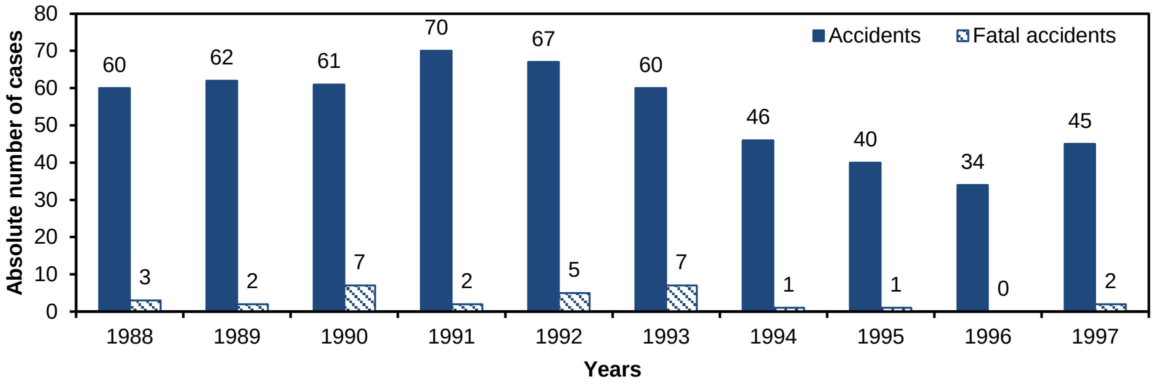

Fig. 9: Paraglider accident numbers 1988-1997 (national and international) Source: FUS, adaptation BFU

1.6.3 Parachutes

A parachute is an air sports equipment which is activated after jumping from aircraft, artificial or natural elevations to reduce the free fall of one to two persons by increasing drag or through aerodynamic lift, respectively. Flight path and speed can be controlled via control lines. According to the LSG-B, 2,177 persons were registered as licenced skydivers, while the DFV registered 21,833.

Based on the DFV publications, the skydiving accident numbers between 2000 and 2019 are depicted in Fig. 10. These show that a total of 1,803 accidents occurred during this time period, of which 109 were fatal accidents. This equals an average of 90 skydiving accidents (SD = 16) and 5 fatal accidents per year.

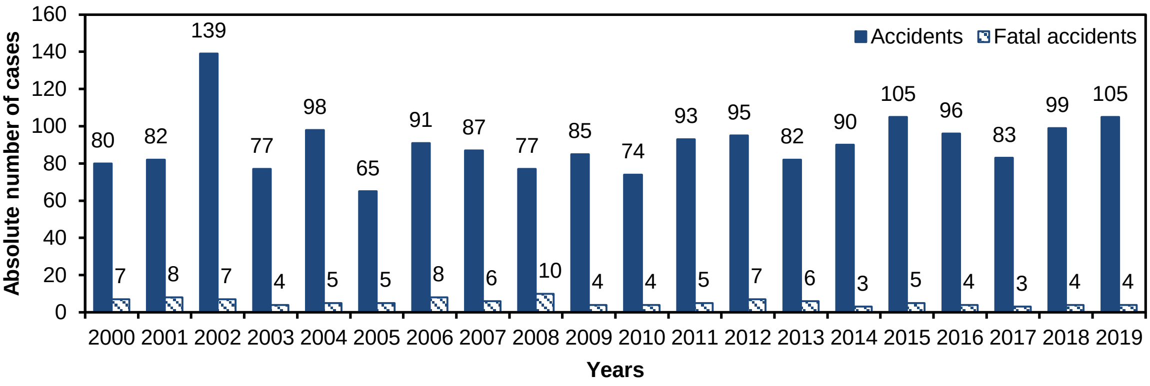

Fig. 10: Skydiving accident numbers, 2000-2019 Source: DFV, adaptation BFU

In comparison, the skydiving accident numbers between 1988 and 1997 show a total of 450 accidents, of which 61 were fatal accidents (Fig. 11). This means an average of 45 skydiving accidents per year (SD = 9), of which on average 6 were fatal accidents.

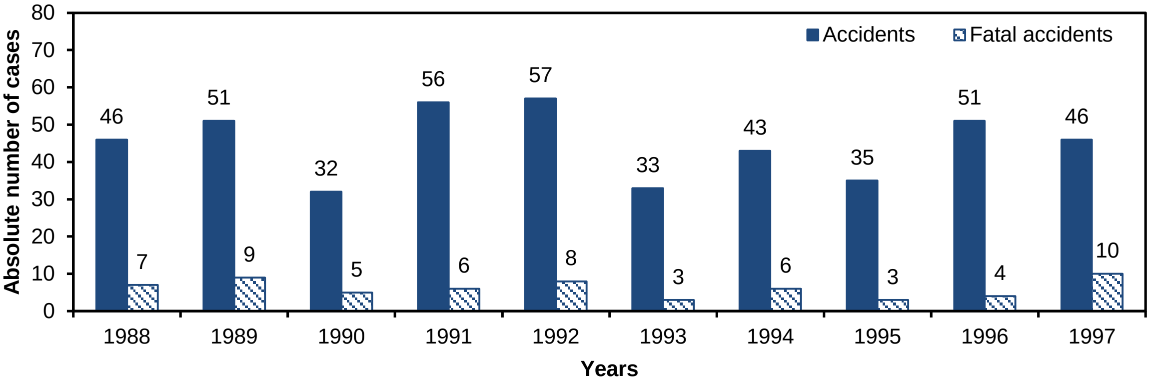

Fig. 11: Skydiving accident numbers 1988-1997 (national and international)

Source: FUS, adaptation BFU

1.6.4 Ultralight Helicopters

Ultralight helicopters are single or two-seat helicopters with a maximum take-off mass of 450 kg (600 kg, including floats 650 kg, since 2019). Since 2016, the LSG-B and DULV are the responsible Air Sports Associations.

According to the DULV, two ultralight helicopter types are certified. At the end of 2019, a total of six ultralight helicopter had a certificate of registration from the LSG-B or DULV. According to the LSG-B, at the end of 2019, 24 persons held an ultralight helicopter licence. In the period considered, the BFU has not received any notifications about accidents or serious incidents involving ultralight helicopters in Germany.

1.6.5 Gyrocopters

Gyrocopters are single or two-seat, motorised rotorcraft which use an unpowered rotor in free autorotation to generate lift and a pusher propeller to produce propulsion. According to the LSG-B annual report, on 31 December 2019, nine gyrocopters had a type certificate and 603 a certificate of registration from DULV or LSG-B (Fig. 12). At the end of 2019, DULV or LSG-B had issued gyrocopter pilot licences to 1,932 persons.

1.6.6 Aerodynamically and Weight-Shift Controlled Ultralights

Ultralight aircraft are single or two-seat motorised air sports equipment, which, depending on the type of control, are divided into aerodynamically and weight-shift controlled ultralight. According to the LSG-B annual report, at the end of 2019, 158 aerodynamically controlled ultralights were certified (Fig. 12). The BFU does not have any information on how many weight-shift controlled ultralights were certified.

At the end of 2019, a total of 4,210 aerodynamically controlled ultralights had a certificate of registration issued by DULV or LSG-B (Fig. 12). In addition, the LSG-B had certified 24 aerodynamically controlled light air sports equipment and 20 powered paragliders. Fig. 12 shows the development of the number of certified aerodynamically controlled ultralight and gyrocopters in Germany between 2003 and 2019. At the end of 2019, DULV and LSG-B had registered a total of 21,611 ultralight pilot licences.

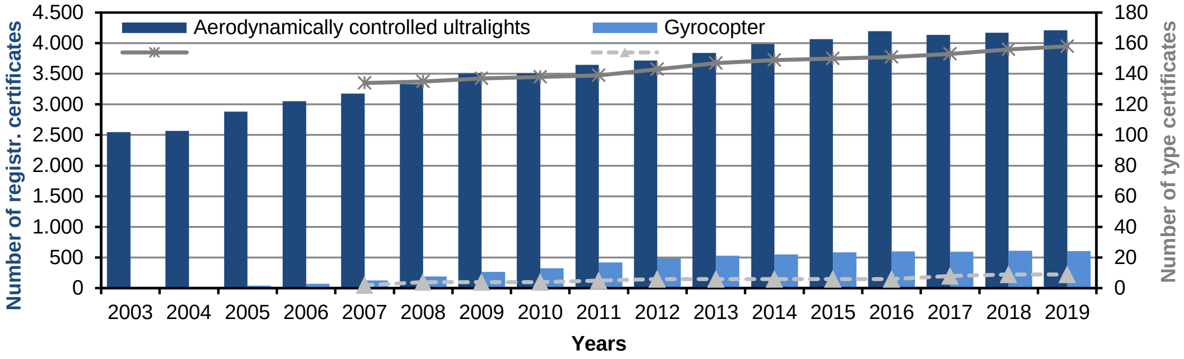

Fig. 12: Registration and type certificates (issued by DAeC) of aerodynamically controlled ultralights and gyrocopters, 2003 and 2019 Source: DAeC/DULV/LSG-B, adaptation BFU

1.6.7 Occurrence Numbers of Ultralights, Gyrocopters and Ultralight Helicopters

It was rather difficult and complex for the BFU to determine the occurrence numbers for ultralights, gyrocopters and ultralight helicopters for the period in question due to the fact that LSG-B and DULV had not recorded or published any accident statistics since 1999.

In the time period concerned, the BFU had received occurrence notifications involving ultralights and gyrocopters from operators, pilots, police, etc. even though there was no obligation by law. These notifications were counted, but not every case could be assigned to a specific air sports equipment or occurrence category nor classified as accident or serious incident. The occurrences the BFU investigated were assigned in accordance with the usual rules.

In addition, the BFU asked LSG-B and DULV to provide their files with occurrence notifications for the time period concerned. These files were differentiated between national and international occurrences. The national occurrences were counted by hand and checked for multiple entries. Fig. 13 depicts the result of this data comparison. For the considered 20-year period, the BFU and the two Air Sports Associations, respectively, registered a total of 1,894 occurrence reports for ultralights and gyrocopters, of which 140 were fatal accidents. This equals an annual average of 95 (SD = 21) occurrences, or an average of 7 fatal accidents per year.

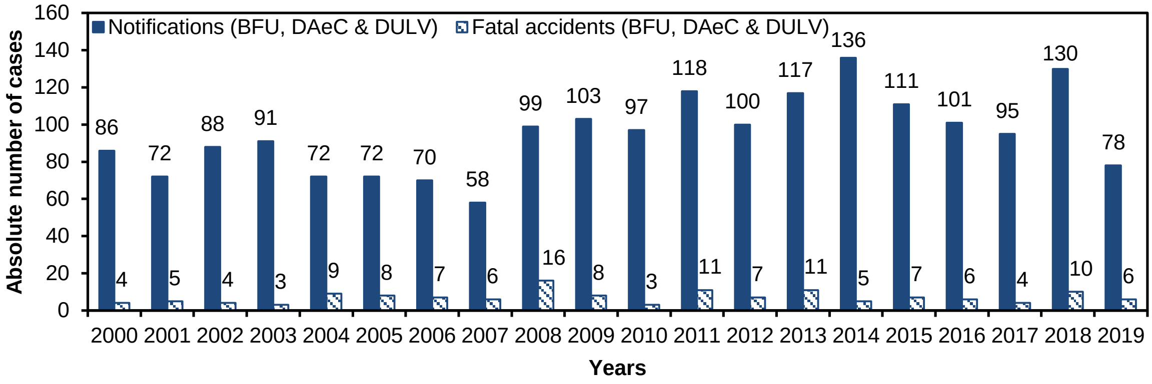

Fig. 13: Occurrence notifications at DAeC, DULV and BFU, 2000-2019 Source: BFU

Fig. 14 shows the attempt of the BFU to depict an annual accident rate of fatal accidents per 100,000 flights with ultralights and gyrocopters in Germany between 2000 and 2019. Starting point was the number of fatal accidents reported to the BFU, supplemented by the few fatal accidents which were only reported to the associations. The BFU is convinced that these numbers quite reliably indicate the total number of fatal accidents involving ultralights and gyrocopters in Germany during the time period considered. For the number of flights, the BFU accessed the recorded and published figures of DESTATIS for take-offs with non-commercial ultralights as DESTATIS does not record take-offs of commercial ultralights. Since the vast majority of ultralights are not commercially operated (Chapter 2.1), this imprecision should not have too great an effect on the data analysis, but should be considered.

For the 20-year time period, this calculation resulted in an average of 1.4 (SD = 0.6) fatal accidents involving ultralights in Germany per 100,000 take-offs. For comparison, the accident rates are stated for 2016 to 2020 for fatal accidents involving non-commercially operated small aircraft with a Maximum Take-off Mass (MTOM) of below 5.7 t (5-year average 0.53 fatal accidents per 100,000 flights) and gliders (5-year average 1.1 fatal accidents per 100,000 flights) EASA (European Aviation Safety Agency) published in the Aviation Safety Review 2021[8].

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[8] https://www.easa.europa.eu/downloads/130515/en

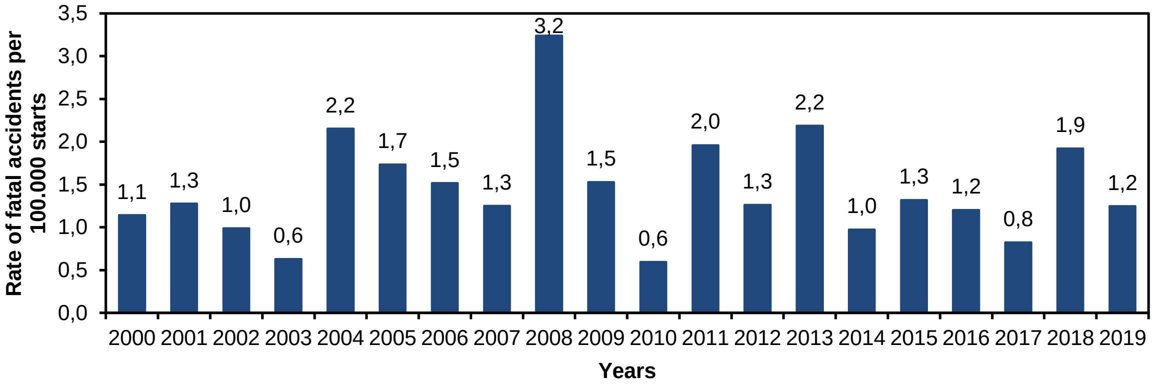

Fig. 14: Accident rate of fatal accidents per 100,000 take-offs, 2000-2019 (DAec, DULV and BFU) Source: BFU

In the 10-year comparison period 1988 and 1997, the FUS recorded a total of 217 ultralight accidents, of which 62 were fatal (Fig. 15). This equals an annual average of 22 accidents (SD = 4) and 6 fatal accidents involving ultralights (SD = 3).

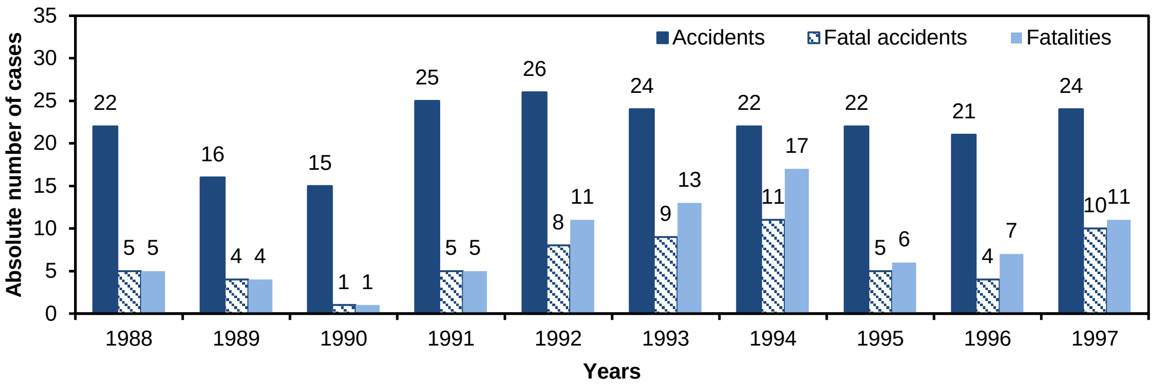

Fig. 15: Accidents involving ultralight 1988-1997 (national and international) Source: FUS, adaptation BFU

2. Investigated Accidents and Serious Incidents involving Air Sports Equipment

Between 2000 and 2019, the BFU investigated occurrences involving 148 air sports equipment. Of the 148 analysed air sports equipment, 101 (68.2%) were involved in a fatal accident, 24 (12.6%) in an accident with serious injuries, 5 (3.4%) in an occurrence with minor injuries and 18 (12.2%) without injuries. In two of the 148 air sports equipment involved in a fatal accident (mid-air collision), their pilots survived the accident severely injured or uninjured, respectively, whereas the other aircraft's occupants suffered fatal injuries.

In all investigated air sports equipment occurrences, a total of 144 persons suffered fatal injuries in 99 fatal accidents involving 101 air sports equipment, 44 persons severe and 8 minor injuries. In the time period considered, 138 occurrences were classified as accidents (93%) and 10 as serious incidents (7%).

The following graphs provide information the occurrence time, broken down by year (Fig. 16), month (Fig. 17), day (Fig. 18) and time of day (Fig. 19), as total numbers and for fatal accidents. As to the graph in Fig. 16, it must be emphasised that it shall not be misinterpreted to be an overview of the total number of accidents and serious incidents with air sports equipment, which occurred in the respective years. The graph only shows the occurrences the BFU investigated in this time period.

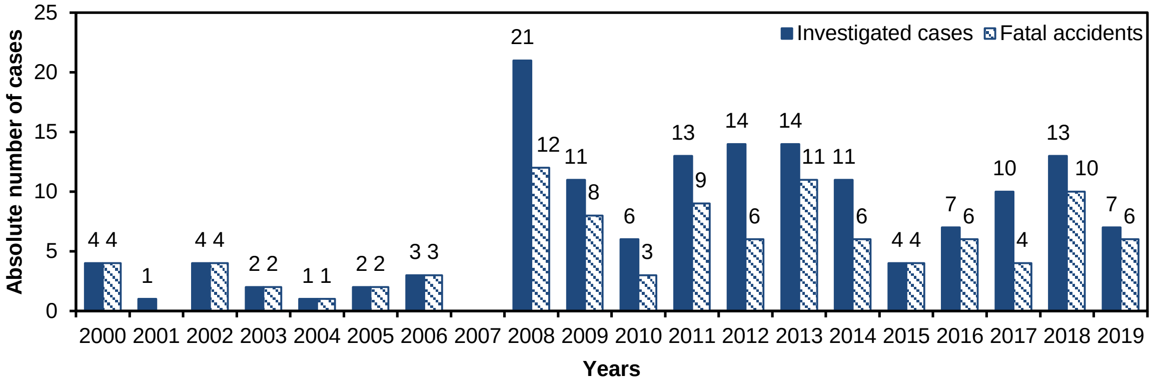

Fig. 16: Occurrences involving air sports equipment the BFU investigated, 2000-2019 Source: BFU

Fig. 17 illustrates that the months November until February had the lowest numbers of investigated occurrences involving air sports equipment, while August, September and May had the highest numbers.

