Contents

A1. Factual information

A1.6 Information on the aircraft

A1.6.1 General information

Registration	HB-HOT
Aircraft type	Ju 52/3m g4e
Characteristics	Three-engined commercial air transport aircraft with radial engines and two-blade fixed-pitch propellers, designed as a self-supporting low-wing monoplane in an all-metal construction and with tailwheel landing gear. Non-pressurised cabin.
Manufacturer	Junkers Flugzeug- und Motorenwerke AG, Dessau, Germany
Year of manufacture:	1939
Serial number	6595
Owner	Swiss Air Force, P.O. Box 1072, 8600 Dübendorf
Operator	*Verein der Freunde der Schweizerischen Luftwaffe* (Association of the Friends of the Swiss Air Force or VFL), Überlandstrasse 271, 8600 Dübendorf. The VFL operated the Ju 52 aeroplanes under the name Ju-Air
Operating hours, airframe	10,189:50 h (TSN[1])
Number of landings	8,783
Engines	Manufacturer: BMW Flugmotoren GmbH, Munich, Germany Type: BMW 132 A3, nine-cylinder radial engine

Left engine (no. 1)

Serial number:	67438
Year of manufacture:	1939
Operating hours:	5,687:14 h (TSN)
	946:50 h (TSO[2])

Centre engine (no. 2)

Serial number:	68842
Year of manufacture:	1939
Operating hours:	7,036:27 h (TSN)
	1,153:11 h (TSO)

Right engine (no. 3)

Serial number:	70578

[1] TSN: Time since new

[2] TSO: Time since overhaul

	Year of manufacture:	1939
	Operating hours:	8,228:00 h (TSN)
		457:49 h (TSO)
Propeller hubs	Manufacturer: Junkers Flugzeug- und Motorenwerke AG, Dessau, Germany	
	Type: Ju-PAK 9.20020.21, two-blade	
	Left propeller hub (no. 1)	
	Serial number:	3201
	Year of manufacture:	1939
	Operating hours:	Unknown (TSN)
		1,270:42 h (TSO)
	Centre propeller hub (no. 2)	
	Serial number:	30520
	Year of manufacture:	Unknown
	Operating hours:	Unknown (TSN)
		489:29 h (TSO)
	Right propeller hub (no. 3)	
	Serial number:	32026
	Year of manufacture:	1939
	Operating hours:	10,058:52 h (TSN)
		41:39 h (TSO)
Propeller blades	Manufacturer: Avia-Propeller Ltd, Prague, Czech Republic	
	Type: Ju-PAK 9.20020.21 (-MT), remanufactured (see section A1.6.17.2.6)	
	Installed on left propeller hub:	
	Serial number:	Blade 1: RA-12004 Blade 2: RA-12005
	Year of manufacture:	Unknown
	Operating hours:	Unknown (TSN) 1,270:42 h (TSO)
	Installed on centre propeller hub:	
	Serial number:	Blade 1: RA-12008 Blade 2: RA-12009
	Year of manufacture:	Unknown
	Operating hours:	Unknown (TSN) 481:29 h (TSO)

	Installed on right propeller hub:	
	Serial number:	Blade 1: P-094 Blade 2: P-095
	Year of manufacture:	Unknown
	Operating hours:	41:39 h (TSN)
Max. permissible mass	Max. permissible take-off mass (see section A1.6.6)	10,500 kg
	Max. permissible landing mass	10,500 kg

Mass and centre of gravity

Based on the reconstruction, the aircraft's mass at take-off was 9,387 kg.

Based on the reconstruction, the aircraft's mass at the time of the accident was 9,206 kg.

Mass was within the permissible limits of the aircraft flight manual (AFM).

Based on the reconstruction, the centre of gravity was outside the permissible limits of the aircraft flight manual (see section A1.6.6.4).

Maintenance

The last interval inspection took place on 31 July 2018 at 10,187:50 operating hours.

The Federal Office of Civil Aviation (FOCA) last inspected the aircraft on 6 April 2018. No complaints were found.

Technical restrictions

The tech log contained no complaints.

In contrast, the following three items were listed under 'Damage/faults/malfunctions' in the hold item list (HIL):

"*1 Aircraft to be fuelled with AVGAS 100 LL only Fuel test*

2 LH + RH booster pumps have been deac tivated due to AVGAS operation only

3 RH propeller 100 h blade nut retightening"

Item 1 and 2 were added to the HIL on 15 February 2007, and item 3 on 27 July 2018.

Approved fuel quality

Aviation gasoline (AVGAS) 100 LL[3] or aviation fuel with an octane grade of 80/87 or higher. A service bulletin (SB) was issued by Ju-Air for its Ju 52 aircraft. This states that motor gasoline (MOGAS) compliant with European Standard (EN) 228, leaded or unleaded, containing no more than 1 % alcohol and with an octane

[3] LL: Low lead

	grade of at least 95 RON[4] may be used for operation (see section A1.6.12.1.4). This SB also states that operation with a mixture of AVGAS and MOGAS is also permitted. However, since 2007, the aircraft type has been operated with AVGAS 100 LL only.
Fuel quality	Based on analysis, the fuel complied with the specifications for aviation gasoline AVGAS 100 LL.
Oxygen equipment	There was a small portable oxygen cylinder with three oxygen masks in the aft fuselage (galley).
Certificate of registration	Issued by FOCA on 16 December 2013, no. 6, valid until deleted from the aircraft register.
Certificate of airworthiness	Issued by FOCA on 7 June 2007, no. 2, valid until revoked.
Confirmation of inspection	Date of inspection: 6 April 2018
	Date of expiry: 13 April 2020
Operating specifications	Commercial
Approved operation	Visual Flight Rules (VFR) by day and night
MOPSC[5]	17 or 18[6]
Minimum flight crew	2 pilots, 1 ISP (in-flight service personnel)
Performance class	C[7]
Technical complexity[8]	Complex motor-powered aircraft

A1.6.2 History

The three Junkers Ju 52/3m g4e aircraft, registered as HB-HOP, HB-HOS and HB-HOT, operated by Ju-Air in 2018, were manufactured in Germany by state-owned armaments company Junkers Flugzeug- und Motorenwerke AG in 1939. That year, the Swiss Confederation, or rather the defence technology division of the Swiss Federal Military Department, procured these three Ju 52 aircraft for their

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[4] RON: Research octane number – the octane number determined using the single-cylinder testing method in accordance with the Cooperative Fuel Research Committee (CFR) of the American Society of Automotive Engineers (SAE).

[5] MOPSC: Maximum operational passenger seating configuration. Specified by European Regulation 965/2012 as "*the maximum passenger seating capacity of an individual aircraft, excluding crew seats, established for operational purposes and specified in the operations manual*."

[6] The MOPSC, which – according to section 8.1.9.1.5 of OM-A – is supposed to be specified in section 6.6 of the AFM is in fact not explicitly stated there. In particular, the status of the seat usually occupied by the ISP (in-flight service personnel) was not clear.

[7] According to European Regulation 965/2012, "*performance class C aeroplanes*" are "*aeroplanes powered by reciprocating engines with an MOPSC of more than nine or a maximum take-off mass exceeding 5,700 kg".*

[8] According to article 3 of EU Regulation 216/2008, a motor-powered aeroplane is considered a complex motor-powered aeroplane if it has a maximum certificated take-off mass exceeding 5,700 kg, or it is certified for a maximum passenger seating configuration of more than 19, or it is certified for operation with a minimum crew of at least two pilots, or it is fitted with one or more turbojet engines or more than one turboprop engine. HB-HOT met at least two of these criteria.

air defence corps[9]. HB-HOT, as it was later known, carried the Swiss military registration number A-702 at the time, and the other two aircraft were registered as A-701 and A-703. Although the three aircraft had been procured as so-called 'classroom aircraft'[10] in 1939, over time they were also or primarily used for transporting military forces and cargo as well as for dropping paratroops. From the 1950s to 1960s, the air defence troops' three Ju 52 aircraft were temporarily registered as civil aircraft for operations abroad – as HB-HOS, HB-HOT and HB-HOP. After this, the aircraft were reissued their military registrations. In 1981, the air defence corps decommissioned the three Ju 52 aircraft. A-702, later known as HB-HOT, had accumulated 3,545 operating hours at that time.

The VFMF [11] association was founded in 1979. In 1982, the VFMF began using A-701 as HB-HOS and A-703 as HB-HOP for commercial passenger flights from Dübendorf Air Base. In addition, as of 1985 A-702 was used as HB-HOT. For this purpose, the three aircraft had needed to be modified and converted for civilian use.

By this time, there were no longer any type certificate holders (TC holders) for the aircraft and engines. This meant that, already at this point in time, there was no longer a TC holder to support and establish fundamentals for guaranteeing the aircraft's continued airworthiness.

The VFMF and the VF Flab [12] associations merged in 1997 to form the new Association of the Friends of the Swiss Air Force (VFL). Its purpose is the preservation of Swiss military aircraft and related equipment. Under the name Ju-Air, the VFL was responsible for the Ju 52 aircraft's flight operations, aircraft maintenance and the continuing airworthiness management organisation (CAMO). The official documents of the certification and supervisory authority were each issued to the VFL (see annex A1.17).

A1.6.3 Certificates of airworthiness and aircraft category

A1.6.3.1 1985 certificate of airworthiness

In order for HB-HOT and its two sister aircraft to be used for civilian passenger flights, these three Ju 52 aircraft were transferred from the military to the civil aircraft register in the 1980s. To this end, the aircraft needed to be granted civil technical approval. This, in turn, required the aircraft to be assigned to an aircraft category. For FOCA, civil technical approval posed "*no major problem as the aircraft had already been civilly registered* [temporarily during their time in the air defence corps]". In 1981, FOCA was of the opinion that there was "*nothing to prevent the aircraft from being assigned to the 'Normal' category*" on the basis that "*the aeroplane was at the time built in line with civilian certification specifications*". On 21 August 1985, FOCA thus issued the first certificate of airworthiness (CofA) for HB-HOT, operated by Ju-Air. In the process, it classified HB-HOT in the 'Standard' aircraft category and 'Normal' subcategory. This certificate stated the following:

"*This Certificate of Airworthiness is issued* […] *pursuant to the Convention of 7*th *December, 1944 on International Civil Aviation* […]"

9 The then air defence corps was renamed the Air Force on 1 January 1996.

10 Classroom aircraft were used by the Swiss air defence corps for training air observers on two-seater aeroplanes. For this purpose, they were fitted most notably with two worktables in the cabin.

11 VFMF: *Verein der Freunde des Museums der Schweizerischen Fliegertruppen* (association of the friends of the Swiss air corps museum)

12 VF Flab: *Verein der Freunde der Fliegerabwehrtruppen* (association of the friends of the air defence corps)

A1.6.3.2 2007 certificate of airworthiness

On 7 June 2007, FOCA replaced HB-HOT's 1985 certificate of airworthiness with a new one. According to this new certificate of airworthiness, the aircraft remained classified in the 'Standard' category and 'Normal' subcategory. The certificate of airworthiness declared once again that it had been issued "*pursuant to the Convention of December 7, 1944 on International Civil Aviation*". FOCA clarified to the STSB that a certificate of airworthiness issued "*in compliance with the Convention on International Civil Aviation of 7 December 1944*" also automatically complies with annex 8 of said agreement (ICAO annex 8).

According to FOCA, the reissue of the certificate of airworthiness on 7 June 2007 was "*part of a mass exchange of all on-board documents of aircraft on the Swiss aircraft register*".

A1.6.3.3 Airworthiness category and legal bases

As of 2011, European Regulation No. 216/2008[13] formed part of the bilateral air transport agreement between Switzerland and the European Union[14]. Annex II of this regulation 216/2008 defined certain categories of aircraft. These categories were necessary so that the applicability of the European regulations could be governed in greater detail based on the aircraft's classification. Ju-Air's Ju 52 aeroplanes exhibited the characteristics for two categories of said annex II:

- Category (a)(ii) ("*aircraft having a clear historical relevance*");
- Category (d) ("*aircraft that have* [previously] *been in the service of military forces*").

Being classified as (a)(ii) and (d) aircraft, as per the aforementioned annex II, Ju-Air's Ju 52 aeroplanes therefore also fell under annex II of European Regulation 216/2008.

Aircraft of categories (a)(ii) or (d) of annex II to European Regulation 216/2008 which are "*used for commercial air transportation*" were excluded from the scope of the European Regulations as per article 4 (4) and (5) of said regulation with regard to certification and maintenance, but not with regard to operation and equipment (see section A1.6.4). As of 2011, in Switzerland, the DETEC[15] Ordinance on the Airworthiness of Aircraft (VLL, SR *748.215.1*) served as the definitive set of rules for the certification and maintenance (continued airworthiness) of aircraft referred to in annex II.

Primarily for the development and manufacturing of aircraft, but also for the purpose of subsequent certification, aircraft are assigned to one of two airworthiness categories according to the VLL – standard or special:

[13] Regulation (EC) No. 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No. 1592/2002 and Directive 2004/36/EC. European Regulation 216/2008 has since been repealed. It was succeeded by Regulation (EU) 2018/1139, which came into force in the EU on 11 September 2018 and in Switzerland on 1 September 2019. As a result, aircraft previously listed in annex II are now listed in annex I.

[14] Agreement on aviation between the Swiss Confederation and the European Community (SR *0.748.127.192.68*).

[15] DETEC: Federal Department of the Environment, Transport, Energy and Communications

- Standard: Aircraft in the 'Standard' category must comply with the applicable European airworthiness directives.[16] Aircraft in the 'Standard' category are approved for operation as per the VLL by means of a certificate of airworthiness (CofA).
- Special: According to the VLL, aircraft which fail to or do not fully comply with the requirements of the 'Standard' category belong to the 'Special' category. For aircraft in the 'Special' category, permission to fly is granted via the issuance of a so-called 'permit to fly'.

According to the VLL, Ju-Air's Ju 52 aeroplanes should in principle have been assigned to the 'Special' category.

As Ju-Air's Ju 52 aircraft did not meet the European airworthiness requirements, it was not possible to issue these aeroplanes with standard certificates of airworthiness under European regulations. Instead, European Commission Decision C(2009) 7633 was applied and national standard certificates of airworthiness were issued for Ju-Air's Ju 52 aircraft (see section A1.6.5).

The HB-HOT entry in FOCA's aircraft register at the time of the accident in fact showed that the aircraft belonged to the 'Normal' airworthiness category. In the aircraft register, *"annex II"* was specified as the "*legal basis*", meaning annex II of European Regulation 216/2008.

A1.6.3.4 Findings

As part of this investigation, Ju-Air and FOCA were unable to provide any evidence or documents that confirm or suggest that HB-HOT or its sister aircraft at Ju-Air ever complied with the requirements of the Convention on International Civil Aviation of 7 December 1944 (ICAO convention), or annex 8 of said agreement (ICAO annex 8). FOCA was also unable to clarify which requirements from the ICAO convention the corresponding entry in the certificate of airworthiness of 7 June 2007 specifically referred to. Nevertheless, FOCA itself concluded in summer 2019 and stated that Ju-Air's Ju 52 aircraft "*did not comply or rather had never complied*" with the requirements of the ICAO convention, or annex 8 of said agreement, that the classification in the 'Standard' category was incorrect and that this had "*never been questioned*" since the certificate of airworthiness was first issued in 1985.

