Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Accident
Date:	28 August 2020
Location:	Arnsberg-Menden
Aircraft:	Airplane
Manufacturer:	Cessna Aircraft Company
Type:	Cessna 401A
Injuries to persons:	Pilot and two passengers suffered serious injuries
Damage:	Aircraft substantially damaged
Other Damage:	Crop damage
State File Number:	BFU20-0721-CX

Published by:

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Abbreviations

Glossary of Abbreviations

AAL	Above Aerodrome Level	Höhe über dem Flugplatz
AD	Airworthiness Directive	Lufttüchtigkeitsanweisung
AFM	Airplane Flight Manual	Flughandbuch
AGL	Above Ground Level	über Grund
AIP	Aeronautical Information Publication	Luftfahrthandbuch
AMSL	Above Mean Sea Level	Über dem mittleren Meeresspiegel
ANSP	Air Navigation Service Provider	Flugsicherungsorganisation
AOM	Airplane Operating Manual	Flugbetriebshandbuch
AOPA	Aircraft Owners and Pilots Association	Verband der Allgemeinen Luftfahrt e.V.
ARC	Airworthiness Review Certificate	Bescheinigung über die Prüfung der Lufttüchtigkeit
ATC	Air Traffic Control	Flugverkehrskontrolle
ATIS	Automatic Terminal Information Service	Automatische Ausstrahlung von Lande- und Startinformationen
BFU	German Federal Bureau of Aircraft Accident Investigation	German Federal Bureau of Aircraft Accident Investigation
BZF	Restricted Flight Radiotelephone Operator's Certificate	Beschränkt gültiges Sprechfunkzeugnis für den Flugfunkdienst
CAS	Calibrated Airspeed	Kalibrierte Fluggeschwindigkeit
CAVOK	Ceiling And Visibility OK (for VFR flights)	Bewölkung und Sichtweiten in Ordnung (für Flüge nach VFR)
CTR	Control Zone	Kontrollzone
EASA	European Union Aviation Safety Agency	Europäische Agentur für Flugsicherheit
ELEV	Elevation	Ortshöhe über dem Meer
FAA	Federal Aviation Administration	US Luftfahrtbehörde
FCL	Flight Crew Licensing	
FDR	Flight Data Recorder	Flight Data Recorder

FL	Flight Level	Flugfläche
ft	Feet	Fuß (1 Fuß = 0,3048 m)
ft/min	Feet per minute	Fuß pro Minute
g	acceleration due to Earth's gravity (9,81 m/s²)	Beschleunigung durch die Erdanziehungskraft (9,81 m/s²)
GA	General Aviation	Allgemeine Luftfahrt
GAFOR	General Aviation Forecast	Vorhersage für die Allgemeine Luftfahrt
GND	Ground	Grund
GPS	Global Positioning System	
GS	Ground Speed	Geschwindigkeit über Grund
HDG	Heading	Steuerkurs
IAS	Indicated Airspeed	Angezeigte Fluggeschwindigkeit
ICAO	International Civil Aviation Organisation	Internationale zivile Luftfahrtorganisation
IFR	Instrument Flight Rules	Instrumentenflugregeln
IMC	Instrument Meteorological Conditions	Instrumentenwetterbedingungen
KIAS	Knots Indicated Airspeed	
kt	knot(s)	Knoten (1 kt = 1,852 km/h)
LBA	Federal Aviation Office (Germany)	Luftfahrt-Bundesamt
LDA	Landing Distance Available	Verfügbare Landestrecke
LDR	Landing Distance Required	Benötigte Landestrecke
LM	Landing Mass	Landing mass
LTA	Airworthiness Directive	Lufttüchtigkeitsanweisung
METAR	Aviation Routine Weather Report	Routine Wettermeldung für die Luftfahrt
MDA	Minimum Descent Altitude	Sinkflugmindesthöhe
ME	Multi Engine	
MEP	Multi Engine Piston	
MLM	Maximum Landing Mass	Maximum landing mass
MPH	Miles per Hour	
MSA	Minimum Sector Altitude	Mindestsektorenhöhe über MSL
MSL	Mean Sea Level	Mittlerer Meeresspiegel
MTOM	Maximum T/O Mass	Maximale Startmasse

NfL	Publications of aviation authorities in Germany	Nachrichten für Luftfahrer (German Language Publication for Aviation)
NM	Nautical Mile(s)	Nautische Meile(n)
NOTAM	Notice to Airmen	Ergänzende Informationen zur AIP
NTSB	National Transportation Safety Board	US Untersuchungsbehörde für Transportsicherheit
OPC	Operator Proficiency Check	
PAPI	Precision Approach Path Indicator	Präzisionsgleitwegbefeuerung
PIC	Pilot in Command	Pilot in Command
PL	Power Lever	Leistungshebel
POH	Pilot's Operating Handbook	
PPL	Private Pilot Licence	Privatpilotenlizenz
psi	pounds per square inch	(14,5 psi = 1 bar)
QFE	altimeter pressure setting to indicate height above aerodrome	
QNH	altimeter pressure setting to indicate altitude AMSL	Luftdruck in Meereshöhe
rpm	revolutions per minute	Umdrehungen pro Minute
RWY	Runway	Runway
SAR	Search and Rescue	
SEP	Single Engine Piston	
SOP	Standard Operating Procedure	Standard-Betriebsverfahren
SP	Single Pilot	
TAS	True Airspeed	Wahre Fluggeschwindigkeit
TAT	Total Aircraft Time	Gesamtflugzeit des Luftfahrzeugs
UTC	Universal Time Coordinated	
VASI	Visual Approach Slope Indicator	
V_{APP}	Approach Speed	Approach Speed
V_{CAS}	Calibrated Air Speed	
V_{NE}	Never exceed Airspeed	
V_R	Rotation Speed	Rotationsgeschwindigkeit
V_{REF}	Approach Reference Speed	

VS	Vertical Speed	Steig-/Sinkgeschwindigkeit
V_{TGT}	Target Speed	Zielgeschwindigkeit im Landeanflug
V_1	T/O Decision Speed	
V_2	T/O Safety Speed	
VFR	Visual Flight Rules	Sichtflugregeln
VHF	Very High Frequency	Ultra Kurz Welle
VMC	Visual Meteorological Conditions	Sichtflugwetterbedingungen
VOR	VHF Omnidirectional radio Range	

Synopsis

On 28 August 2020 at 1610 hrs[1], the German Federal Bureau of Aircraft Accident Investigation (BFU) was informed by the Rettungsleitstelle Hochsauerlandkreis that a twin-engine aircraft was involved in an accident at Arnsberg-Menden Airport. The BFU dispatched a team of three who began with the investigation at the accident site the same day.

It was determined that an in-flight loss of control occurred during final approach and the airplane impacted the ground short of the runway. The three occupants suffered severe injuries and the airplane was substantially damaged.

The accident was due to:

- The pilot did not correct the approach by increasing engine power or did not abort the approach.
- The pilot did not monitor the airspeed during the final approach and steered the airplane into an uncontrolled flight attitude during the flare.

To the accident contributed that:

- The approach was not stabilised and not aborted.
- The pilot did not pay attention to the PAPI indication and did not perceive the stall warning.
- The large number of continuously changing approach parameters most likely exceeded the limits of the pilot’s capabilities and subsequently, the airplane was no longer controlled in a goal-oriented manner.
- The runway markings did not comply with the required standards.

[1]All times local, unless otherwise stated.

1. Factual Information

1.1 History of the Flight

At 1541 hrs, the airplane took off from Marl-Lohmühle Airfield with the pilot and two passengers on board to a VFR flight to Arnsberg-Menden Airfield approximately 30 NM to the south-east. Prior to take-off, the pilot had met the persons known to him at Marl-Lohmühle Airfield and spontaneously offered to take them on the flight. One of the passengers was seated in the right-hand seat next to the pilot and the other in the passenger seat behind him.

The radar recording of the air navigation service provider showed that the airplane climbed to a cruise level of 2,200 ft AMSL. Ten minutes after take-off, the pilot established radio contact with Dortmund Tower with the request to cross Dortmund Airport control zone via reporting point WHISKEY towards reporting point ECHO on his way to Arnsberg. At 1552:14 hrs, the tower controller answered: "[…] melden Sie WHISKEY und dann erwarten Sie Durchflug nach Arnsberg oder ECHO, wie Sie möchten, QNH eins null null eins (report WHISKEY and then expect crossing to Arnsberg or ECHO, as you like, QNH one zero zero one)". The pilot confirmed QNH and entry point WHISKEY.

At 1555:22 hrs, the pilot reported having reached reporting point WHISKEY at 2,200 ft AMSL. The controller approved crossing the control zone towards the south.

The GPS and radar data showed that at 1556 hrs, the airplane turned right towards 120° for a direct heading to Arnsberg. At 1559 hrs, the airplane was once again outside the control zone and the controller issued the clearance to leave the frequency.

At 1600 hrs, about 2.5 NM west of the destination aerodrome, the airplane turned left in an easterly direction. About one minute later, the airplane crossed the extended runway centre line of runway 23, at a distance of 0.7 NM from the threshold at about 1,400 ft AAL with an eastern heading. At the time, ground speed was approximately 150 kt. At 1601:39 hrs, the airplane turned left towards the final approach of runway 23. During the turn, the airplane had a bank angle of 45°. After the pilot had finished the turn, at 1602:32 hrs, the airplane reached the extended runway centre line at about 1,500 ft AMSL (about 700 ft AAL), approximately 1 NM from the runway threshold (Fig. 1), and turned toward the landing direction. At the time, ground speed was approximately 100 kt.

During the last 30 s of the final approach, airspeed decreased continuously. At 1602:44 hrs, the airspeed undershot the Blue Line Speed[2] and 2 s later the minimum approach speed. At 1603:04 hrs, airspeed fell below the minimum control speed and at 1603:15 hrs, below the stall speed for flaps 30°. The airplane impacted a slope more than 200 m in front of the runway threshold.

The pilot stated that coming from Dortmund he initially flew in a south-easterly direction and then turned left heading directly for the final approach to runway 23. During the final approach, he had maintained Blue Line Speed of 117 mph (102 KIAS). He had focused on the beginning of the runway and then pulled the engine power into idle.

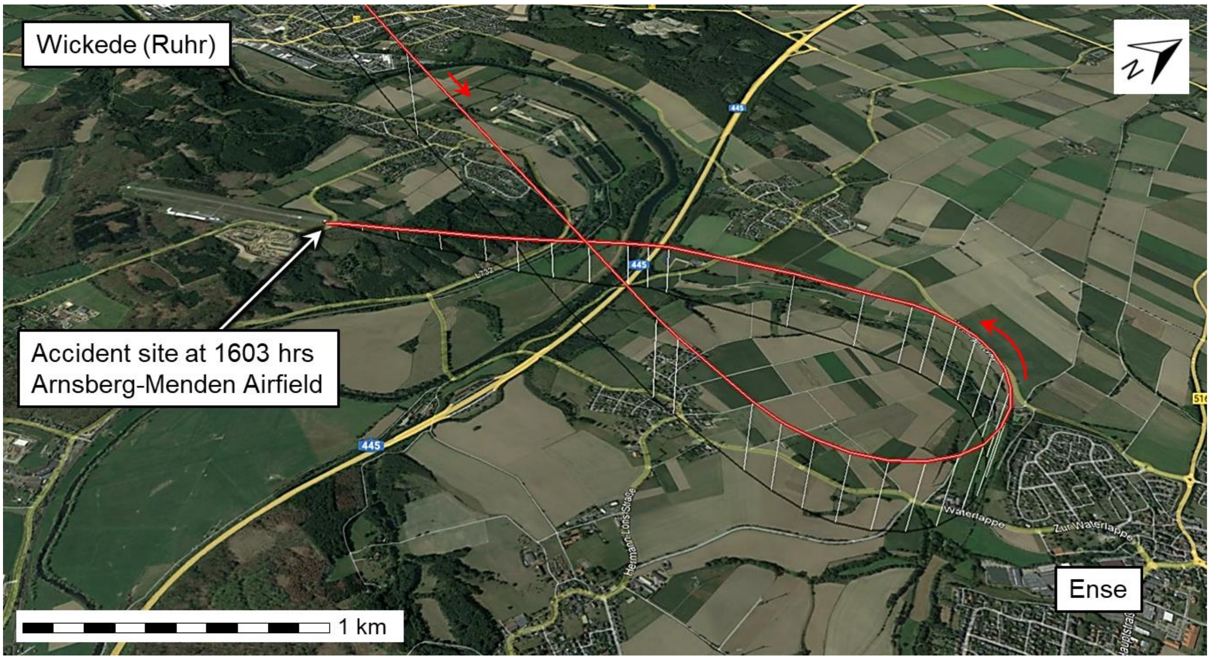

Fig. 1: Approach based on GPS data Source: Google Earth™, adaptation BFU

The Flugleiter[3] stated that during the approach the wind came from 230° with 12 kt. According to him, the airplane's landing gear and flaps had been extended during final approach. The approach looked normal. He then stopped observing the airplane for a short time to make entries in the computer. His colleague had then addressed him and drew his attention to the low speed of the airplane. The Flugleiter then saw that the airplane had a large pitch-up attitude, then plunged and disappeared from his field of vision.