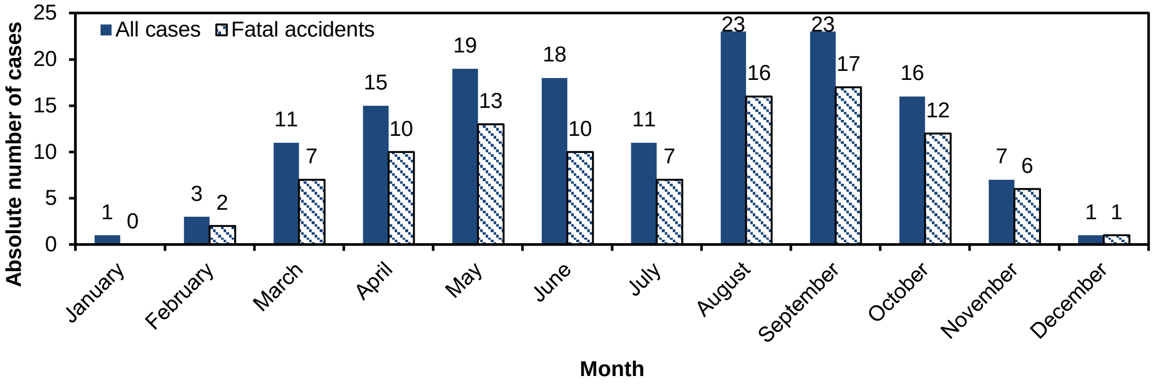

Fig. 17: Distribution of all investigated cases and fatal accidents by month Source: BFU

The distribution by days of the week (Fig. 18) shows that almost half of all investigated occurrences and fatal accidents occurred at the weekend (Saturday, Sunday).

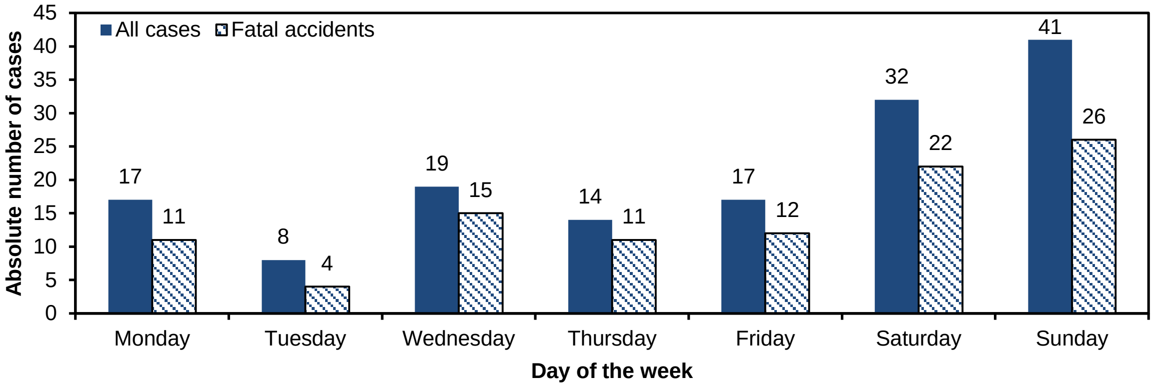

Fig. 18: Distribution of all investigated cases and fatal accidents by days of the week Source: BFU

The analysis determined that the total number of investigated occurrences and fatal accidents occurred during the second half of the day (Fig. 19).

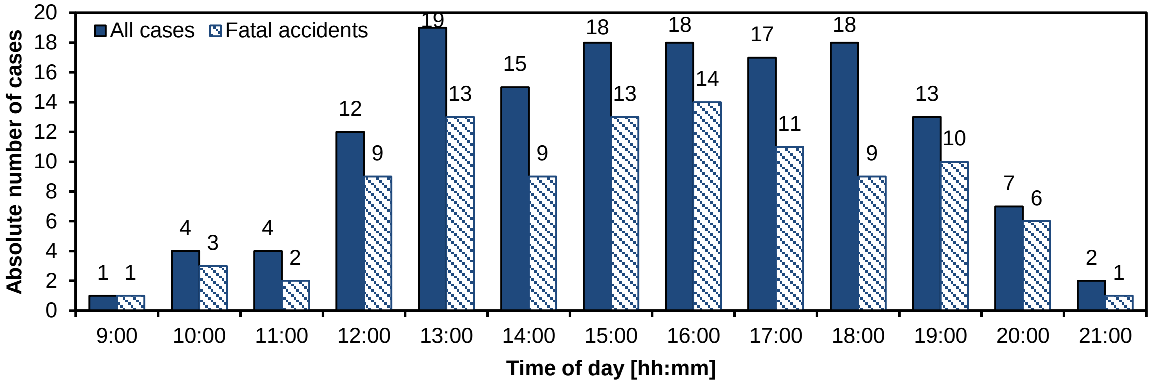

Fig. 19: Time of day at which the investigated occurrences happened (rounded up) Source: BFU

2.1 Operating Mode

Concerning the operating mode of the air sports equipment, the analysis (Fig. 20) showed that the vast majority (87%) of the investigated occurrences were private flights (86% fatal accidents). In 7% of the occurrences investigated by the BFU (7% fatal accidents), accidents or serious incidents occurred during training of air sports equipment pilots and in 6% (7% fatal accidents) during commercial operations.

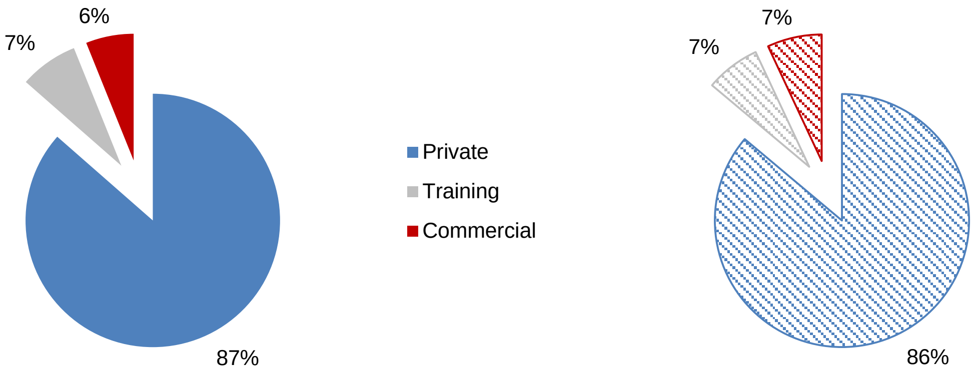

Fig. 20: Occurrences (left) and fatal accidents (right) involving air sports equipment by operating mode

Source: BFU

In spite of the number of commercially operated air sports equipment being low in the time period considered, the BFU addressed the following safety recommendation to the BMDV more than 10 years ago:

No 05/2011:

The Federal Ministry of Transport, Building and Urban Affairs (BMVBS) should provide aeronautical stipulations which only allow commercial passenger transport with air sports equipment if a high level of flight safety, comparable to commercial passenger transport, e.g. with aeroplanes, can be ensured.

2.2 Operating Phases

The investigated occurrences were analysed in regard to the operating phase of the air sports equipment. Using the data definition standard[9] of the ECCAIRS data base, each occurrence was assigned at least one operating phase. Depending on the case, several phases were distinguished, e.g.:

Example 1: During the landing phase, the aircraft touched down hard.

Example 2: The aircraft was in the initial climb phase when the cabin door opened. During the subsequent return to the airport a loss of control occurred in the final approach phase.

2.2.1 First Operating Phase

The following graph (Fig. 21) gives an overview of the number and percentage of the different operating phases in which the air sports equipment operated at the beginning of the occurrence. Depicted are the total number of occurrences as well as the fatal accidents.

As Fig. 21 shows, one occurrence happened during taxiing to the runway. Of the 37 occurrences during the take-off phase (25%, 21.8% fatal accidents), 28 occurred during initial climb and 9 during climb. The majority of occurrences, 45 in total (30.4%) and 30 (29.7%) fatal accidents, began during cruise flight. In addition to the pure cruise flight, this also included one occurrence each in descent, in holding flight and in the climb to cruising level. During the manoeuvring phase, a total of 30 cases (20.3%) and 25 (24.8%) fatal accidents began. Among them, 27 (18.2%) occurrences during low level flight. This operating phase of manoeuvring accounted for the second largest share of fatal accidents.

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[9] https://skybrary.aero/sites/default/files/bookshelf/1814.pdf

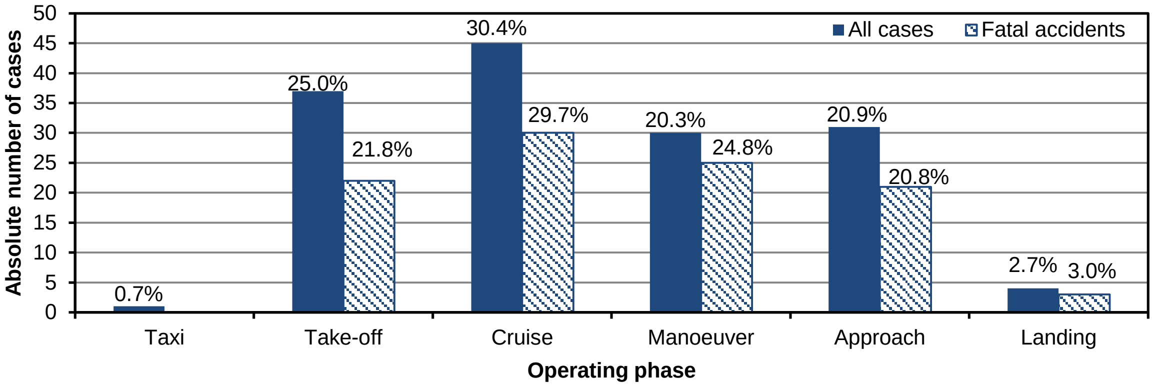

Fig. 21: Operating phase when the occurrence began (absolute in bars, percentages in numbers) Source: BFU

During approach, 31 cases, i.e. 20.9% of all occurrences (20.8% fatal accidents) occurred. Among them, 5 cases in the downwind leg, one in the base leg and 17 during final approach to airports with and without specified traffic patterns, as well as 7 cases during missed approach and go-around procedures.

Four occurrences began during landing (2.7% of all cases, 3% fatal accidents) including flare and touch-down as well as aborted landings with go-around after touchdown. The high percentage of occurrences during cruise flight and the low percentage of occurrences during landing compared with other accident analyses (e.g. EASA Aviation Safety Review 2021) are certainly due in part to the special nature of the notification obligations for air sports equipment as opposed to other aviation areas and the fact that the BFU mainly investigates occurrences involving air sports equipment with serious consequences.

2.2.2 Second Operating Phase

In 23 of 148 cases (16%), the occurrence was characterised by two operating phases. Of these cases, 22 were classified as accidents, one as serious incident. In this serious incident, a glider collided with a paraglider during thermal flight. The wing of the paraglider partially collapsed. During the subsequent emergency landing, the pilot remained uninjured.

In two accidents, engine failure occurred during initial climb. In one case followed by the final approach to an emergency landing without engine power and in the other the ultralight entered an uncontrolled flight attitude during climb. In another case, part of the engine cowling separated during initial climb, the pilot then attempted to turn back to the aerodrome of departure, and the ultralight entered an uncontrolled flight attitude. In two of four accidents, which started during cruise flight, engine failure occurred in this phase and during the subsequent approach to an emergency off-field landing the accident happened. In 12 accidents which began during approach or landing, a subsequent event occurred in the phase of initial climb during go-around.

2.3 Occurrence Categories

BFU assigns each occurrence to at least one occurrence category and enters it into the occurrence database together with an abundance of other data. ICAO specifies these more than 30 occurrence categories for worldwide consistent use and interpretability of the recorded data by all ICAO member states (Appendices). Depending on the case, more than one occurrence category might be assigned, e.g.:

> Example 1: During landing, the aircraft touched down hard (Abnormal Runway Contact, ARC)).
>
> Example 2: Due to a navigation error (Navigation Error (NAV)), the aircraft entered the control zone of an airport, afterwards an airprox with a departing aircraft (Airprox/TCAS Alert/Loss of Separation/Near Midair Collisions/Midair Collisions (MAC)) occurred.
>
> Example 3: An aircraft suffered an engine failure (System/Component Failure (Power Plant) (SCF-PP)), followed by a Loss of Control-Inflight (LOC-I), and after impact it caught fire (Fire/Smoke Post-Impact (F-POST)).

The analysis of all investigated accidents and serious incidents involving air sports equipment (Fig. 22, Abbreviations in Chapter 5. Appendices) shows that the occurrence category of uncontrolled flight attitudes (LOC-I) accounts for the largest share with a total of 98 cases (66.2%). This is followed by the occurrence categories post-impact fire (F-POST) with 36 cases (25%) and operation in low altitude (LALT) with 29 cases (19.6%).

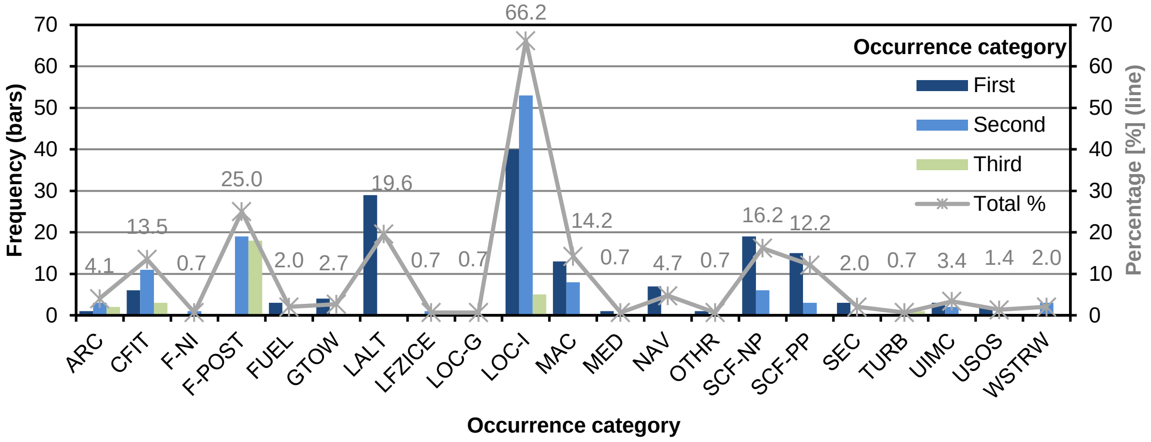

Fig. 22: Occurrence categories of investigated occurrences involving air sports equipment, 2000-2019

Source: BFU

Fig. 23 shows the occurrence categories in regard to fatal accidents. The percentage of uncontrolled flight attitudes (LOC-I) is 76 (75%) followed by 34 cases with F-POST (35%) and 26 cases of LATL (26%). Occurrences where the aircraft enters an uncontrolled flight attitude are most often fatal.

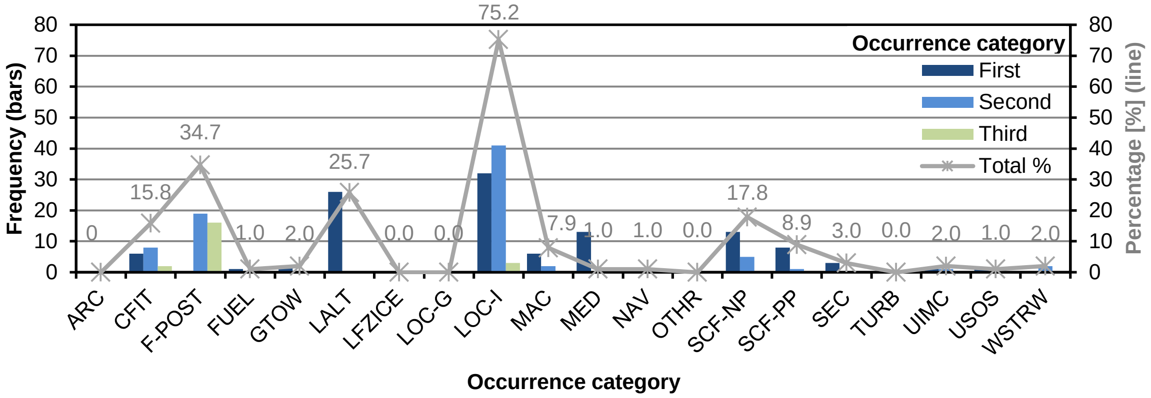

Fig. 23: Occurrence categories of investigated fatal accidents involving air sports equipment, 2000-2019

Source: BFU

Fig. 24 shows the most common combinations of the first and second occurrence category of the BFU investigated occurrences involving air sports equipment. The second occurrence category is colour-coded above the respective first, e.g.:

Example 1: In seven cases where first navigational problems (NAV) occurred, an airprox or a collision with another aircraft (MAC) followed.

Example 2: In 12 cases where first the engine failed, lost power or suffered other problems (SCF-PP), this was followed by flight into terrain (CFIT) in four cases and loss of control in flight (LOC-I) in eight cases.

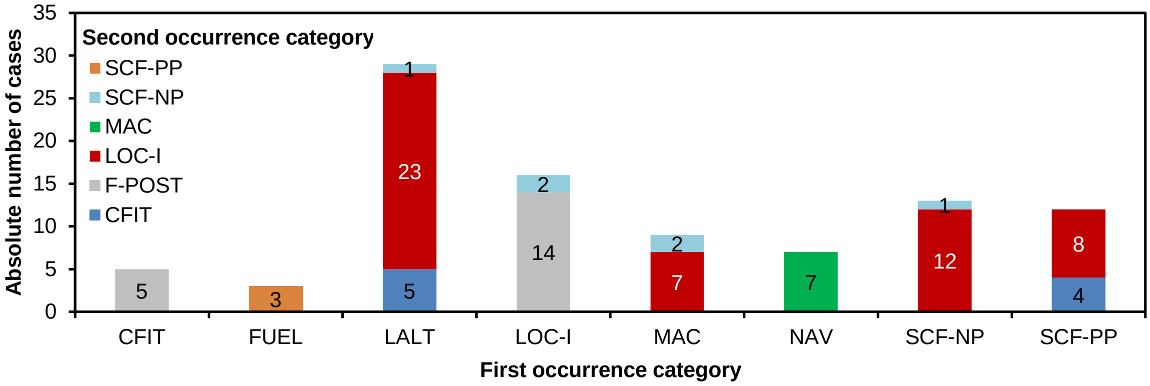

Fig. 24: Most common combinations of first and second occurrence category (colour-coded) of investigated occurrences involving air sports equipment, 2000-2019 Source: BFU

In 29 cases (20%) a third occurrence category was determined. In 18 (64%) of these cases, this was the occurrence category F-POST. Hereafter, the most common occurrence categories are examined more closely.

2.3.1 Loss of Control-Inflight

The occurrence category Loss of Control-Inflight (LOC-I) is the category with the highest number of fatal accidents in all of aviation (Fig. 25). During such occurrences the flight crew is not able to remain control of the aircraft with the result of unintentional extreme deviation from the planned flight path.

In all occurrences involving air sports equipment investigated by the BFU, the occurrence category LOC-I accounted for the largest share both overall and as the first occurrence category. In 40 of the 98 cases with LOC-I (41%) this was the first occurrence category. Of these 98 cases, 76 (78%) were fatal, 15 (15%) ended with serious, 3 (3%) with minor and 4 (4%) cases without injuries. A total of 107 persons suffered fatal, 31 serious and 4 minor injuries. These LOC-I cases involved different air sports equipment, from 7 gyrocopters, one weight-shift controlled ultralight, one light air sports equipment, one paraglider to 88 aerodynamically controlled ultralight.

Fig. 25: Photos of a fatal accident with loss of control (stall and spinning) after a steep turn in low altitude

Source: Surveillance camera airport

In at least half of all LOC-I cases, centre of gravity was within the permissible range, in 41% it could not be determined. The permissible centre of gravity was exceeded backward in 7% of the LOC-I cases; in 1% forward. Therefore, in 8% of all cases with loss of control, recovering from the uncontrolled flight attitude was made more difficult for the pilot due to the unfavourable centre of gravity position. In 14 cases where the air sports equipment entered an uncontrolled flight attitude, the aircraft caught fire after impact.