In summary, it can be stated that:

- FOCA issued HB-HOT's 1985 certificate of airworthiness "*pursuant to the Convention of 7th December, 1944 on International Civil Aviation*". Neither FOCA nor Ju-Air were able to provide evidence for this certification.
- FOCA renewed the 2007 certificate of airworthiness without reviewing the framework and without relevant evidence.
- After European Regulation 216/2008 came into force, "*annex II*" was added to the classification of HB-HOT in the aircraft register.

A1.6.4 Exemptions concerning equipment for commercial air transport operations

A1.6.4.1 Applications by the air operator

The requirements concerning equipment for aircraft used in commercial air transport were outlined in the JAR[17]-OPS regulations between 1997 and 2006. As

[16] Certification specifications CS-23 and CS-25, in particular, are considered European airworthiness directives.

[17] JAR: Joint aviation requirements. After the civil aviation authorities merged to form the Joint Aviation Authorities (JAA), Switzerland was a member of the JAA from the late 1990s until 1 December 2006. The JARs were the JAA's set of rules and regulations.

Ju-Air's Ju 52 aircraft failed to meet several of these requirements, in February 2004, Ju-Air requested for FOCA to grant exemption for the following 15 requirements:

- JAR-OPS 1.640 (b)(2): Landing lights
- JAR-OPS 1.645: Windshield wipers
- JAR-OPS 1.650 (n): Power failure warning
- JAR-OPS 1.650 (d): Airspeed indicators
- JAR-OPS 1.652 (j): Two independent static pressure systems
- JAR-OPS 1.652 (k): Heated pitot system
- JAR-OPS 1.652 (l): Standby attitude indicator
- JAR-OPS 1.670: Airborne weather detecting equipment
- JAR-OPS 1.710: Cockpit voice recorder
- JAR-OPS 1.730 (a)(4): Shoulder harness
- JAR-OPS 1.735 (a): Internal doors and curtains
- JAR-OPS 1.780 (a)(1): Protective breathing equipment
- JAR-OPS 1.800: Marking of break-in points
- JAR-OPS 1.815 (3): Emergency lighting
- JAR-OPS 1.1255: Flight deck security

Two such applications are presented in the following excerpts: one application to waive the use of two independent static pressure systems and another to waive the use of a cockpit voice recorder (CVR).

At the time, Ju-Air explained the reasoning behind its application to FOCA for an exemption for JAR-OPS 1.652 (j), two independent static pressure systems, as follows:

"*The JU-52 have been designed and manufactured according to applicable certification rules which do not require two independent static pressure systems. A retrofit with the equipment would create various challenges in respect of the structural engineering works.*

The JU-AIR JU-52 operation, however, is restricted to VFR only and has been performed for the recent decades with the above mentioned installation and not experiencing any difficulties in relation to it. A retrofit seems, therefore, out of proportion considering the gain of safety compared to the effort and uncertainties involved in the installation."

Ju-Air justified the reasoning behind the application for an exemption for JAR-OPS 1.710, cockpit voice recorder (CVR), as follows:

- *"The installation of a CVR requires an electrical power supply from the existing electrical system. The JU-52 as well as the DC-3 electrical systems are supplied by a set of batteries and by the engine-driven DC-generators.*
- *A CVR would have to be electrically supplied from one of the available electrical buses. The respective bus is buffered by a 12 V 20 Ah battery and would have – in order to allow for continuous operation of the CVR – have to remain operational even in the case of a major electrical failure, thus providing emergency lighting, navigation, communication and instrumentation for the required period*

of time. An additional power demand caused by a CVR is not desired since the DC generators only feed electrical energy to the electrical system when the engines run considerably above idle power. The aircraft ground operation takes place with engines running at idle RPM, thus feeding all electrical systems exclusively with battery power. The resulting unnecessary draft of electrical emergency power during the typically lengthy ground operation would cause a reduction of the safety margins in the case of an electrical main bus failure.

- *The crashworthy mechanical installation of the CVR in the area below the rear part of the cabin requires enforcement of the aircraft's structure. This would add – not mentioning the cost of the project – weight to the rear structure of the aircraft. The center of gravity would therefore move further aft and loading to the full passenger complement would be impossible.*
- *In order to supply the CVR with the required audio signals a major redesign of the audio system would be required. The CAM (Cockpit Area Microphone) channel could not be provided in a satisfactory quality due to the noise of the aircraft.*
- *The installation of a CVR requires a large financial investment into the vintage aircraft. The permanent decrease in payload due to the shift of the center of gravity to the aft of the aircraft would reduce the full passenger complement. The readability of the recorded data seems questionable due to the high cockpit noise.*

Summing up these arguments, the gain of CVR data in the case of an accident or incident compared to the trade off in flight safety and commercial margins does not seem to justify this modification."

A1.6.4.2 Approval of exemptions by FOCA

On 15 April 2004, FOCA approved all 15 applications submitted by Ju-Air. The exemption permits applied to the entire fleet of, at the time, four Ju 52 aircraft.

In 2008, the version of the JAR-OPS rules dating 1 January 2005 were used as a basis to supplement European Regulation 3922/91[18] with European Regulation 1899/2006[19]. This amendment included in particular annex III, which contained common technical requirements and administrative procedures applicable to commercial transportation by aeroplane. Annex III of European Regulation 3922/91 came into force in the EU on 16 July 2008. In 2012, these rules were transferred into European Regulation 965/2012[20]. Throughout this amendment of the legislation, the content of the rules remained largely, but not entirely, identical. Despite this, the 15 exemptions granted and the new regulations were not reviewed or reassessed by FOCA when the legislation was amended. In particular, the requirement applicable since 2012 of being equipped with a terrain awareness warning system (TAWS) as per CAT.IDE.A.150 of European Regulation 965/2012 was not recognised (see annex A1.17).

Whilst in the days of JAR-OPS, FOCA was allowed to "*grant exemptions from some of these requirements* [JAR-OPS] *in justified cases, in particular to avoid*

[18] Council Regulation (EEC) No. 3922/91 of 16 December 1991 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation.

[19] Regulation (EC) No. 1899/2006 of the European Parliament and of the Council of 12 December 2006 amending Council Regulation (EEC) No. 3922/91 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation.

[20] Commission Regulation (EU) No. 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No. 216/2008 of the European Parliament and of the Council.

cases of hardship or to stay abreast of technical developments", this was not so feasible after 2006 for the relevant requirements of the European regulations. At this time, according to article 8 (3) of European Regulation 3922/91, and later according to article 14 (6) of European Regulation 216/2008, no such exemptions from the applicable regulations could be granted or tolerated without proof of an equivalent level of protection/safety and without completion of a process involving the European Commission and EASA. However, FOCA continued to tolerate derogation from the applicable regulations in accordance with the exemptions granted in 2004 without proof of an equivalent level of protection/safety and without the process involving the European Commission and EASA having been completed. FOCA justified its tolerance to the STSB with a letter from the European Commission dated 2 December 2014. The Office understood this letter to FOCA "*as covering all derogations from the operational rules resulting from the design of the JU-52 without additional specific exemption approval (for each individual derogation)*." In its letter, however, the European Commission approved of Ju-Air's commercial air transport operations with Ju 52 aircraft based on its understanding that these operations would be conducted in full compliance with the operational rules, including the rules regarding equipment, with the exception of OPS 1.180 (a)(1) (see section A1.6.5).

Subsequently, Ju-Air's Ju 52 aircraft were not fitted with the following equipment or systems according to the European Regulation 965/2012 for several years until and including 4 August 2018, meaning they did not achieve the level of safety required for commercial air transport:

- CAT.IDE.A.115 (b)(2): Landing lights;
- CAT.IDE.A.120: Equipment to clear windshield;
- CAT.IDE.A.125 (a)(2) and CAT.IDE.A.130 (c): Equipment of indicating when the supply of power to the required flight instruments is not adequate (power failure warning);
- CAT.IDE.A.130 (e): Equipment of annunciating to the flight crew the failure of the heated pitot system;
- CAT.IDE.A.130 (f): Two independent static pressure systems;
- CAT.IDE.A.130 (i): Standby equipment of measuring and displaying the aircraft's attitude;
- CAT.IDE.A.150 (b): Terrain Awareness Warning System (TAWS);
- CAT.IDE.A.160: Airborne weather detecting equipment;
- CAT.IDE.A.185: Cockpit Voice Recorder (CVR);
- CAT.IDE.A.205 (a)(5) A seat belt with upper torso restraint system on each flight crew seat and on each observer seat in the cockpit;
- CAT.IDE.A.205 (a)(6): A seat belt with upper torso restraint system on each seat for the minimum required cabin crew;
- CAT.IDE.A.245: Protective breathing equipment for the crew;
- CAT.IDE.A.260: Marking of break-in points;
- CAT.IDE.A.275: Emergency lighting.

A1.6.5 Exemption regulation for obtaining an air operator certificate

A1.6.5.1 Initial situation

For commercial air transport (CAT) operations, such as those conducted by Ju-Air, the air operator must hold an air operator certificate. For an air operator certificate, on the other hand, the operated aircraft are required to possess a certificate of airworthiness (CofA) in line with the requirements of European regulations. Since 2012, this results from ORO.AOC.100 (c)(2) of European Regulation 965/2012, before 2012 from OPS 1.180 (a)(1) of European Regulation 3922/91, supplemented in this respect by European Regulation 1899/2006. The Ju 52 aircraft did not possess a certificate of airworthiness in accordance with the requirements of the European regulations but they were issued with a national standard certificate of airworthiness (see section A1.6.3.3). The following two sections set out the relevant information.

A1.6.5.2 European Commission Decision C(2009) 7633

European Regulation 3922/91, supplemented in this respect by Regulation 1899/2006, gave European Community member states the option to derogate from the European regulations subject to certain conditions. The air transport agreement, which made the European aviation regulations applicable to Switzerland as well, provided Switzerland with the option of derogating from the rules under certain circumstances. Article 8 of European Regulation 3922/91 specifically permitted member state authorities to derogate from the common technical requirements and administrative procedures, provided that "*a safety level equivalent to that attained by the application of the common technical requirements and administrative procedures* [...] *can be achieved by other means*". The aforementioned article 8 also specified the relevant administrative procedure: a member state intending to derogate from the common technical requirements and administrative procedures must notify the European Commission of its intention and state "*the reasons therefor and the conditions laid down in order to ensure that an equivalent level of safety is achieved*". The European Commission is then to decide whether the derogation proposed by the member state may be applied. If it is decided that it may, the European Commission communicates its decision to all member states. In line with the fundamental concept of the European single market, all member states are then entitled to apply the relevant measures.

In Germany, Deutsche Lufthansa Berlin-Stiftung conducted commercial air transport operations using a Ju 52 aircraft. Thus, OPS 1.180 (a)(1) of European Regulation 3922/91, supplemented in this respect by European Regulation 1899/2006, could not be complied with. This rule states that an air operator certificate may only be granted and remains valid only when a standard certificate of airworthiness has been issued for the aircraft operated in accordance with European Regulation 1702/2003. The Ju 52 belonging to Deutsche Lufthansa Berlin-Stiftung did not possess such a certificate of airworthiness. Germany therefore approached the European Commission on 12 September 2008 and requested permission to derogate from said rule.[21] For the Ju 52 aircraft concerned, the measures that Germany intended to take to achieve an equivalent level of safety were as follows:

- Certificate of airworthiness as per annex 8 (ICAO annex 8) of the Convention on International Civil Aviation of 7 December 1944 (ICAO convention);

[21] At the same time, Germany also requested permission to derogate from OPS 1.180 (a)(1) for a number of other historic aircraft, including a Douglas DC-3 and an Antonov AN-2.

- Continuing airworthiness by maintenance organisations which hold permits in accordance with annex II (part 145) of European Regulation 2042/2003;
- Regular review of procedures for continuing airworthiness by the authorities.

The European Commission subsequently concluded that the measures specified by Germany would ensure an equivalent level of safety. In its Decision C(2009) 7633, the European Commission communicated its approval of derogation from OPS 1.180 (a)(1), subject to the conditions proposed by Germany, as follows[22]:

Article 2: "*Germany may, by derogation from OPS 1.180 (a)(1) of Regulation (EEC) No 3922/1991, issue an Air Operator's Certificate* […] *for the operation of aircraft of the type Junkers Ju52* […]."

Article 5 (1): "*The aeroplanes subject to the derogations described under Articles 1 to 4 shall have a certificate of airworthiness issued in accordance with national rules and meeting the requirements of Annex 8 to the Convention on International Civil Aviation, signed in Chicago on 7 December 1944.*"

Article 5 (2): "*The operators concerned by the derogations described under Articles 1 to 4 shall comply with Regulation (EC) No 2042/2003 or have in place equivalent continued airworthiness and maintenance arrangements approved by the competent national Authority.*"

Article 5 (3): "*The operations concerned by the derogations described under Articles 1 to 4 shall be conducted in full compliance with all provisions of Regulation (EEC) No 3922/91 which are not covered by these derogations.*"

In addition, the Commission specified in article 6 that a certificate issued in accordance with this decision should state "*that it has been issued in accordance with this decision by way of derogation from Regulation (EEC) No. 3922/91*". In its decision, the European Commission also stated that the envisaged derogations were "*necessary in order to maintain the commercial air transport operations of the aircraft concerned*". It goes on to state that, "*The alternative to the derogations related to the standard certificate of airworthiness would be to cease commercial operations or to undertake the effort to be issued a standard certificate of airworthiness in accordance with Regulation (EC) 1702/2003* [...]. *However, the cost of such certification would be excessive, if not prohibitive, and disproportionate in the light of the ensured level of safety.*"

During this investigation, the Commission was unable to provide any evidence or documents that confirm or suggest that an equivalent level of safety could indeed be achieved by using the approved measures. Furthermore, the Commission was unable to state which requirements for a certificate of airworthiness "*meeting the requirements of Annex 8 to the Convention on International Civil Aviation* […]" it understood as needing to be concretely fulfilled.

A1.6.5.3 Application of Decision C(2009) 7633 by Switzerland

In a letter dated 10 December 2009, FOCA notified the European Commission with regards to article 8 (3) of Regulation 3922/91 of its intention to permit the air operator Ju-Air, with its four Ju 52 aircraft, to derogate from OPS 1.180 (a)(1). When doing so, FOCA referred to European Commission Decision C(2009) 7633 of 14 October 2009. In its letter dated 10 December 2009, FOCA listed the following

[22] Decision C(2009) 7633 also concerned similar exemption permits granted to Austria, the United Kingdom and Malta by the European Commission.

measures which it intended to take to ensure an equivalent level of safety and which were comparable with the measures taken by the German authorities:

- National standard certificate of airworthiness as per annex 8 (ICAO annex 8) of the Convention on International Civil Aviation of 7 December 1944 (ICAO convention);
- Continuing airworthiness by maintenance organisations, which hold permits in accordance with annex II (part 145) including annex I (part M) of European Regulation 2042/2003. Furthermore, it was noted that Ju-Air was approved as a continuing airworthiness management organisation (CAMO);
- Annual airworthiness inspection by the regulatory authority.

FOCA concluded its reasoning by stating that, with these measures, Ju-Air's Ju 52 aircraft would meet the same safety requirements as aircraft used in commercial air transport operations which are not listed in annex II of European Regulation 216/2008.