[2] For multi-engine aircraft, the best climb speed consequent to failure of one of the engines.

[3] A person required by German regulation at uncontrolled aerodromes to provide aerodrome information service to pilots

The airplane impacted the ground and the three occupants suffered severe injuries.

The Flugleiter stated he had tried in vain to contact the pilot twice more and then raised the alarm. His colleague and other first aiders had immediately driven to the accident site.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Total in aircraft	Other
Fatal	0	0	0	0
Serious	1	2	3	0
Minor	0	0	0	NN
None	0	0	0	NN
Total	1	2	3	0

1.2 Damage to Aircraft

The aircraft was substantially damaged.

1.4. Other Damage

Crop damage occurred.

1.5 Personnel Information

The 73-year-old pilot held a Private Pilot Licence (PPL(A)) issued on 15 September 2014 by the Bezirksregierung Münster (District Council) in accordance with Part-FCL. The licence listed the ratings for Multi-Engine Piston land (MEP(land) and Single-Engine Piston land (SEP(land)) and the night flight qualification. The last proficiency check MEP (land) was conducted on 11 August 2020.

His class 2 medical certificate was issued on 5 August 2020 and valid until 21 July 2021. The medical certificate listed the limitations: VML (Correction for defective distant, intermediate and near vision), TML (Time Limitation), and SIC (Specific regular medical examination(s) contact licensing authority).

According to the pilot, he had a total flying experience of about 6,300 hours. The recordings in two pilot log books (March 1984 to April 1988 and August 2017 to July

2020), the aircraft log book and the flights recorded in the pilot's tablet showed that he had a total flying experience of about 500 hours on type. In the last 90 days he had flown 14:09 hours on type.

1.6 Aircraft Information

The airplane Cessna 401A is a twin-engine low-wing aircraft in all-metal construction with retractable landing gear in nose wheel configuration and a fuselage-mounted horizontal stabilizer.

Manufacturer:	Cessna Aircraft Company
Type:	Cessna 401A
MTOM:	2,858 kg (6,300 lbs)
Empty weight:	1,914 kg (4,219 lbs)
Manufacturer's Serial Number:	401A0046
Year of Manufacture:	1969
Engines:	Continental TSIO-520-E
Propeller:	McCauley 3AF32C87NR
Total Operating Time:	4,568:20 hours, 5,945 cycles

The aircraft was registered in the United States of America, owned by a Trustee and operated by the pilot. The registration certificate of the Federal Aviation Administration (FAA) was valid until 31 October 2023.

According to the maintenance records of the airplane, on 17 June 2020 the last 100-hour-inspection at an operating time of 4,560 hours had been performed. On 18 June 2020, the annual inspection was certified by FAA authorized maintenance personnel.

The seats in cockpit and cabin were equipped with lap belts but not with shoulder harnesses.

On the upper surfaces of the wings and both sides of the vertical fins vortex generators were installed in accordance with Supplemental Type Certification (STC) No. SA5900NM. With the installed vortex generators, stall speed was 85 MPH CAS (74 KIAS) with 0° bank angle and retracted landing gear, with flaps 15° and extended landing gear 82 MPH CAS (71 KIAS) and with flaps 45° and extended landing gear 75 MPH CAS (65 KIAS).

The airplane was equipped with a stall warning horn, which sounds in all configurations 5-10 MPH (4-9 KIAS) prior to stall speed, according to the Owner's Manual.

At the time of the accident, the airplane had a mass of about 2,300 kg, including fuel and occupants.

The landing distance required for the airplane type from 50 ft above the threshold was about 538 m (1,765 ft, not considering the wind).

The Before Landing checklist contained the following:

1. Fuel selectors	*MAIN TANKS (FEEL FOR DETENT)*
2. Auxiliary fuel pumps	*ON*
3. Cowl flaps	*CLOSED*
4. Alternate air controls	*IN*
5. Mixtures	*FULL RICH*
6. Propellers	*FORWARD*
7. Flaps	*DOWN 15° below 180 MPH CAS*
8. Gear	*DOWN below 160 MPH CAS*
9. Flaps	*DOWN 45° below 160 MPH CAS*
10. Minimum approach speed	*110 MPH IAS*
11. Minimum control speed	*95 MPH IAS*

1.7 Meteorological Information

According to the statement of the Flugleiter, visual meteorological conditions prevailed at Arnsberg-Menden Airfield with the following observations:

Wind:	230°, 10-15 kt, at 2,000 ft AMSL 240°, 20 kt
Cloud:	3-4 octas at 4,700 ft AMSL, 8 octas at 21,000 ft AMSL
Visibility:	More than 10 km
Temperature:	19°C
Dewpoint:	9°C

QNH: 1,002 hPa

At the time of the accident daylight prevailed, the sun was at an azimuth of 191° and an elevation 47.5°.

1.8 Aids to Navigation

At Arnsberg-Menden Airfield, both landing directions were equipped with Precision Approach Path Indicators (PAPI, Fig. 2). They were set to a glideslope of 3°. According to the Flugleiter, the PAPI for runway 23 was active during the airplane’s approach.

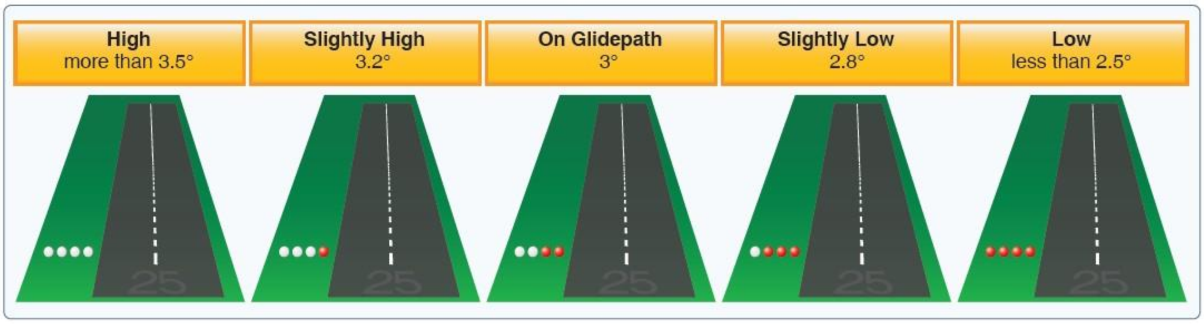

Fig. 2: PAPI indications of different approach angles Source: FAA

As navigation support and back-up system, a tablet with navigation software was mounted to a permanently installed holder above the instrument panel in the centre of the windscreen and connected to the on-board power supply. During the flight, the tablet was on and the navigation software active.

1.9 Radio Communications

The Flugleiter at Arnsberg-Menden Airfield stated that the radio communications with the pilot had been conducted in German.

The airfield was equipped with a radio communications recording system. According to the statement of the regional civil aviation authority Dusseldorf, communications at the time of the accident were not recorded, due to a technical malfunction of the system.

Radio communications between Dortmund Tower and the pilot were recorded by the air navigation service provider and made available to the BFU for evaluation.

1.10 Aerodrome Information

1.10.1 General Information

Arnsberg-Menden Airfield (EDLA) is located about 3 NM north-west of Neheim-Hüsten (City of Arnsberg). It was certified for airplanes of up to a MTOM of 5.7 t and helicopters of up to 6 t MTOM. Aerodrome elevation is 778 ft AMSL on a plateau.

The airfield was owned by a commercial enterprise which had three business jets, among others, stationed there for non-commercial company flights. One of these business jets had a MTOM of more than 5.7 t. The Bezirksregierung Münster stated that they had issued a respective exception for the operation of this airplane.

A traffic pattern had not been published for the airfield. According to the aerodrome chart published in the AIP (Fig. 3), at the time of the accident, it had one 920 m long and 20 m wide asphalt runway with the orientation 048°/228°. The elevation of the threshold of runway 23 was 762 ft AMSL. It increased within about 700 m to 794 ft AMSL and decreased again at the end of the runway to 793 ft AMSL. The aerodrome chart indicated the Landing Distance Available (LDA) with 920 m. At the time of the accident, runway 23 was in use.

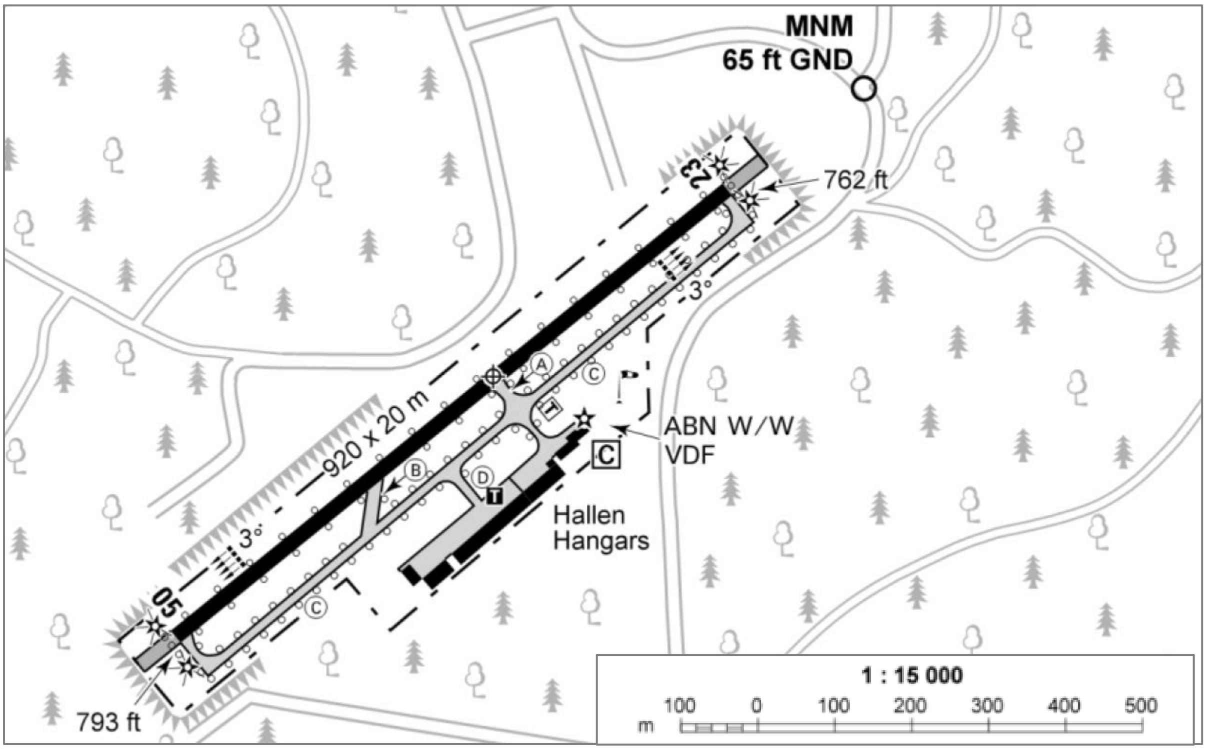

Fig. 3: Excerpt of the aerodrome chart published at the time of the accident (as of 7 June 2018) Source: AIP

1.10.2 On-Site Findings

The BFU documented the condition of runway 23 (Fig. 4) during the on-site investigation. It was determined that an asphalt strip of about 80 m length and about 20 m width was located in front of the threshold of runway 05. In front of the threshold of runway 23 there was an asphalt area of about 200 m length and 20 and 25 m width, respectively. These areas were covered with several white markings. Between the runway threshold 23 and an area of approximately 20 m x 15 m painted white, were several white centre line markings. At the north-east end of the asphalt area was another white painted area of 25 m x 10 m (Fig. 5).