Considering only fatal accidents, the occurrence category uncontrolled flight attitude (LOC-I) had the largest percentage with 76 cases (as first occurrence category 32, as second 40 and as third 3 cases). In these 76 fatal accidents, 107 persons suffered fatal and 10 serious injuries.

2.3.2 Low Altitude Flight Operations

The occurrence category Low Altitude Operations (LALT) encompasses occurrences related to intentional flying close to the ground (except during take-off and landing).

This includes, for example, manoeuvring in low altitude around residential buildings or landmarks, the so-called “visitor’s turn”.

The Standardised European Rules of the Air (SERA) chapter SERA.5005 (f) stipulates minimum altitudes. These shall only be undershot during take-off and landing, if necessary, and by gliders, hang gliders and paragliders on condition of operation. Over cities, other densely populated areas and open-air gatherings, the minimum altitude is 300 m (1,000 ft) above the highest obstacle in a radius of 600 m, in all other cases 150 m (500 ft) above ground.

In the 29 cases where LALT was the first occurrence category, in 23 cases the air sports equipment entered an uncontrolled flight attitude (LOC-I), five times there was a subsequent collision with the ground or an obstacle (CFIT, Fig. 26), and in one case there was a system component failure (SCF-NP). In these cases, five gyrocopters, one weight-shift controlled ultralights, one light air sports equipment and 69 aerodynamically controlled ultralight were involved. Except for three cases, all others were fatal accidents. Forty persons suffered fatal injuries and nine serious injuries.

Fig. 26: An ultralight collided with a 20 kV power line in about 9 m hight, one pylon was broken off and another damaged (hanging cables in the background) Source: BFU

2.3.3 System/Component Failure or Malfunction

The occurrence category System/Component Failure or Malfunction (SCF) is divided into 2 subcategories based on whether the component or system is part of the engine, including propeller, gearbox, mounting parts and engine controls (System/Component Failure or Malfunction (Powerplant (SCF-PP)) or whether it is another component or system of the aircraft itself (System/Component Failure or Malfunction (Non-Powerplant) (SCF-NP)). Overall, there were 42 SCF- cases, of which 18 Powerplant-related (SCF-PP) and 24 Non-Powerplant-related (SCF-NP).

System/Component Failure or Malfunction (Powerplant)

In the total of 18 cases with SCF-PP, 12 persons suffered fatal, 13 serious and one minor injuries. These cases involved one light air sports equipment and 17 aerodynamically controlled ultralights. During 10 of the 18 accidents, the ultralight subsequently entered an uncontrolled flight attitude (LOC-I).

In 11 cases an engine failure occurred, in 5 loss of power. In one case a propeller blade fractured, in another the engine cowling opened, both with subsequent loss of control in-flight. In 6 of these 11 cases, the BFU determined maintenance deficits on the engine, propeller or fuel system. In 2 accidents, engine failure was related to insufficient fuel management of the pilot.

System/Component Failure or Malfunction (Non-Powerplant)

A total of 24 cases investigated by the BFU involved failure, rupture or loss of components (SCF-NP) of the air sports equipment. In the 24 SCF-NP cases, 24 persons suffered fatal injuries, 5 serious injuries and one minor injuries. In these cases, two gyrocopters, two weight-shift controlled ultralight and 21 aerodynamically controlled ultralights were involved.

In two cases, the component failure occurred after collision with another aircraft. In 13 cases, wing structure failure occurred (Fig. 27), in 5 cases the canopy or cabin door opened or was lost, twice the elevator or tail section fractured, twice the aileron was affected (once loss of the mass balance weight with subsequent wing structure failure, once of the aileron dampener), once cracks in the fuselage appeared and once the rotor impacted the cabin of the gyrocopter.

Fig. 27: Wing structure failure of an ultralight in-flight Source: Police, adaptation BFU

2.3.4 Airprox/(Near) Midair Collisions

The occurrence category Airprox/(Near) Midair Collisions (MAC) includes actual collisions and airproxes of aircraft. The German Plan for Aviation Safety named this occurrence category as one of the focal points of flight safety work in Germany. Nineteen of the investigated occurrences were classified as MAC. Ten of these occurrences were classified as serious incidents and 9 as accidents. Eleven persons suffered fatal and three serious injuries. The 19 occurrences involved 21 air sports equipment; two gyrocopters, one paraglider and 18 aerodynamically controlled ultralights. In addition to the two air sports equipment, other types of aircraft were also involved as conflicting traffic of these 19 MAC-occurrences, in 6 cases transport aircraft, once an airplane with a MTOM of 2-5.7 t, in four cases an aircraft with a MTOM of 2 t (one of them in airspace E, under IFR) and in six cases a glider (Fig. 28).

The six airproxes involving ultralight and transport aircraft occurred twice in airspace C and four times in airspace D (control zone) of four different airports. The closest distances between the involved aircraft were between 0.07 NM and 1 NM laterally and 0 ft and 600 ft vertically. In all six cases, navigation errors by the ultralight pilots and insufficient communication between the pilots and the air navigation service provider occurred. In one of the six airproxes, the air traffic control radar only showed a primary target of the ultralight (without altitude information) and this at a time when the closest distance had already occurred. In the other five cases the ultralights were equipped with a functioning transponder and were thus visible on the air traffic control radar and the Airborne Collision Avoidance System (ACAS) on board of the transport aircraft. In these five cases, ACAS generated a resolution advisory (RA) in the cockpit of the transport aircraft.

Fig. 28: Collision of a glider and an ultrallight during the approach to land Source: Witness

Airproxes of air sports equipment and significantly larger and heavier aircraft, e.g. transport aircraft, not only pose the risk of collision but also of it entering an uncontrolled flight attitude or experiencing structural overload due to flying into their wake turbulence.

In seven of the nine accidents, the air sports equipment was not equipped with a collision warning system. In one of these cases, one ultralight was equipped with such a device but not the second.

In 2017, the BFU published the Study *Concerning Airproxes and Collisions of Aircraft in German Air Space 2010-2015*[10]. On the one hand, this safety study illustrates the limitations of the principle See and Avoid and on the other, it emphasises the use of transponder and collision warning systems.

2.4 Type of Air Sports Equipment

As Fig. 29 shows, 130 (88%) of the occurrences involving air sports equipment the BFU investigated concerned aerodynamically controlled ultralight and 12 (8%) gyrocopter. The other six cases (4% other) included parachutes, paraglider, light air sports equipment and weight-shift controlled ultralight.

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[10] www.bfu-web.de/DE/Publikationen/Statistiken/Tabellen-Studien/Tab2017/Studie_AIRPROX_2017.pdf

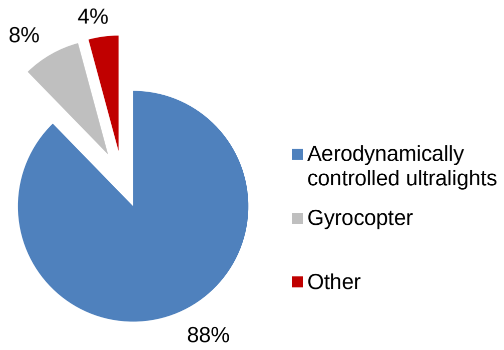

Fig. 29: Occurrences involving air sports equipment the BFU investigated, according to type Source: BFU

2.5 Considerations on Mass and Centre of Gravity of the investigated Ultralights and Gyrocopters

2.5.1 Number of Occupants

A total of 225 occupants were on board of the 148 air sports equipment. In 71 (48%) of the air sports equipment, the pilot was the sole occupant, while in 77 (52 %) two persons were on board. In the time period concerned, the BFU investigated 72 accidents involving aerodynamically controlled ultralight, where two persons were on board. These accidents were examined in more detail in regard to their mass and centre of gravity as follows.

2.5.2 Design Requirements

These 72 ultralight aircraft included 28 different manufacturers and 39 different types. Among other things, the different design requirements stipulated the MTOM, minimum flying speed V_{S0}, payload (persons or fuel) and the determination of the empty weight (Tab. 1).

Tab. 1: Certification specifications on mass and other operating limitations in the design requirements for ultralights in Germany by comparison Source: Design Requirements

Design Requirement	BFU 84	BFU 10/95*	LTF-UL 2003	LTF-UL 2019
UL Type	Ultralight total	Ultralight total	Aerodynamically controlled ultralights	Aerodynamically controlled ultralights
Coming into effect	October 1984	October 1995	January 2003	January 2019
MTOM	SECTION A §2 Single seat 115 kg empty mass plus (additional) equipment Twin seat 150 kg empty mass plus (additional) equipment BPRS: no information	Chapter A 2. 450 kg BPRS: no information	LTF-UL 1 Single seat 300 kg Twin seat 450 kg (+ overall max. 22.5 kg BPRS)	LTF-UL 1 600 kg (650 kg including floats) Including BPRS
Minimum speed V_{S0}	SECTION A §2 ≤ 45 km/h with 110 kg Payload ≤ 50 km/h at maximum Payload	Chapter A 2. ≤ 65 km/h	LTF-UL 1 ≤ 65 km/h	LTF-UL 1 ≤ 83 km/h
Occupants Mass	SECTION B §7 90 kg (single seat) 180 kg (twin seat)	Chapter B I. 3. (2) min. 70 kg (single seat) min. 140 kg (twin seat)	LTF-UL 25 min. 100 kg (single seat) min. 170 kg (twin seat)	LTF-UL 25 min. 110 kg (single seat) min. 200 kg (twin seat)
Payload Fuel	Full tank	Fuel for at least 30 min cruise flight at max. continuous engine output	Fuel for at least 30 min cruise flight at max. continuous engine output	Fuel for at least 60 min cruise flight at max. continuous engine output
Empty mass by weighing	SECTION B §8 […] without other easily removable payload [...]	Chapter B I. 4. […] without other easily removable payload [...]	LTF-UL 29 [...] Including BPRS […] without other easily removable payload [...]	LTF-UL 29 [...] Including BPRS […] without other payload [...]

*Note:
1) Occupants mass should not be estimated to be less than 90 kg
2) Maximum fuel and possibly additional payload should be considered (consider mass increase due to change in equipment, repairs).

The analysis based on certification showed that of the 72 accident ultralights, 3 had been certified in accordance with Certification Specification BfU84, 16 with BfU95 and 53 with LTF-UL2003 (Fig. 30, left). As Fig. 30 (right) shows, a larger number of ultralights had originally been certified in accordance with BfU84 and later supplementary with BfU95 and LTF-UL2003, respectively. None of the ultralights investigated had been certified in accordance with LTF-UL2019, which came into force in 2019.

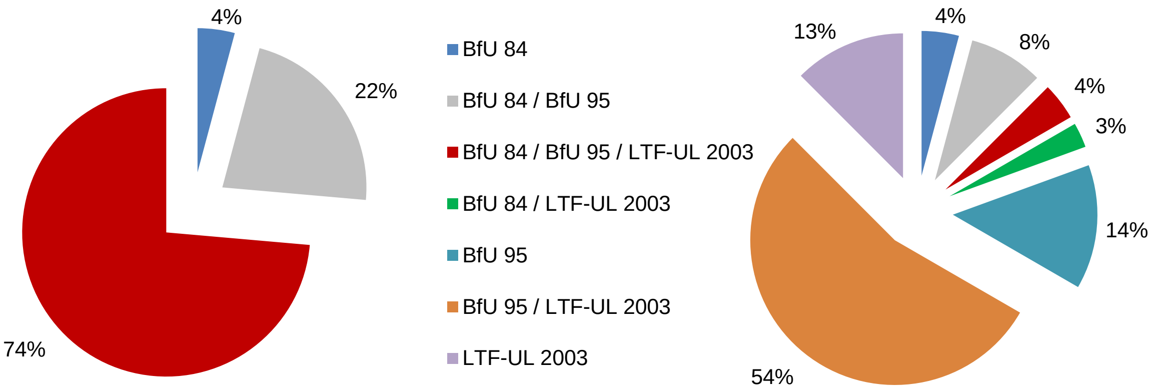

Fig. 30: Certification standards of the 72 accident ultralights with two occupants Source: BFU

Of the 72 aerodynamically controlled ultralight with two occupants involved in accidents, three certified in accordance with BfU84 had a MTOM of 350 kg, 360 kg and 400 kg, respectively. Of the 16 ultralights certified in accordance with BfU95, the MTOM of 14 ultralights was 450 kg and of two 472.5 kg. Of the 53 ultralights certified in accordance with LTF-UL2003, the two ultralights had a MTOM of 450 kg and 51 of 472.5 kg. None of the 72 investigated accidents during the period in question involved an ultralight with a MTOM of 600 kg.

2.5.3 Payload of Ultralights

The difference between the maximum take-off mass and the empty mass is the maximum permissible payload of an aircraft, which in turn consists of the occupants' mass including clothing, fuel, baggage and additional equipment (e.g. tablet, hand-held GPS, life vest, etc.). The depicted example of a pilot's clothing and equipment (Fig. 31) illustrates that several kilograms per person can add up very quickly, which has to be included in the mass calculation in addition to the body mass. The following three subchapters include findings of the 72 accidents in regard to fuel mass in relation to flight duration and consumption, permissible payload considering their maximum permissible MTOM and their centre of gravity. Detailed information regarding the determined body weight of the occupants can be found in Chapters 2.6.1 and 2.6.4.

Fig. 31: Example of an ultralight pilot's clothing and equipment – total mass about 10 kg Source: BFU

2.5.3.1 Flight Duration until the Occurrence

The BFU analysed the investigated occurrences involving air sports equipment in regard to flight duration until the occurrence. Fig. 32 shows the results for the occurrences in total and for aerodynamically controlled ultralights with two persons on board. The data show that in both cases, for about 70% of all occurrences, flight duration until the occurrence was at most 30 min. On average, the flight duration until the occurrence was about 28 min (SD = 37 min, median[11] 14 min) and 30 min (SD = 40 min, median 15 min), respectively. Based on the design requirements and the insights gained through the investigations in regard to flight duration until the occurrence and the mass of the equipment on board, typical fuel consumptions were further considered with regard to the payload.

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[11] Value separating the higher half from the lower half of a data sample. Compared to the mean/average, it is not skewed by a small proportion of extremely large or small values, and thus provides a better representation of a "typical" value.

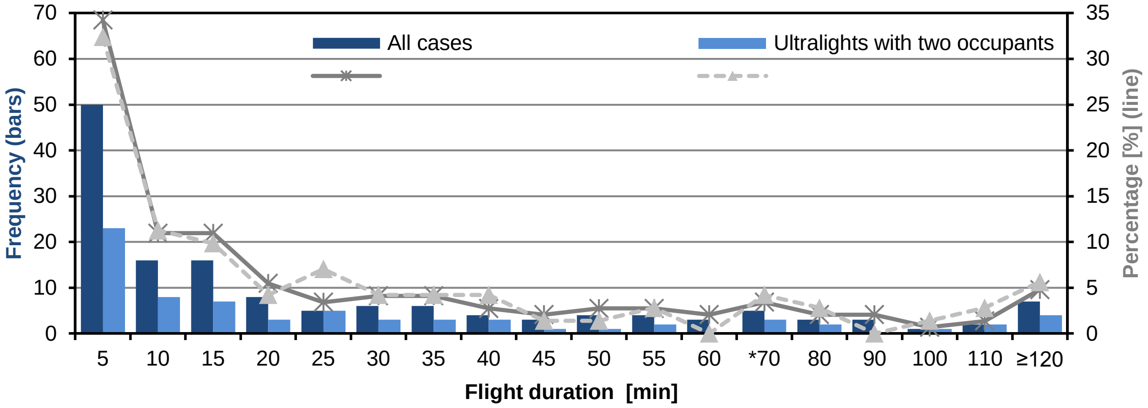

Fig. 32: Flight duration until the occurrence Source: BFU

2.5.3.2 Fuel

The fuel requirement or consumption of motorised air sports equipment differ significantly depending on the aircraft and/or engine type. Under maximum continuous engine power, the fuel consumption of a Rotax 912 UL (80 HP) is 22.5 l per hour, of a Rotax 912 ULS (100 HP) about 25 l per hour. At a specific weight of 0.75 kg per litre MoGas this equals about 16.88 kg and 18.75 kg per hour, respectively. According to design requirement LTF-UL2003, which was relevant for three fourth of the BFU-investigated ultralights, a fuel quantity of at least 30 min under maximum continuous engine power was required for mass calculation. For the engines mentioned above this would mean at least 8.4 to 9.4 kg of fuel.

Fig. 33 shows an overview of 67 of the 72 investigated ultralight accidents with two occupants, for which the BFU had information about the empty weight of the aircraft. The BFU either gained this information during the investigation by weighing the ultralight or from the available weighing report. The MTOM was part of the type certificate data sheet. Fig. 33 shows the number of ultralights in relation to the permissible payload[12]. In this regard, 75% of offered less than the permissible payload of 175 kg (Fig. 33, outside of the green area). Only 17 (25%) of the 67 ultralights allowed for a permissible payload of 175 kg or more (Fig. 33, within the green area). The minimum payload was 114 kg, the average 163 kg and the maximum 204 kg. In the opinion of the BFU, this low permissible payload from the start limits the possibilities

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[12] Difference between MTOM and empty weight of the respective ultralight.

for ultralight operators and pilots to operate their ultralight within the operating limits, when two occupants were to be on board.

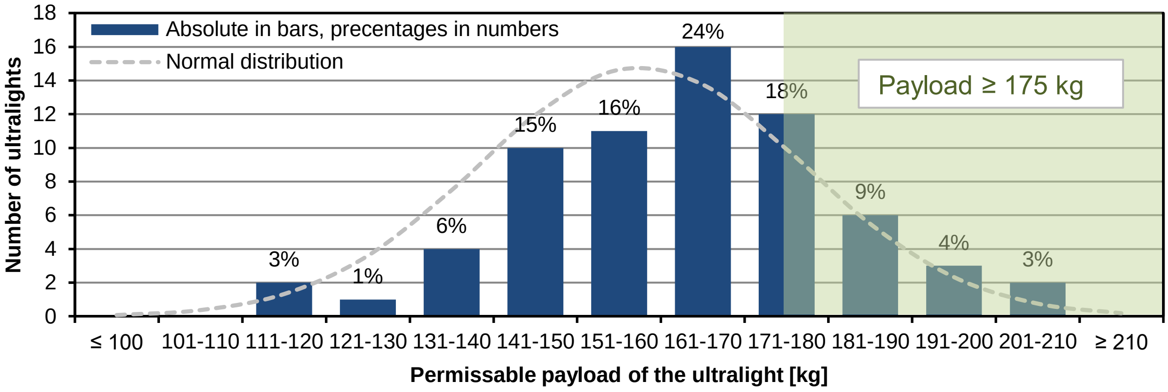

Fig. 33: Permissible payload of the 67 investigated ultralight with two occupants and know empty weight

Source: BFU

2.5.3.3 Mass and Centre of Gravity

In 50 (75%) of the 67 accidents described in Fig. 33 the aerodynamically controlled ultralight was overloaded. The permissible payload of the 50 overloaded ultralights was on average 156 kg (SD = 17 kg), the minimum 114 kg and the maximum 183 kg. This analysis shows that 88% of all overloaded ultralights offered less than the payload of 175 kg the design requirements stipulated. In seven of these cases, the ultralight was already overloaded without fuel.