There is no written response available from the European Commission to the Swiss authorities.

On 30 September 2014, FOCA wrote to the European Commission and EASA. In this letter, FOCA stated that, based on article 6 (2) of European Regulation 965/2012, it intended to maintain this derogation for the four Ju-Air Ju 52 aircraft in future under the conditions covered by Decision C(2009) 7633, which FOCA communicated to the European Commission on 10 December 2009.

The European Commission wrote to FOCA on 2 December 2014 acknowledging receipt of the above-mentioned letter. In said letter, the Commission clarified its understanding that the flight operations for which FOCA had applied or sought exemption would be carried out in full compliance with European Regulation 3922/91 ('EU-OPS') with the exception of OPS 1.180 (a)(1), and that the derogation from OPS 1.180 (a)(1) was covered by European Commission Decision C(2009) 7633. Based on this observation, the Commission and EASA concluded that the envisaged derogation did not differ from the previous derogation that had already been authorised.

A1.6.6 Mass and centre of gravity

A1.6.6.1 Previous developments relating to maximum permissible take-off mass

The sales documentation and the operating instructions of Junkers Flugzeug- und Motorenwerke from 1939 specified a maximum flight mass of 10,000 kg for the Ju 52/3m g4e classroom aircraft, which applied to serial numbers 6580 (later HB-HOS), 6595 (later HB-HOT) and 6610 (later HB-HOP).

In September and October 1939, a Swiss delegation took performance measurements using one of the three Ju 52/3m g4e aircraft ordered by Switzerland (see section A1.6.10.5). The flights were carried out with a mass of 10,000 kg.

A maximum flight mass of 10,500 kg was listed in the Junkers Flugzeug- und Motorenwerke takeover deed of 4 October 1939.

The military pilot's manual from 1948 specified a maximum flight mass of 10,500 kg.

HB-HOT's first civilian-aircraft flight manual, issued on 9 August 1985, also specified a maximum flight mass of 10,500 kg. Since then, there has been no known change in the maximum flight mass.

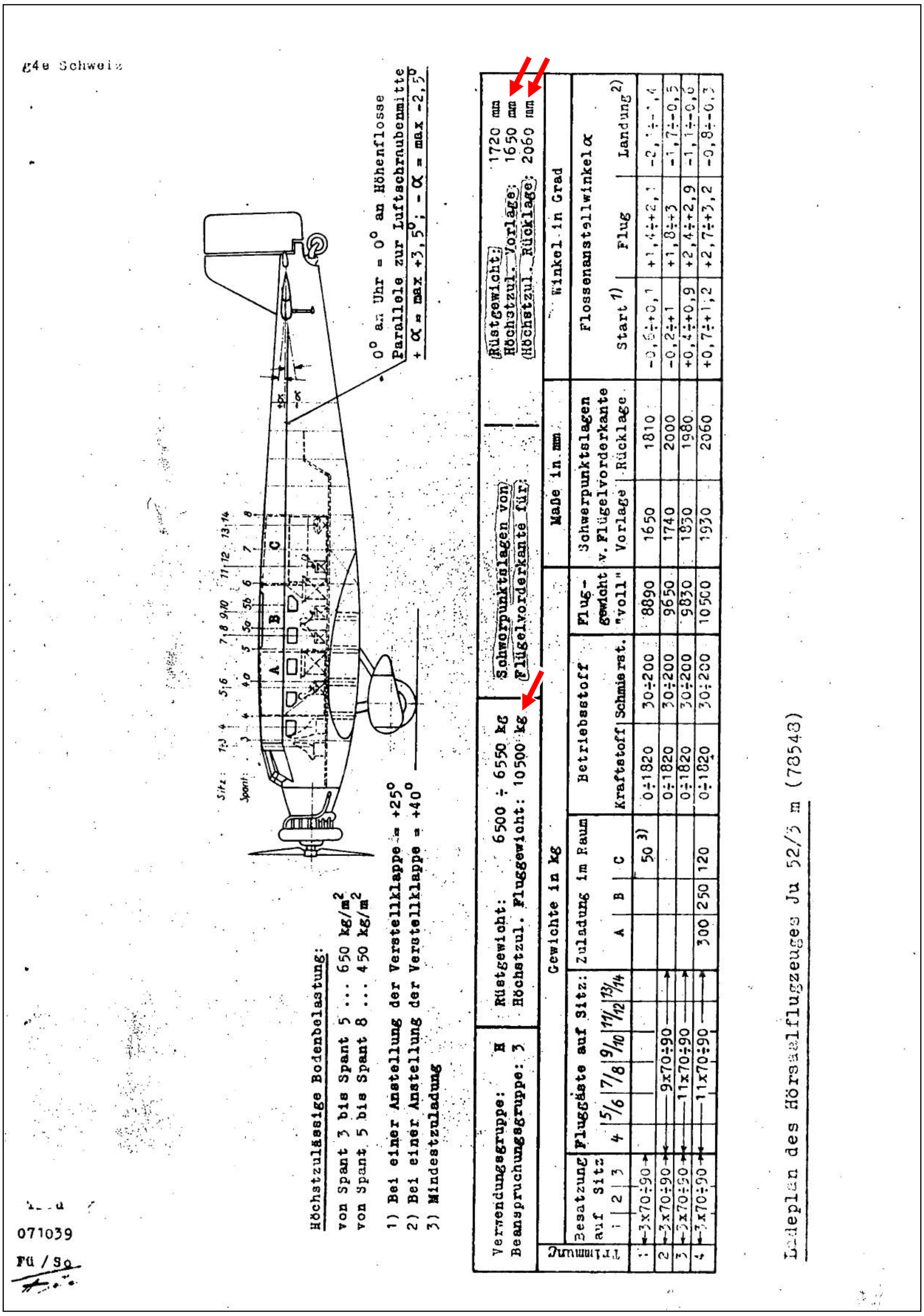
A1.6.6.2 Developments relating to operation and centre of gravity determination

A1.6.6.2.1 1939 to 1981

When the three Ju 52/3m g4e aircraft were procured in Germany in 1939, the philosophy there regarding the loading of (Ju 52) aircraft was different to that of today – at least this is what is suggested by historical documents obtained and sighted from archives during the investigation. Nowadays, it is the task of every flight crew (or, for an airline, usually the task of a dispatch service) to themselves determine an aircraft's flight mass and centre of gravity and to keep these within the defined limits based on information in the flight manual – in particular information on the arms. The philosophy in Germany in 1939, however, seemed to have been that flight crews loaded and refuelled their aircraft primarily for 'standard loading operations', following an accurately defined 'loading plan'. There were other loading plans, including for the use of 'cargo transport aircraft', 'passenger aircraft', 'paratroopers and airborne troops aircraft' or 'classroom aircraft'. These had previously been drawn up by the aircraft manufacturer's engineers, taking into consideration all limits for flight mass and centre of gravity. Observing the loading plans for loading and refuelling was meant to ensure that the flight mass and balance remain within the permissible limits. Only in the second instance, i.e. For 'unforeseen unique instances' of load distribution, did crews of German Air Force Ju 52 aircraft have the option of "*determining a new centre of gravity and comparing whether this lies within the permissible limits using the* [...] *weight and moment tables* [in the loading regulations]." These loading instructions also included information on arms for the aircraft's various loading areas. In contrast to the civilian loading plans written by Junkers Flugzeug- und Motorenwerke AG, which could be exported abroad, the loading instructions were military service regulations of the German Air Force and "*for official use only*".

When the three Ju 52/3m g4e aircraft were handed over to the Swiss Confederation, a loading plan drawn up by Junkers Flugzeug- und Motorenwerke AG for the use of 'classroom aircraft' was supplied (see figure 1). This loading plan was part of the operating instructions[23] supplied by Junkers and specified the maximum permissible flight mass (10,500 kg) and permissible balance limits (maximum of 1,650 mm forward and 2,060 mm aft, measured from the leading edge of the wing). This loading plan was subsequently signed off by a department of the Swiss military administration and provided to the air defence corps as the 'TD 9560' loading plan (see figure 2). Although the air defence corps provided its Ju 52 pilots with the 'TD 9560' loading plan, investigation by the STSB revealed that it was evidently not used by the pilots. It could not be proven that loading plans were provided to Swiss air defence pilots for other purposes. There was also evidently no known alternative system for determining the mass and centre of gravity, as was the case with the loading instructions in Germany. Instead, the Swiss Ju 52 aircraft were loaded, refuelled and operated by the air defence corps based on experience passed on informally. Load sheets were not completed. As anecdotal examples show, the limits for flight mass and balance were regularly ignored by the Swiss air defence corps during operations.

[23] In the 1980s, Ju-Air acquired multiple versions of the 'Ju 52/3m g4e operating instructions for Switzerland' from September 1939, along with the aforementioned 'loading plan for classroom aircraft'.



Trimmung	Besatzung auf Sitz 1 | 2 | 3	Fluggäste auf Sitz: 4, 5/6, 7/8, 9/10, 11/12 13/14	Zuladung im Raum A	B	C	Betriebsstoff Kraftstoff	Schmierst.	Fluggewicht "voll"	Schwerpunktslagen v. Flügelvorderkante Vorlage	Rücklage	Flossenanstellwinkel α Start 1)	Flug	Landung 2)
1	3x70÷90				50 3)	0÷1820	30÷200	8890	1650	1810	-0,6÷+0,1	+1,4÷+2,1	-2,1÷-1,4
2	3x70÷90	9x70÷90				0÷1820	30÷200	9650	1740	2000	-0,2÷+1	+1,8÷+3	-1,7÷-0,5
3	3x70÷90	11x70÷90				0÷1820	30÷200	9830	1830	1980	+0,4÷+0,9	+2,4÷+2,9	-1,1÷-0,6
4	3x70÷90	11x70÷90	300	250	120	0÷1820	30÷200	10500	1930	2060	+0,7÷+1,2	+2,7÷+3,2	-0,8÷-0,3

Figure 1: Loading plan supplied to the Swiss Confederation in 1939. The red arrows point to information regarding the maximum permissible centres of gravity and maximum permissible flight mass. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

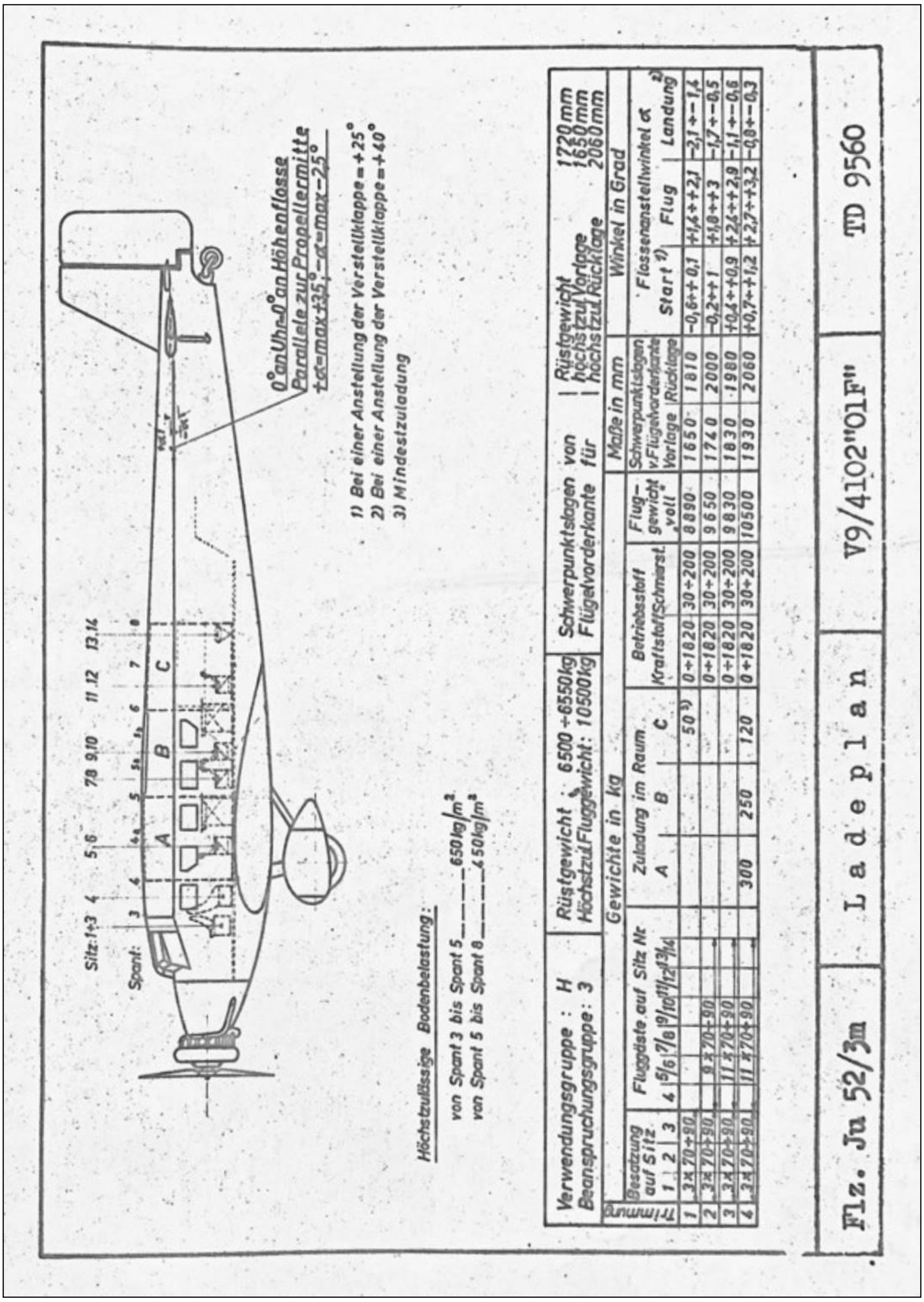


Figure 2: 'TD 9560' loading plan, drawn up by a department of the Swiss military administration, which was provided to the air defence troops and their pilots.

A1.6.6.2.2 1982 onwards

For the transferral of the three Ju 52 aircraft from the air defence corps to Ju-Air, Ju-Air first needed to create an aircraft flight manual (AFM) based on civilian features and approved by the Federal Office of Civil Aviation. To a large extent, the content of the operating instructions supplied by Junkers in 1939 (see section A1.6.6.2.1) was used to create the first edition of the AFM from 1982 and the subsequent revisions. However, the Junkers and 'TD 9560' loading plans, both drawn up for the use of the Ju 52 as a classroom aircraft, could no longer be used. Firstly, a loading plan for the use of the aeroplane as a classroom aircraft was not applicable to the Ju-Air aircraft now fitted with airline seats. Secondly, the 'loading plan philosophy' was no longer common in the aviation industry. Only the maximum permissible flight mass (10,500 kg) and the permissible balance limits (maximum of 1.65 m forward and 2.06 m aft) were transferred to the AFM for the 'Mass and centre of gravity' section. The arm values for the various stations[24] within the aircraft had to be ascertained using measurements taken on the aircraft.