The aerodrome operator stated that the markings and the yellow light metal construction at the slope in front of the asphalt area and its lighting were installed to serve as visual approach references, especially at dusk and during night flights (Fig. 5 and Fig. 6). The asphalt area had not been part of the airfield’s operating areas. The metal construction should make the steep slope more recognizable for pilots. According to the aerodrome operator, the markings were based on the example of various foreign airports.

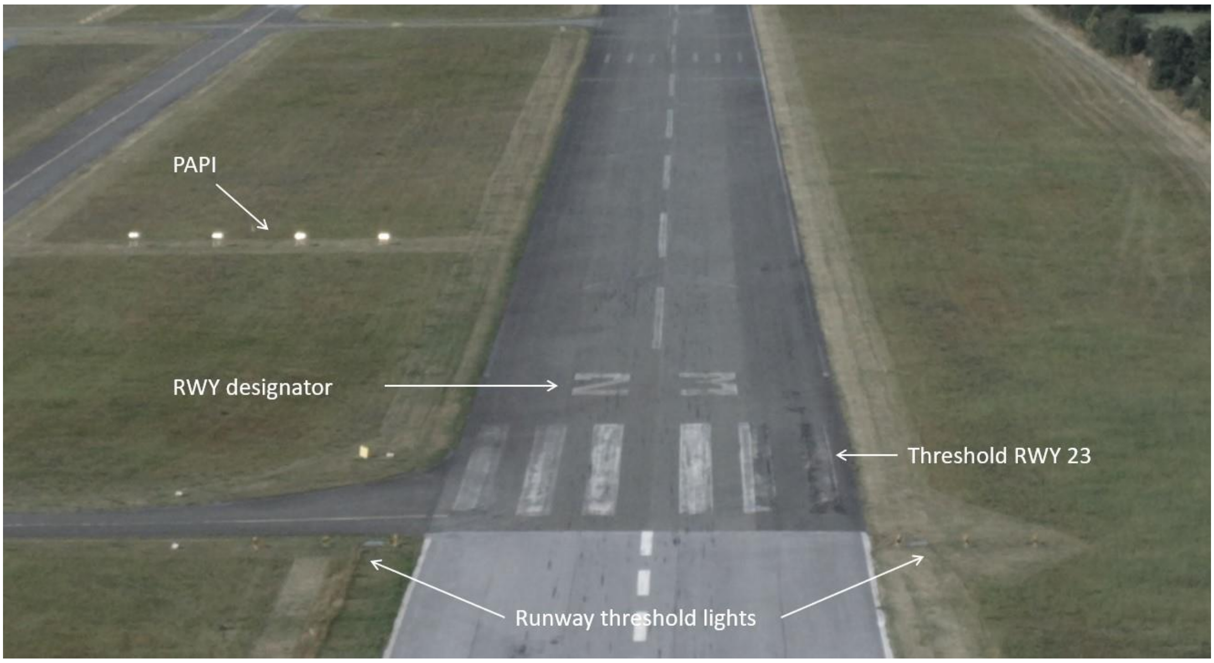

Fig. 4: Runway 23 markings and lighting (taken on 29 August 2020) Source: BFU

Fig. 5: Markings in front of runway 23 (taken on 18 September 2020) Source: Google Earth™, adaptation BFU

The pre-threshold asphalt area of runway 23 was equipped with lighting. Two non-directional lights were located at the edges of the north-east end of it. A light each was installed at the centre of the white area in 90° to the approach direction, facing the extended runway centreline. At the northern and the southern end, about half the length of the asphalt area, a light was located and directed towards the approach sector of runway 23 (Fig. 6).

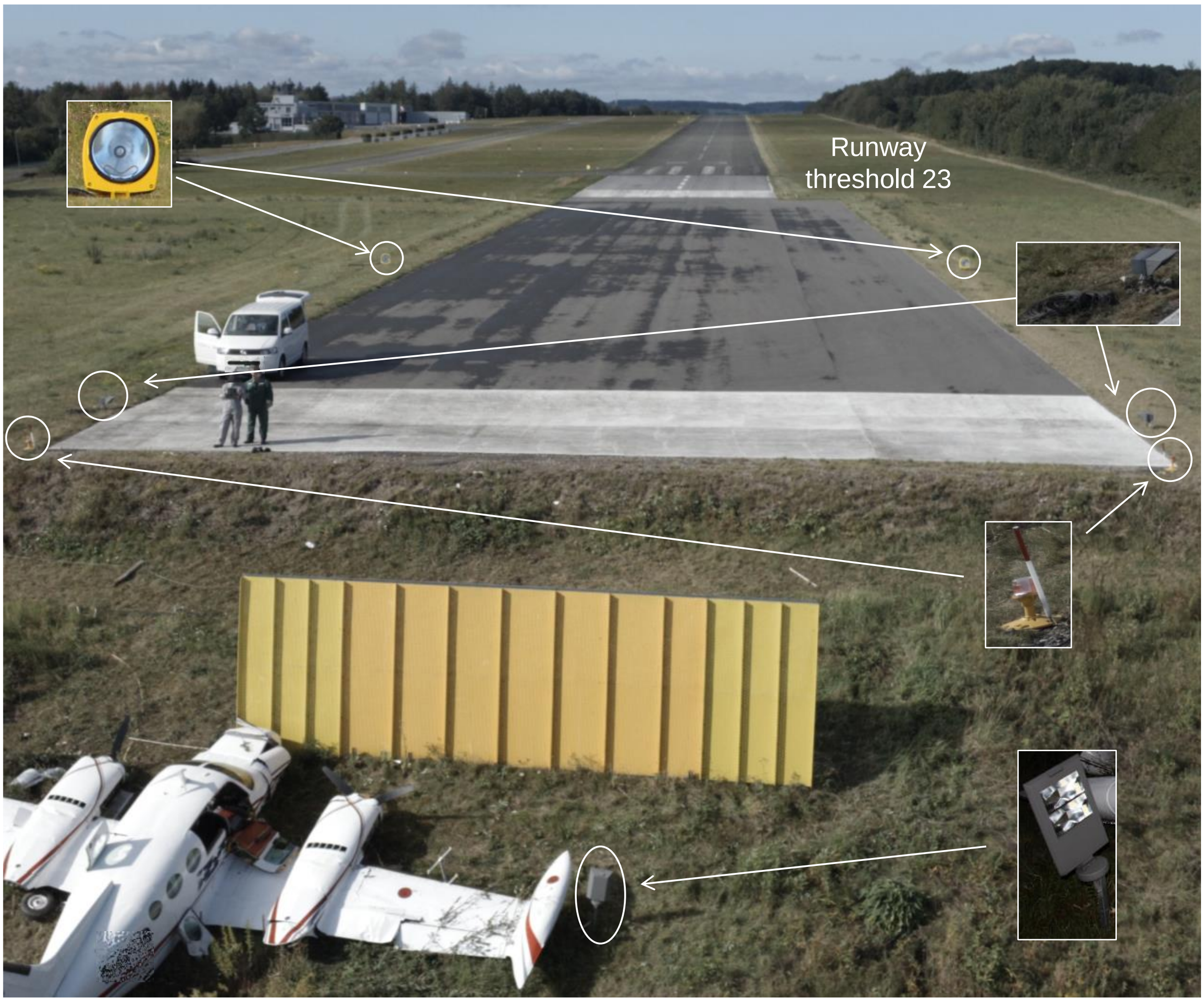

Fig. 6: Lighting in front of runway 23 and metal construction at the slope Source: BFU

1.10.3 Airfield Operating Permit

The first operating permit for the airfield was issued by the Bezirksregierung Münster in January 1970. In March 2009, the aerodrome operator applied to the Bezirksregierung Münster for amendment to the permit for the site and operation of Arnsberg-Menden Airfield. According to this application, the take-off and landing area including the safety strip was to be enlarged from 920 m x 80 m to 1,175 m x 80 m and the runway from 920 m x 20 m to 1,055 m x 25 m. On 19 December 2013, the Bezirksregierung approved this application.

The permit included several stipulations, among others:

[…]

*b. To ensure proper operation, the flight operations areas of the aerodrome are to be marked in accordance with the c*ommon principles of the federal government and the states on markings and lighting of aerodromes with visual air traffic *of 18 February 2003 (NfL I-94/03).*

[…]

1.10.4 Constructional Changes at the Airfield

After the approval was granted, the lower area east of runway 23 was filled up with soil and then asphalted. An analysis of several photos (Google Earth) of the airfield between 2013 and 2020 showed that this work was completed in 2016. The photos also showed that the pre-threshold asphalt area was initially marked with a number of white Xs. A Google Earth photo of March 2019 shows the markings later found at the time of the accident.

1.11 Flight Recorders

The aircraft was not equipped with a cockpit voice recorder or flight data recorder. These were not required by relevant aviation regulations.

The flight path of the aircraft was recorded by the air navigation service provider and made available to the BFU for evaluation purposes.

1.11.1 GPS Data Analysis of the Accident Flight

The Tablet of the pilot had recorded GPS data of the accident flight as well as of numerous other flights. The BFU analysed the data.

Fig. 7 shows the top view, the vertical profile and the ground speed of the accident flight. For comparison, the lower depiction of the vertical profile also shows the 3° PAPI approach angle.

The calculated turn radius was 500 m; considering the ground speed, this corresponds with a bank angle of 45°.

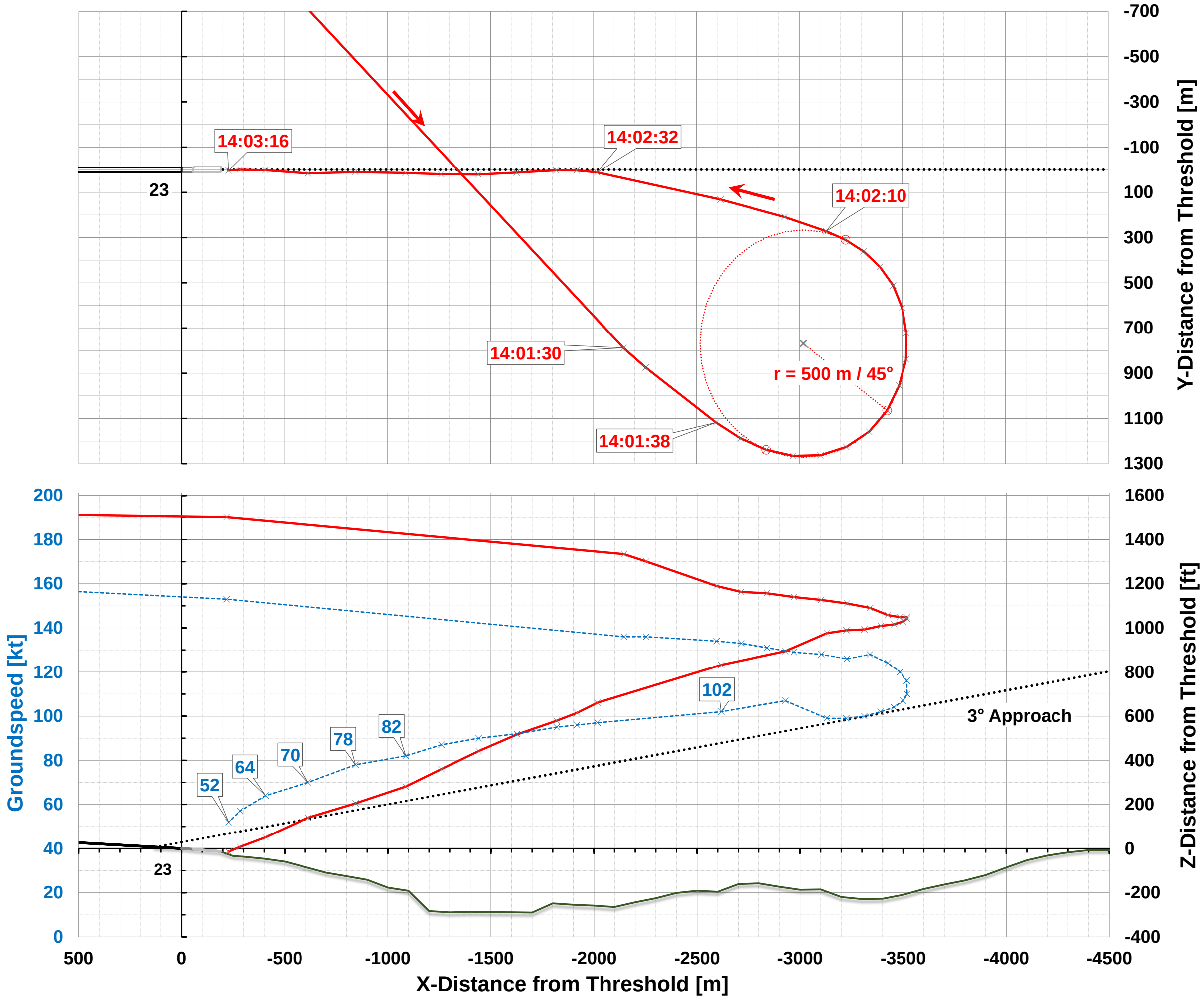

Fig. 7: Top view and vertical profile with 3° PAPI approach angle and ground speed Source: BFU

1.12.2 Analysis of other Flights

The accident flight and six other flights with landings on runway 23 of Arnsberg-Menden Airfield the pilot had conducted between April and August 2020 and which had also been recorded, showed that he had approached the airfield twice from a westerly direction, once from the north and twice each from a north-eastern and eastern direction (Fig. 8).