In 50 cases where the ultralight was overloaded, the pilots had an average body weight of 90 kg (SD = 16 kg). The range here was from 62 kg to 150 kg. The second occupant had an average body weight of 78 kg (SD = 14 kg); the lowest value was 20 kg (a child) and the maximum 110 kg. Based on these average weights of two occupants, the sum is 168 kg, which is just 7 kg below the permissible payload of the 175 kg as per design requirements and neither includes fuel nor baggage.

In 9 of the 50 (18%) accidents with overloaded ultralight, the investigation found evidence that the centre of gravity was outside the permissible range. Of these, eight exceeded the rear centre of gravity and one the front.

2.5.4 In-flight Break-up

In the scope of this safety study, the term in-flight break-up means an accident where the structure of a wing or horizontal stabiliser of an aircraft failed, followed by or as a result of an uncontrolled flight attitude. Thus, in-flight break-up is part of the occurrence category SCF-NP but without cabin door loss, or similar. Of the 16 in-flight break-ups, 14 were aerodynamically controlled ultralights and two weight-shift controlled ultralights of 13 different manufacturers. Nine of these ultralights (56%) were overloaded (Fig. 34) with an aircraft mass of 10 to 81 kg above the MTOM. In several of these accidents neither the amount of fuel on board nor the weight of the occupants could be determined so that total mass was unknown and overload might have been even greater.

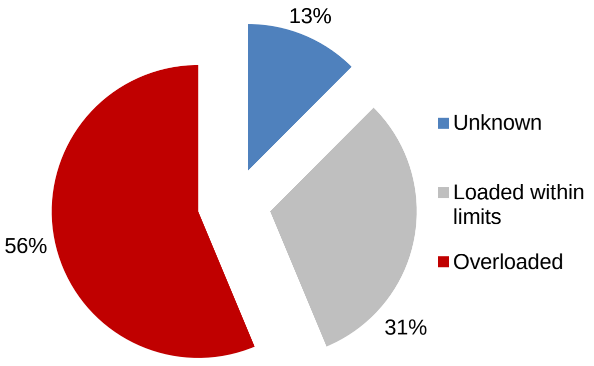

Fig. 34: Overload in cases of in-flight break-up Source: BFU

The BFU determined constructive deficits in 6 of the 16 in-flight break-ups and manufacturing deficits in one case. Pre-existing damage on the aircraft was found in four cases. The aircraft's V_{NE} was exceeded in two cases and in another two the ultralight entered an uncontrolled flight attitude followed by wing failure.

2.6 Occupants of the Investigated Aircraft

2.6.1 Pilots

The analysis showed that all pilots were male, except for one. Their age was between 18 and 79 years (average 53, SD = 12 years). As Fig. 35 shows, slightly more than a third of the pilots was 50 years old or less (37%), another third between 50 and 60 years (33%) and almost a last third 60 and above (30%).

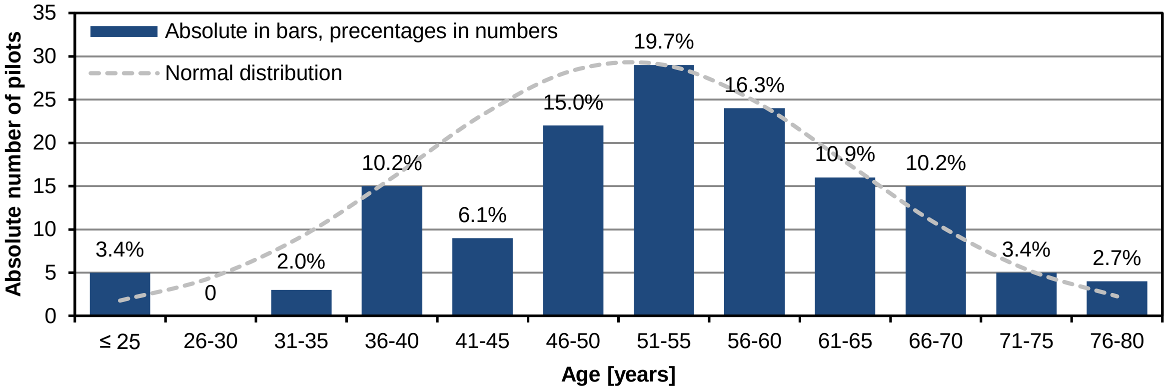

Fig. 35: Pilot age distribution over occurrences with air sports equipment Source: BFU

The body weight of the pilots (Fig. 36) was between 62 and 150 kg. This resulted in an average of 85.6 kg (SD = 13.1 kg).

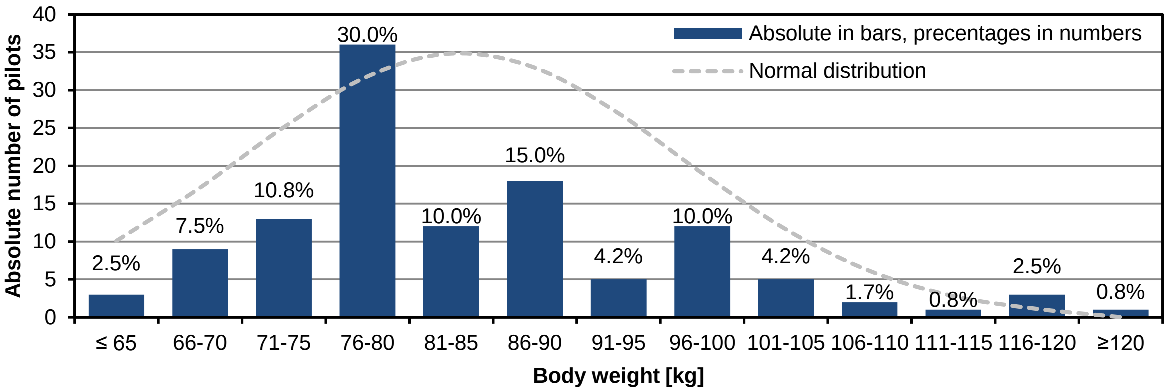

Fig. 36: Pilot body weight distribution over occurrences with air sports equipment Source: BFU

2.6.2 Licences and Ratings of Pilots

Of the air sports equipment pilots 63 (43%) did not hold any other licence besides the one for aerodynamically controlled ultralights (Fig. 37). Six of the pilots (4%) also held a commercial/air transport pilot license (CPL/ATPL), 54 (36%) a private pilot license (PPL) and four (3%) a licence for weight-shift controlled ultralights or hang gliders.

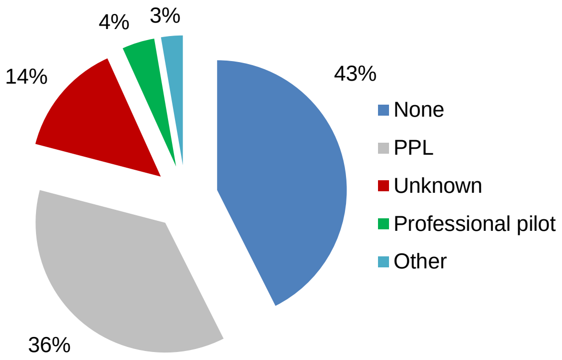

Fig. 37: Further licences of the pilots Source: BFU

In two cases, where a passenger was on board, the pilots did not have the required passenger transport rating. Between 2000 and 2019, there were four cases where the pilots did not have a valid medical certificate.

2.6.3 Flying Experience of the Pilots

The pilots of all 118 investigated occurrences, where total flying experience was known, had an average total flying experience of 808 h (SD = 1,773 h); minimum was 23 h (student pilot) and maximum 12,575 h. Due to the fact that the average flying experience was distorted by a few very experienced pilots, the median was calculated as well. The median for total flying experience was 282 h, which means that 50% of all pilots had a total flying experience of less than 282 h. In more than a quarter (27%) of the 118 cases the pilots even had a total flying experience of less than 100 h. Fig. 38 provides an overview of how the known flying experience was distributed overall and for the air sports equipment class. The average flying experience in the air sports equipment class comprised 295 h (SD = 415 h, median 100 h). About half of all 118 pilots had a class flying experience of 100 h or less. The average flying experience on type was 84 h (SD = 118 h); the median 45 h.

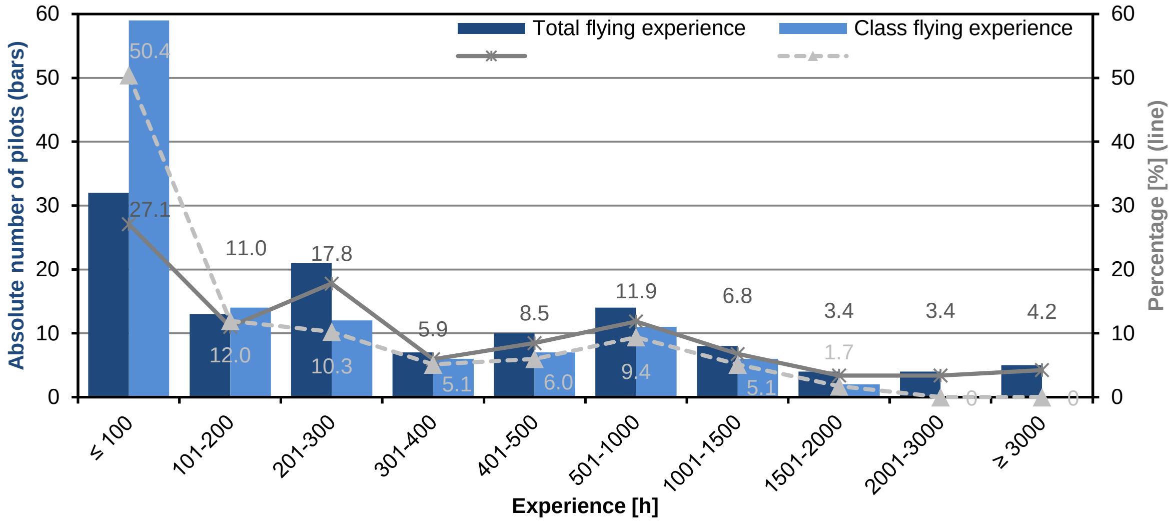

Fig. 38: Total and air sports equipment class flying experience of the 118 licence holders with known experience

Source: BFU

The total flying experience of pilots, who only held an ultralight licence and no other licence, was known for 54 of the 60 pilots. It was between 30 and 2,000 h with an average of 331 h (SD = 452 h) and a median of 129 h. Almost half of these pilots (44%) had a flying experience on ultralight of 100 h or less, whereas 70% had 300 h or less. Average type experience was 96 h (SD = 123 h, median 54 h).

2.6.4 Other Occupants

With more than half of the occurrences, two persons were on board of the air sports equipment, meaning in 77 (52%) cases of the 148 occurrences and in 55 (55%) of the 101 fatal accidents. In 21 cases (27%), the second person on board verifiably had flying experience, in 56 cases (73%) not.

Female persons were on board in 20 cases; in 53 male persons. In two cases there was no information regarding the sex of the persons, in another two cases there were children on board. The body weight of the second person on board was between 49 kg and 92 kg (average 67 kg) for females and between 67 kg and 110 kg (average 83 kg) for males.

According to the micro census 2017 of the Statistical Bundesamt (DESTATIS), mean body mass of a German female adult is 69 kg and of a male 85 kg.

2.7 Medical and Pathological Information, Suicide

Of the 99 fatal accidents, the BFU was provided with post-mortem reports of 71 pilots and of 35 other occupants. In seven cases (9%) the post-mortem reports offered relevant medical or toxicological findings or evidence of pre-existing conditions of the pilots. Polytrauma[13] was identified as cause of death for 71 of the fatally injured pilots and for 34 of the other occupants. Hence, of a total of 144 fatally injured persons 73% died due to polytrauma. In two cases, where pilots survived, accident-relevant pre-existing conditions were determined. The BFU investigation of fatal accidents involving air sports equipment found clear indications of suicide in three cases (3%). These three cases are part of the Human Factors analysis concerning Preconditions for Unsafe Acts (Condition of Operator: Mental State).

2.8 Meteorological Conditions

As part of the investigation of accidents and serious incidents, the BFU routinely gathers data on the weather conditions prevailing during and/or prior to an occurrence. If necessary, the BFU obtains an official aviation weather report or expert opinion from the Deutsche Wetterdienst (German meteorological service provider). Very good visual meteorological conditions with horizontal visibilities of more than 10 km prevailed in 131 (89%) of the BFU investigated occurrences involving air sports equipment in the relevant time period. For most of the investigated occurrences, the weather conditions/phenomena, such as cloud base, wind direction/speed, as well as temperatures presented no distinct characteristics, only in 48 cases (32%). These included, cross or tailwind during take-off or landing, possible glare in relation to the flight or gaze direction (Fig. 39), strong gusts or icing conditions. In 30 of these cases, the BFU assessed the distinct weather conditions as causal or contributory factors; e.g. spatial disorientation due to poor visibility or stall during strong gusts. Only a total of seven (5%) of these occurrences were associated with the air sports equipment entering instrument meteorological conditions (IMC).

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[13] Multiple injuries, each of which individually or in combination had led to the person's death.

Fig. 39: Example of visibility impairment due to sun glare Source: Witness

2.9 Ballistic Parachute Recovery System

For operation in Germany, ultralights, hang gliders and paraglider must be equipped with a ballistic parachute recovery system (BPRS). The Regulation on Operation of Aircraft (LuftBO) §3 (2) stipulates:

> *Air sports equipment shall only be operated with a certified ballistic parachute recovery system. Pilots of air sports equipment and passengers must wear a suitable head protection to prevent injuries due to accidents or other incidents. The representative may allow exceptions. […]*

In ultralights the BPRS is firmly connected to the aircraft, so that in the event of deployment, occupants and aircraft are brought to the ground together at a maximum descent rate of about 7.5 m/s, according to the BPRS design requirements. The deployment altitude hence is at least 80 m. BPRS of seven different manufacturers were installed in the ultralights the BFU investigated. One manufacturer’s BPRS was installed in 50, another in 29 cases. No information concerning the manufacturer and/or type of BPRS were available to the BFU in 18 cases. Four more manufacturers were present ten times, eight times, twice and once.

In the 20-year time period considered, a BPRS was installed in 123 of the 138 accidents involving ultralights investigated by the BFU. In 14 cases no BPRS was installed as these were ultralights with foreign registration certificates or an aircraft type, where such a device was not mandatory in Germany (e.g. gyrocopter, ultralight helicopter). Of the 123 air sports equipment with installed BPRS involved in accidents, in 51 (41%) cases it was activated, in 69 (56%) not. In three cases activation could not be clarified because the wreckage was lost at sea, for example. In the DULV files, nine additional cases were found, in which the BPRS of the ultralight had apparently been activated successfully. However, the BFU did not include these cases in this analysis since not enough detailed information was available.

2.9.1 Activation of the Ballistic Parachute Recovery System

Out of the 51 investigated cases with BPRS activation, the pilots activated the BPRS in 26 (51%) cases (Fig. 40). In 10 accidents (20%), the impact of the ultralight activated the system and once (2%) in-flight structural damage activated it. Fire occurred at or after impact in 14 cases (28%) with activated BPRS. Due to the degree of destruction by fire, it was not possible to determine with reasonable certainty whether the BPRS had been activated by fire, impact forces or the pilot. Fig. 40 depicts these cases under “unclear activation”. In three cases, the safety pin was still securing the activation handle of the recovery system (Fig. 41).

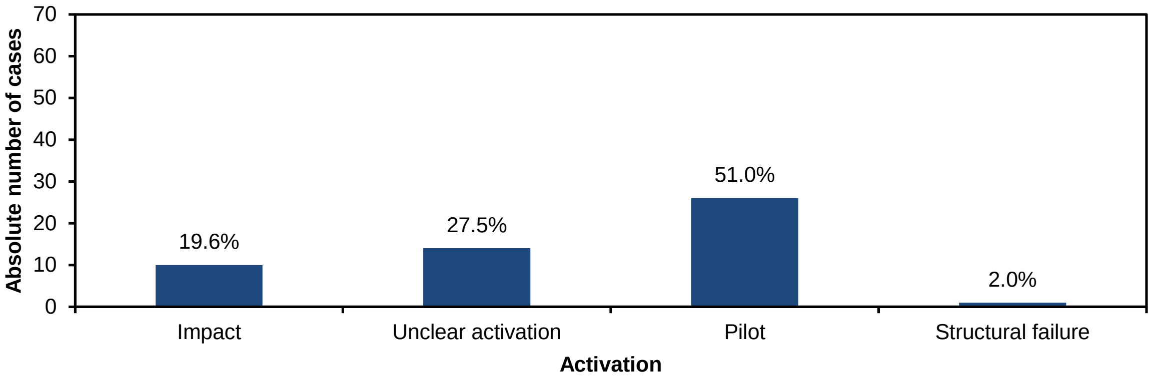

Fig. 40: Activation of the BPRS (absolute numbers in bars, percentages above) Source: BFU

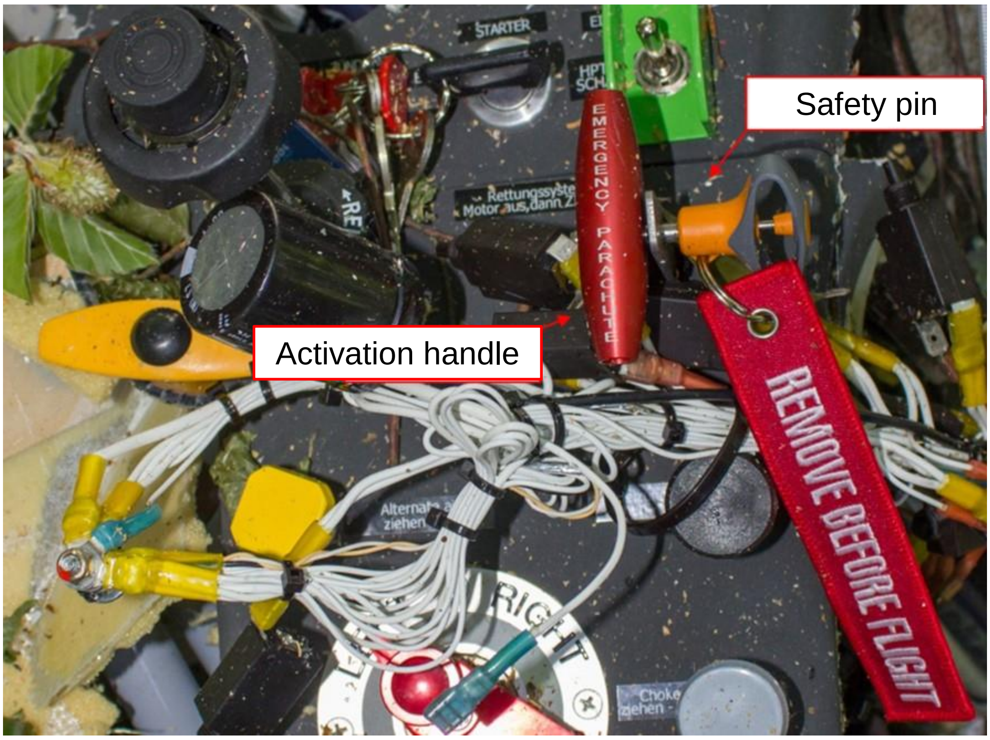

Fig. 41: Safety pin still securing the activation handle of the BPRS in an accident ultralight Source: BFU

2.9.2 Circumstances of Ballistic Parachute Recovery System Activation

The BFU examined 26 occurrences more closely in terms of the exact circumstances in which the pilots activated the BPRS. Initially, these occurrences were differentiated according to the most frequent occurrence categories which prompted the pilots to activate the BPRS and eventually according to the operating phase at activation.