The development of the AFM from 1982 until its last revision on 1 June 2017 could be partially reconstructed based on archived documents. The AFM, which had initially been created only for HB-HOS, the first Ju-Air aircraft, also applied to the sister aircraft HB-HOP and HB-HOT when they later joined the Ju-Air fleet. Milestones in the development of the AFM:

- The first AFM was created in 1982 and was approved by FOCA. What exactly it covered is unknown.
- As of January 1983, the AFM included information for calculating the centre of gravity. The authors were clearly aware of the different arms of the various fuel cells. There was relevant information at two locations within the AFM: On the "*Weight and CG determination for flight*" page and in the "*Fuel & loading tables*". According to the "*Fuel & loading tables"*, cells 1 to 3 (referred to elsewhere as cells I to VI, one of each in the left- and right-hand outer wings) had an arm of 2.30 m, cells 4 (referred to elsewhere as cells VII, one in the left-hand and one in the right-hand outer wing) had an arm of 3.20 m. The rear underfloor storage compartment was not mentioned in the AFM until at least January 1983.
- As of no later than February 1986, the AFM included a "*Payload moment table*" which referred to the rear underfloor storage compartment[25] as "*cabin cargo*" with an arm value of 1.95 m. Next to this, the comment "*Same values as in PAX ROW 3*"[26] was added. "*PAX ROW 3*" was also listed with an arm value of 1.95 m in this table. It can be seen from the station plan in this edition of the AFM that, together, seats 5 and 6 form row 3 (see figure 3).
- As of no later than December 1986, there was no longer any difference in the arms for the various fuel cells on the "*Weight and CG determination*" page in the AFM. However, there were still differences in the "*Fuel & loading tables*". As of no later than this time, this page also included a diagram, from which the setting of the horizontal-stabiliser trim for take-off is to be taken. According to this diagram, the necessary setting of the horizontal-stabiliser trim depends only on the take-off mass (see figure 4).

[24] In relation to the calculation of the mass and balance of an aircraft, 'stations' are understood to be all of the points within the aircraft at which a load is placed when refuelling and loading cargo or boarding passengers. These include, most notably, passenger and crew seats, fuel cells and cargo or luggage compartments. For the centre of gravity calculation, each station is assigned an arm value, i.e. a distance from a defined reference point (datum).

[25] For the aircraft supplied to the Swiss Confederation in 1939, the area used by Ju-Air as rear underfloor storage was not intended by the manufacturer as storage space for luggage, but as a passageway to a ventral and foldable machine gun rack for military use. To this end, this compartment was equipped with a ladder. However, when the Ju 52/3m was originally designed in 1932, it was intended as a civilian aircraft for transporting passengers and freight. In this variant, the areas below what referred to as the 'main usable area', i.e. the passenger cabin, were already being used to store luggage.

[26] 'PAX ROW 3' refers to the third row of passenger seats (row 3), counted from front to back.

- As of no later than January 1998, the rear underfloor storage compartment was marked in the station plan diagram as ‘cabin cargo’ with an arm value of 1.95 m. Although there was a ‘cabin cargo’ entry in the “*Weight and CG determination*” table at the time, there was no arm value.
- As of no later than January 2005, the rear underfloor storage compartment was recorded on the “*Mass and CG determination*” page (previously “*Weight and CG determination*”) as ‘cabin cargo’ with an arm value of 1.95 m (see figure 4). In the same table, an arm value of 2.3 m was now also stated for the fuel.
- The “*Fuel & loading tables*” from 1983 remained unchanged in the AFM issued in January 2005, as well as in the latest edition of the AFM from June 2017.

Re-measurements taken as part of the investigation on one of HB-HOT’s sister aircraft revealed that the rear underfloor storage compartment begins 2.72 m behind the reference datum[27] and ends 3.58 m behind it. The centre of the rear underfloor storage compartment is therefore 3.15 m behind the reference datum. The rear underfloor storage compartment is situated approximately in line with row 5 consisting of seats 9 and 10 (see figure 3).

In addition, the arm values for the various fuel cells, as they have been included at various points in the AFM since 1983, were verified as part of the investigation on the sister aircraft. Both values – 2.30 m for cells 1 to 3 (I to VI) and 3.20 m for cells 4 (VII) – were correct (see figure 5).

In 2005, the “*Mass and CG determination*” page from the AFM served as a basis for the programming of the flight planning software ‘JU-OFP’.

When Ju-Air commenced operations in 1982, all of its pilots were former military Ju 52 pilots from the air defence corps. The flight instructor who was to retrain the pilots for civilian flight operation on the aircraft type had also previously been a military Ju 52 pilot. According to this flight instructor, the topics of load distribution and the calculation of the centre of gravity were not discussed as part of this retraining. This flight instructor also stated that they all agreed that this was not necessary due to the flying experience the aspiring Ju-Air pilots had gained during their time with the air defence corps or civil aviation companies.

[27] The reference datum from which all arms are measured is an imaginary plane vertical to the longitudinal axis of the aircraft, which runs through the leading edge of the wing at the root.

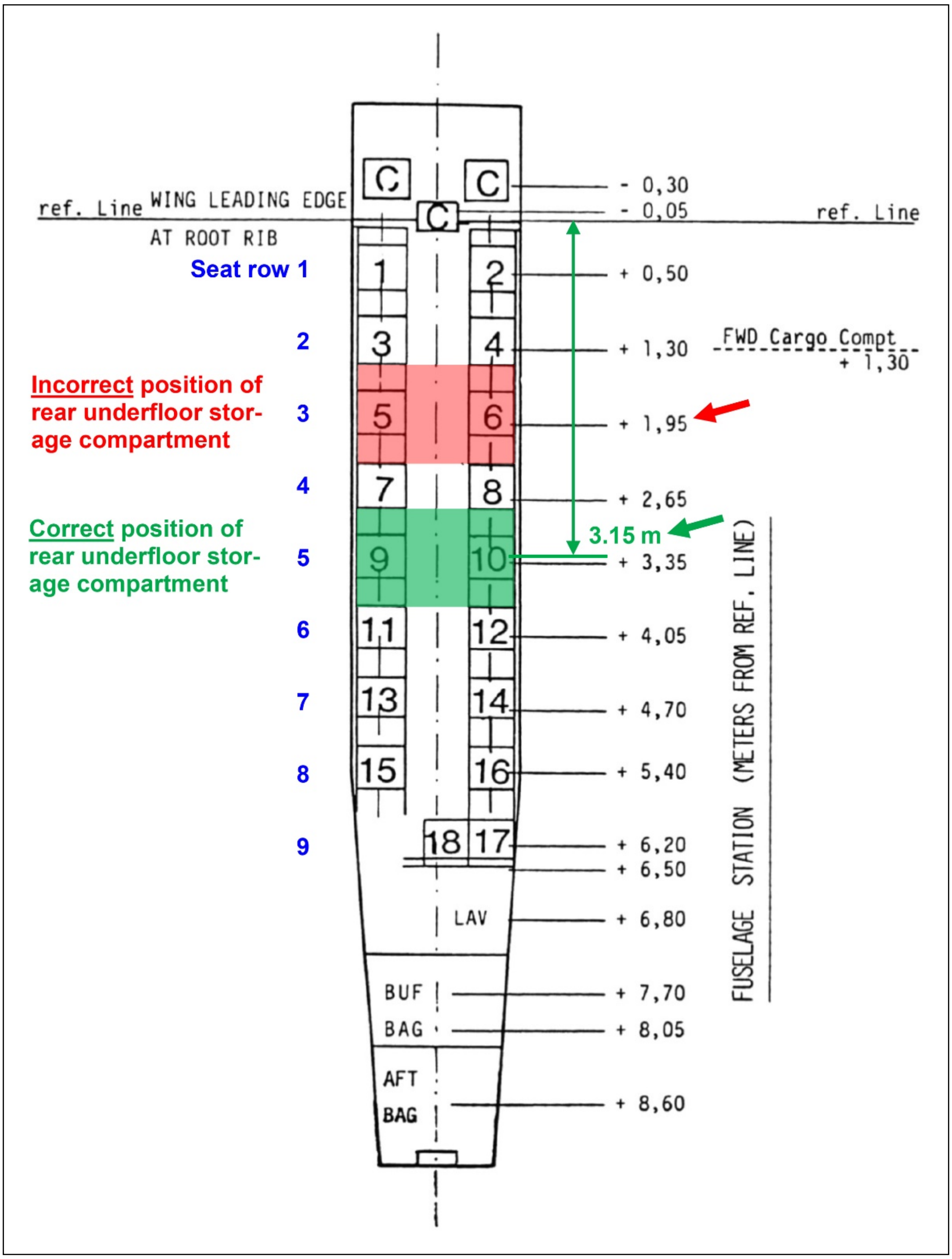


Figure 3: Station plan taken from the AFM from February 1986, with annotations by the STSB in blue, red and green.

The passenger cabin seats are numbered 1 to 18 in black

The seat rows are numbered 1 to 9 in **blue** from front to back

The (at the time incorrectly assumed) position of the rear underfloor storage compartment (cabin cargo) is marked in **red** with an arm value of 1.95 m for seat row 3

The correct position of the rear underfloor storage compartment is marked in **green** with the correct arm value of 3.15 m determined during the investigation

Source of station plan: Ju-Air AFM from 1986.

PAYLOAD CALCULATION		example max PAX Payload	Moment
JUMP SEAT	-0.05	0	0.0
ROW 1	0.50	184	92.0
ROW 2	1.30	184	239.2
ROW 3	1.95	184	358.8
ROW 4	2.65	184	487.6
ROW 5	3.35	184	616.4
ROW 6	4.05	184	745.2
ROW 7	4.70	184	864.8
ROW 8	5.40	184	993.6
ROW 9	6.20	92	570.4
FWD CARGO	1.30		0.0
CREW LUGGAGE	1.30	30	39.0
CABIN CARGO	1.95		0.0
PAX LUGGAGE	1.95	170	331.5
LAVATORY	7.00		
BAGGAGE	8.05		
AFT BAGGAGE	8.60		
FLIGHT KIT klein #	1.30	25	32.5
Motorendecken #	1.95	12	23.4
PAYLOAD		1801	5394.4

Flight Kits siehe Kapitel 6.10

BASIC EMPTY MASS	meters from reference	Maß kg	Moment mkg
see M&B record	Ø 1.75	Ø 7200	Ø 12850
Crew 2x92 kg	-0.30	184	-55.2
ROW9 F/A 68 kg	6.20	68	421.6
Flight Kit groß	1.30	75	97.5
DRY OPERATING MASS	Ø 1.73	Ø 7500	Ø 13300
PAYLOAD		1801	5394.4
ZERO FUEL MASS	Ø 2.01	9301	Ø 18695
FUEL (1715 l)	2.30	1235	2840.5
RAMP MASS	2.04	10536	21535.5
Taxi + Run up 50 l	2.30	36	82.8
TAKE OFF MASS	2.04	10500	21452.7

MAX TAKE OFF AND MAX LANDING MASS	between **1.65** and **2.06**	**10'500**	between **17325** and **21630**

TRIMSETTING				
7 - 8	8 - 9	9 - 10	10 - 10.5	TOW TONS
TRIM				
0	+ 0.5	+ 1.0	+ 1.5	HB - HOP/S/T
-1.0	-0.5	0	+ 0.5	HB - HOY

Figure 4: Excerpt from the "*Mass and CG determination*" page of the AFM from January 2005. Incorrect values which were transferred to the JU-OFP flight planning software are indicated in red. The bottom right-hand corner shows the table, from which the setting of the horizontal-stabiliser trim for take-off is to be taken depending on the take-off mass (Take-Off Weight – TOW). Source: Ju-Air AFM from 2005.

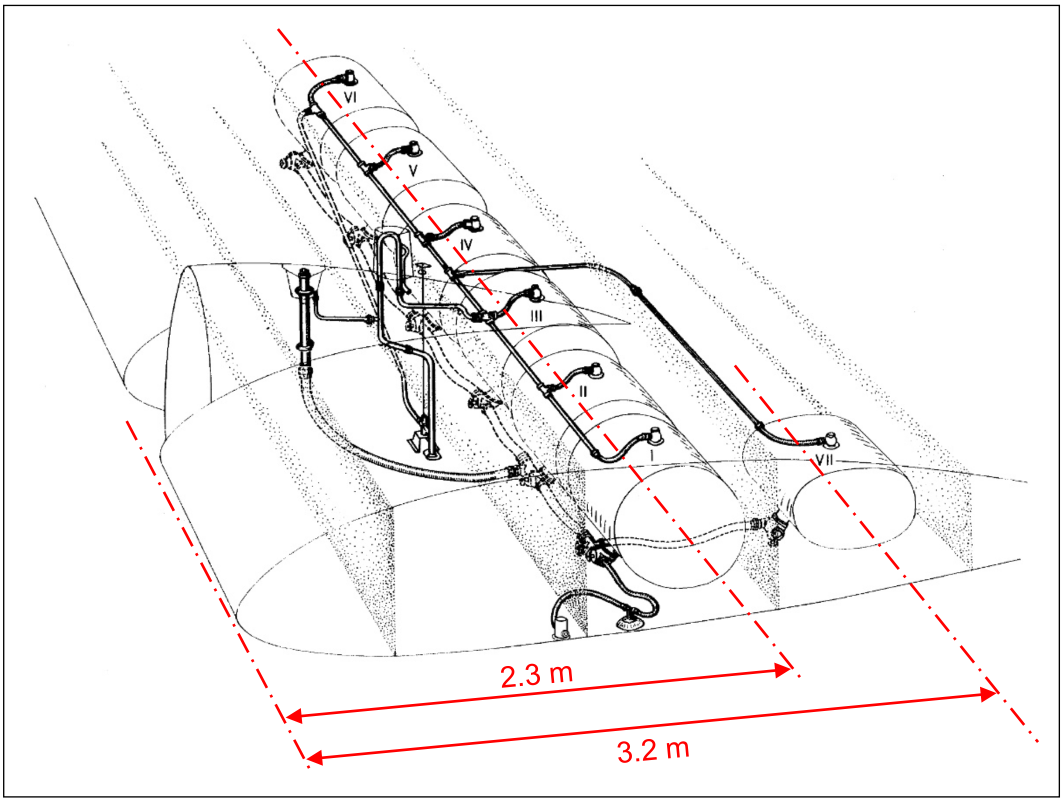


Figure 5: Diagram showing fuel cells I to VII in the right-hand outer wing. View from the root of the wing outwards. Direction of flight to the left. Engine is not shown. The different arm values for cells I to VI (2.3 m) and VII (3.2 m) have been added in red. Source: Ju-Air AFM from 2017, dimensioning by the STSB.

A1.6.6.3 Applicable limits for mass and centre of gravity

According to the 'Operating limits' section of Ju-Air's Ju 52 AFM, the following limits were applicable for mass and centre of gravity:

- Max. permissible flight mass: 10,500 kg
- Rearmost permissible centre of gravity: 2.060 m behind the reference line
- Foremost permissible centre of gravity: 1.650 m behind the reference line

The reference line was defined as the "*vertical tangent to the leading edge of the wing at the root*".

A1.6.6.4 Mass and centre of gravity for the 2018 Locarno adventure tour

Pilot A, the person responsible for flight preparations, created the OFP for the outbound and return flights on the morning of 3 August 2018 (see annex A1.1). To do this, he used the flight planning software 'JU-OFP' on a computer in the briefing room at the Air Force Center. Creating an OFP for a flight also involves calculating the mass and balance for the flight in question.