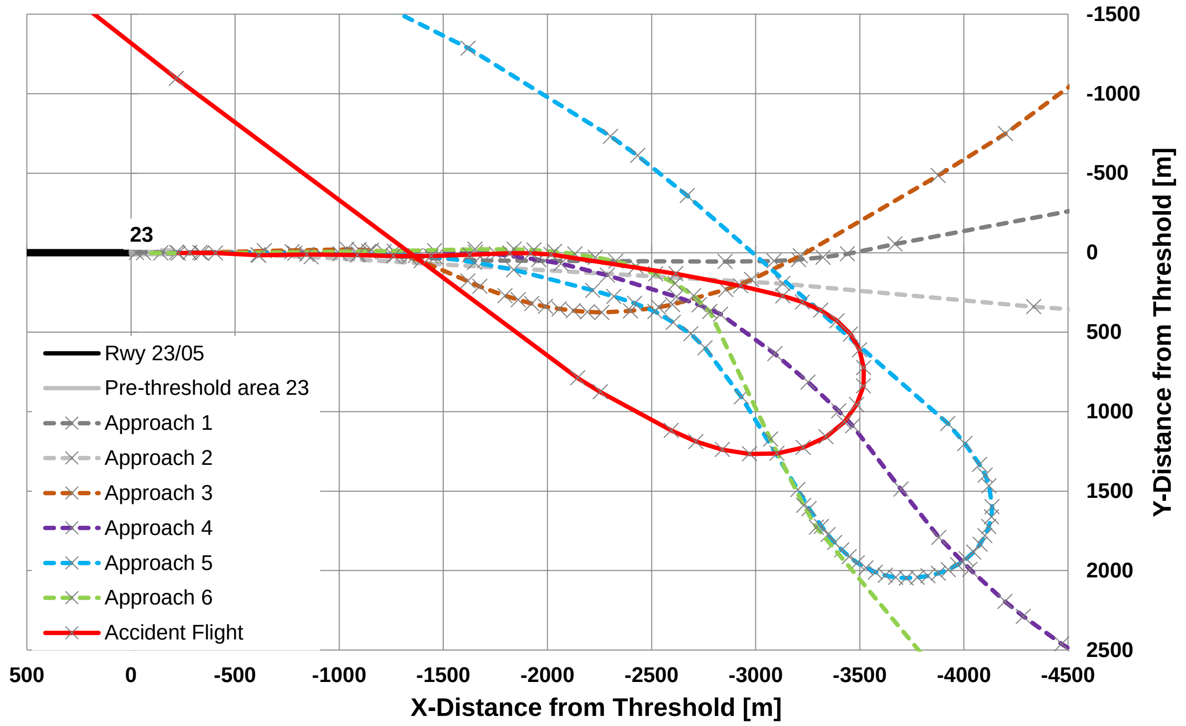

Fig. 8: Top view of the six approaches to runway 23 at Arnsberg-Menden Airfield (accident flight red)

Source: BFU

The vertical profiles of the flights show that the airplane had come short in five of them during the final approach (Fig. 9). For one of the six landings (Approach 2) it is not possible to make a statement in this regard due to a missing data point.

The pilot stated that during these flights he had used the 530 m “from the touchdown point of the extension to the taxiway in the centre of the runway” for “short landings”.

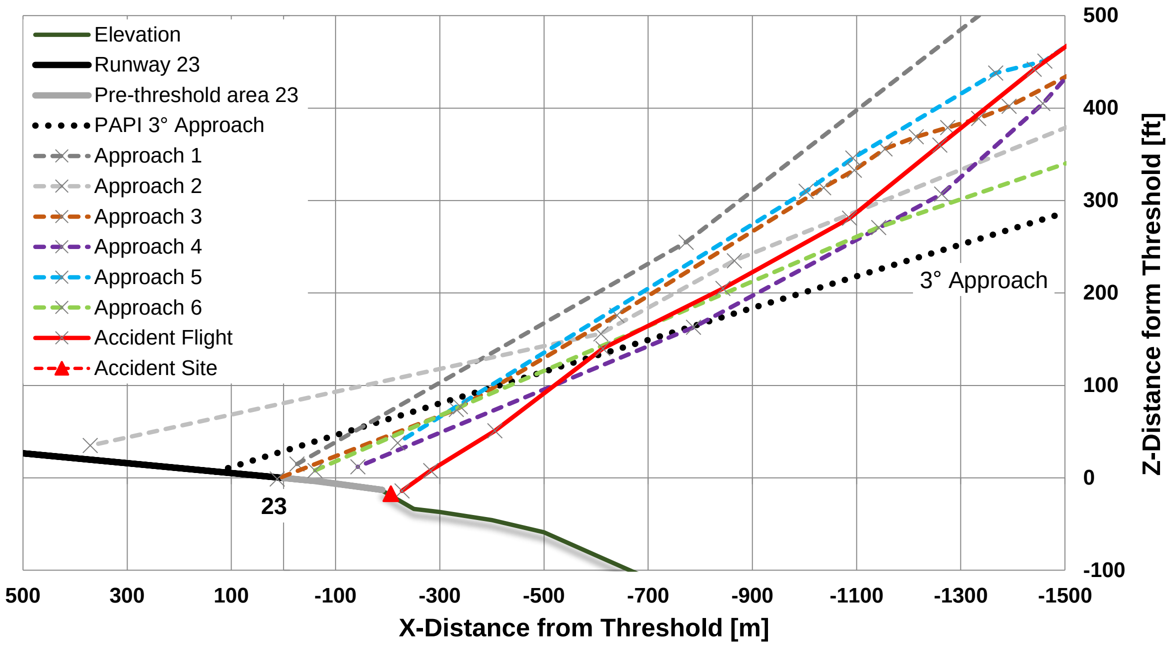

Fig. 9: Vertical profile of the six approaches to runway 23 at Arnsberg-Menden Airfield (accident flight red)

Source: BFU

For comparison, the BFU analysed recordings of landings the pilot had performed at Marl-Lohmühle, his home base, on runway 07, which is also a runway with a displaced threshold. It was determined that during all landings there, the airplane never touched down in front of the runway threshold.

1.12 Wreckage and Impact Information

The accident site was located on the extended runway centre line, about 225 m north-east of the threshold of runway 23, below the asphalt flight operation area located on a plateau on a slope rising about 15° (Fig. 10).

Fig. 10: Accident site, view to the south-west towards runway 23 Source: BFU

The aircraft had initially impacted the base of the slope with the landing gears and the fuselage's underside. After sliding uphill for about 10 m, it had come to a stop in front of a 10 m wide and about 2.5 m high yellow light metal construction. In the process it had collided with two lamps of the light metal construction and an aerodrome sign.

The fuselage underside showed substantial damage, especially the front part up to approximately the wing roots (Fig. 11). On the left propeller two blades were bent backwards and on the right one. The drive shafts of both propellers were fractured. The rotation plane of the propellers had been bent forward by about 45°. The spinners were damaged.

The landing gears were fractured. The nose landing gear had been pushed into the wheel bay. The left main landing gear strut, including the severed wheel, was lying beneath the left engine nacelle. The wheel of the right main landing gear had also been severed and was lying about 2 m behind the right engine nacelle.

Fig. 11: Damage at the front of the fuselage Source: BFU

The entire width of the left wing's upper surface up to the aileron, was fractured at about 2 m from the wing tip.

The elevator did not show any damage. The tip of the rudder including counterweight was bent to the left. The rudder trim was in the neutral and the elevator trim in the slightly nose-up position.

One of the first aiders, an aircraft maintenance engineer, stated that after he arrived at the accident site, he heard the sound of the auxiliary fuel pumps in the wing tip tanks running at normal speed. Through the open left cockpit window, he had turned off the master switch, the alternators and the magnetos. Then he had broken the window on the entry door to unlock the door from the inside. The first aider also stated that he had put the left fuel selector lever in the OFF position and switched off the Emergency Locator Transmitter (ELT). For the right fuel selector lever, this had only been possible up to an intermediate position. After the rescue personnel had arrived, he had disconnected the battery and then checked the wreckage for fuel leakages. This had not been the case.

The landing gear selector lever was in the DOWN position. The flap control lever was in position 0° and the indication in position 30°. At the barometric altimeter 1,001 hPa were selected.

The centre quadrant with the engine control levers, trim and autopilot panel was deformed and twisted (Fig. 12). The elevator trim wheel was in a slight nose-up position. Both power levers were bent left by about 60°. The left power lever was about 1 cm and the right about 3 cm away from the aft stop. The two propeller pitch control levers were about 1 cm away from the "high pitch" stop and the levers of the respective governor were at the "low pitch" stop. The two mixture control levers were about 1 cm from the aft stop (Idle Cut Off (ICO)), whereas the respective mechanisms at both engines were at the "full rich" stop.

Fig. 12: Twisted centre quadrant including engine control levers Source: BFU

In the fuel manifold valve assemblies of both engines, a small amount of fuel was found. Fuel was also found in the filters of both engine throttle and control assemblies.

During test activation after the accident, the stall warning horn and the electrical drive of the flaps functioned properly.

Approximately 60 l fuel were drained from each of the wing fuel tanks.

1.13 Medical and Pathological Information

The occupants suffered severe injuries due to impact forces. Each person suffered a combination of injuries of which already one or their combination is life-threatening (multiple trauma). Leading injury types were complex vertebral body fractures (bursting fractures, chance fractures) in the transition between the thoracic spine and the lumbar spine in terms of flexion, -distraction trauma. In one case, this resulted in incomplete paraplegic symptoms (Conus Cauda Syndrome) as neurological deficiency. Additionally, two occupants fractured their sternum, one their hip joint. Both occupants in the front seats suffered rib fractures resulting in Pneumo- and Hematothoraces which required further treatment. In the area of the facial bones, they suffered large and complex injuries of bones and soft tissue, partially with cranial nerve damage. Furthermore, both occupants in the front seats fractured their ankle joint and metatarsus, respectively.

1.14 Fire

There was no evidence of fire in flight or after the impact.

1.15 Survival Aspects

At the airfield, several people had become aware of the accident and driven to the accident site via the flight operations areas. According to the statement of the Flugleiter, they had been at the site within two minutes, at 1605 hrs.
Up until the rescue services arrived at 1628 hrs, the first aiders provided first aid, removed the aft passenger seats and cut lateral accesses into the fuselage to facilitate the rescue of the persons in the cockpit.

After recovery, all occupants were transported to various hospitals by Helicopter Emergency Medical Services.

The Flugleiter stated that after the accident he received a phone call from Search and Rescue (SAR), because they had picked up the ELT signal of the accident airplane.

1.16 Tests and Research

Not applicable.

1.17. Organisational and Management Information

1.17.1 Approach Procedure of the Pilot

The pilot stated that during landing he usually approaches with Blue Line Speed, i.e. 117 mph (102 KIAS). He generally puts flaps to 30° and shortly before touch-down he would extend them fully if required. His reason was the high drag of the airplane's split flaps.