Pilots activated the BPRS in 18 cases after the ultralight had entered an **uncontrolled flight attitude (LOC-I)**. These 18 LOC-I cases occurred four times after a mid-air collision (MAC), in 3 cases each during low altitude operations (LALT) or in the course of a component failure (SCF-NP) and once due to engine problems (SCF-PP). In three more cases weather-related events caused the loss of control (wind shear twice, entering IMC once).

In eight cases, pilots activated the BPRS after a **system component had failed (SCF-NP)**. In six of these eight cases, wing structure failure was the reason; once each the elevator fractured or the fuselage developed cracks.

In four cases, pilots activated the BPRS after **colliding with another aircraft (MAC)**. The accident depicted in Fig. 42 shows that a BPRS was even able to carry both aircraft wedged into each other to the ground decelerated so that the two ultralight occupants and the pilot of the glider only suffered minor injuries.

Fig. 42: BPRS activation after collision of an ultralight and a glider on final approach Source: Police

The consideration of the operating phase during which pilots activated the BPRS showed that in 12 cases the ultralight was in cruise flight, six cases occurred during manoeuvring, five during approach and three during take-off.

2.9.3 Complications during Ballistic Parachute Recovery System Activation

Of the 26 pilot-induced BPRS activations, complications occurred in almost two thirds of the cases (17, i.e. 65%) during the deployment or inflation of the parachute. In half of the cases (13 of the 26), the ultralight was too low to the ground for the parachute to fully open (Fig. 43). In eight cases (31%), the investigation revealed that the deploying BPRS came in contact with ultralight components or determined installation deficits so that the parachute could not fully open (Fig. 44).

Fig. 43: Activation of the BPRS in low altitude Source: Witness

Fig. 44: Incomplete opening of a BPRS Source: BFU

A total of 28 persons suffered fatal injuries, 7 serious and 4 minor injuries during these 26 accidents with pilot-induced BPRS activation. Four persons remained uninjured. However, this seemingly high injury rate during pilot-induced BPRS activation, must be viewed against the background that occurrences with less severe consequences did not have to be reported to or were not investigated by the BFU. Therefore, these numbers do not provide a complete picture of all pilot-induced BPRS activations.

2.10 Hazards at the Accident Site

Aircraft accident sites are generally hazardous locations. Fires or ignition of fuel, sharp edges, pathogenic agents and substances, wreckage parts falling from tree tops, and damaged structures (e.g. buildings) are just a few examples of such hazards at accident sites.

2.10.1 Hazards due to Non-Activated Ballistic Parachute Recovery Systems

During 67 accidents where the air sports equipment was severely damaged or destroyed, the installed BPRS was not activated. This posed an increased hazard for the first responders at the accident site, which resulted from the fact that the ground impact deformed the aircraft’s airframe. This could cause the activation cable of the BPRS to be pre-tensioned and the rocket to be about to activate. Over the years, it has been noted that BPRS manufacturers have developed and published training material, and government agencies and associations have supported and conducted training for fire brigades and police. On the one hand, it must be said that part of this personnel is better informed about the hazards resulting from the BPRS installed in ultralights and other aircraft and is trained in regard to appropriate risk mitigation measures. On the other hand, there is still demand for corresponding training to achieve a comprehensive and standardized understanding of the hazards and the handling requirements of BPRS.

2.10.2 Hazards due to Burnt Carbon Fibre

In the time period considered, 38 (28%) of the 138 accidents involving air sports equipment resulted in a fire of the aircraft. In 10 (26 %) of these cases with fire, parts of the aircraft consisted of Carbon Fibre Reinforced Plastics (CFRP), which forms very sharp fracture edges when broken. When exposed to fire for approximately 20 min or longer at temperatures of more than 650 °C, very small fibres are formed, which can be whirled up into the air and – since they are respirable due to their small size (3 µm x 5 µm) – can be inhaled (Fig. 45). When coming in contact with CFRP fibres after fire exposure, additional protective gear and measures are required for the fire brigade, first responders and accident investigators (Fig. 46).

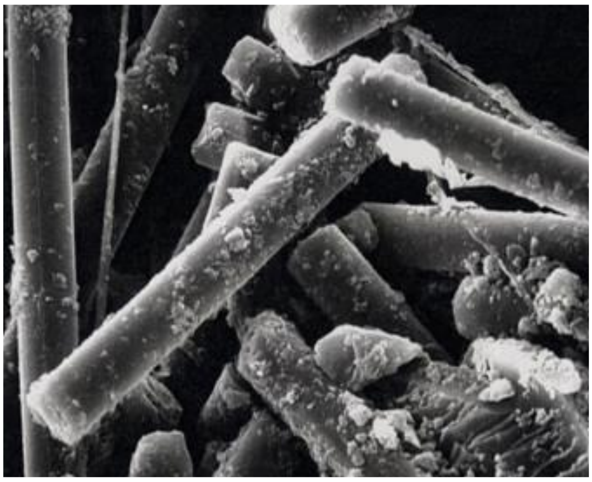

Fig. 45: Burnt carbon fibre debris (microscopic picture) Source: ICAO[14]

Fig. 46: Protective gear at the accident site with burnt CFRP components Source: BFU

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[14] ICAO (2008). Hazards at Aircraft Accident Sites (Cir 315).

2.11 Human Factors Assessment[15][16][17][18]

Humans are both a source of safety risks and an integral part of detecting and preventing them. Human Factors (HF) deal with the application of what we know about people, their capabilities, characteristics and limitations as well as the design of the work equipment they use, the environment in which they act and the tasks they perform. Human factors should always be considered for safe operations irrespective of whether flight or cabin crews, airport personnel or any other aviation personnel is concerned.

The relation between task demand and the human physical and mental capabilities to cope with the demands placed on them determines the success and how safe, effective and efficient a system functions (Task-Capability-Interface-Model, Fuller, 2000[19]). As long as human capabilities exceed task demands, the situation remains under control. How much task difficulty people accept at any given time, e.g. what weather conditions to fly in, also depends on motivational aspects such as the subjective risk assessment of the situation. Conversely, if the task demand is higher than the human capabilities to handle a situation safely or when the task demand is generally high, as in suddenly critical situations, human errors become more likely.

To cope with tasks, people continuously gather, filter and process information from their environment to develop and weigh up suitable actions, to select and execute the best action accordingly. A mental model of the current situation is developed (“Theory of Situation Awareness” by Endsley, 1995[20]). However, there are always filters or limiting factors so that people are susceptible to errors and undesirable behaviour: physical (noise, glaring sunlight and visual obstructions), perceptive (perceptual thresholds/illusions, spatial disorientation) and cognitive (inappropriate expectations, experience or motives, attention distribution, mental overload; Rumar, 1985[21]).

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[15] Wiegmann, D. A., & Shappell, S. A. (2003). A human error approach to aviation accident analysis: The human factors analysis and classification system. Burlington, VT: Ashgate Publishing, Ltd.

[16] Shappell, S. A., & Wiegmann, D. A. (2000). The Human Factors Analysis and Classification System – HFACS. Final Report (DOT/FAA/AM-00/7). https://skybrary.aero/sites/default/files/bookshelf/1481.pdf

[17] https://skybrary.aero/articles/human-factors-analysis-and-classification-system-hfacs

[18] ICAO (2021). Manual on Human Performance (HP) for Regulators (Doc 10151). https://www.icao.int/safety/OPS/OPS-Section/Pages/HP.aspx

[19] Fuller, R. (2000). The task-capability interface model of the driving process. *Recherche Transports Sécurité, 66*, 47-59.

[20] Endsley, M. R. (1995). Towards a Theory of Situation Awareness in Dynamic Systems. *Human Factors, 37*(1), 32-64.

[21] Rumar, K. (1985). The role of perceptual and cognitive filters in observed behavior. In: L. Evans & R. C. Sching (Eds.), *Human Behavior and Traffic Safety* (pp. 151-170). New York, USA: Plenum Press.

In addition, human skills vary greatly both intra-individually and inter-individually. No one can always achieve the same level of performance and it also depends on the time of day. For example, human performance may deteriorate due to illness, boredom, stress or fatigue. Despite all limitations, humans are able to master new situations and adapt their capabilities to meet the demands of a complex and dynamic environment, if they are well supported. Adaptability is a human quality that enables the global aviation system to function.

Humans interpret situations differently and perform task in ways that seem meaningful to them. In hindsight, it is often easy to see how decisions and actions resulted in undesired outcomes and how these could have been prevented, but at the time the decision was made or the action taken, it seemed appropriate to that person. The unintended consequences were unknown and possibly not predictable. Human actions must therefore be considered in context and understood from the perspective of the individual at the time of action. Humans, as part of a system, are constantly interacting with others, technologies and the environment. Although everyone is different and can be unpredictable in certain ways, all humans have the ability to understand goals, assess risks and compromise. This allows humans to find overall acceptable solutions or ways of accomplishing tasks in such a complex working environment as aviation. ("Risk Homeostasis Theory" by Wilde, 1982[22]; "Zero-Risk-Theory" by Näätänen & Summala, 1974[23]; "Comfort Zone Model" by Summala, 2007[24]).

2.11.1 Human Factors Analysis and Classification System

The Human Factors Analysis and Classification System (HFACS, Wiegmann & Shappell, 2003) was originally developed for the US Air Force for the investigation and analysis of human factors in aviation. It is based on the "Swiss cheese" model (Reason, 1990[25]) and offers different multidimensional perspectives of flight-safety-related HF. The HFACS framework enables accident investigators to identify failures on all levels of a system, which have contributed to a (near) accident or negatively influenced safety on a case-by-case basis. A retrospective assessment of multiple occurrences over the

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[22] Wilde, G. J. S. (1982). The theory of risk homeostasis: Implications for safety and health. *Risk Analysis, 2*, 209-225.

[23] Näätänen, R. & Summala, H. (1974). A model for the role of motivational factors in drivers' decision-making. Accident Analysis and Prevention, 6(3-4), 243-261.

[24] Summala, H. (2007). Towards understanding motivational and emotional factors in driver behaviour: Comfort through satisficing. In P. Cacciabue (Ed.), *Modelling driver behaviour in automotive environments: Critical issues in driver interactions with intelligent transport systems* (pp. 189-207). London: Springer-Verlag.

[25] Reason, J. (1990). Human Error. Cambridge, UK: Cambridge University Press.

past years can reveal recurring trends and problems concerning human performance and system deficiencies. As a result, weaknesses can be identified and targeted data-based actions can be taken to reduce accident and injury rates.

Additionally, the HFACS framework provides a structure to systematically review and analyse accident and safety data. It assesses the human contributions to an occurrence including deeper, underlying factors for safety-critical behaviour. The model can be used to categorise and quantify occurrences and contributory human factors, both on a case-by-case basis and to develop better accident databases to improve the overall quality and accessibility to human factors accident data. For instance, common trends within an organisation can thus be derived from comparing the psychological origins of active, unsafe acts or the latent conditions which enabled these actions within the organisation. Identifying these common trends helps to determine and prioritise areas for intervention within an organisation. Hence, the HFACS framework is a practical tool to support the investigation process, to perform targeted trainings and implement preventive measures.

The HFACS model (Fig. 47) is divided into four levels, whereby the lowest level of Unsafe Acts is considered first when analysing a case. If an active error and/or violation is uncovered and categorised accordingly, then the next higher level of Preconditions of Unsafe Acts is analysed to penetrate the underlying system of Unsafe Supervision or even Organisational Influences at the top level deeper with each step.

Although there is not always a flight operations organisation in place in General Aviation, particularly with air sports equipment, the investigation of cases and the data analysis found a number of relevant factors in this area as well. For example, there were joint ownerships, clubs, air sports associations and supervisory authorities which more or less directly enabled or, in some case, even aided Unsafe Acts.

The use of HFACS as higher-level data analysis tool, complementary to the findings in investigation reports, was a relatively new method for the BFU. The BFU aimed at gaining additional insight into relevant human factors. The decision to use the HFACS model was also made because other organisations such as FAA (Federal Aviation Administration) and EASA are using it and it therefore provides the advantage of better comparability of results. The BFU intends to use HFACS also for future studies concerning accidents involving other General Aviation aircraft types.

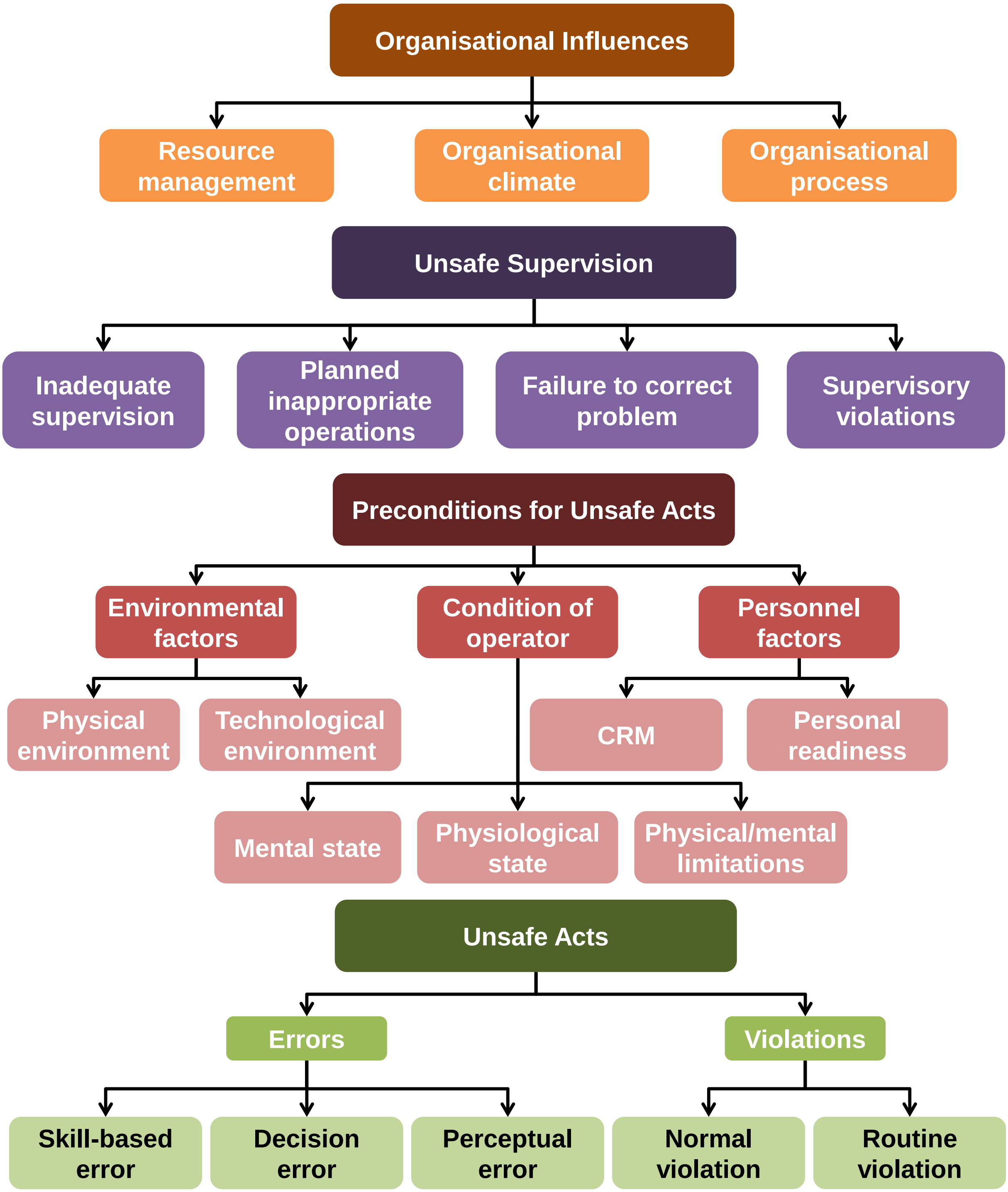

Fig. 47: Overview HFACS framework Source: Wiegmann & Shappell (2003), adaptation BFU

Analysing the accidents and serious incidents involving air sports equipment in the scope of this safety study with regard to human factors, the BFU found at least one Unsafe Act in 93% of all cases (92% for fatal accidents) and at least one Precondition for these Unsafe Acts in 80% of all cases and fatal accidents (Fig. 48). This illustrates the great importance of human factors in accidents and serious incidents and also shows that more in-depth analyses are necessary to understand why these Unsafe Acts occur and which factors promote them. Understanding preconditions and other influencing factors in turn enables the development of future accident prevention measures. Unsafe Supervision was found in almost a quarter of all cases (22%) and a fifth of fatal accidents (20%, Fig. 48). In 14% of all cases and fatal accidents, the Unsafe Acts could even be retraced to the highest level of the Organisational Influences which shows a strong causal linkage of individual influences, which were obviously of systemic nature.

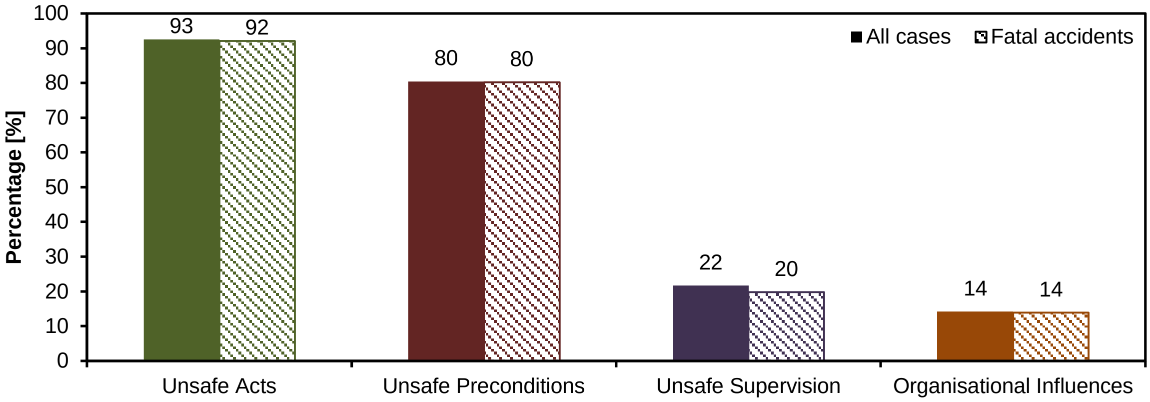

Fig. 48: Percentage of cases with at least one HFACS model factor assigned Source: BFU

2.11.2 HFACS Level 1: Unsafe Acts[26]

The level of Unsafe Acts is divided into two categories – errors and violations – and these are in turn subdivided in sub-categories (Fig. 49). Errors are unintentional behaviours, while violations represent a wilful disregard of rules and regulations.