The OFP for the outbound flight and the OFP for the accident flight were secured from the wreckage of HB-HOT. When examining these OFPs, it stood out that the table used to calculate the mass and centre of gravity had not taken into account the passengers' and ISP's luggage (together approximately 120 kg in reality, or 239 kg when calculated using standard values), whilst 25 kg had been included for a flight kit which was not actually on board. Both of these factors led to the presumed centre of gravity being further forward.

During the investigation, the aircraft's mass and balance were reconstructed as it must have been at various points in time during the 2018 Locarno adventure tour. In addition, diligent flight preparation by the pilots was simulated using flight planning software. The following table compares these scenarios against the values from the OFP taken from the wreckage and the corresponding limits.

	According to the operational flight plan (OFP) from the wreckage		Simulation of diligent flight preparation		Reconstruction of actual situation		Limits (see section A1.6.3.3)	
	Mass	Centre of gravity	Mass	Centre of gravity	Mass	Centre of gravity	Maximum flight mass	Rear centre of gravity limit
Take-off from Dübendorf 3 August	9,965 kg	1.99 m	10,180 kg	2.00 m	9,714 kg	2.098 m	10,500 kg	2.060 m
Take-off from Locarno 4 August	9,737 kg	1.98 m	9,858 kg	1.99 m	9,387 kg	2.077 m		
Entry into accident basin	–	–	–	–	9,206 kg	2.071 m ([28])		

Table 1: Comparison of various scenarios for mass and centre of gravity.

Green means that the relevant limit has been observed

Red means that the relevant limit has not been observed

For the reconstruction of the actual situation for take-off from Dübendorf on 3 August 2018, the values for mass and centre of gravity corresponded to a 'moment' (mass × arm) of 20,375 kg×m (see annex A1.1, figure 9, OFP1, red cross).

For the reconstruction of the actual situation for take-off from Locarno on 4 August 2018, the values for mass and centre of gravity corresponded to a 'moment' of 19,499 kg×m (see annex A1.1, figure 10, OFP2, red cross).

The calculations for the simulation of diligent flight preparation are based on the following assumptions and values in particular:

- Mass and arm of the basic aircraft, i.e. when empty, based on values recorded in the flight planning software, but not true to reality;
- Standard masses for the crew and passengers based on values recorded in the flight planning software and OM-A;
- Standard person/seat allocation based on values recorded in the flight planning software, OM-A and the AFM;

[28] The arms for all people, storage compartments and fuel cells, mass for the people, and mass for the fuel were calculated using an assumed tolerance of ±10 cm, ±2.5 kg and ±10 % respectively, which produced the following: The extreme values calculated for the centre of gravity, which could only occur in the unlikely event of all values shifting in the same direction, are 2,032 m and 2,111 m. According to a Monte Carlo error calculation and based on the above assumptions, the centre of gravity was >2,060 m with a probability of >99.5 %, i.e. behind the rearmost permissible centre of gravity position.

- Standard masses for the luggage belonging to the crew and passengers based on values recorded in the flight planning software and OM-A;
- Identical arm for all passenger luggage based on the value recorded in the flight planning software and the AFM, but not true to reality;
- Identical arm for all crew luggage based on the value recorded in the flight planning software, but not true to reality;
- No flight kit based on the situation found at the accident site;
- Fuel density of 0.71 kg/l based on the value recorded in the flight planning software;
- Arm for the total remaining fuel, independent of the fuel remaining, based on the value recorded in the flight planning software and on the AFM, but not true to reality.

The calculations for the reconstruction of the actual situation are based on the following assumptions and values in particular:

- Mass and arm of the basic aircraft, i.e. when empty, based on the applicable weight sheet;
- Realistic masses for crew and passengers based on information from relatives;
- Realistic person/seat allocation based on reconstruction using photos and videos; one person per seat;
- Masses for luggage belonging to the crew and passengers based on the weight of the luggage taken from the accident site (totalling 121 kg);
- Realistic arm for the luggage found in the rear underfloor storage compartment based on the re-measurement of a sister aircraft;
- Arm for the luggage found in the front rear storage compartment based on the AFM;
- No flight kit based on the situation found at the accident site;
- Fuel density of 0.72 kg/l based on the AFM;
- Real arms for the different fuel cells based on the re-measurement of a sister aircraft (and confirmed by section 6.7 of the AFM);
- Realistic distribution of the remaining fuel among the various cells based on modelling of the fuel tank system;[29]
- Average fuel consumption based on the AFM.

It can be concluded from table 1 and the underlying assumptions and values that:

- HB-HOT's centre of gravity was outside the permissible range at all times between its take-off from Dübendorf on 3 August 2018 and the accident on 4 August 2018.
- Even with the pilots conducting diligent flight preparation, they could not have noticed that the centre of gravity was outside the permissible range. This is due to the incorrect values recorded in the flight planning software and, in turn, to some extent the incorrect values in the AFM.

[29] Modelling of the fuel tank system and of the cell emptying regime was based on the simplified assumption that all 14 cells lie horizontally and are cuboidal, but differ in base area and height, and are vertically tiered following the inclination of the top of the wing. In reality, the cells are shaped rather like sloped, elliptical cylinders. The simplifications between the model and reality are considered permissible for the purpose in question.

A1.6.6.5 Shifting of the centre of gravity by passengers

For the accident flight, simulations were created to determine how the balance would have been affected if certain passengers had moved further back in the aircraft.

Scenario 1: the passenger weighing 99 kg, who was sitting in the front row, goes to the toilet. Result: the centre of gravity shifts backwards by approximately 7 cm.

Scenario 2: the passenger weighing 99 kg, who was sitting in the front row (rear-facing seat), moves to the access door level with row 9 for a view down through the window, which is blocked by the wing from their seat. Result: the balance shifts backwards by approximately 6 cm.

Scenario 3: the passenger weighing 92 kg, who was seated in seat row 4, moves to the access door level with seat row 9 for a view down through the window, which is blocked by the wing from their seat. Result: the centre of gravity shifts backwards by approximately 4 cm.

The problem that the balance can shift backwards by several centimetres in such scenarios and thus fall outside the permissible limits was not addressed in OM-B or the AFM.

In the images and video footage available that had been captured from inside HB-HOT, there was no evidence of anyone moving within the aircraft or not sitting in their seat between the period when the aeroplane entered the basin south-west of Piz Segnas and up to the beginning of its downward spiral trajectory. The video footage revealed that, in particular, the heaviest person on board the aircraft (99 kg) was in their seat in the front row until impact.

A1.6.7 Navigation equipment

Ju-Air's Ju 52 aircraft were fitted with equipment and displays for conventional radio navigation (VOR and DME) as well as a GPS device. However, navigation in the mountainous terrain was carried out by visual clues – either using paper charts or knowledge of the terrain from memory.

HB-HOT's equipment included one copy of each of the following charts and reference books:

- ICAO aeronautical chart, 1:500,000 ("*Switzerland Liechtenstein, Aeronautical Chart ICAO, GND – FL 195, 47th edition, 2018 MAR 29*");
- Military aeronautical chart, 1:500,000 ("*Mil Airspace Chart, 2018 MAR 29*");
- Area chart for Geneva and Zurich, 1:250,000 ("*Zurich Area / Geneva Area, Area Chart ICAO, 1:250,000, GND – FL 195, 9th edition, 2018 MAR 29*");
- 'VFR Manual' from commercial provider Jeppesen including approach and aerodrome charts for Switzerland and surrounding countries.

The first three charts mentioned above covered the area surrounding the accident site. At the scene of the accident, these three charts were found neatly folded in the cockpit pocket provided for the storage of these charts.

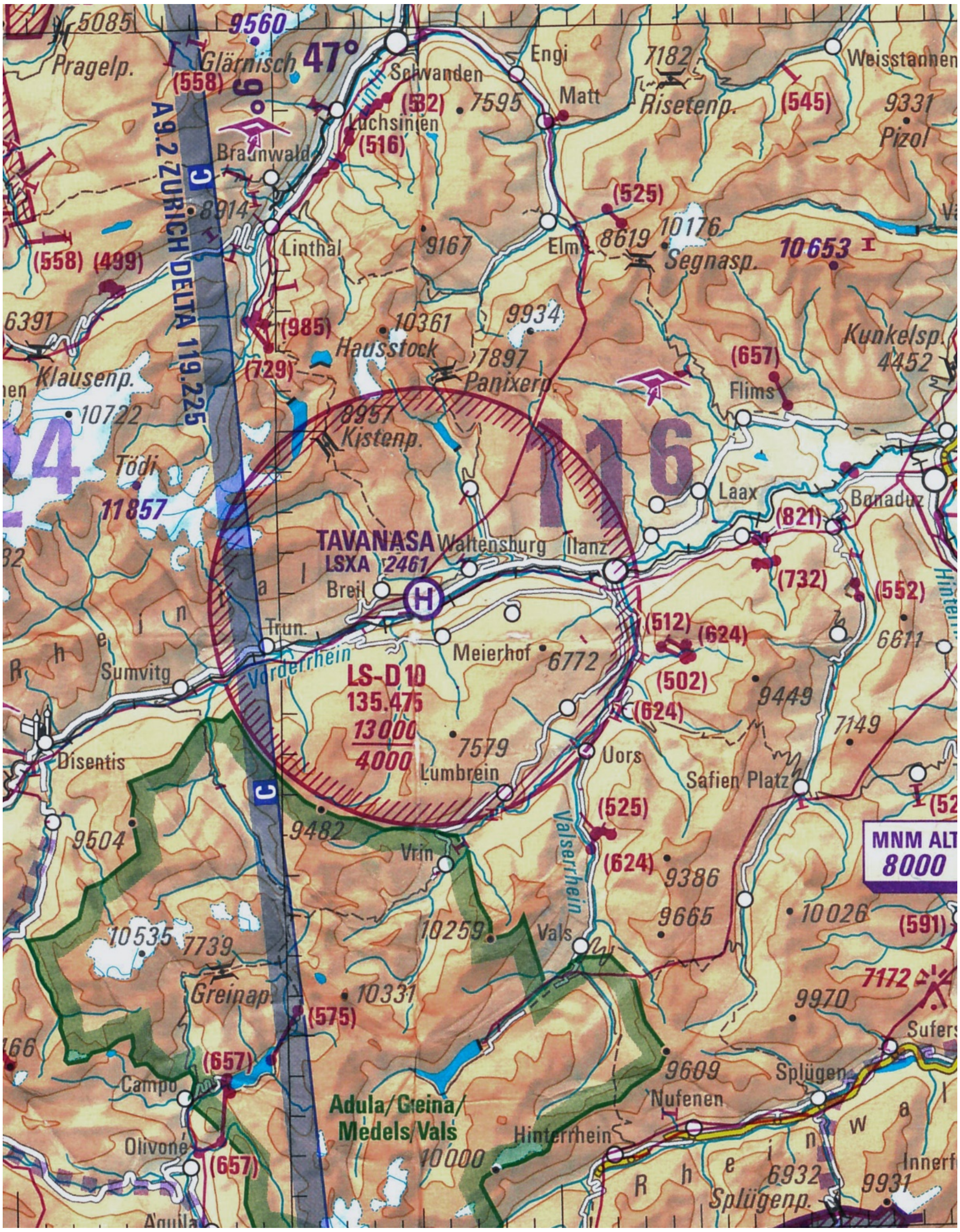


Figure 6: Excerpt (not to scale) from the ICAO aeronautical chart, 1:500,000, on board HB-HOT. Altitude information is given in feet.

HB-HOT's equipment did not include copies of the aeronautical information publication (AIP) of Switzerland, the official VFR Manual for Switzerland (published by Skyguide) or the official VFR-Guide for Switzerland, and these were not on board the aircraft. As specified in section 8.1.14 of OM-A, one copy of the AIP, the VFR Manual and the VFR-Guide should have been on board.

The GPS device that was installed in Ju-Air's Ju 52 aircraft only had a small display. The device was not primarily intended for navigational purposes, but served predominantly to maintain the scheduled flight time.

A1.6.8 Structural features

A1.6.8.1 General information

The type Ju 52/3m g4e aeroplane was developed in Germany as a three-engined aircraft by Junkers Flugzeug- und Motorenwerke AG and had its maiden flight in 1932. The aircraft was made predominantly of Duralumin[30], whilst important connecting pieces were made of high-strength steel. Light cast metal components as well as connection bolts and turned parts made of standard steel were also used in the construction of the aircraft. The Ju 52/3m g4e is an all-metal aircraft, which features an airframe covered in corrugated sheet panelling attached using snap head rivets (solid rivets).

The Ju 52/3m g4e, registered as HB-HOT, originally procured by the Swiss Army as a classroom aircraft, was converted to a passenger aircraft in 1985.

A1.6.8.2 Fuselage

The fuselage consists of four spar caps with fuselage frames perpendicular to the longitudinal axis. The partitioning frames of the fuselage are veed out.

Corrugated sheet metal attached using snap head rivets, which is partially reinforced by stringers, serves as panelling. The fuselage and the centre wing are firmly connected to each other. The ends of the three main, load carrying spars (spars I, II and III) and the auxiliary spar (spar IV) in the centre wing each bear two halves of the ball joints, known as ball sockets, to which the two outer wings are attached.

Both the vertical stabiliser, using four ball joints, and the adjustable horizontal stabiliser are fixed to the end of the fuselage.

The control components in the main usable area are installed in a channel that is easily accessible through hatches. All inspection hatches and covers on the fuselage are attached using quick-release fasteners or countersunk bolts.

A1.6.8.3 Wing

The self-supporting wing of the Ju 52/3m g4e consists of a centre wing and two outer wings. The centre wing is connected to the fuselage to form a single unit. The outer wings are trapezoidal and consist of a fixed main wing and an adjustable auxiliary wing. The outer part of the auxiliary wing is the aileron, and the inner part is the flap. The outer wings are removable, which makes it easier to inspect the inside of the wing and the control components.

The wings are connected to spars I, II, III and IV in the centre wing using eight ball joints (see figure 7). The fuel cells are integrated into the wing and are accessible through hatches on the underside of the outer wings. The spars are composed of a lower and an upper spar tube, which are connected to one another using stiffeners. The spars are connected to each other with cross bracings and struts. The connection points are called joints. The spars consist of several tubes, which are joined together and tapered in diameter towards the wing tip. The spars form a torsion box together with the ribs and the shear-resistant corrugated sheet panelling.

[30] Duralumin is an aluminium alloy that is stronger and harder than pure aluminium.