He, as VFR pilot, usually flew an approach with a steeper approach angle than 3°. If an aerodrome had an approach angle indication such as a PAPI, he only used it for control purposes, i.e. to not go below the PAPI approach angle.

1.17.2 Regulatory Oversight over Airports

The Ministry of Transport was the highest aviation authority in the Federal State North Rhine-Westphalia and responsible for oversight of the airports Dusseldorf, Cologne/Bonn and Münster/Osnabrück. Oversight over all other airports had been assigned to the Bezirksregierungen (District Council).

The Bezirksregierung Münster was responsible for approval and oversight over the airports in the Regierungsbezirken (District) Arnsberg, Detmold and Münster.

The Bezirksregierung Münster was responsible for:

- 4 Airports
- 11 Airfields
- 19 Special Airfields
- 15 Glider Fields
- 21 Helicopter Fields
- 9 Balloon Take-off Sites
- 10 Ultralight Fields
- Approx. 140 Model Fields

At the four airports, local Aviation Supervision Offices were established, while the other airfields and sites were attended to in the scope of supra-local supervision. The tasks of the supra-local supervision included regular on-site inspections of local airports. According to the Bezirksregierung Münster, each of the 11 airfields was visited on average about 30 times per year by the supra-local Aviation Supervision Office.

During these inspections, the aerodromes are checked to ensure that the condition complies with the approval. Inspected were the conditions of the runway and the surrounding safety strips, the runway markings, obstacle clearance, the signal area, the wind sleeve condition and the provision of fire and rescue services, among other things. However, not all of these items were inspected during each visit, the attention was also on flight operations, aircraft and their crews.

1.17.3 Supervision of Arnsberg-Menden Airfield

According to the Bezirksregierung Münster, in the scope of supervision of Arnsberg-Menden Airfield, it had been inspected about three times per month.

The supra-local supervision had been at the airfield 14 days prior to the accident. The orientation of the landing T had been objected to during this visit.

The supra-local supervision had known about the markings and lighting of the pre-threshold asphalt areas, but had not objected to them because they were outside the designated flight operations areas. According to the Bezirksregierung Münster, these pre-threshold asphalt areas were only intended as backtrack area for pilots based at the airfield. The lighting of the pre-threshold area served to mark the slope. The structural condition present at the time of the accident corresponded with a preliminary state in that the extension towards the east was already 25 m wide but the existing runway still had the original width of 20 m. The threshold for runway 23 including PAPI was at the original position. At the time of the accident, the extension area did not have an aeronautical dedication and at best the character of a paved strip. It was decided not to install runway markings.

The light-metal construction at the slope and its lighting had not been objected to by the Bezirksregierung Münster because it was located outside the safety areas of Arnsberg Airfield and below the slope edge.

1.18 Additional Information

1.18.1 Airport Markings - National Regulation

The German Language Publication for Aviation (NFL I 94/03) Common principles of the federal government and the states on markings and lighting of aerodromes with visual air traffic (of 18 February 2003) stipulated the markings of aerodromes in Germany based on ICAO Annex 14.

It stipulated and described in detail the markings for paved runways and pre-threshold areas (Fig. 13), among other things. Thus, a displaced threshold was to be marked with a white strip running across the runway and the area in front with arrows.

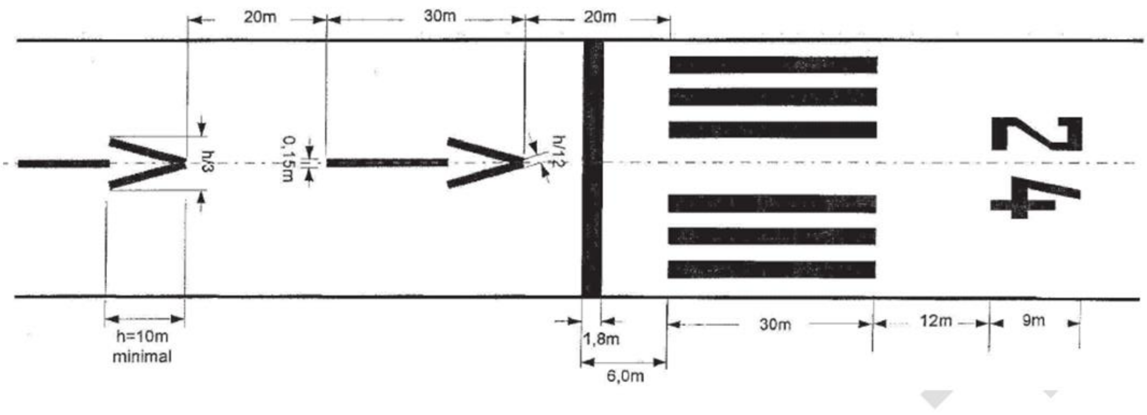

Fig. 13: Runway marking with displaced threshold in accordance with NFL I 94/03 Source: NfL

As a result of the investigation of a similar accident in Werneuchen (Brandenburg,) in 2002 (State File Number AX002-02), the BFU determined inadequate markings of the operations and non-operations areas as one of the systemic causes.

1.18.2 Human Factors

1.18.2.1 Information Acquisition and Processing

While flying, pilots continuously acquire a lot of different information (visual, acoustic, haptic or vestibular), filter and process them to finally translate them into actions. By taking in information, interpreting it and anticipating the future, pilots form a mental model of the flight situation (e.g. about flight attitude, course, position, especially in relation to obstacles or other aircraft on possible collision course, weather phenomena and aircraft characteristics as well as their own capabilities) to which they adapt their behaviour (“situational awareness”[4]). At any point during information processing, errors can occur.

[4] Endsley, M. R. (1995a). Measurement of Situation Awareness in Dynamic Systems. Human Factors, 37(1), 65-84. und Endsley, M. R. (1995b). Towards a Theory of Situation Awareness in Dynamic Systems. Human Factors, 37(1), 32-64.

So-called filters or limiting factors determine how well pilots recognise and process environmental information and how large the difference is between the actual and the perceived reality[5], respectively, e.g.:

- Physical filters, such as noise, blinding sunlight or visual obstructions due to aircraft parts.
- Perceptual filters, such as human perception thresholds especially during night flights or when estimating distances and speeds of oncoming aircraft
- Cognitive filters, such as experience, age-related limitations, expectations or motives, attention distribution, distraction or mental overload, especially when working on several tasks simultaneously - Multitasking[6] [7]

When important information is not or wrongly included into the mental model of the situation or is misinterpreted, e.g. because relevant cues are overlooked, perceptual errors occur. This can in turn result in erroneous action planning or goal setting. Analyses of road traffic accidents show that most accidents are caused by perception and decision errors [8] [9].

Pilots develop a mental image (model) of a coherent final approach from all former approaches and landings, which they unconsciously recall during each landing and apply to the current landing procedure. Usually, pilots use visual cues to determine if an approach is above, below or on the familiar glideslope. These include the apparent shape and size of the runway, the distance and size of runway markings, the relative size of objects in the vicinity, such as the wind sleeve, vehicles and buildings, and the way how objects move in relation to each other and the aircraft. Pilots constantly compare these and other cues with their mental model to determine if the approach is proceeding as expected. If the current approach deviates from the model, pilots make

[5] 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.

[6] Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ, USA: Prentice-Hall.

[7] Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159-177.

[8] National Highway Traffic Safety Administration (NHTSA) (1995). *Synthesis report: examination of target vehicular crashes and potential ITS countermeasures* (Report No. DOT HS 808 263). Washington, DC, USA.

[9] Vollrath, M., Briest, S., & Drewes, J. (2006). *Ableitung von Anforderungen an Fahrerassistenzsysteme aus Sicht der Verkehrssicherheit.* Berichte der Bundesanstalt für Straßenwesen, Fahrzeugtechnik, F 60. Bremerhaven: Wirtschaftsverlag NW.

appropriate adjustments, e.g. by correcting the power settings, the flight attitude or heading, changing the landing configuration or possibly perform a missed approach.[10]

An unusual runway width, ascending/descending terrain, irregular terrain and other characteristics of the airport, but also lighting conditions, weather conditions and aerodrome lighting can interfere with the visual perception and lead to illusions [11] [12]. For example, an ascending runway and terrain ascending ahead of the runway can give pilots the visual illusion of approaching too high or having too steep an approach angle. This may cause pilots to possibly increase the rate of descent or not notice an approach angle that is actually too shallow. Therefore, it is recommended to use additional cues for orientation, e.g. a PAPI as well as mental preparation and understanding of these possibly occurring circumstances to succumb less to visual illusions [13].

1.18.2.2 Attention Allocation

Since the available offer of information outside and inside the airplane exceeds the capacity limits of the visual system, pilots always have to select and direct their attention to the actually relevant objects and sections of the perceptual field, respectively. According to the SEEV Model (Salience, Expectation, Effort, Value) by Wickens and colleagues[14], attention allocation is either involuntarily/stimulus-driven (bottom-up, e. g. stall warning horn) or deliberately/pilot-driven (top-down, e. g. consciously scanning the cockpit instruments and airspace). The salience of a stimulus and the effort required for information acquisition determine the stimulus-driven processing of information, whereas the pilots' expectation or the value attributed to certain information influence pilot-driven processing.

Objects can stand out from the background through certain properties, such as colour, shape or movement, and thus catch people's attention more quickly. These insights are primarily used for the user-oriented design of instruments and warning systems. Since a stall is a very critical flight state which requires immediate attention allocation and reaction from pilots, stall warnings often use very striking warning sounds to

[10] Watson, D. (XXXX). Illusions during the approach and landing. http://www.pilotfriend.com/aeromed/medical/app_landing.htm#r, 14.12.2022

[11] Flight Safety Foundation (FSF) (2000). *FSF Approach- and Landing Accident Reduction (ALAR) Briefing Note, 5.3 – Visual Illusions* (August-November 2000).

[12] AOPA (2022). AOPA Safety Letter – Fehler beim Landen (April, Heft Nr. 60). https://aopa.de/wp-content/uploads/ASL_FEHLER_BEIM_LANDEN_Nr_60.pdf

[13] Airbus (2005). Flight Operations Briefing Notes. Human Performance. Visual Illusions Awareness. https://www.skybrary.aero/bookshelf/books/177.pdf

[14] Wickens, C. D., Goh, J., Helleberg, J., Horrey, W. & Talleur, D. A. (2003). Attentional models of multi-task pilot performance using advanced display technology. Human Factors, 45(3), 360-380.

convey increased urgency and really reach the pilot by means of the auditory sensory channel (hearing) instead of the already highly demanded visual channel (seeing)[15].

Besides these positive and intended effects, certain design characteristics can also have negative and distracting effects. For example, if non-flight-relevant or supposedly relevant objects (such as runway markings in front of the threshold which are significantly more salient and better visible from the aircraft than the threshold itself) draw the pilots' attention to such an extent that they neglect other important environmental stimuli and cues (such as the actual threshold or PAPI). Especially in demanding situations, like during landing, tunnel-like attention allocation can occur with often problematic effects so that for instance warnings are not perceived or the visual scanning of the instruments and airspace is neglected.

1.18.2.3 Potential Influences of Aging on Flying Skills

With the natural ageing process of humans, factors of psychophysical performance important for flying often deteriorate[16], e. g.

- Perceptual impairments, such as reduced hearing (radio communications) and sight (limited peripheral vision, impaired near and night vision and difficulties to quickly change the focus)
- Musculoskeletal problems: Loss of strength, reduced mobility, earlier onset of fatigue in the cockpit due to heat and turbulences, difficulties with fine motor skills, e.g. pushing of small buttons
- Increased Fatigue: Sleep environment, work schedule, medical conditions, jetlag, etc. affect fatigue more strongly
- Memory: Problems in remembering altitudes, transponder codes and radio frequencies (additionally influenced by fatigue)
- Problems with attention distribution, information processing, problem solving, decision making and psychomotoric coordination

[15] AOPA (2014). AOPA Safety Letter – Überziehen (Februar, Heft Nr. 12). https://aopa.de/wp-content/uploads/12_ASL_Ueberziehen.pdf

[16] AOPA (2018). AOPA Safety Letter – Ältere Piloten (Oktober, Heft Nr. 39). https://aopa.de/wp-content/uploads/39_ASL_Aeltere_Piloten.pdf

In general, age-related changes are individually very different, proceed variably and are difficult to pin on a certain age[17] [18].