Errors

- **Skill-based error:** Occurs without much thought while performing routine and highly trained actions, often due to forgetfulness, inattention, or individual flying technique (e.g., attention distribution, omitted checklist items, bad habits)

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[26] Adapted from https://skybrary.aero/articles/human-factors-analysis-and-classification-system-hfacs

- **Decision error:** Occurs when the behaviour or the acts proceed as intended but the chosen plan proves to be inadequate to reach the desired final state (e.g., exceeding capabilities, rule-based errors, inappropriate procedures)
- **Perceptual error:** Occurs when a pilot's sensory input is impaired and a decision is made based on erroneous information

Violations

- **Normal violation:** An individual case and is neither typical for the pilot nor regularly condoned by the responsible supervisory authority
- **Routine violation:** A pilot commits on a regular basis which is tolerated by the responsible supervisory authority

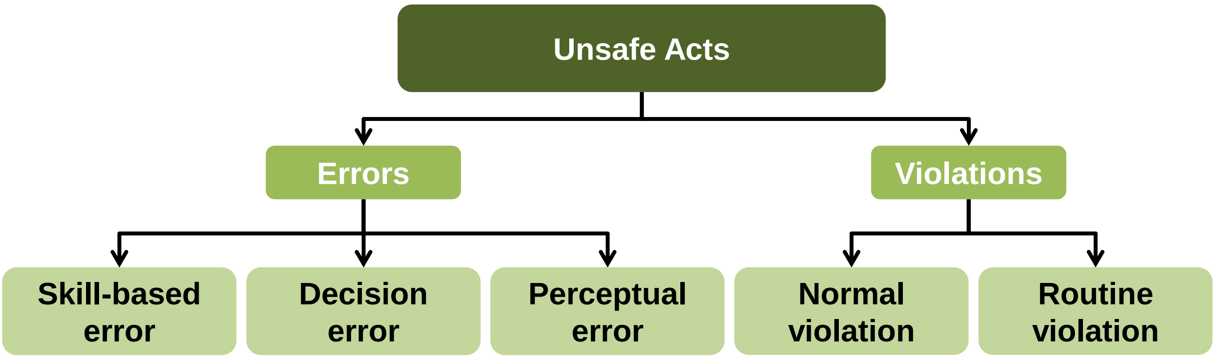

Fig. 49: Classification of Unsafe Acts

Source: HFACS, adaptation BFU

Cases with Unsafe Acts

The data analysis revealed that only in 11 (7%) of the 148 cases (8 (8%) of the fatal accidents) no Unsafe Acts existed. Hence, in 137 (92%) of all cases (93 (92%) fatal accidents) at least one Unsafe Act was found. In 81% of all cases (120 cases, 81 (80%) fatal accidents) more than one Unsafe Act occurred, and in 72% of all cases (106 cases, 70 (69%) fatal accidents) even more than two Unsafe Acts per occurrence were found; in one case up to ten different Unsafe Acts of various types. This illustrates that safety-critical situations are most often a combination of factors and there is rarely the one error/violation or causal factor.

All Unsafe Acts

The analysis of all 148 cases determined a total of 465 Unsafe Acts (330 errors, 135 violations). In the 101 data records examined for the 99 fatal accidents, there were

305 Unsafe Acts (209 errors, 96 violations). Considering all recorded Unsafe Acts (including multiple occurrences of an Unsafe Acts category per case, Fig. 50, Tab. 2), skill-based errors were found in about half of the Unsafe Acts in both all cases and fatal accidents (a total of: 220, fatal accidents: 151, Fig. 50 and Tab. 2). In second place, accounting for almost one fifth of all Unsafe Acts relative to the total number of cases and of all fatal accidents, were normal violations (a total of: 87, fatal accidents: 151), followed by decision errors (total: 66 (14%), fatal accidents: 37 (12%)), routine violations (total: 48 (10%), fatal accidents: 35 (11%)) and finally perceptual errors (total: 44 (10%), fatal accidents: 21 (7%), Fig. 50, Tab. 2).

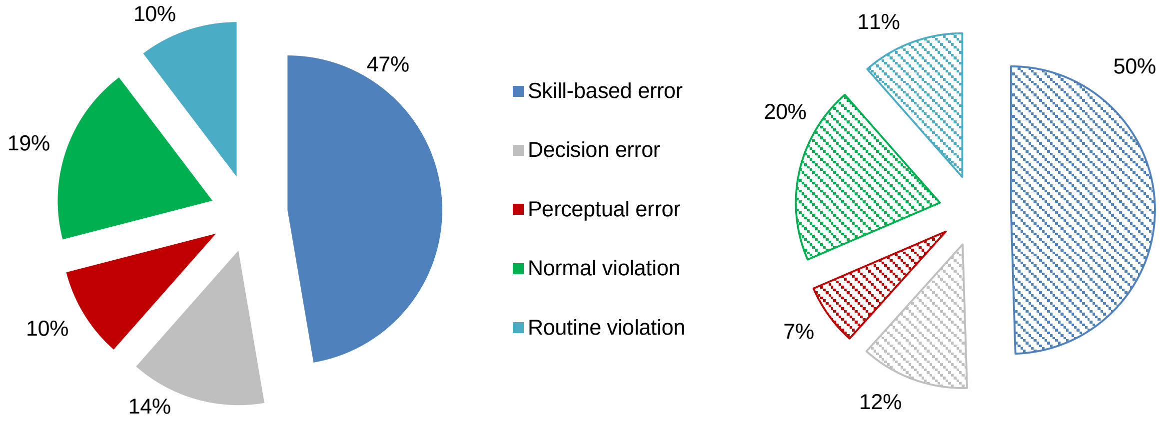

Fig. 50: Percentage distribution of all Unsafe Acts among sub-categories for all cases (left) and fatal accidents (right) Source: BFU

2.11.2.1 Errors

Cases with Errors

The data analysis revealed that only in 18 (12%) of the 148 cases or in 14 (14%) of the 101 fatal accidents there were no detectable errors. Hence, in 130 (88%) of all cases (87 (86%), fatal accidents), at least one Unsafe Act of the pilot was found. In 74% of all cases (109 cases, 73 (72%) fatal accidents), more than one error, and in 44% of all cases (65 cases, 39 (39%) fatal accidents) even more than two errors per occurrence were found; in three cases, up to six different errors were determined. As Fig. 51 shows, three quarters of both all cases and fatal accidents involved at least one skill-based error (111 of 148 cases and 74 of 101 fatal accidents), in about one third at least one decision error (49 of 148 cases and 30 of 101 fatal accidents) and in a quarter of all cases and in 16% of fatal accidents at least one perceptual error was found.

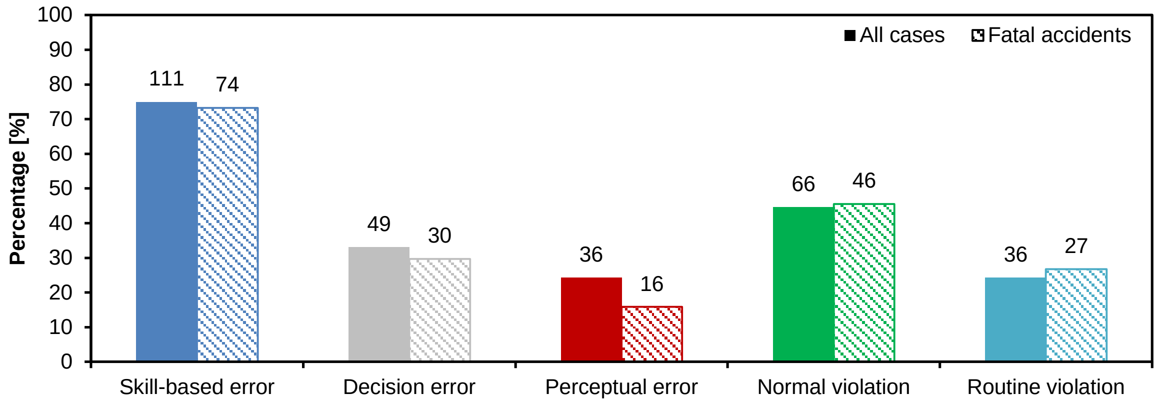

Fig. 51: All occurrences and fatal accidents with at least one Unsafe Act (percentages in bars, absolute number of cases as numeric values above) Source: BFU

All Errors

As Tab. 2 shows, the most common skill-based errors across all cases and fatal accidents were aircraft control errors and stalls, which usually occurred together, especially if the pilot could not regain control of the aircraft after the stall. Together, these two errors accounted for two thirds of all skill-based errors, followed by “See and Avoid” problems, poor flying technique/airmanship and breakdown in visual scan. Exceeded (pilot) ability, insufficient pre-flight preparation or an inappropriate selection of flight path were the most common decision errors. Visual perception problems, followed by misjudging distance, altitude, clearance and speed, and misjudging weather conditions as well as spatial disorientation/vertigo were by far the most common perceptual errors (Tab. 2).

Tab. 2: Overview over all errors Source: BFU

Errors	All cases:	330	Fatal cases:	207
	Number	**Percentage [%]**	**Number**	**Percentage [%]**
Skill-based error	**220**	**66.7**	**149**	**72.0**
Stall/spin	67	30.5	60	39.7
Control aircraft	71	32.3	57	38.3
Problems during “See and Avoid”	20	7.9	6	4.0
Poor flying technique/airmanship	14	6.4	5	3.3
Breakdown in visual scan (of instruments)	11	5.0	5	3.3
Omitted checklist item	10	4.5	5	3.3
Omitted step in procedure	9	4.1	4	2.6
Other	18	9.4	7	5.5
Decision error	**66**	**20.0**	**37**	**17.9**
Exceeded (pilot) ability	18	27.3	12	32.4
Insufficient pre-flight preparation	13	19.7	7	18.9
Selection of flight path	12	18.2	7	18.9
Inappropriate manoeuvre or procedure	9	13.6	6	16.2
Other	14	21.2	5	13.5
Perceptual error	**44**	**13.3**	**21**	**10.1**
Visual/aural perception	22	50.0	11	52.4
Misjudging distance, altitude, clearance, airspeed	11	25.0	5	23.8
Misjudging weather conditions	6	13.6	3	14.3
Spatial disorientation/vertigo	5	11.4	2	9.5

2.11.2.2 Violations

As mentioned above, a violation is a wilful disregard of rules and regulations, which the HFACS model divides into normal and regular/routine violations. In the scope of this safety study, the BFU assessed violations only as regular if the occurrence investigation revealed clear evidence of their regularity. All other violations were considered as exceptional (normal violation).

Cases with Violations

In almost two thirds (89 cases) of the 148 examined data records (60%) at least one violation was found. As Fig. 51 shows, in 66 of these cases at least one violation occurred without provable regularity, but in 36 of these cases (24% in total, 40% of all violations) the investigation revealed clear proof that at least one routine violation was present, sometimes even in addition to the normal violations already determined. Only in 59 cases (40%) and in 35 fatal accidents (35%), there were no violations of any kind.

With the fatal accidents, the portion of cases with violations was slightly higher. Of the 101 fatal accident data records analysed, 66 cases (65%) had at least one violation. In 46 of the 66 fatal accidents with violations (46% fatal accidents, 70% of all violations), there was at least one normal violation without provable regularity, while in 27 of the 66 fatal accidents (27% fatal accidents, 41% of all violations) at least one routine violation occurred (Fig. 51). In 24% of all cases (35 cases, 25 (25%) fatal accidents) more than one violation, and in 6% of all cases (9 cases, 5 (5%) fatal accidents) even more than two violations per occurrence were found; in two cases, up to four different violations.

All Violations

As Tab. 3 shows, normal violations without provable regularity most often involved exceeded aircraft limits (especially overload), hazardous flight manoeuvres (low altitude) and disregard of known procedures. The routine violations were mostly exceeded aircraft limits, violation of orders, regulations or SOPs, and operation of an aircraft with known deficiencies.

Tab. 3: Overview over all violations

Source: BFU

Violations	**All cases:**	**135**	**Fatal cases:**	**96**
	Number	**Percentage [%]**	**Number**	**Percentage [%]**
Normal violation	**87**	**64.4**	**61**	**63.5**
Exceeded aircraft limits	43	49.4	30	49.2
Hazardous flight manoeuvres (low altitude)	18	20.7	15	24.6
Disregard of known procedures	8	9.2	2	3,3
Accepted unnecessary hazard	6	6.9	6	9.8
Other	12	13.8	8	13.1
Routine violation	**48**	**35.6**	**35**	**36.5**
Exceeded aircraft limits	12	25.0	12	34.3
Violation of orders, regulations, SOPs	12	25.0	7	20.0
Operation of an aircraft with known deficiencies	9	18.8	4	11.4
Hazardous manoeuvres (low altitude)	6	12.5	5	14.3
Other	9	18.8	7	20.0

2.11.3 HFACS Level 2: Preconditions for Unsafe Acts[27]

Preconditions for Unsafe Acts are divided into three categories with further sub-categories which may influence the practices, conditions and actions of individuals and may result in human errors or safety-critical situations (Fig. 52).

Environmental Factors

- **Physical environment:** Both the direct operational setting (e.g. weather, altitude, terrain) and the ambient environment (e.g. heat, vibration, lighting, toxins)
- **Technological environment:** A variety of design and automation aspects including the design of equipment and controls, display and interface characteristics, checklist layouts, task factors and automation

Condition of Operator

- **Mental state:** Mental conditions which affect performance (e.g. stress, mental fatigue, motivation, attitude or situational awareness)
- **Physiological state:** Medical or physiological conditions which affect performance (e.g. physical fatigue, medical illness, hypoxia)
- **Physical/mental limitations:** Lack of physical or mental capabilities to cope with a situation and this affects performance (e.g. visual limitations, insufficient reaction time)

Personnel Factors

- **Crew Resource Management (CRM):** Communication, coordination, planning and teamwork issues (e.g. with crew members, guests, other pilots, air traffic controllers)
- **Personal readiness:** Off-duty activities, required to perform optimally on the job (e.g. adherence to crew rest requirements, alcohol restrictions and other off-duty mandates)

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[27] Adapted from https://skybrary.aero/articles/human-factors-analysis-and-classification-system-hfacs

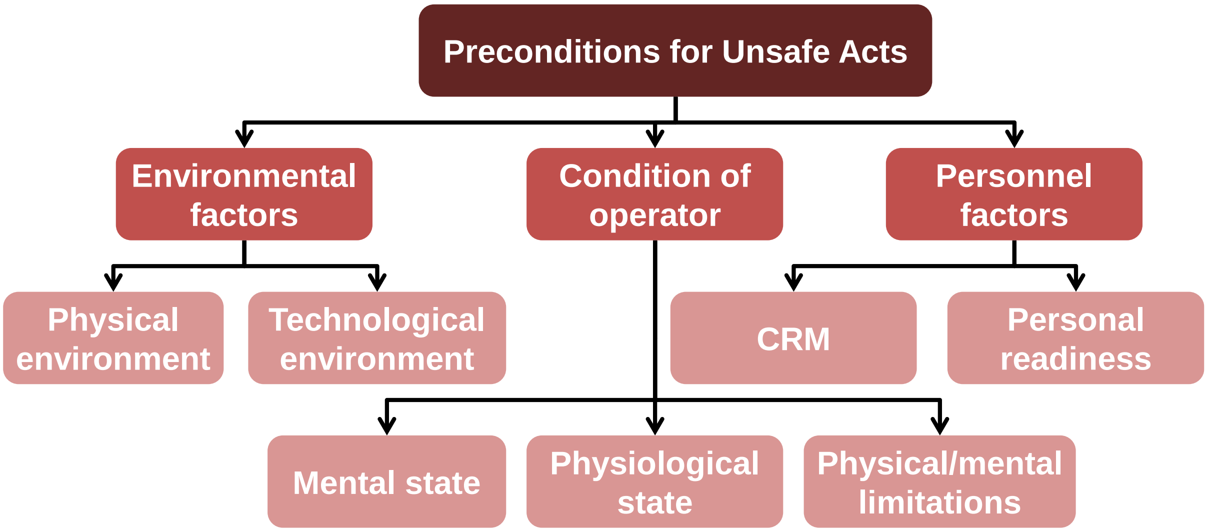

Fig. 52 Classification of Preconditions for Unsafe Acts Source: HFACS, adaptation BFU

Cases with Preconditions for Unsafe Acts

The data analysis showed that no Preconditions for Unsafe Acts were present in only 29 (20%) of the 148 cases (20 (20%) of the 101 fatal accidents). In contrast, in 119 (80%) cases (81 (80%) fatal accidents) at least one and in 85 (57%) cases (55 (55%) fatal accidents) at least two Preconditions for Unsafe Acts were determined; in 43 (29%) cases (27 (27%) fatal accidents) as many as three to six Preconditions for Unsafe Acts per case. This illustrates that not only active errors or violations should be considered but an investigation should go much deeper. Such preconditions pose a risk for further errors or violations.

As Fig. 53 shows, in more than half of both all cases and fatal accidents, at least one Precondition for Unsafe Acts in the area of the pilot’s mental state was present (83 of 148 cases and 57 of 101 fatal accidents). In about one third each, at least one factor of the physical environment (49 cases and 31 fatal accidents) or of the personal readiness (44 cases and 29 fatal accidents) contributed. In almost one fifth of all cases and fatal accidents, a technological environmental factor was found as precondition (26 cases and 18 fatal accidents).

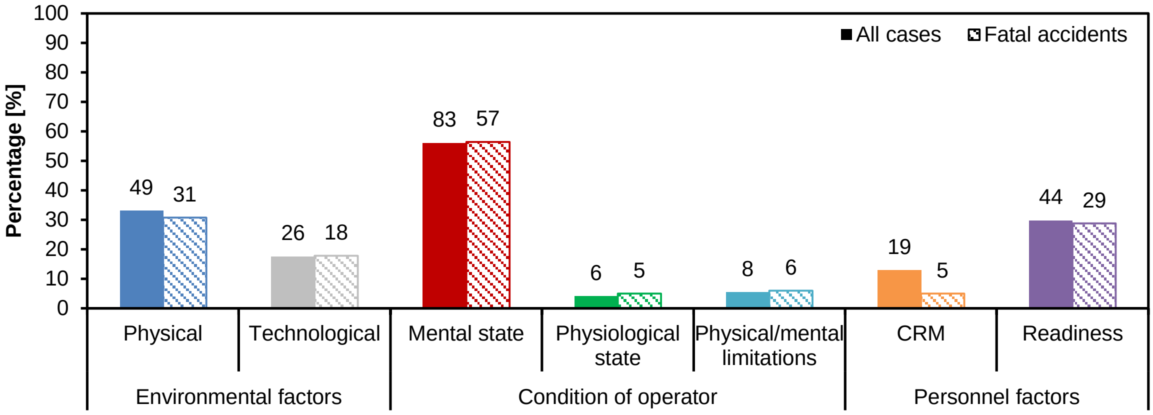

Fig. 53: All occurrences and fatal accidents with at least one Precondition for Unsafe Acts (percentage in bars, absolute number of cases as numeric values above) Source: BFU

All Preconditions for Unsafe Acts

In total, 281 Preconditions for Unsafe Acts were identified in the 148 cases. In the 101 data records examined for the 99 fatal accidents, there were 176 Preconditions for Unsafe Acts (Tab. 4). Considering the sum of all Preconditions for Unsafe Acts (including multiple occurrences of one precondition category per case), it shows that 111 (40%) of the preconditions were related to the pilot’s mental state, 55 (20%) to the physical environment and 48 (17%) to personal readiness (Fig. 54, left).

For fatal accidents, the pilot’s mental state also leads the Preconditions for Unsafe Acts with 72 cases (41%), followed by the physical environment with 36 cases (21%) and personal readiness with 32 cases (18%, Fig. 54, right). This shows that in both all cases and fatal accidents, the condition of the operator takes up the largest share of all Preconditions for Unsafe Acts, accounting for nearly half. Environmental factors follow with about one third each and personnel factors with about one quarter (Fig. 54, Tab. 4).