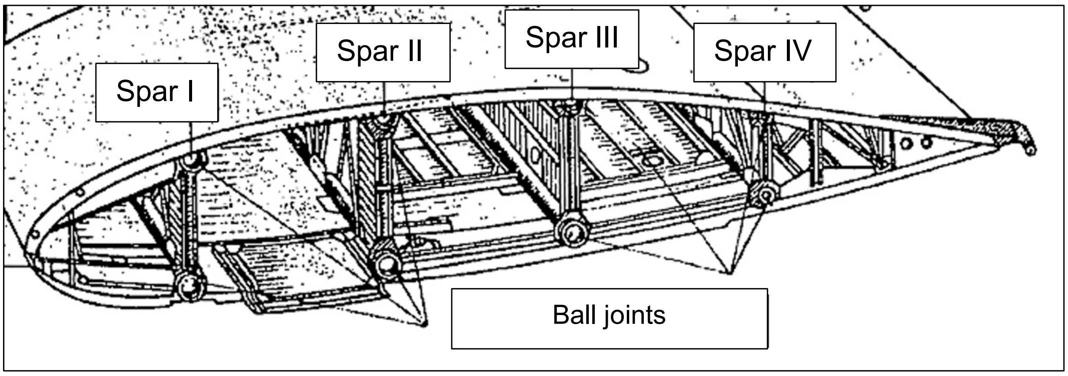
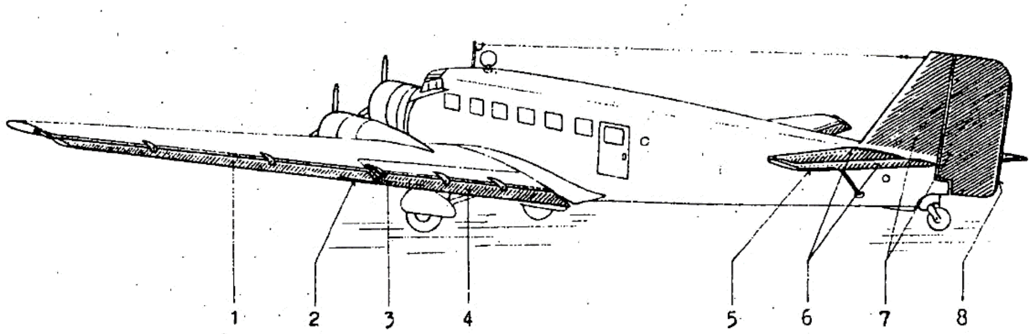


Figure 7: Outer wing including spars and ball joints. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.4 Control surfaces

A1.6.8.4.1 General

The control surfaces comprise the horizontal stabiliser (see figure 8), vertical stabiliser, ailerons and adjustable flaps.



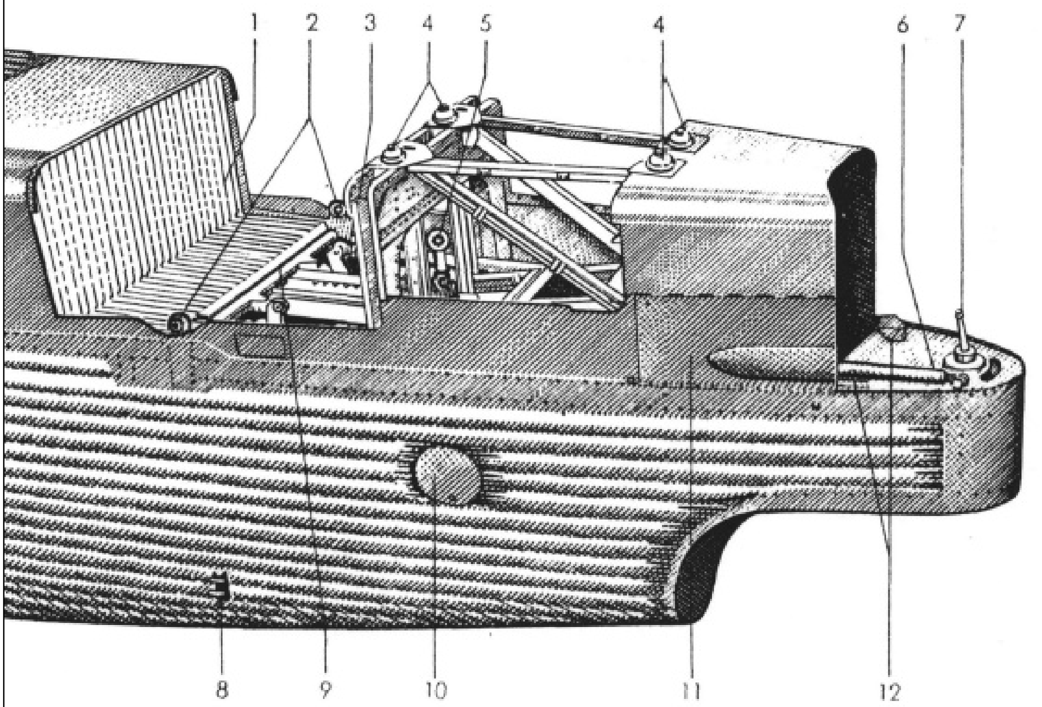
1) Aileron = outer adjustable flap
2) Trim tab for aileron
3) Trim tab for flap
4) Inner adjustable flap
5) Elevator trim tab
6) Horizontal stabiliser
7) Vertical stabiliser
8) Rudder trim tab

Figure 8: Overview of the control surfaces: Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.4.2 Horizontal stabilisers

The horizontal stabilisers, which are covered with corrugated sheet panelling, are attached to fuselage frame 8 using two ball bushings (see figure 9, (2)) and each feature a support strut on the respective side of the fuselage. Their angle can be adjusted within a range of +/- 3 degrees. In the centre of each stabiliser, an adjustment spindle (5) is engaged via a push-pull rod.

The horizontal stabilisers are adjusted from the cockpit using a hand wheel. A scale at the end of the fuselage and an indicator on the left-hand side of the cockpit display the angle set for the stabilisers.



1) Aft fuselage frame 8a
2) Opening with ball bushings for horizontal stabiliser
3) Aft fuselage frame 9
4) Ball joint for vertical stabiliser
5) Push-pull rod of the adjustment spindle for horizontal stabiliser
6) Push-pull rod for rudder
7) Bolt for rudder mounting
8) Bracket for horizontal stabiliser support strut
9) Aft fuselage frame 8
10) Hatch with quick-release fastener
11) Hatch with hinge and pin
12) Rudder stop

Figure 9: Mounting of the empennage. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.4.3 Elevators

The elevators are covered with corrugated sheet panelling. Each elevator with partial weight compensation is mounted onto three brackets on the respective horizontal stabiliser. Deflections of the elevators are limited in the cockpit by stops on the control column. Both elevators feature trim tabs on the outer trailing edge, which serve to trim small differences in the empennage components.

A1.6.8.5 Controls

A1.6.8.5.1 General

The controls consist of elevator, rudder and aileron controls as well as flap adjustment.

The flaps and ailerons are referred to as the auxiliary wing. The entire structure, including the outer wings, is also referred to as a 'double wing' construction.

The rudder and elevator trim tabs are used to trim the respective stabilisers and are set during maintenance test flights. The aileron trim tabs counterbalance the control force around the longitudinal axis of the aircraft. The flap trim tabs are automatically deployed when the flaps are activated. The aileron and flap trim tabs can only be adjusted on the ground.

The movements from the actuating elements are transferred to the control surfaces using push-pull rods, cables, chains, bevel gears, universal shafts and adjustment spindles. The connecting linkages can be set; the control cables must have the correct pretension.

A1.6.8.5.2 Elevator control

The actuating element for elevator control is the control column in the cockpit. The movement of the control columns is transferred to the elevators purely mechanically using levers, joints, push-pull rods and cables.

The elevator control is set according to set-up diagrams in the operating instructions (see figure 10).

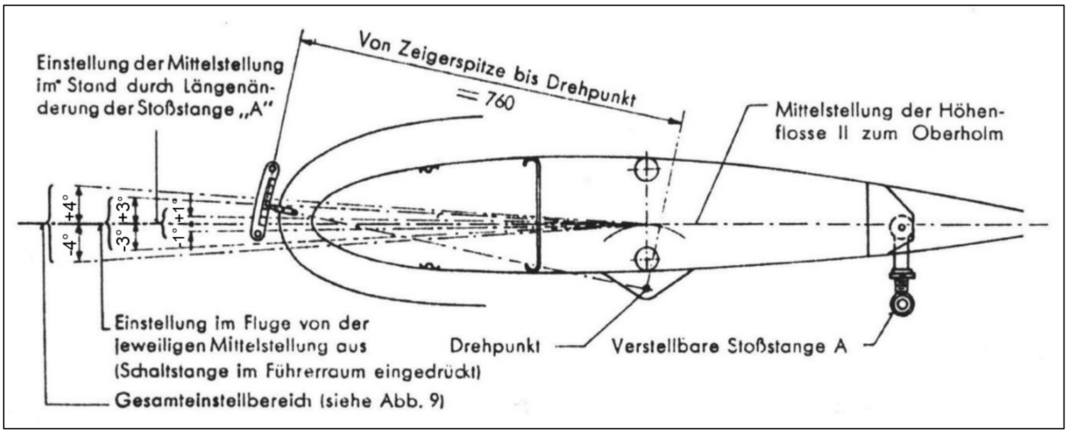


Figure 10: Set-up diagram for horizontal stabiliser. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.8.5.3 Rudder control

The rudder is operated using a pair of foot pedals, which transfer the pilot's inputs via a bevel gear and other mechanical elements.

A1.6.8.5.4 Ailerons

The ailerons are operated using the hand wheel on the control column in the cockpit. The control input is transferred purely mechanically via joints, push-pull rods and transmission levers.

A1.6.8.5.5 Auxiliary-wing and horizontal-stabiliser adjustment

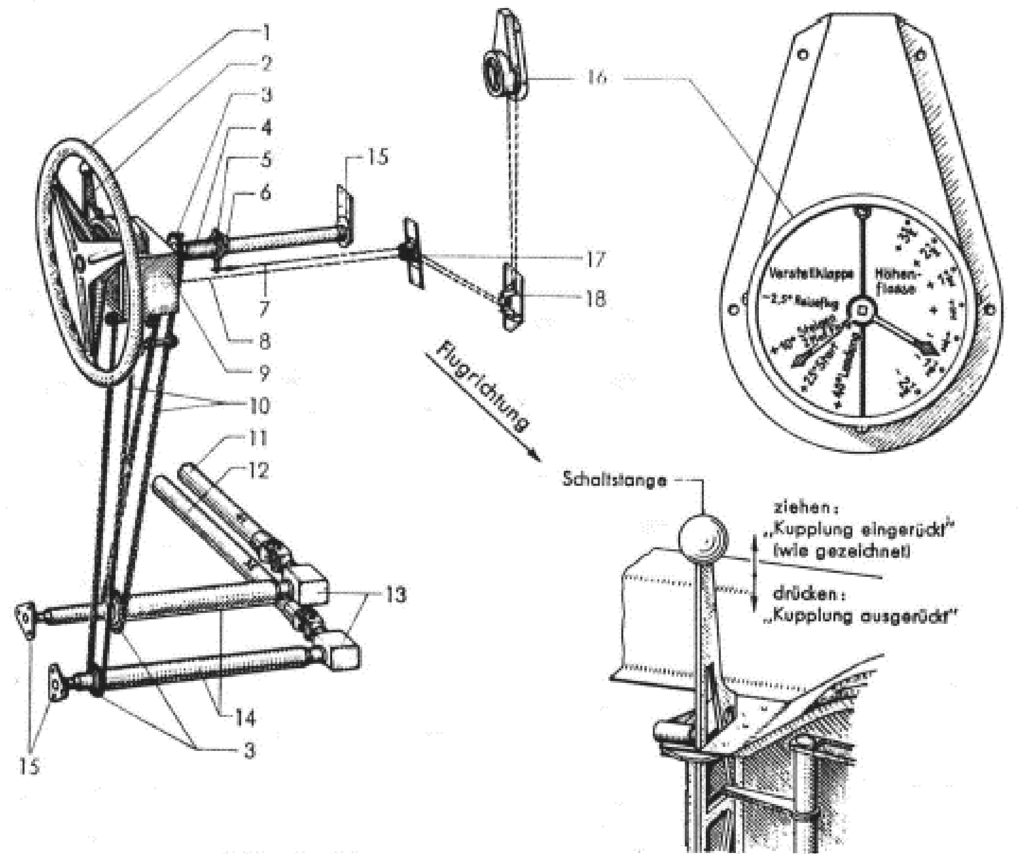
The auxiliary wings, consisting of the flaps and ailerons, as well as the horizontal stabiliser, are adjusted using the device shown in figure 11. It is operated using the hand wheel (1) next to the left-hand pilot seat and transfers the input adjustments via sprockets (3), chains (10), sprocket shafts (14), bevel gears (13), universal joint shafts (11) and (12), push-pull rods with pendulum guide and bell cranks.

The auxiliary-wing adjustment mechanism includes a safety device consisting of a spring assembly and an oil shock absorber. The safety device has the following function: If the dynamic pressure becomes too high when the auxiliary wing is at an angle, the reaction force in the actuating rods becomes greater than the strength of the spring assembly. As a result, the piston in the cylinder of the oil shock absorber slides back until an equilibrium is established between the spring strength and dynamic pressure. The angle of the auxiliary wing is thereby reduced. The oil shock absorber's cylinder thereby has a damping effect and compensates for sudden movements of the flaps.

When the control rod (2) is engaged, the auxiliary wing and horizontal stabiliser are adjusted together when the hand wheel (1) is operated. The control rod can be engaged with the flaps and horizontal stabiliser in any position. When the flaps and horizontal stabiliser are engaged in the zero position, the deflections are as follows:

Flap:	42° = 39°30' downwards + 2°30' upwards
Aileron:	14°30' = 12° downwards + 2°30' upwards
Horizontal stabiliser:	3°30' (for landplanes and seaplanes)

where the hand wheel (1) must make approximately 10½ turns. When the control rod (2) is disengaged (pushed in), the hand wheel can make 18 turns, adjusting only the horizontal stabiliser within a range of +/- 3 degrees. It is not possible to adjust the auxiliary wings alone.



1) Hand wheel
2) Control rod
3) Sprocket
4) Spindle shaft
5) Stop nut
6) Stop pin
7) Cable for horizontal stabiliser position indicator
8) Cable for flap position indicator
9) Control box
10) Chain
11) Universal joint shaft for stabiliser adjustment
12) Universal joint shaft for flap activation
13) Bevel gear
14) Sprocket shaft
15) Mounting
16) Indicator
17) Diverter pulley
18) Cable guide lever

Figure 11: Auxiliary-wing and horizontal-stabiliser adjustment. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

There is an indicator on the left-hand wall in the cockpit (see figure 11, (16)), which displays the position of the flaps and the horizontal stabiliser in degrees. The display is transmitted via cables (7 and 8), which are linked to the stop nuts (5) on spindle shaft (4). The cables (7 and 8) guided over pulleys (17) each engage with a lever for guiding the cable (18) and thus adjust the indicator's spring-loaded needles. In addition, there is another indicator at the end of the fuselage, from which the horizontal stabiliser position can be read.

The horizontal-stabiliser adjustment spindle (see figure 12) is incorporated in the fuselage frame (9). It is adjusted from the cockpit using a hand wheel (see figure 11 (1)), which transfers the inputs via a shaft (15) with a universal joint (14). The horizontal-stabiliser adjustment dimensions, as per the limit positions and zero position of the stabiliser, can be learned from figure 12. The relevant adjustment is made using the push-pull rod sleeve (1) and the locknut (2).