Investigations and findings from road traffic show that above all impaired vision, problems with attention distribution and general slowdown, especially with decision making, planning and execution of actions, influence the accident risk of older drivers[19]. Similarly, various aviation studies reviewed by the Aircraft Owners and Pilots Association (AOPA) [20] [21] show that accident rates reduce with increasing total flying experience, but older pilots in particular have higher accident rates with low current flight time (mainly with less than 50 hours per year). Regardless of the current age, it is generally the case that accident rates increase with age when pilots have less than 1,000 hours of total flying experience and less than 50 hours of flight time per year.

Pilots can counteract various age-related changes to a certain degree with (long-time) experience, training and behavioural changes. For example, they can choose shorter legs or flights, plan more time for them (mainly with IFR flights), take co-pilots along for support, avoid high traffic airspaces and time periods, choose good and calm flying weather or also adjust personal minima to the current capabilities[22]. In addition, pilots can also continuously attempt to maintain their skills, for example by training demanding situations or tasks intensely, improving their equipment for more comfort and safety, or by increased use of technical as well as social support options.

1.18.3 Stabilised Approach

In a study on reducing approach and landing accidents, the Flight Safety Foundation determined (2000[23]) that non-stabilised approaches (e.g. too low/slow or too high/fast approaches) often contribute to approach and landing accidents. In particular, pilots experience difficulties handling the aircraft (e.g. control of airspeed, altitude and rate of descent), attempt to comply with demanding air traffic control clearances, hasten

[17] Schlag, B. (2008). Leistungsfähigkeit und Mobilität im Alter. Köln: TÜV Media.

[18] Tsang, P. S. (1997). Age and pilot performance. In R. A. Telfer & P. J. Moore. Aviation Training: Learners, Instruction and Organization, edited by. Aldershot: Avebury Aviation, S. 21-39.

[19] Vollrath, M. & Krems, J. (2011). Verkehrspsychologie. Ein Lehrbuch für Psychologen, Ingenieure und Informatiker. Stuttgart: Kohlhammer.

[20] AOPA (20XX). Aging and the general aviation pilot. Research and Recommendations. https://www.aopa.org/-/media/Files/AOPA/Home/Pilot-Resources/Safety-and-Proficiency/Physiology/1302agingpilotreportpdf, 30.11.2022

[21] https://www.aopa.org/training-and-safety/online-learning/safety-spotlights/aging-gracefully

[22] www.airsafetyinstitute.org/vfrcontract

[23] Flight Safety Foundation (FSF, 2000). *Approach and Landing Accident Reduction (ALAR) Tool Kit. 7.1 Stabilized Approach.* Flight Safety Digest, August-November. https://flightsafety.org/toolkits-resources/past-safety-initiatives/approach-and-landing-accident-reduction-alar/alar-briefing-notes-in-english/

the approach, use automation systems improperly or have to manage adverse wind conditions. The study recommends that pilots take enough time to plan, prepare and perform a stabilised approach.

In a study on stabilised approaches, the IATA (2017[24]) indicates that approach and landing accidents are often preceded by a poorly executed, non-stabilised approach as well as by the omission to abort the approach. At the same time, very short decision times, high workload and little manoeuvre options characterise the approach phase and especially the final approach. Among many other factors, loss of situational awareness, poor visibility and visual illusions, insufficient monitoring by the pilots and excessive altitude and/or airspeed (inadequate energy management) at the beginning of an approach contribute to non-stabilised approaches.

A stabilised approach provides the foundation for a good landing and allows pilots to benefit from optimal conditions to flare, land and stop the aircraft in a timely manner. The goal of a stabilised approach is to reach a focussed aiming point on the runway with a constant glideslope and approach speed. Therefore, pilots have to bring the airplane into the correct configuration, flight attitude, airspeed, thrust and power setting, rate of descent as well as into the correct position over the runway. All these stabilisation criteria should be within a certain range throughout the final approach (i. e., depending on the aircraft type, meteorological conditions and acceptable safety margins). Stabilised approaches reduce the pilots' workload, help them to recognise potential deviations early and offer clear indications for the decision to initiate a go-around.

The Flight Safety Foundation[25] issued a Tool Kit with recommendations for visual approaches. Thus, pilots should avoid a continuous turn towards the runway threshold and not exceed a bank angle of 30° when turning into the base leg. Before reaching the final approach (depending on the distance to the threshold) pilots should extend the flaps, anticipate crosswind effects and start to adopt final approach speed. It is recommended that visual references such as PAPI or tress and buildings surrounding the airport be used to estimate the glideslope. Once 500 ft AAL are reached, the

[24] International Air Transport Association (IATA), International Federation of Air Line Pilots' Associations (IFALPA), International Federation of Air Traffic Controllers' Associations (IFATCA) & Civil Air Navigation Services Organisation (CANSO, 2017). Unstable Approaches: Risk Mitigation Policies, Procedures and Best Practice. https://canso.org/publication/unstable-approaches-risk-mitigation-policies-procedures-and-best-practice-third-edition/

[25] Flight Safety Foundation (FSF, 2000). *Approach and Landing Accident Reduction (ALAR) Tool Kit. 7.4 Visual Approach.* Flight Safety Digest, August-November. https://flightsafety.org/toolkits-resources/past-safety-initiatives/approach-and-landing-accident-reduction-alar/alar-briefing-notes-in-english/

airplane should be aligned with the runway (wings level) and final approach speed constant. Pilots should keep the aiming point in sight to avoid inadvertently descending below the final approach path.

The Flight Safety Foundation[26] recommends, for example, that the aircraft be stabilised at 1,000 ft AAL in IMC and 500 ft AAL in VMC and specifies the following criteria:

> *1. The aircraft is on the correct flight path;*
>
> *2. Only small changes in heading/pitch are required to maintain the correct flight path;*
>
> *3. The aircraft speed is not more than V REF + 20 knots indicated airspeed and not less than VREF ;*
>
> *4. The aircraft is in the correct landing configuration;*
>
> *5. Sink rate is no greater than 1,000 feet per minute; if an approach requires a sink rate greater than 1,000 feet per minute, a special briefing should be conducted;*
>
> *6. Power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual;*
>
> *7. All briefings and checklists have been conducted;*
>
> *8. Specific types of approaches are stabilized if they also fulfill the following: instrument landing system (ILS) approaches must be flown within one dot of*
>
> *the glideslope and localizer; a Category II or Category III ILS approach must be flown within the expanded localizer band; during a circling approach, wings should be level on final when the aircraft reaches 300 feet above airport elevation; and,*
>
> *9. Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.*
>
> *An approach that becomes unstabilized below 1,000 feet above airport elevation in IMC or below 500 feet above airport elevation in VMC requires an immediate go-around.*

[26] Flight Safety Foundation (FSF, 2000). *Approach and Landing Accident Reduction (ALAR) Tool Kit. 7.1 Stabilized Approach.* Flight Safety Digest, August-November. https://flightsafety.org/toolkits-resources/past-safety-initiatives/approach-and-landing-accident-reduction-alar/alar-briefing-notes-in-english/

Even though the concept of stabilised approaches has evolved and become established in commercial flight operations, it is recommended for use by all pilots (General Aviation). The European Union Aviation Safety Agency (EASA, 2020)[27] and AOPA (2000)[28] are generally in favour, because stabilised approaches reduce the workload for pilots, improve their situational awareness, and help them to decelerate the aircraft for landing in time. As a result, pilots are provided with more time to process information and to perform adequately without reaching their own limits or becoming overwhelmed. Similarly, a stabilised approach allows for more capacity to recognise potential changes such as wind direction/speed or unexpected events and react appropriately. The FAA also recommends that General Aviation use the criteria for stabilised approaches and indicates that an approach with constant speed and rate of descent represents the lowest workload for pilots. If the approach is not stabilized at 500 ft AAL (1,000 ft for IFR flights) it is recommended to go-around[29].

1.18.4 Occupant Restraint Systems – Energetic Consideration

Even today, different occupant restraint systems can still be found in the aircraft types of the General Aviation. In older aircraft these mostly consisted of lap belts, the newer models have multi-point or shoulder harnesses, partially with airbags. In 1969, the FAA stipulated for US registered aircraft in the framework of the Amendments 23-7 to Part 23 in Chapter 23.785: "[…] (g) Each occupant must be protected from head injury by – (1) a safety belt and shoulder harness that will prevent the head from contacting any injurious object […]." For aircraft which received type certificate before 14 September 1969 it stated: "For those aircraft owners who would like to install shoulder harnesses in their own aircraft, FAA AC No. 43, 13-2, Chapter 9, Shoulder Harness Installations, contains the information necessary for an acceptable method of installation."[30] The AC No. 43, 13-2, Chapter 9 described, among other things, that the momentum distribution on the harness should dissipate 60% of the generated energy through the shoulder straps and 40% through the lap straps and that the harness had to be able to effectively protect occupants against forces of up to a maximum of 9 g

[27] European Union Aviation Safety Agency (EASA, 2020). Sunny Swift: Stabilized approaches (Issue 23). https://www.easa.europa.eu/downloads/116015/de

[28] AOPA (2000). The Stabilized Approach – Just say no to unwieldy ATC requests on final. https://www.aopa.org/news-and-media/all-news/2000/november/pilot/the-stabilized-approach

[29] Federal Aviation Administration (FAA, 2020). Fly Safe: Prevent Loss of Control Accidents. https://www.faa.gov/newsroom/fly-safe-prevent-loss-control-accidents-35?newsId=95378

[30] Federal Aviation Regulations; Amendment 23-7 to Part 23, Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes (effective: September 14, 1969)

horizontally. For aircraft types certified prior to September 1969, this value had to be increased by a factor of 1.15.

FAR Part 23, Sec.23-561 described that an aircraft had to be designed in a way that it effectively protects its occupants against the following forces in the event of an emergency landing: 9 g horizontally forward, 1.5 g laterally, 6 g vertically positive and 3 g vertically negative.

The National Transportation Safety Board (NTSB, 1985) analysed 500 accidents with General Aviation aircraft as part of the „General Aviation Crashworthiness Projects“[31]. They concluded that the use of shoulder harnesses would have prevented 88% of all severe and 20% of all fatal injuries. The respective Safety Recommendations A85-122 to 125, addressed to FAA, among others, mandated the installation of shoulder harnesses for all seats in General Aviation aircraft types, certified after 12 December 1986. Furthermore, they stated as an approximation, that due to the occurring energies survivable accidents in General Aviation occurred between 45 kt at 90° impact angle, 60 kt at 45° impact angle and 75 kt at 0° impact angle.

Already in 1952, De Haven and employees examined retrospectively the occurrence, the distribution and the injury severity of 800 General Aviation accidents survivors.[32] They concluded that both the most life-threatening and the most frequent injuries occurred primarily in the area of the head and chest, which was caused by the fact that the occupants, who were only secured with lap belts, performed a jack-knife-like forward, backward movement with their upper bodies and the pelvis as the lateral axis of rotation, due to the forces occurring during the impact (Fig. 14). Thus, head and upper body collided with cockpit parts. The rotational movement overloaded individual vertebral bodies in the transition between the thoracic spine, which is relatively rigid due to the thorax, and the flexible lumbar spine causing these vertebral bodies to compress and fracture at the front or rear edges. If this fractured vertebral body widens geometrically this can lead to compression of the spinal cord located in the immediate vicinity of the spinal canal with neurological failure including paralysis (Fig. 15).

[31] NTSB (1985). General Aviation Crashworthiness Project: Phase Two – Impact Severity and potential injury prevention in general aviation accidents; NTSB/SR-85/01.

[32] DeHaven, H. (1952). The Site, frequency and dangerousness of injury sustained by 800 survivors of light plane accidents. Dept. of Public Health and Preventive Medicine, Cornell University Medical College.