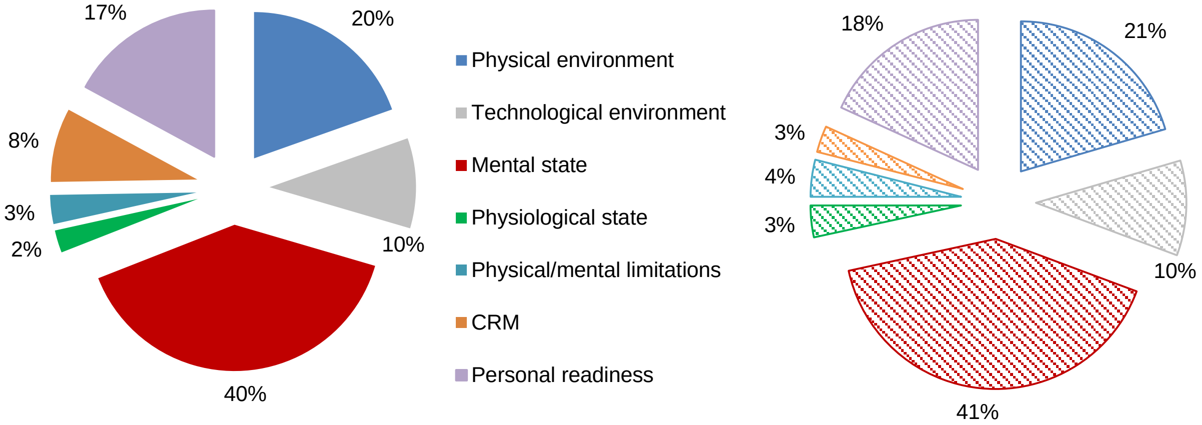

Fig. 54: Percentage of the sub-categories of the Preconditions for Unsafe Acts over all occurrences (left) and fatal accidents (right) Source: BFU

As Tab. 4 on the Preconditions for Unsafe Acts shows, the physical environmental Preconditions for Unsafe Acts were mostly weather, altitude and terrain. As technological environmental Preconditions for Unsafe Acts, mostly maintenance and the design of equipment/controls were of relevance. Concerning the condition of operator, mostly the mental state with phenomena such as overconfidence, loss of situational awareness, stress as well as poor flight monitoring/vigilance were of importance. In terms of the personnel factors, personal readiness, insufficient experience or risk assessment were contributory, whereas in regard to CRM, poor communication within the flight crew or with air traffic control were frequent. Tab. 4 summarises all Preconditions for Unsafe Acts found.

Tab. 4: Overview Preconditions for Unsafe Acts Source: BFU

Preconditions for Unsafe Acts	**All cases:**	**282**	**Fatal cases:**	**176**
	Number	**Percentage [%]**	**Number**	**Percentage [%]**
Environmental Factors	**83**	**29.4**	**54**	**30.7**
Physical environment	**55**	**19.5**	**36**	**20.5**
Weather	25	45.5	15	41.7
Altitude	18	32.7	12	33.3
Terrain	12	21.8	9	25.0
Technological environment	**28**	**10.0**	**18**	**10.2**
Maintenance	14	50.0	10	55.6
Equipment/control design	6	21.4	3	16.7
Traffic control in airport range	4	14.3	3	16.7
Other	4	14.3	2	11.1
Condition of Operator	**128**	**45.6**	**85**	**48.3**
Mental state	**112**	**39.9**	**72**	**40.9**
Overconfidence	33	29.5	27	37.5
Loss of situational awareness	22	19.6	10	13.9
Stress	17	15.2	9	12.5
Poor flight monitoring/vigilance	11	9.8	6	8.3
Channelized attention	8	7.1	5	6.9
Complacency	8	7.1	5	6.9
Other	13	11.6	10	13.9
Physiological condition	**7**	**2.5**	**6**	**3.4**
Intoxication	3	42.9	3	50.0
Medical illness	4	57.1	3	50.0
Physical/Mental Limitations	**9**	**3.2**	**7**	**4.0**
Incapacitation	3	33.3	3	42.9
Inadequate experience for complexity of the situation	2	22.2	1	14.3
Insufficient reaction time	2	22.2	1	14.3
Lack of aptitude to fly	2	22.2	2	28.6
Personnel Factors	**71**	**25.3**	**37**	**21.0**
CRM	**23**	**8.2**	**5**	**2.8**
Poor communication within/between the flight crew and ATC	17	73.9	5	100.0
Misinterpretation of traffic calls	2	8.7	0	0.0
Insufficient use of resources	2	8.7	0	0,0
Insufficient briefing	1	4.3	0	0,0
Lack of teamwork	1	4.3	0	0.0
Personal readiness	**48**	**17.1**	**32**	**18.2**
Insufficient experience	25	52.1	16	50.0
Insufficient risk assessment	19	39.6	13	40.6

2.11.4 HFACS Level 3: Unsafe Supervisions[28]

Unsafe Supervision is divided into four categories (Fig. 55).

Inadequate Supervision:

Neglect of any supervisor to provide their personnel with sufficient opportunity to succeed, guidance, training, leadership, oversight or incentives to ensure the tasks are performed safely and efficiently

Planned Inappropriate Operations:

Operations which are normally, except during emergencies, regarded as unacceptable (e.g. risk management, crew pairing, operational tempo)

Failure to Correct Known Problem:

Unabated continuance of deficiencies known to the supervisory authority (e.g. no reporting unsafe tendencies, initiating corrective actions or correcting safety hazards)

Supervisory Violations:

Supervisors wilfully disregard existing rules and regulations (e.g. failure to enforce rules and regulations, authorised unnecessary hazards, inadequate/fraudulent documentation)

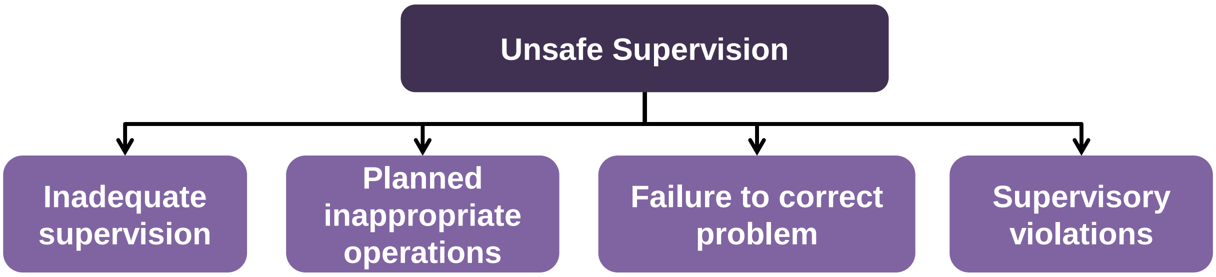

Fig. 55: Classification of Unsafe Supervisions

Source: HFACS, adaptation BFU

Cases with Unsafe Supervisions

The investigated accidents and serious incidents revealed in a number of cases deficiencies in the area of Unsafe Supervision. In particular, organisations such as joint ownerships, clubs, flying schools or associations were affected. Predominately with air sports equipment, individuals (pilot and owner in one person) were involved instead of organisations so that supervision was not an issue. It has to be noted that only in the

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[28] https://skybrary.aero/articles/human-factors-analysis-and-classification-system-hfacs

last years, organisational aspects have been given more consideration when investigating General Aviation occurrences (including air sports equipment) and will continue to be given increasing consideration.

The data analysis showed that in 116 (78%) cases (81 (80%) fatal accidents) no Unsafe Supervision existed. In contrast, the BFU determined in 32 (22%) cases (20 (20%) fatal accidents) at least one Unsafe Supervision, in 13 (9%) cases (7 (7%) fatal accidents) at least two and once even three. As Fig. 56 of the individual sub-categories for Unsafe Supervision shows, in 13% of all cases and 14% of fatal accidents, at least one inadequate supervision was present (19 of 148 cases and 14 of 101 fatal accidents). In 12% of all cases and 7% of all fatal accidents (17 of 148 case and 7 of 101 fatal accidents) at least one supervisory violation contributed, whereas planned inappropriate operations and failure to correct known problems were rather rare.

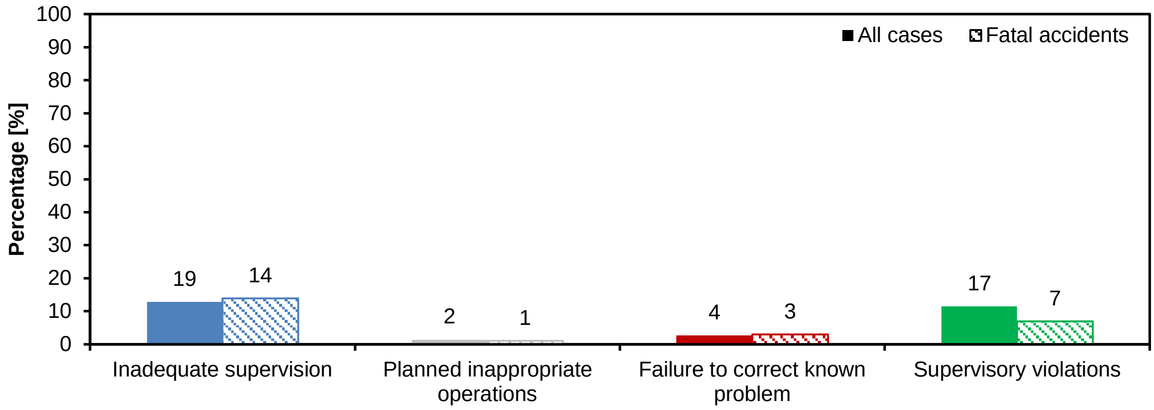

Fig. 56: All occurrences and fatal accidents with at least one Unsafe Supervision (percentage in bars, absolute number of cases as numeric values above) Source: BFU

All Unsafe Supervisions

In total, the BFU identified 46 Unsafe Supervisions in the 148 cases. For 101 examined data sets of the 99 fatal accidents, 27 Unsafe Supervisions were found (Tab.). Considering all Unsafe Supervisions (including multiple occurrences of one Unsafe Supervision category per case), 43.5% (20 cases) each are attributable to inadequate supervision and supervisory violations; in 9% (4 cases) planned inappropriate operations and in 4% (2 cases) failure to correct known problems existed (Fig. 57, left). For fatal accidents, inadequate supervision also led the Unsafe Supervisions with 55% (15 cases), followed by supervisory violations with 30% (8 cases), planned inappropriate operations (3 cases) and failure to correct known problems with 11% (one case) in third place (Fig. 57, right).

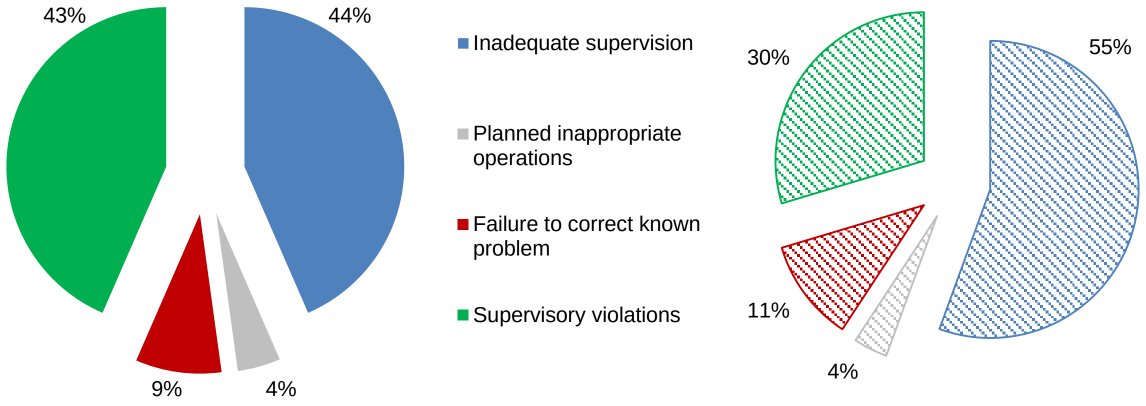

Fig. 57: Percentage of the sub-categories of Unsafe Supervision over all occurrences (left) and fatal accidents (right) Source: BFU

As Tab. 5 on the Unsafe Supervisions shows, inadequate supervision was mostly found to be a loss of supervisory situational awareness or insufficient professional guidance/oversight, while as supervisory violations mostly insufficient enforcement of rules and regulations and violations of procedures were determined. Tab. 5 summarises all Unsafe Supervisions found.

Tab. 5: Overview of all Unsafe Supervisions Source: BFU

Unsafe Supervisions	All cases:	46	Fatal cases:	27
	Number	Percentage [%]	Number	Percentage [%]
Inadequate Supervision	**20**	**43.5**	**15**	**55.6**
Loss of supervisory situational awareness	12	60.0	9	60.0
Insufficient professional guidance/oversight	5	25.0	3	20.0
Failed to track qualifications	2	10.0	2	13.3
Failed to track performance	1	5.0	1	6.7
Planned Inappropriate Operations	**2**	**0.7**	**1**	**1.2**
Failure to provide adequate briefing time/supervision	1	50	0	0.0
Insufficient professional guidance/oversight	1	50	1	100.0
Failure to Correct Known Problem	**4**	**1.4**	**3**	**3.6**
Failure to correct a safety hazard	3	75	2	66.7
Failure to correct/identify inappropriate/risky behaviour	1	25	1	33.3
Supervisory Violations	**20**	**7.1**	**8**	**9.5**
Insufficient enforcement of rules and regulations	7	35	0	0.0
Violation of procedures	6	30	5	62.5
Fraudulent documentation	4	20	3	37.5
Inadequate documentation	3	15	0	0.0

2.11.5 HFACS Level 4: Organisational Influences[29]

Organisational influences are divided into three categories (Fig. 58).

Resource Management:

Decision making at the organisational level in regard to allocation and maintenance of organisational assets (e.g. human and monetary resources, equipment and facilities)

Organisational Climate:

Working atmosphere within the organisation (e.g. structure, policies, culture)

Organisational Process:

Organisational decisions and rules which govern everyday activities within an organisation (e.g. operations, procedures, supervision)

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[29] Adapted from https://skybrary.aero/articles/human-factors-analysis-and-classification-system-hfacs

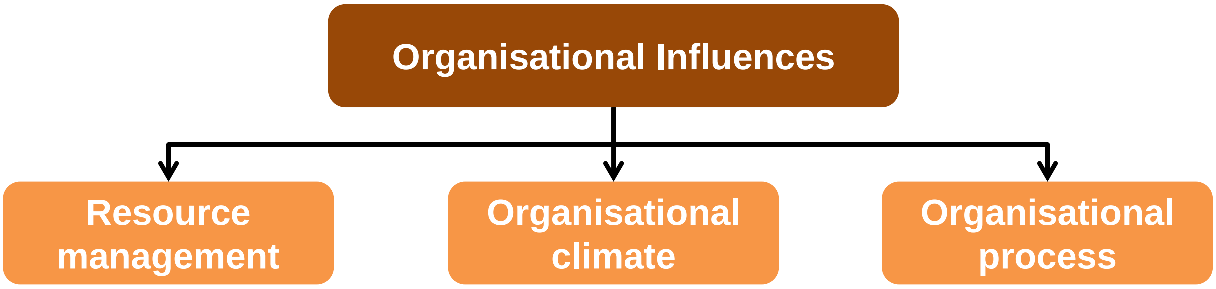

Fig. 58: Classification of the Organisational Influences Source: HFACS, adaptation BFU

Cases with Organisational Influences

The data analysis showed that in 127 (86%) cases (87 (86%) fatal accidents) no Organisational Influences existed. In contrast, the BFU determined in 21 (14%) cases (14 (14%) fatal accidents) at least one Organisational Influence, in 7 (5%) cases (7 (7%) fatal accidents) at least two and in two fatal accidents even three. Regarding the sub-categories of Organisational Influences, in 7% of all cases and 9% of fatal accidents, at least one resource management influence was present (10 of 148 cases and 9 of 101 fatal accidents). At least one organisational process was found each in 8% of all cases and in fatal accidents (12 of 148 cases and 8 of 101 fatal accidents), whereas organisational climate influences were rather rare (3%).

All Organisational Influences

A total of 30 Organisational Influences were identified across the 148 cases. In the 101 data records examined for the 99 fatal accidents, there were 23 Organisational Influences (Tab. 6). Considering all Organisational Influences (including multiple occurrences of one Organisational Influence category per case), it appears that resource management and organisational processes each accounted for 12 (40%) of the Organisational Influences, and organisational climate for 6 (20%, Fig. 59, left). For fatal accidents, resource management led the Organisational Influences with 11 cases (48%), followed by organisational processes with 8 cases (35%) and organisational climate with 4 cases (17%, Fig. 59, right).

Fig. 59: Percentage of the sub-categories of Organisational Influences over all occurrences (left) and fatal accidents (right) Source: BFU

As Tab. 6 on Organisational Influences shows, the resource management influence was mostly provision of unsuitable equipment and the organisational process influence mostly management's insufficient monitoring and checking of resources, climate and processes, whereas the organisational climate influence was mostly the organisational culture. Tab. 6 summarises all Organisational Influences found.

Tab. 6: Overview of all Organisational Influences Source: BFU

Organisational Influences	**All cases:**	**30**	**Fatal cases:**	**23**
	Number	**Percentage [%]**	**Number**	**Percentage [%]**
Resource Management	**12**	**40.0**	**11**	**47.8**
Provision of unsuitable equipment	6	50.0	6	54.5
Poor aircraft/aircraft cockpit design	3	25.0	2	18.2
Background checks	2	16.7	2	18.2
Failure to correct known design problems	1	8.3	1	9.1
Organisational Climate	**6**	**19.4**	**4**	**16.7**
Organisational culture	3	50.0	1	25.0
Other	3	50.0	1	25.0
Organisational Process	**12**	**40.0**	**8**	**34.8**
Monitoring and checking of resources, climate, & processes to ensure a safe work environment	7	58.3	4	50.0
Procedures/instructions about procedures	2	16.7	2	25.0
Other	3	25.0	2	25.0

2.12 Prevalent Occurrence Categories and their HFACS

This chapter considers the prevalent occurrence categories and their causal human and contributory factors or circumstances by means of HFACS.

2.12.1 Loss of Control-Inflight

In the prevalent occurrence category, Loss of Control-Inflight (LOC-I), skill-based errors (a total of: 189) and violations (a total of: 79) were most common. In 91% of all 98 uncontrolled flight attitude cases, at least one skill-based error (90 cases), in 29% one decision error (28 cases), in 11% one perceptual error (11 cases) and in 61% at least one violation (60 cases) was found (Fig. 60).

In-flight aircraft control errors (69 of all LOC-I cases, 70%) and stalls/spins (67 cases, 68%) occurred mostly together and represent more than two thirds of all skill-based errors in this occurrence category, followed by poor airmanship (13 cases, 13%), omitted checklist items or steps (8 cases, 8% each) and breakdown in visual scan (7 cases, 7%). Decision errors (a total of: 34) were mostly found to be exceeded ability of the pilot (17 of all LOC-I cases, 17%) and inappropriate manoeuvres/procedures (6 cases, 6%). While with the 14 perceptual errors, visual/aural perception problems (7 cases, 7%) were mostly significant.

The violations found were in 37 cases (38% of all LOC-I cases) exceeded aircraft limits (mostly overload), including 10 (10%) routine violations. In addition, in 19 cases (19%) hazardous manoeuvres (descending below the minimum safe altitude), in 7 cases (7%) aircraft operation with known deficiencies and in 5 cases each (5%) violations of orders, regulations, SOPs and acceptance of unnecessary hazards were found.

In 81% of all uncontrolled flight attitude cases (80 cases), a Precondition for Unsafe Acts was also present, mostly in the area of the condition of operator regarding the pilot’s mental state (43 of all LOC-I cases, 53%; Fig. 61). These primarily included overconfidence (27 cases, 28%), stress (11 cases, 11%), loss of situational awareness (9 cases, 9%), channelized attention (6 cases, 6%), poor flight vigilance and complacency (5 cases each, 5%). Preconditions regarding personal readiness (34 cases, 35%) represented mostly insufficient experience (22 cases, 22%) and risk assessment (12 cases, 12%). Unsafe Supervision occurred in 25 cases (26% of all LOC-I cases). Of these, the most common was loss of supervisory situational awareness with 9 cases (9%). In addition, in 13% of these cases Organisational

Influences at the highest HFACS level contributed, such as poor aircraft/cockpit design or provision of unsuitable equipment.