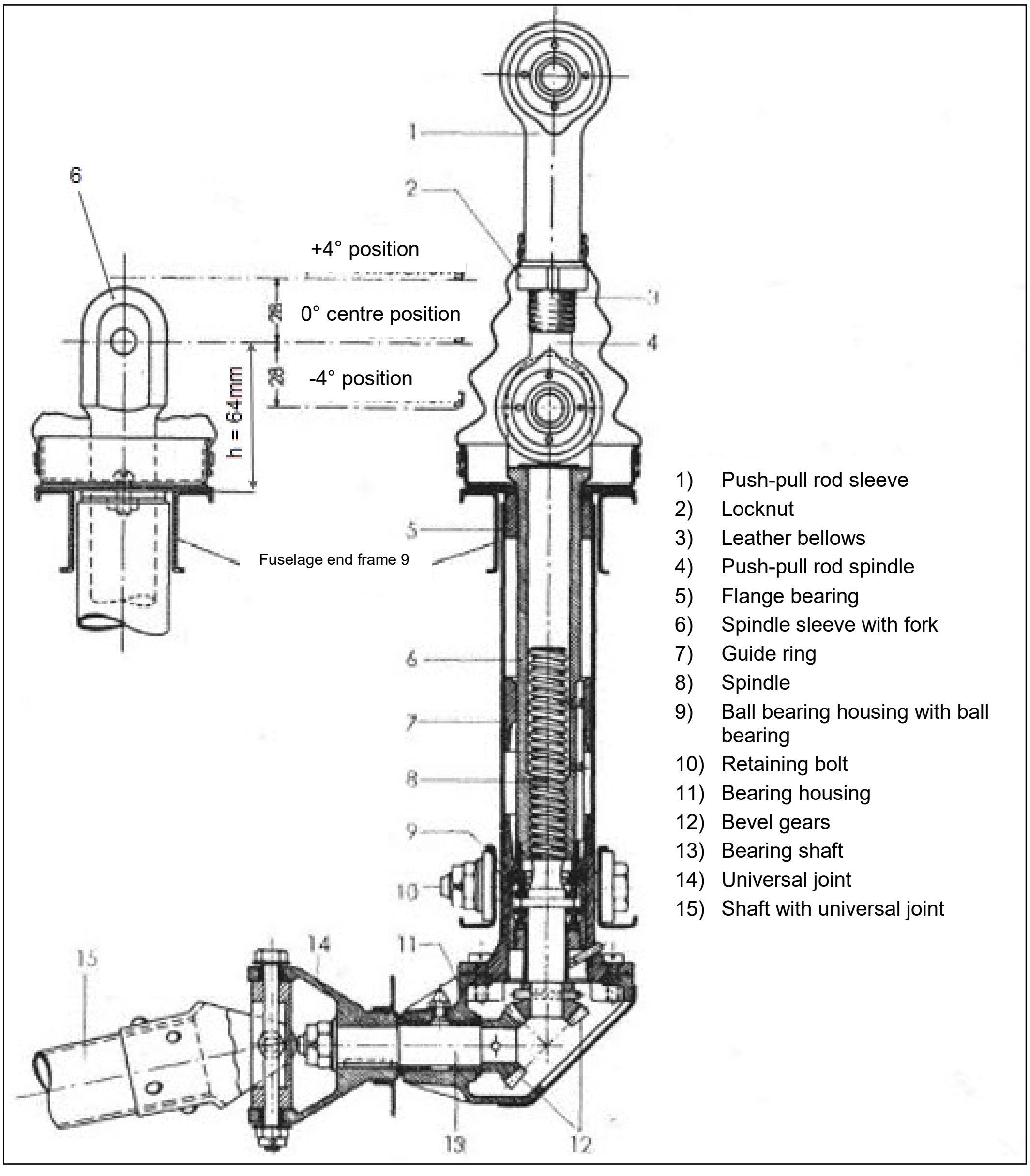


Figure 12: Horizontal-stabiliser adjustment spindle. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

When installing the horizontal-stabiliser adjustment spindle, the spindle sleeve is set to the correct position in line with the operating instructions. With this setting, the distance between the fuselage frame and the point of connection with the horizontal stabiliser (hole in the spindle sleeve's fork) is 64 mm (= h). In this position, the pitch of the horizontal stabiliser and the indicator in the cockpit are then adjusted to an angle of 0 degrees.

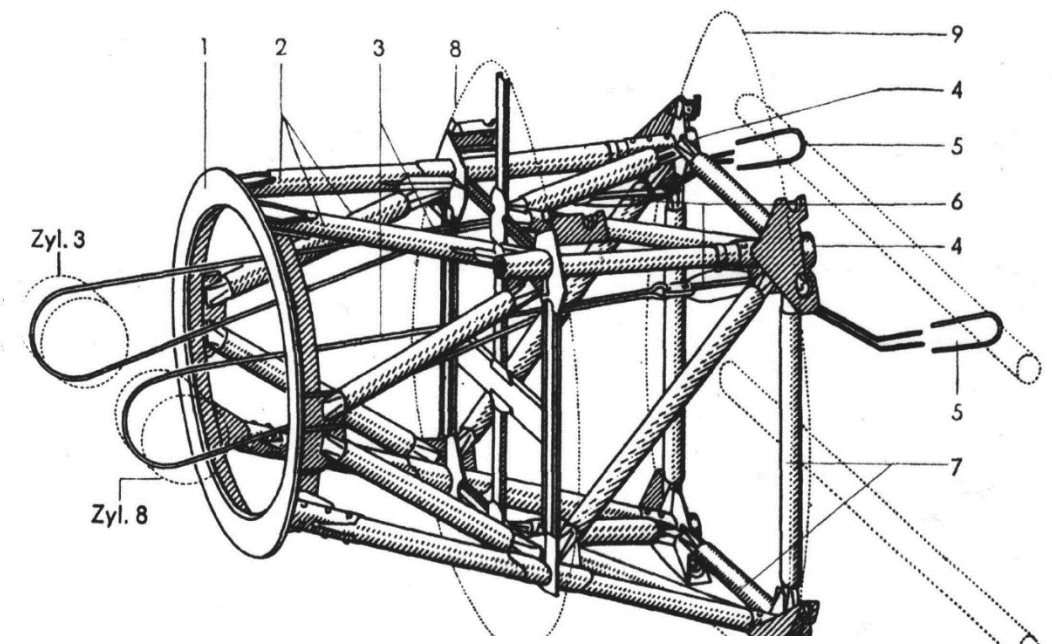
It should be ensured that the spindle sleeve with fork (6), in which the spindle rotates, is almost completely filled with grease at all times.

As specified in section 6.5.1 of the aircraft flight manual (AFM), the horizontal stabiliser must be adjusted based on the take-off mass prior to each flight. These values were also presented in the operational flight plan (OFP).

A1.6.8.6 Engine frame

The engine frames for the three engines are each mounted to the respective outer wing and fuselage connection frame using four ball joints (see figure 13 for the frame used for the left and right engines). They consist of the engine mount including tubular struts, the firewall and safety cables.

The engine mount, to which the engine is fitted, is riveted to the struts of the tubular frame using gusset plates. There are ball joints at the four rear ends of the struts for attaching the engine frame to the respective outer wing and fuselage connection frame.



1) Engine mount
2) Tubular frame
3) Engine safety cable
4) Ball joint
5) Bracket for attaching safety cable to upper spar I
6) Expansion rod
7) Tubular struts of the connection frame
8) Firewall
9) Outer wing connection frame

Figure 13: Engine frame for the left or right engine respectively. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

A1.6.9 Engines

A1.6.9.1 General

HB-HOT was installed with BMW 132 A, series 3 aircraft engines manufactured by BMW Flugmotorenbau GmbH in Munich. These are air-cooled nine-cylinder radial engines built under licence based on a Pratt & Whitney Aircraft Co. (USA) design that was modified by BMW based on their own experience from 1928 onwards.

The engine is equipped with a supercharger and a carburettor; the auxiliary equipment is mounted on the back of the engine. The propeller is driven directly by the engine's crankshaft. The design of this engine mainly makes use of the metric system.

BMW produced these engines until the end of the Second World War.

The information on the engine is based on the 1938 manufacturer's description and operating instructions for the air-cooled BMW 132 A3 aircraft engine.

A1.6.9.2 Cylinders

The nine air-cooled cylinders are bolted to the crankcase in a star shape. The cylinders consist of a thin-walled steel barrel with cooling fins and a cast aluminium-alloy cylinder head. The cylinder head also features numerous cooling fins. It is bolted onto the barrel when warm. The diameter of the bore when new is 155.56 to 155.60 mm; the wear limit is 155.80 to 155.90 mm. According to the operating instructions, a cylinder must be replaced with a new component when the wear limit is reached. The manufacturer also states that it is not permitted to re-bore the cylinder.

A1.6.9.3 Cam discs

The intake and exhaust valves of the radial engine are controlled by the cams on cam discs using a series of tappets, push-pull rods and rocker arms.

The cam disc for the exhaust valves and the disc for the intake valves each have four cams.

The cam discs are part of the cam drum. The cam drum is driven by the crankshaft via a gear transmission; it rotates in the opposite direction to the crankshaft at ⅛ of the crankshaft's speed. Each valve is actuated one after the other by the four cams.

A1.6.9.4 Magnetos

The air-fuel mixture is ignited in the cylinder by two spark plugs located in the cylinder head. The voltage required for this is supplied by two magnetos, which are mounted on the auxiliary equipment carrier of each individual engine. In each case one spark plug from each cylinder is connected to one of the two magnetos, so that – even if one magneto fails – proper ignition is guaranteed. However, the engine speed must not drop by more than 50 rpm.

A coupling is fitted between the gearbox in the auxiliary equipment carrier and the magneto to prevent damage to the gearbox in the event of a blockage in the magneto. As part of service bulletin no. 1025, four steel cams were soldered onto the sleeves of these couplings (see section A1.6.17.2.7). These generate the pulses in the proximity switches for the electronic tachometers.

The magnetos are designed for a nine-cylinder engine. The ignition sequence is determined in the magneto. In normal operation, the magneto permanently works in early ignition mode.

A1.6.9.5 Carburettors

A1.6.9.5.1 General

The BMW 132 A3 engine is fitted with a dual carburettor manufactured by Pallas with the part number NAY-9 A (see figure 14). This design is based on a licence from Stromberg and features the following:

- Fuel efficiency regulation
- Altitude control regulation
- Accelerator pump

These systems ensure that the engine receives the correct fuel mixture to ensure good efficiency at low cylinder temperatures under various working conditions and in different flight situations.

Since the nozzle setting suitable for proper operation of the engine has been determined as a result of extensive testing, modifications should only be made when sufficient test data are available to assess the nature and extent of the modification with certainty.

The purpose of the fuel efficiency regulation is to adjust the fuel mixture when cruising at medium load in order to achieve efficient fuel consumption; this same system also allows the engine to operate at high load for a short period of time without unacceptable increases in cylinder temperature by enabling more fuel to be used.

The altitude control mechanism adjusts the air-fuel mixture to the most efficient consumption, in order to counteract the mixture becoming richer as altitude increases.

The accelerator pump ensures that when the butterfly valve is opened quickly, and the engine speed increases accordingly, the required larger quantity of fuel enters the carburettor’s air funnel.

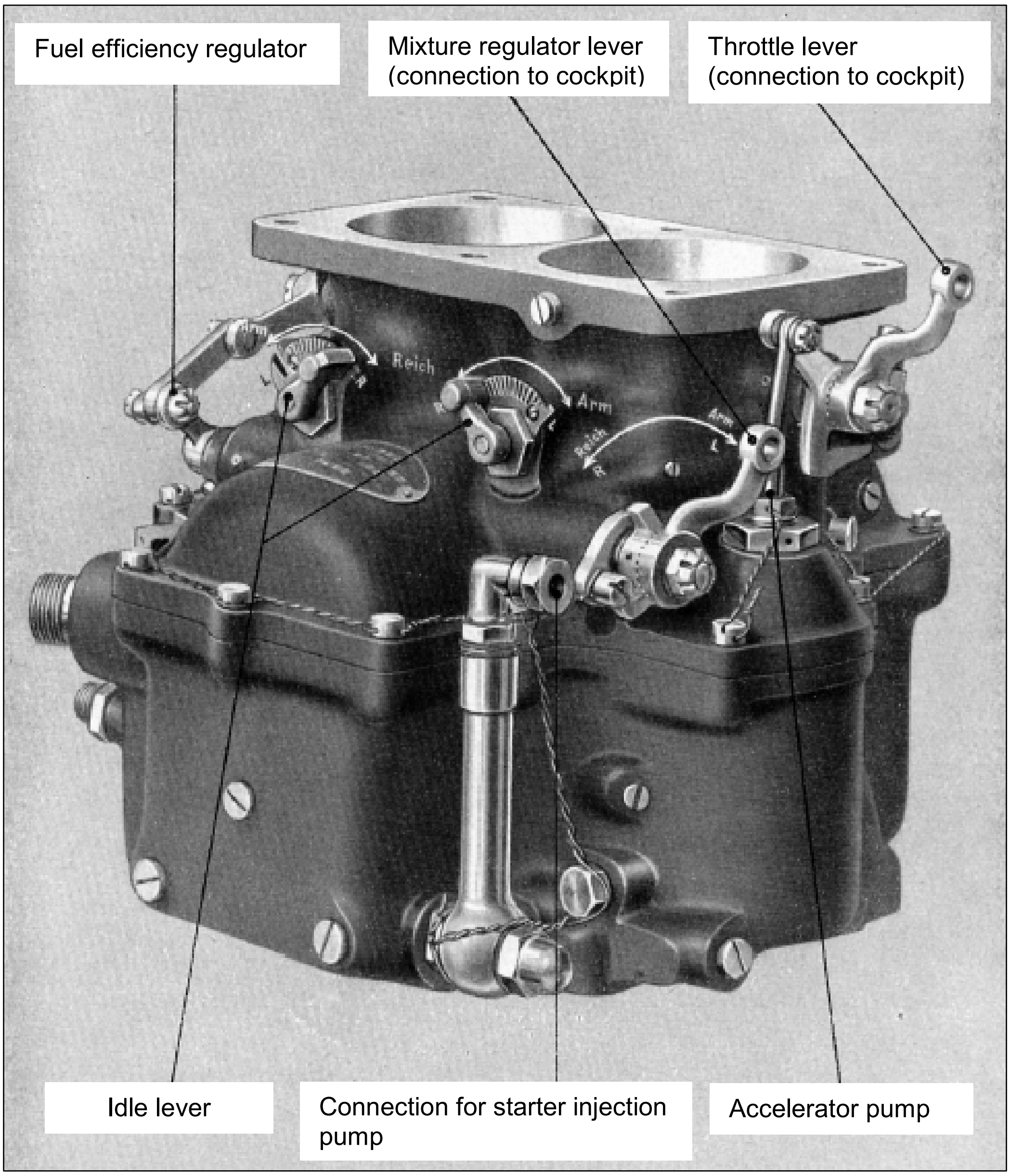


Figure 14: Pallas dual carburettor. Source: "*Betriebsanleitung des BMW-132-A3-Motors*" (instruction manual).

A1.6.9.5.2 Accelerator pump

In order to supply the engine with the larger quantity of fuel required when the engine speed is rapidly increased, the carburettor is equipped with an accelerator pump.

The accelerator pump is located in the lower part of the carburettor and consists of a pump cylinder in which a piston moves vertically. The lift rod of the piston is connected to the throttle lever by a linkage. The accelerator-pump piston's stroke from the 'fully closed' to 'fully open' throttle positions is about 24 mm.

A1.6.9.5.3 Adjusting the idle air-fuel mixture

The idle air-fuel mixture and idle engine speed are adjusted at the carburettor when the engine is warm. The air-fuel mixture is adjusted to be as rich as possible. The idle engine speed is set using the adjusting screw on the butterfly valve lever. Further basic settings on the carburettor are not possible.