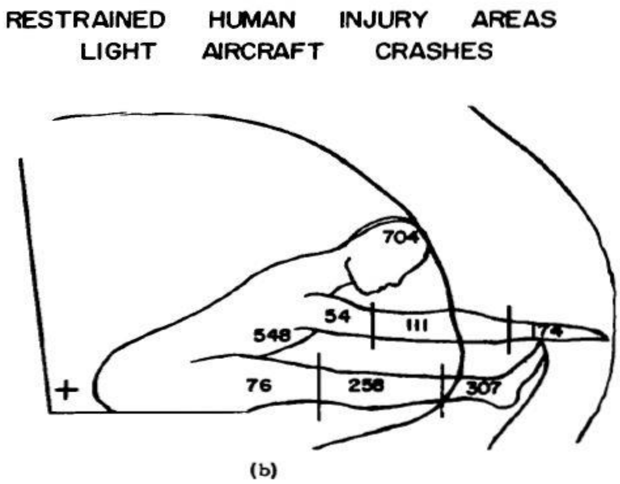

Fig. 14: Movement of an occupant secured with a lap belt during impact and number of occurring injuries per body area Source: De Haven et al. (1952)

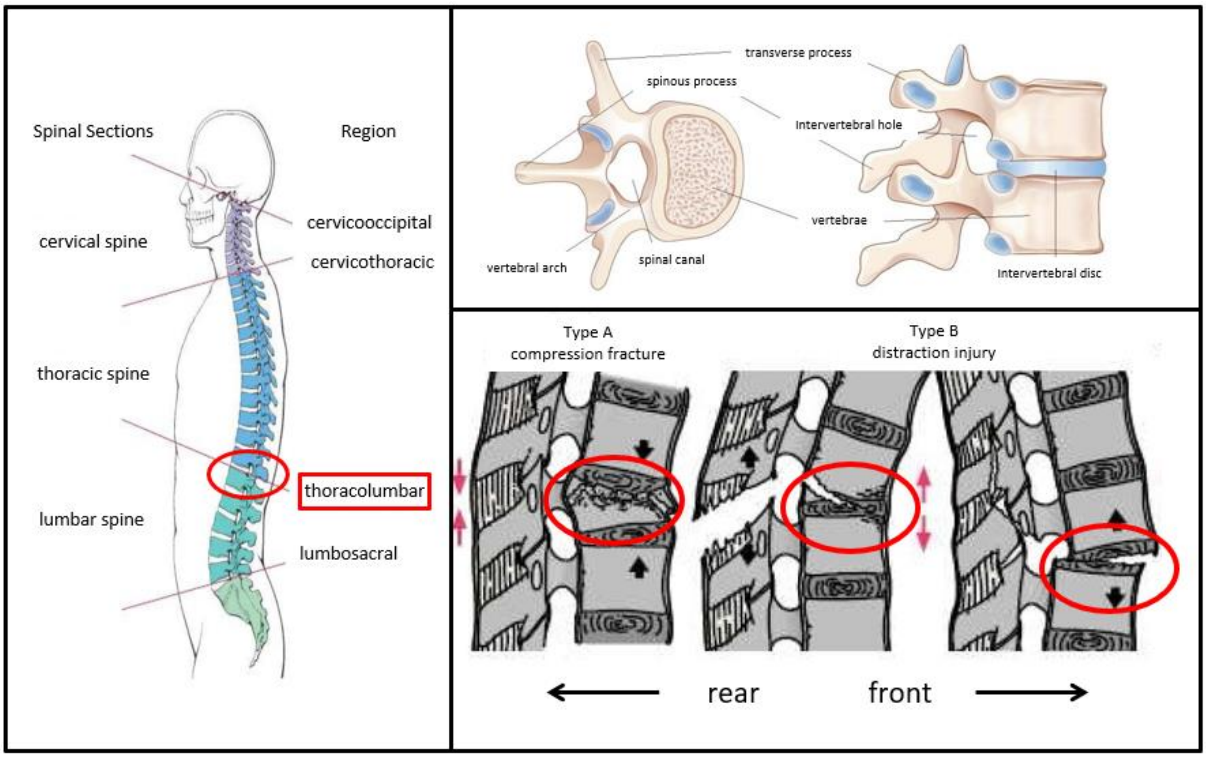

Fig. 15: Anatomy of the spine and vertebral bodies; compression and distraction fractures
Source: Niedhard und Pfeil (2003), Thieme Verlag; Eysel und Fürderer (2004), Thieme Verlag

The analysis of recorded flight data, witnesses' observations at the airport and the aircraft damage showed that the airplane had impacted the ascending terrain with a high angle of attack and a high positive pitch angle. Main landing gear and fuselage parts of the aft door frame impacted first (Fig. 16). This created an additional pitching moment of the entire airframe at the time of impact which was transferred to the occupants and intensified the jack-knife-like movement of the occupants secured with lap belts described above.

For further evaluation of the forces that occurred during the impact, the BFU roughly interpolated them for the horizontal and vertical components. The results were about 6 g for horizontal and about 2.5 g for vertical components.

In 1972, the FAA published an Aerospace Medicine Tec Report with the title „The benefits of the use of shoulder harness in general aviation aircraft“ (FAA-AM-72-3). They concluded that an aircraft occupant adequately secured with harnesses tolerates acceleration forces of 30 to 40 g in the longitudinal axis of the aircraft and up to 20 g laterally without sustaining serious injuries. The authors concluded: “It is concluded that if shoulder harnesses were installed in general aviation aircraft, considerable benefit to the users of these harnesses would accrue.”

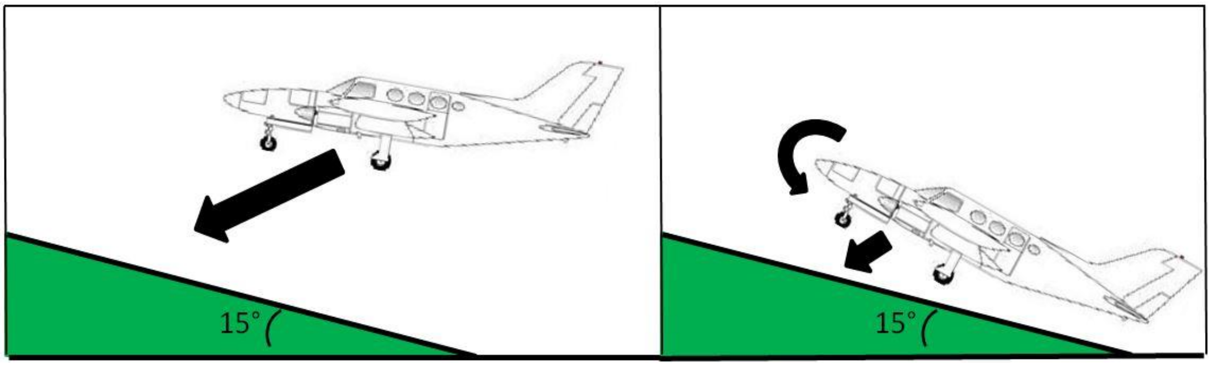

Fig. 16: Schematic depiction of the airplane’s impact and the resulting pitching moment of the fuselage

Source: BFU

In 2018, Ekman und Debacker published an article on the survivability of accidents involving commercially operated transport aircraft[33]. They established the CREEP acronym to simplify the assessment of survivability. The letters stood for the following factors influencing the survivability of an accident with a transport aircraft:

- C = CONTAINER (was sufficient survival space physically maintained around the occupants within the airframe)

[33] Ekman, S. K. & Debacker, M. (2018). Survivability of occupants in commercial passenger aircraft accidents. *Safety Science, 104:* 91-98.

- R = RESTRAINT (was the occupant strapped in and what type of belt was used)
- E = ENVIRONMENT (was the environment in which the accident occurred survivable (climactic, geographical, political))
- E = ENERGY ABSORPTION (which impact forces did the occupants experience and how were they distributed)
- P = POSTCRASH CONDITIONS (was there a fire, how long did it take for rescue services to arrive, how was the medical infrastructure)

Even though this assessment algorithm was developed for use with transport aircraft it also allows the assessment of survivability of General Aviation accidents.

In 1993, the Air Accident Investigation Authority at the LBA, the predecessor of the BFU, published a flight accident information[34] with the title “Schultergurte können Lebensretter sein” (Shoulder belts can be lifesavers") for which various accidents were analysed. Among other things, this publication recommended pilots and aircraft owners to use the existing shoulder harnesses and to consider the installation of them if there were none.

1.19. Useful or Effective Investigation Techniques

Not applicable.

[34] https://www.bfu-web.de/DE/Publikationen/Flugsicherheitsinformationen/Berichte/V110%20-%20Flugunfall-info%20Schultergurte.pdf?__blob=publicationFile&v=1

2. Analysis

2.1 General

The traces on the wreckage and the accident site show that the aircraft impacted the ground without significant bank angle in descent with very slow horizontal speed. The damage on the airplane also shows that it had a significant upward pitch angle at the time of impact with the ascending slope. This flight attitude corresponds with a stalled flight.

The investigation did not reveal any evidence of accident-relevant technical deficiencies in the aircraft. The fact that the stall warning system still functioned after the accident indicates that it is highly likely that it was functioning prior to the accident.

The rearward position of the two power and propeller control levers and of the two mixture control levers did not reflect the condition prior to the accident but is the result of the deformation of the quadrant during the impact of the aircraft and the impact of the occupants. This is evident from the findings on the governor and the mechanics of the mixture control of both engines as well as the fuel found directly on the engines.

2.2 Pilot Actions

The available flight path data show that the pilot crossed the extended runway centre line of runway 23 with eastern heading and then performed a teardrop turn towards the final approach, instead of flying a normal final approach via the downwind and base legs. This personally chosen approach placed a much greater demand on the pilot's performance capabilities than a standard traffic pattern. For the control of the aircraft, the pilot still had to decrease speed considerably within a short time period, adjust the power to the respective configuration changes, trim the aircraft accordingly and simultaneously control the teardrop turn radius so that he could hit the extended runway centre line.

The pilot's statement and the findings on the wreckage show that he had not fully extended the flaps on final approach, but only to about 30°. This configuration resulted in slightly less drag and a stall speed which was about 3 kt higher.

The radar and GPS data analysis shows that during final approach, about 1,500 m prior to the threshold, the airplane fell below a ground speed of 90 kt. Considering the headwind of 12 kt, the airplane was below the Blue Line Speed of 102 KIAS at this time. From about this distance up until the threshold of runway 23 the terrain was ascending. Airspeed continued to decrease within the next 34 s up until impact and at a distance of 1,000 m prior to the threshold, the ground speed was less than about 80 kt, i.e. about 92 KIAS. The pilot did not recognise this. The recorded data show a temporary levelling of the approach angle down to about 3°, but then it increased again significantly. The levelling of the approach angle with a simultaneous decrease in speed indicates that the pilot controlled this by pulling the yoke without increasing engine power.

Beginning about 14 s prior to impact at a ground speed of 70 kt (82 KIAS), the airplane was below the 3° approach path. At the latest when the PAPI was indicating “four red”, aircraft too low, the pilot should have increased engine power to still reach the runway threshold or initiate a go-around. The fact that he did not realise the “migration” of the aiming point on the runway and did not increase engine power while at the same time speed continued to decrease indicates that at least in this phase he was aiming at the pre-threshold asphalt area for landing and was neither paying sufficient attention to the PAPI indication nor the airspeed.

The available data of the continuously decreasing airspeed show that during the last approximately 8 s prior to impact, the airplane was in a speed range in which it is highly likely that the acoustic stall warning was permanently active. The recorded data do not indicate that in the seconds leading up to the impact the pilot had attempted to reduce the angle of attack and/or increase engine power.

2.3 Specific Conditions

The pilot was experienced referring to total time and on type. He flew regularly and had a good level of training, even between March and August 2020 under SARS-CoV-2 pandemic conditions. The fact that the pilot had spontaneously offered passengers to take them with him indicates that he was confident in his flying skills and felt fit.

According to the aerodrome operator of Arnsberg-Menden Airfield, the markings and lighting of the pre-threshold asphalt areas of the runway had been installed to serve as visual references for pilots approaching during marginal visibility conditions. The kind of lighting installed at these areas and the respective tyre marks prior to the runway threshold show that the asphalt areas were not only used as backtrack areas but also for landings. The markings and lighting did neither meet the requirements and recommendations of ICAO Annex 14 nor of the national regulations. The large white markings on the pre-threshold asphalt areas were visually much more distinctive than the much older, faded markings of the threshold and runway markings of runway 23 itself. The BFU is of the opinion that this underscores the fact that the markings on the pre-threshold area could cause confusion and distraction for approaching pilots.

The GPS data analysis shows that the approach had been too short during five of the six other approaches to runway 23 at Arnsberg-Menden Airfield, whereas during approaches to runway 07 at his home base, he had not once touched down prior to the displaced threshold. The pilot's statement that during these landings he wanted to reach taxiway A located about 530 m from the "touchdown point of the extension" shows that he had interpreted the pre-threshold area as flight operations area.