2.12.2 Low Altitude Flight Operations

In the occurrence category, low altitude flight operations (LALT), violations and skill-based errors were most common. In 86% of all 29 LALT cases, at least one skill-based error (25 cases), in 35% (10 cases) at least one decision error (mainly exceedance of one's own abilities), in 14% (4 cases) one perceptual error and in 93% (27 cases) at least one violation was found (Fig. 60).

Not every low altitude flight results in an accident, however, if the minimum safe altitude is infringed the risk increases, so that even small flying errors or another missing safety barrier can escalate the situation. For example, a stall near the ground can often not be recovered in time because there is not enough distance to the ground or obstacles to regain control. If an aircraft is also overloaded or the pilot's capabilities were already exceeded by the low-level manoeuvre, low altitude flight operations may result in disaster. In addition, the BPRS must be activated in time, i.e. at an appropriate altitude, so that it can function as a "safety net". In 86% of all LALT cases, the minimum safe altitude was infringed. Regularity of such low-level flights (routine violation) could be proven in at least 4 of these cases (14%), for example by video documentation or radar data of previous flights.

In 93% (27 cases) of all low-level flight cases, at least one Precondition for Unsafe Acts existed, mostly in the area of the pilot's mental state (23 LALT cases, 79%, Fig. 61). In 19 of the 29 low-level flight cases (66%), pilot overconfidence occurred. The 11 preconditions regarding personal readiness (38%) were mostly experience, insufficient training and already a habit of poor risk assessment. In six cases (21%), Unsafe Supervision occurred, like training flights conducted repeatedly, deliberately and over a longer period of time close to the ground, so that a bad example was set for the student pilot and the flight training organisation did not remedy this either.

2.12.3 System/Component Failure or Malfunction

In the occurrence category, 2.3.3 System/Component Failure or Malfunction (SCF-PP and SCF-NP), violations (a total of: 36) and skill-based errors (a total of: 28) were most common. In 24 (57%) of all 42 system component failure cases, at least one skill-based error, in 10 (24%) one decision error, in 7 (17%) one perceptual error and in 23 (55%) at least one violation was found (Fig. 60).

In-flight aircraft control errors (11 cases, 26%) and stalls/spins (10 cases, 24%) constituted a large part of the skill-based errors, followed by poor airmanship (8 cases, 19%) and omitted steps in procedures (8 cases, 19%). Violations primarily involved operation of an overloaded aircraft (15 system component failure cases, 36%) or with known deficiencies (6 cases, 14%). In 8 cases (19%), an omitted procedure/checklist step and in 9 cases (22%), an insufficient checklist check, such as proper canopy or cabin door closure, was found.

Preconditions for Unsafe Acts were found in 69% (29 cases) of all System/Component Failure or Malfunction cases, with 57% mainly for environmental factors (technological 45%, physical 21%, Fig. 61). These included 11 cases (27%) of mostly maintenance problems. Unsafe Supervision occurred in 29% (12 cases) of all SCF cases, in particular, supervisory violations (7 cases (17%)) and inadequate supervision (5 cases (12%)). For example, often professional guidance or supervision of student pilots by flight instructors was inadequate and compliance with procedures not enforced. In addition, in 29% of these cases Organisational Influences at the highest HFACS level contributed, like provision of unsuitable equipment, insufficient monitoring/checking of resources, climate, and processes, and poor aircraft/cockpit design.

2.12.4 Airprox/(Near) Midair Collisions

In the occurrence category airprox/mid-air collision (MAC, 19 cases, 21 pilots and air sports equipment involved) skill-based errors (a total of: 27) and perceptual errors (a total of: 19, Fig. 60) were most common. With 15 (71%) of the 21 involved pilots, skill-based errors occurred during the airprox (Chapter 2.11.2.1). The principle “See and Avoid” did not work sufficiently for 14 pilots (52%). Contributory factors were mostly insufficient airspace observation, stress and environmental factors. Perceptual errors occurred with 17 of the 21 pilots (81%). The conflict partner was often not seen at all or too late, its altitude and direction of flight wrongly assessed, the warning radio call not heard or the pilots generally lost orientation or situational awareness. With 7 (33%) pilots at least one violation and with 6 (29%) pilots at least one decision error contributed to the MAC occurrence.

Preconditions for Unsafe Acts were present in 19 (91%) of all MAC cases (Fig. 61). With 16 of the 21 pilots, poor communication between pilots and other parties involved were determined as occurrence-relevant (76% resource management). This included, for example, insufficient or inaccurate position reporting or traffic information from ground stations, which resulted in misunderstandings, or there was no communication at all. The pilot’s mental state was identified as Precondition for Unsafe Acts with 15 (71%) of the pilots, 9 each (43%) lost their situational awareness or showed poor flight vigilance, channelized attention (4 pilots, 19%) or were stressed (3 pilots, 14%).

At least one Precondition for Unsafe Acts in the physical environment was found for 9 (43%) of the air sports equipment involved in MAC cases. Although, all MAC cases occurred under Visual Meteorological Conditions (VMC), the weather affected the perception of five (24%) of the pilots involved. One of these pilots had to change the flight path due to locally poor weather, the other four suffered from visual impairment due to sun glare. For another 4 pilots (19%), other environmental factors had an adverse effect on the perception of conflicting traffic, such as visibility restrictions due to objects and vegetation at low altitude, design-related visibility obstructions, e.g. when looking up in a high-wing aircraft or due to human-anatomy-related limited visibility when an aircraft is approaching from behind.

Unsafe Supervisions were determined with 6 (29%) pilots involved. Air traffic control plays a major role in airprox cases, as they have a mental model of the entire airport traffic and can inform pilots about hazardous airproxes. However, due to various reasons, this was not always the case or there were no procedures for mixed flight operations at the airport or they were not adhered to. Thus, with 3 (14%) of the pilots involved, there were safety-critical Organisational Influences on the highest HFACS level. In two cases, procedures for mixed flight operations at the airport were neither analysed for risks nor adapted accordingly. In one case, agreements concerning mixed flight operations were insufficient.

2.12.5 Summary

In summary, the HFACS analysis of the most common occurrence categories, similar to the result over all cases, shows that skill-based errors and violations represent the largest share of Unsafe Acts on the lowest HFACS level. Fig. 60 depicts the most common occurrence categories with their corresponding percentage of Unsafe Acts, and Fig. 61 with their corresponding percentage of Preconditions for Unsafe Acts.

The factors identified with the HFACS analysis in this safety study show the interaction of Human Factors, other flight operations and environmental factors during the occurrence of an aircraft accident. The study found evidence of Unsafe Acts, Preconditions for Unsafe Acts and other circumstances which contributed to the occurrence of accidents or serious incidents. Safety culture deficiencies and indications of an absent or insufficient Safety Management System (SMS) were revealed. At the same time, the study shows that analysis models, like the HFACS framework, can be helpful to identify safety deficiencies and to develop appropriate safety measures.

The General Aviation organisations should focus their efforts on the advancement of a safety culture. This should include establishing an SMS which is commensurate with the complexity and capabilities of General Aviation. An essential factor for the acceptance by pilots and for the implementation of the safety culture also lies in the role model function of the functionaries such as flight instructors, club board members, aircraft examiners and others.

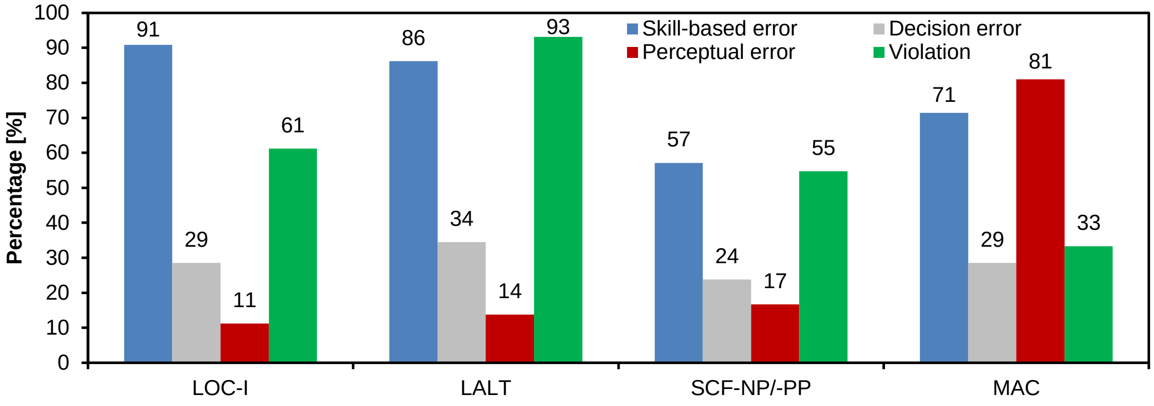

Fig. 60: Cases with at least one Unsafe Act per occurrence category Source: BFU

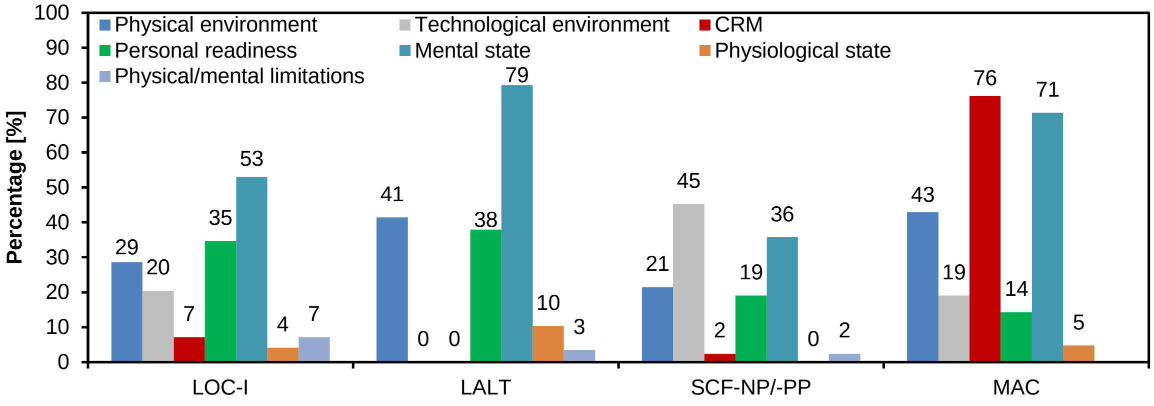

Fig. 61: Cases with at least one Precondition for Unsafe Act per occurrence category Source: BFU

3. Conclusions

In this safety study, the BFU statistically evaluated and with the HFACS framework additionally analysed all accidents and serious incidents involving air sports equipment (predominantly aerodynamically controlled ultralights) investigated over a time frame of 20 years (2000-2019). As a result of this study, the BFU comes to the following conclusions:

Accident Figures

- The two Air Sports Associations, DHV and DFV, recorded accident figures and published extensive activities of their flight safety work over the years (lectures, statistics, etc.).
- DULV and DAeC did not keep an overview of occurrence figures or the severity of accidents and serious incidents reported to them in their area of responsibility during this time period. The associations neither systematically evaluated the reported occurrences nor differentiated, for example, between the air sports equipment involved (ultralight, gyrocopter, etc.). It was therefore not possible for the DAeC and DULV to make a fact-based assessment of the accident situation in their area of responsibility.

Number of Flights

- In addition to the accident figures, the DFV also recorded the number of skydives completed per year.
- The BFU could not find comparable figures about the number of flights from the other Air Sports Associations.
- For non-commercial ultralight operations, the BFU calculated an accident rate per 100,000 flights, based on number of flights data from DESTATIS and the number of fatal accidents investigated by the BFU.
- As is the case in other areas of General Aviation, there was no data concerning the number of flight hours conducted per year with air sports equipment. For the time period considered, it was not possible to validly state the total number of accidents and serious incidents and their differentiation, e.g., between aerodynamically or weight-shift controlled ultralight, gyrocopters or ultralight helicopters. Therefore, the BFU could not conduct a precise accident risk calculation based on flight hours.

Operating Phases

- The accidents and serious incidents involving air sports equipment BFU investigated, mostly occurred in the cruise flight phase, both in total numbers and fatal accidents, followed by the take-off (all cases) or manoeuvring phase (for fatal accidents), respectively.

Prevalent Occurrence Categories

- The majority of the accidents involving air sports equipment BFU investigated, were accidents in the occurrence category Loss of Control-Inflight (LOC-I), which is also one of the high-risk categories for fatal accidents worldwide.
- The data of the safety study show that flight operations with air sports equipment in low altitude (LALT) also pose a high accident risk. In case of an uncontrolled flight attitude, there is a risk that it can neither be recovered before ground impact nor the BPRS can be activated in time.
- In the occurrence category airprox and mid-air collisions (MAC), the generally known weaknesses of the principle “See and Avoid” also became apparent for air sports equipment. The use of functioning transponders or collision warning systems can significantly contribute to ensuring that air traffic control and pilots can be warned of impending collisions in due time.

Mass Considerations

- The body weight of occupants determined during investigations corresponds with the average values from DESTATIS.
- With an average German male weight of 85 kg, an air sports equipment with two male occupants without fuel or baggage would already be overloaded in 66% of cases.
- Close attention should be paid to the mass determination during manufacturing as well as in the airworthiness approval and review process.
- The increase in MTOM to 600 kg for aerodynamically controlled ultralights in the LTF-UL 2019 should actually be available for the occupants and not negated by fitting additional equipment.

Pilots

- The pilots in the cases the study considered were mostly male. Two thirds were 50 years of age or older.
- Almost half of the pilots had no other pilot licence, whereas more than one third held an additional private pilot license (PPL).
- Half of all pilots had a total flying experience of less than 282 hours, and over a quarter (27%) had only 100 hours or less. Flying experience on the air sports equipment type involved was less than 54 hours for half of the pilots.

Ballistic Parachute Recovery System

- The BPRS was activated in 41% of all air sports equipment accidents investigated.
- In half of these cases, the pilot activated the BPRS, mostly after loss of control, component failure or mid-air collision. In almost two thirds of these cases, complications in opening of the parachute canopy occurred, mostly due to a low altitude during activation so that complete opening was no longer possible, or due to installation-related problems.

Hazards at the Accident Site

- In addition to the increasing use of carbon composite components in the construction of air sports equipment and the resulting risks, non-activated BPRS in particular pose a not inconsiderable hazard for first responders. These hazards should be further addressed with information, training and safety precautions.

Data Analysis using the HFACS Framework

- The analysis of accidents and serious incidents involving air sports equipment in regard to Human Factors showed in almost all cases (93%) at least one Unsafe Act and in three quarters of all cases (80%) at least one precondition for these Unsafe Acts. In almost one quarter of all cases (22%), at least one Unsafe Supervision and in 14% of all cases Organisational Influences were found. This illustrates the significant part Human Factors play in the occurrence of Preconditions for Unsafe Acts and where particular action is needed in terms of flight safety.

- Concerning the examined air sports equipment occurrences, flight safety improvement actions should aim at reducing skill-based errors, such as stall and other aircraft control errors, and violations.

General Conclusions and Outlook

- Based on the data analysis, the BFU concludes that for a reduction of the number of fatal accidents in the area of air sports equipment a decrease in Loss of Control-Inflight (LOC-I) occurrences is crucial. The BFU is of the opinion that this should be the focal point of flight safety actions by all parties involved.
- The BFU is convinced that implementation and further development of a SMS specifically designed for air sports equipment can help to further increase flight safety.
- From the BFU's point of view, the goal of improving flight safety can only be achieved with additional effort to develop a safety culture on all levels in the Air Sports Associations, in flying schools, clubs and private operators.
- The insights and experiences derived from the compilation of this study prompt the BFU to continue this concept.

4. Safety Recommendations

As a result of this safety study, the BFU issued the following Safety Recommendations to the Federal Ministry for Digital and Transport (BMDV):

Safety Recommendation No. 07/2022

In order to develop a data-based hazard and risk management system for the operation of air sports equipment, the Federal Ministry for Digital and Transport (BMDV) should ensure that all authorised Air Sports Associations record accident and incident reports and analyse them on a regular basis.

Safety Recommendation No. 08/2022

The Federal Ministry for Digital and Transport (BMDV) should ensure that the authorised Air Sports Associations develop measures to promote flight safety in the area of the air sports equipment which result in reduction of the number of fatal accidents.

The measures the Air Sports Associations DAeC and DULV responsible for ultralights and gyrocopters develop should include the following focal points, among other things:

- Reduction of skill-based errors such as stall and other aircraft control errors
- Reduction of the number of violations

Safety Recommendation No. 09/2022

The Federal Ministry for Digital and Transport (BMDV) should promote the development of an effective information system to support rescue forces in averting hazards at ultralight accident sites.

The purpose of such an information system is that rescue forces are informed faster about specific hazards posed by air sports equipment and can take adequate protective measures.

Aircraft manufacturers should report type-related data and information required for such an information system to the responsible Air Sports Association on a regular basis, which are then used to update the system.

The BFU issued the following Safety Recommendation to the Luftfahrt-Bundesamt:

Safety Recommendation No. 10/2022

The Luftfahrt-Bundesamt (LBA) should, in the scope of their obligatory supervision of the authorised Air Sports Associations, ensure that they establish an effective and efficient Safety Management System and develop measures to promote a safety culture.

Investigators in charge:	Jens Friedemann, Dr. Susann Winkler
Assistance:	Roger Knoll, Frank Stahlkopf

Braunschweig, 18.11.2022

5. Appendices

Appendix 1 All Occurrence Categories[30]

AVIATION OCCURRENCE CATEGORIES

ABNORMAL RUNWAY CONTACT (ARC)

ABRUPT MANEUVER (AMAN)

AERODROME (ADRM)

AIRPROX/TCAS ALERT/LOSS OF SEPARATION/NEAR MIDAIR COLLISIONS/MIDAIR COLLISIONS (MAC)

ATM/CNS (ATM)

BIRD (BIRD)

CABIN SAFETY EVENTS (CABIN)

COLLISION WITH OBSTACLE(S) DURING TAKEOFF AND LANDING (CTOL)

CONTROLLED FLIGHT INTO OR TOWARD TERRAIN (CFIT)

EVACUATION (EVAC)

EXTERNAL LOAD RELATED OCCURRENCES (EXTL)

FIRE/SMOKE (NON-IMPACT) (F–NI)

FIRE/SMOKE (POST-IMPACT) (F–POST)

FUEL RELATED (FUEL)

GLIDER TOWING RELATED EVENTS (GTOW)

GROUND COLLISION (GCOL)

GROUND HANDLING (RAMP)

ICING (ICE)

LOSS OF CONTROL–GROUND (LOC–G)

LOSS OF CONTROL–INFLIGHT (LOC–I)

LOSS OF LIFTING CONDITIONS EN ROUTE (LOLI)

LOW ALTITUDE OPERATIONS (LALT)

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[30] https://www.icao.int/SAM/Documents/2017-SSP-GUY/CICTT%20Occurrence%20Category.pdf

MEDICAL (MED)

NAVIGATION ERRORS (NAV)

OTHER (OTHR)

RUNWAY EXCURSION (RE)

RUNWAY INCURSION (RI)

SECURITY RELATED (SEC)

SYSTEM/COMPONENT FAILURE OR MALFUNCTION (NON-POWERPLANT) (SCF–NP)

SYSTEM/COMPONENT FAILURE OR MALFUNCTION (POWERPLANT) (SCF–PP)

TURBULENCE ENCOUNTER (TURB)

UNDERSHOOT/OVERSHOOT (USOS)

UNINTENDED FLIGHT IN IMC (UIMC)

UNKNOWN OR UNDETERMINED (UNK)

WILDLIFE (WILD)

WIND SHEAR OR THUNDERSTORM (WSTRW)