The fact that the terrain and the runway at Arnsberg-Menden Airfield ascend in approach direction, aides a possible optical illusion of a too steep approach angle. This possibly contributed to the pilot not noticing that in the last about 14 s prior to impact the airplane had been too low.

In accident statistics, falling below the required airspeed and stalling are comparatively common pilot errors. In this particular case, the pilot was experienced and had a routine in operating his airplane. On the other hand, the data allow the conclusion that over a relatively long period of time (34 s) during final approach, he had controlled the glideslope by pulling the elevator and not by increasing engine power.

This suggests that in this phase his attention allocation neglected the scanning of flight instruments, especially the airspeed indicator. It is highly likely that the pilot instead focused on the situation outside of his airplane. He lost situational awareness, was possibly struggling with optical illusions and monitored the flight progress and instruments insufficiently.

Even the acoustic stall warning sounding for a total of about 8 s prior to impact did not result in a noticeable reaction of the pilot. This is also reflected by the large upward pitch attitude witnesses described. The airspeed, which according to the flight data continued to decrease, reached the stall speed of about 68 KIAS within about 4-5 s. Although the airplane had already been at a very low height, the stall could still have been avoided, if the pilot had reacted immediately. He probably suffered from a tunnel-like attention allocation so that he neither noticed the approach angle becoming critical, the decreasing airspeed nor the stall warning horn. While the pilot was experienced and had flown frequently in the last 90 days, age-related limitations in his attention allocation (multitasking) and a slower reaction time may have affected his actions.

At the time of the accident, visual meteorological conditions were very good. During the approach, a headwind of 12 kt prevailed. The weather conditions had no causal effect on the accident.

The acceleration forces caused by the impact occurred in a low-energy range due to the flight phase, the stall condition and the low height. Even though the BFU could only approximate the absolute numerical values for the horizontally and vertically acting force components, due to inaccurate initial data, they were still certainly in a significantly lower range than the 30 g to 40 g horizontally postulated by the FAA (1972), above which injuries of occupants secured with shoulder harnesses had to be expected. This assumption is supported by the fact that the airplane’s seats and their mountings, which had been certified for 9 g horizontally and 6 g positive vertically, were still in their guides, functioning and had not separated from the airplane.

2.4 Safety Defences

In the scope of this investigation, the term safety defences refer to technical systems, measures, procedures, and features intended to minimise the effects of technical or human error to maintain flight safety.

As described above, investigations of various landing accidents in the past have shown that approach and landing accidents are often preceded by non-stabilised approaches. In order to prevent landing accidents, stabilised approach criteria were developed as a decision-making aid for pilots, whose non-adherence at a so-called safety gate (1,000 ft AAL at IMC and 500 ft AAL at VMC) should result in the termination of the approach. Operators in commercial air traffic implemented this procedure as a standard. However, it can generally be applied in General Aviation and for Single Pilot Operation. In the present case, the changes in approach angle and speed during the final approach show that the pilot did not perform a stabilised approach. This was also due to the fact that the pilot had previously chosen a flight path which required a turn with a 45° bank angle to reach the final approach instead of a standard downwind and base leg approach (traffic pattern). This left him less time to configure the airplane and complete checklists.

The data of further approaches the pilot had flown to runway 23 of Arnsberg-Menden Airfield showed that he had repeatedly conducted approaches which varied more or less and did not follow a standardised traffic pattern procedure. They also show that he had not applied the concept of a stabilised approach.

The main advantage of a stabilised approach is that it frees up pilots' mental capacity to better process other information since the approach requires only minimal corrective actions. This also allows pilots to conduct a safe approach even when challenging situational characteristics (bad day, age-related reduced human performance, etc.) arise. In addition, a repeated standardised approach contributes to a training effect which allows pilots to recognise deviations or unforeseen events earlier and more reliably.

Generally, as a safety mechanism a failed approach can be aborted and a go-around flown. Hence, pilots must monitor the approach parameters closely, correct them and make a timely and consequent decision to abort the approach. Even though first the approach speed, then the approach angle did not fit and the aiming point increasingly migrated, the pilot did not make this important decision to abort the approach but instead continued the approach.

The airplane was equipped with an acoustic stall warning system which is designed to warn pilots with a warning tone in a timely manner when approaching the critical angle of attack. The stall warning was functioning properly, but there are no clear indications in the pilot's statement that he had become aware of the warning or reacted to it.

The general stall recovery procedure for twin-engine airplanes stipulated to first reduce the angle of attack until the stall warning stops, then to eliminate a possible bank angle and finally to cautiously increase engine power smoothly (both engines equally).

Applying the CREEP acronym to analyse the impact in terms of survivability[35] shows that except for the "Restraint" all other factors influenced the result positively and thus contributed to a positive outcome for the occupants.

The fact that the seats of the aircraft had only been fitted with lap belts but not with shoulder harnesses clearly contributed to the occurrence of serious injuries during this impact, despite the relatively low impact forces overall.

This applies to the vertebral body fractures in the transition between the thoracic spine and the lumbar spine all occupants suffered which resulted in incomplete paraplegic symptoms with one occupant and the other injuries which were caused by the impact of the upper body or head on parts of the airframe or its equipment. The bony pelvis fracture of one occupant was most likely caused by the transfer of a large part of energy from the lap belt to the underlying bony structures of the pelvis.

[35] Ekman, S. K. & Debacker, M. (2018). Survivability of occupants in commercial passenger aircraft accidents. *Safety Science, 104:* 91-98.

As required and demonstrated in the certification requirements, the use of combined lap belts and shoulder harnesses would have resulted in a better distribution of the generated impact energies over the occupants' bodies and would have prevented the selective overloading of individual bony structures and the impact of the upper body and head with parts of the airplane. This would almost certainly have significantly reduced the direct injury consequences of the aircraft occupants.

Clear and unambiguous marking of flight operation areas, in particular runways, is a crucial safety mechanism for safe landings and the prevention of accidents. A runway must be clearly recognisable from the air, distinguishable and separable from other areas that are not designated as flight operation areas. The markings at Arnsberg-Menden Airfield did neither meet the requirements and recommendations of ICAO Annex 14 nor of the national regulations.

2.5 Organisational Framework

Over the years, the aerodrome operator has made changes to the airfield, such as extending areas of the airfield, the metal construction on the slope, the lighting and markings. Over time, the airfield's constructional condition deviated more and more from the depiction on the aerodrome chart.

This discrepancy between reality and the published aerodrome chart did not result in any actions to have the aerodrome chart updated, neither on the part of the aerodrome operator nor the supervising authority.

The markings and lighting of the pre-threshold areas at Arnsberg-Menden Airfield, which deviated from the applicable aviation regulations, had existed for years, but the Bezirksregierung Münster as supervising authority never objected to them. They justified it with the argument that these areas were outside the dedicated flight operations areas.

The areas marked with white colour at the edge of the asphalt surface corresponding with the respective construction stage of the airfield in combination with the type of lighting installed in front of runway 23 clearly shows that this area was also designed for use during landings. The illuminated light metal construction on the slope ahead of the asphalt area also supports this.

3. Conclusions

3.1 Findings

- The pilot held the required licenses and ratings to conduct the flight. He was experienced regarding total time and on type.
- The investigation did not reveal any acute health impairment of the pilot.
- Indications of accident-relevant technical defects in the aircraft were not found.
- The aircraft mass was within the permissible range.
- The weather conditions had no causal effect on the accident.
- Instead of a standard approach, the pilot chose a flight path which required a turn with large bank angle to reach the final approach.
- The pilot did not comply with the criteria for a stabilised approach. The chosen approach instead required continuous control inputs to reduce speed and adjust engine power to accommodate configuration changes.
- During the short final approach, the pilot allowed his control inputs to cause the airspeed to fall below the planned approach speed (Blue Line Speed) and the airspeed to continue to decrease, aided by the insufficient monitoring of the airspeed indicator.
- The pilot most likely concentrated his attention on the area ahead of the runway and did not notice the red PAPI indication when it indicated an undershoot of the correct approach angle. He failed to correct the approach angle by increasing engine power and instead pulled on the elevator.
- The pilot did not react to the acoustic stall warning and the airplane entered an uncontrolled flight attitude.
- The traces at the accident site and the damage to the wreckage show that the airplane impacted the ground with a high pitch attitude.
- Due to the comparatively low impact energy, the accident was survivable. The severity of the occupants' injuries was intensified by the fact that the aircraft seats had only been fitted with lap belts. Combined lap belts and shoulder harnesses could have reduced the injury consequences significantly.

- At the time of the accident, the aerodrome chart published in the AIP did not correspond to the actual constructional condition of the pre-threshold areas in front of runway 23 for years.
- The lighting, markings and obstacle designations installed by the aerodrome operator on the pre-threshold asphalt areas at Arnsberg Airfield neither met the requirements and recommendations of ICAO Annex 14 nor the national regulations; permission from the responsible state authority had not been applied for.
- For years, the responsible aviation authority within the framework of the supervisory management did not object to the deviation of the markings and lighting at the airfield from the valid regulations and the discrepancy between the constructional condition and the published aerodrome chart.
- The large white markings on the pre-threshold asphalt areas were visually much more striking than the markings of the threshold of runway 23 and likely suited to distract the pilots' attention on approach to land.

3.2 Causes

The accident was due to:

- The pilot did not correct the approach by increasing engine power or did not abort the approach.
- The pilot did not monitor the airspeed during the final approach and steered the airplane into an uncontrolled flight attitude during the flare.

To the accident contributed that:

- The approach was not stabilised and not aborted.
- The pilot did not pay attention to the PAPI indication and did not perceive the stall warning.
- The large number of continuously changing approach parameters most likely exceeded the limits of the pilot’s capabilities and subsequently, the airplane was no longer controlled in a goal-oriented manner.
- The runway markings did not comply with the required standards.

4. Safety Recommendations

As result of the investigation of two other accidents (State File No. BFU18-0211-3X and BFUCX001-13), the BFU addressed the following safety recommendation to EASA:

BFU SR No 04/2020

The European Aviation Safety Agency (EASA) should amend the Safety Promotion for General Aviation to the effect that training material for Single Pilot Operation CRM and application of Safety Gates is provided for pilots.

In March 2021 EASA responded to the safety recommendation as follows:

> *The European Union Aviation Safety Agency's (EASA) Safety Promotion Plan for General Aviation (GA) has already identified the need to focus on pilot decision making in single pilot operations. A new Safety Promotion activity is being developed for launch in Q3 2021 to cover the key decision-making factors for GA pilots from take-off to landing. This intends to highlight the key decision-making points, and particular attention will also be paid to landing preparation, approach and touch-down. This material is planned to consist of videos, blog articles, guides and also a "serious game" to use the scientifically-proven approach of game-based learning to assist pilots in learning and improving their CRM and decision-making skills in a safe environment at no cost in order to help achieve maximum reach in the pilot community.*
>
> *Status Open*

The BFU issued the following safety recommendations:

01/2023

The Flugplatzgesellschaft Arnsberg-Menden mbH should ensure that the markings and lighting correspond with the ones stipulated in the common principles by the federal government and the sates.

02/2023

In case of planned constructional changes and simultaneous continued operation of the aerodrome, the Flugplatzgesellschaft Arnsberg-Menden mbH should analyse in particular the transition phase from the old to the new condition with regard to possible hazards and mitigate risks by appropriate measures.

03/2023

The Bezirksregierung Münster, as responsible state aviation authority, should ensure that in the scope of local and supra-local supervision, aerodromes in their area of responsibility meet the aeronautical requirements for safe flight operations.

It should especially be ensured that the markings and lighting of the flight operation areas of the aerodromes in their area of responsibility correspond with the ones stipulated in the common principles by the federal government and the sates.

04/2023

The Bezirksregierung Münster should ensure in case of planned constructional changes and simultaneous continued operation of an aerodrome that the aerodrome operator in particular analyses the transition phase from the old to the new condition with regard to possible hazards and mitigates risks by appropriate measures.

05/2023

The German Federal Ministry for Digital and Transport (BMDV) should review the valid standards for supervision of aerodromes by the respective state aviation authority and ensure that a uniformly high level is guaranteed nationwide.

The main focus should be on unambiguous markings and lighting of the flight operations areas of aerodromes in accordance with valid national and international regulations.

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Braunschweig, 25 October 2023

5. Appendices

None