A1.6.9.6 Supercharger

A1.6.9.6.1 General

The air-fuel mixture produced in the Pallas dual carburettor is drawn into a supercharger via an oil-heated preheater and fed to the individual cylinders under pressure. The supercharger is a single-stage turbo compressor with a radial design.

A1.6.9.6.2 Functionality

The supercharger shaft is driven by the rear end of the crankshaft via a transmission gear. This increases the speed of the supercharger shaft to 10 times the engine speed. A reliably functioning supercharger is essential for safe engine operation. The selection, lubrication and sealing of the high-speed rolling bearings for the supercharger shaft must be suitably exacting.

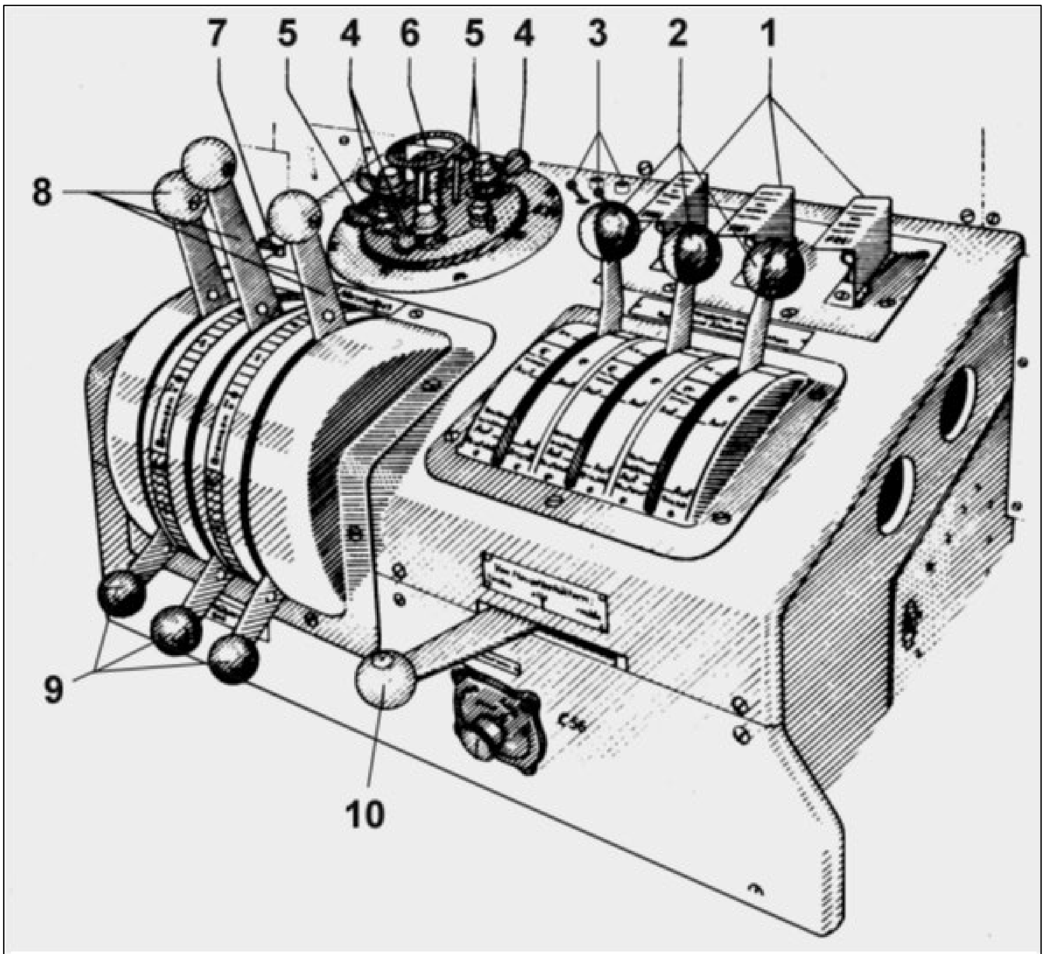
A1.6.9.7 Engine power controls

A1.6.9.7.1 General

The levers, switches, knobs and hand wheels required to operate the engines are located on the control panel (see figure 15) in the centre of the cockpit, to the left and right of it and on the equipment panel.

The main throttle levers (8) and high-altitude throttle levers (9) are located on the left-hand side of the control panel.

When set to ‘on’, the full-throttle limiter (7) restricts the travel of the main throttle lever (8), and when set to ‘off’ it allows the lever to travel fully.



1) Starter switch
2) Valve-battery lever (oil-fuel selector)
3) Booster-pump switch and lights
4) Ignition switch
5) Early/late ignition adjuster
6) Main ignition switch
7) Full-throttle limiter
8) Main throttle levers
9) High-altitude throttle levers
10) Fuel cell selector

Figure 15: Control panel for the Ju 52/3m g4e. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

From the control levers and hand wheels mounted in the cockpit, the movement is transmitted to the engines, switching units, etc. by linkages consisting of rods and cables.

The travel of the three main throttle levers as well as the three high-altitude throttle levers is transferred to the butterfly valve and the carburettor's mixture control via a system of rods, joints and bell cranks.

When removing rods, the adjustable rod ends must not be changed in length. If this has been done, the linkage must be readjusted so that the positions of the control levers on the cockpit control panel correspond to the positions of the end levers.

A1.6.9.7.2 Main throttle lever and its adjustment

The carburettor's butterfly valve is actuated via adjustable linkages using the main throttle lever on the control panel. With the butterfly valve fully open, the power output at a CINA[31] normal atmosphere of 0 (760 mm Hg, 15°C) is 725 PS at 2,050 rpm. As the engine is subject to excessive thermal stress when the butterfly valve is fully opened at altitudes below 900 m AMSL, it may only be operated with a fully-opened[32] butterfly valve in exceptional cases. For this reason, the travel of the main throttle lever is limited by a full-throttle limiter. When the full-throttle limiter is set to 'on', the main throttle lever cannot travel to its full extent (see figures 16 and 17). On the other hand, when set to 'off' the main throttle lever can travel to its full extent and the butterfly valve can be opened fully. This is called the full-throttle position. The travel of each main throttle lever is limited by adjustable stop bolts.

The full-throttle limiter on Ju-Air aircraft could be secured in the 'on' position using a copper wire and a lead seal. Turning the full-throttle limiter to 'off' breaks the seal. The aircraft manufacturer never provided for such a safety device. According to Ju-Air, this safety device had been installed since about 1995 to monitor the pilots, as the full-throttle limitation had been repeatedly deactivated. Each broken seal had to be recorded in the tech log and justified by the pilot.

According to the operating instructions, there is a mark on the carburettor for correctly adjusting the main throttle lever with the full-throttle limiter set to 'on'. With the throttle not fully opened, the engine speed should not exceed 1,965 rpm at a CINA standard atmosphere of 0. When passing the limit stop, the engine should deliver the short burst of increased power at 2,050 rpm below 900 m AMSL and the short burst of power at 2,050 rpm above 900 m AMSL.

31 CINA: *Commission Internationale de Navigation Aérienne*, International Commission for Air Navigation (ICAN). CINA was replaced by the International Civil Aviation Organisation (ICAO).

32 When the butterfly valve is fully open, the valve is at an angle of 10 degrees from vertical.

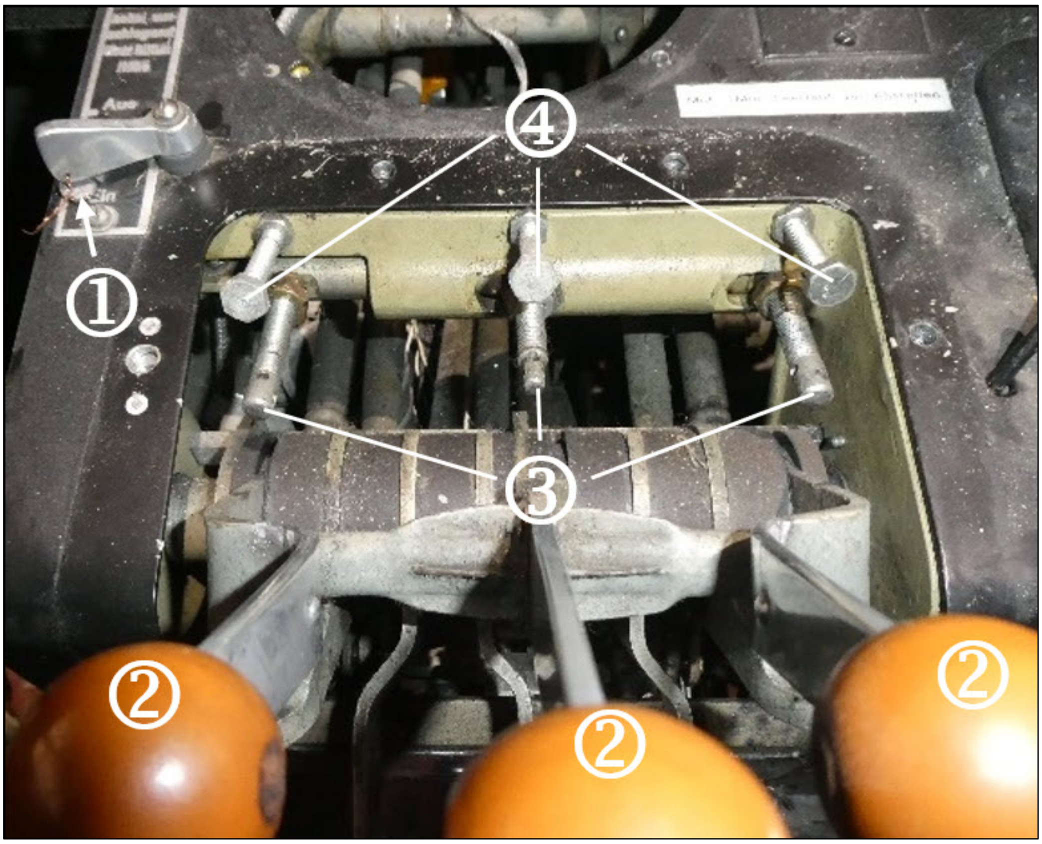


Figure 16: Full-throttle limiting mechanism in the 'on' position. Full-throttle limiter with lead-sealed wire lock (1); main throttle levers (2); stop bolts for full-throttle limiting (3); stop bolts for full throttle (4).

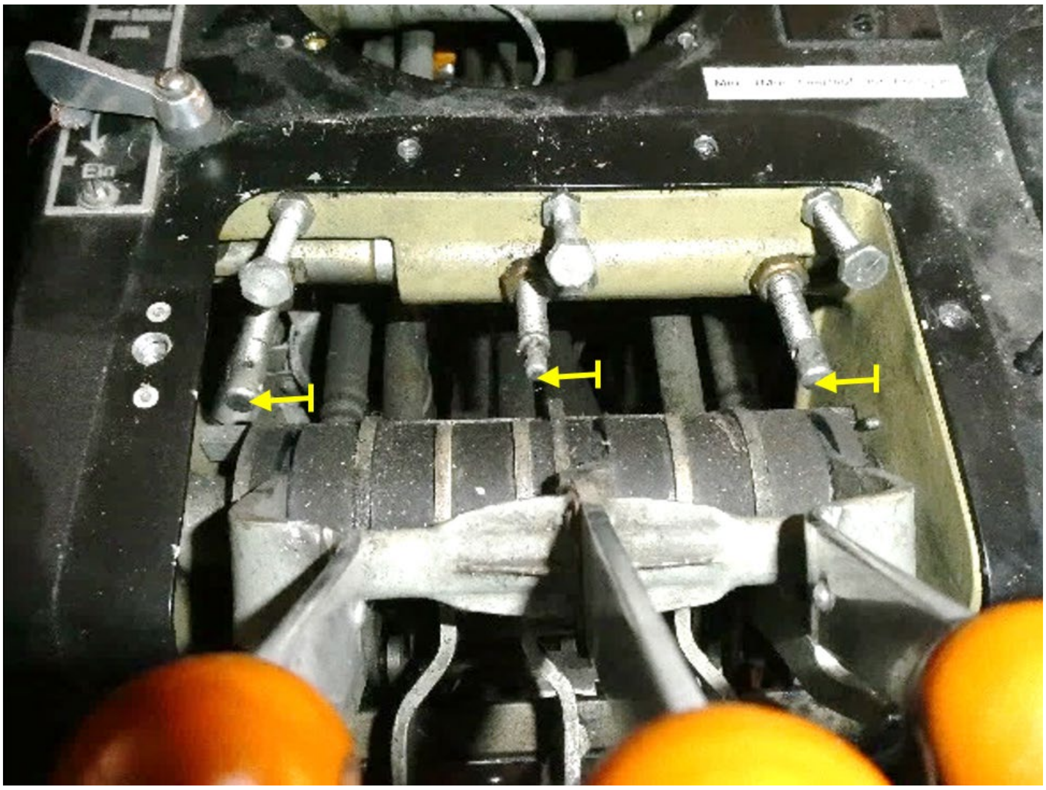


Figure 17: Full-throttle limiting mechanism in the 'off' position. Stop bolts for full-throttle limitation are moved to the left (yellow arrows).

A1.6.9.7.3 Altitude control regulation and its adjustment

With increasing altitude, i.e. decreasing air density, the air-fuel mixture becomes richer. In order to avoid an excessive increase in fuel consumption, the carburettor is fitted with altitude control regulation.

The altitude control regulation is operated by the pilots using the high-altitude throttle levers.

When adjusting the high-altitude throttle, it has to be ensured that the corresponding high-altitude throttle lever on the control panel is in the 'rich mixture' position when the adjustment lever on the carburettor is in the 'R' position, i.e. rich.

A1.6.10 Engine power

A1.6.10.1 Performance data terms defined by the manufacturer

The following information on the engine is based on the 1938 manufacturer's description and operating instructions for the air-cooled BMW 132 A3 aircraft engine:

"All power output values in PS are to be understood as the useful power available at the propeller shaft.

I. Full power Normal 0

is the net power the engine delivers at a CINA standard atmosphere of 0, i.e. air pressure of 760 mm Hg and + 15 °C, at full-throttle and for the maximum permissible operating speed (short-burst speed), if the engine were allowed to run at such high loads. (In urgent cases, it may be used for the BMW 132 A for take-off as a short burst of increased power up to a maximum duration of 1 minute).

II. Operational power outputs

are the maximum net power ratings permitted for certain specified operating modes. They are limited

1. *by the charging pressures given for the operating mode and the respective flight altitudes.*
2. *by the maximum engine speed selected for the operating mode and/or by the attainable take-off speeds in horizontal flight whilst maintaining the prescribed charging pressures below the short-burst power altitude with a fixed-pitch propeller.*

For flight operations, the following marginal power operating modes have been defined.

a) *Short-burst power is the maximum power drain permitted for the flight operation. It may only be used for the shortest possible time (maximum 5 minutes) during take-off and in case of an urgent need of power.*

b) *Increased continuous power is permitted only when necessary for accelerated climbing and in special cases, but must be limited to a maximum of 30 minutes.*

c) *Continuous power is the maximum permissible continuous load on the engine.*

d) *Recommended cruise power is the power level at which the engine operates most efficiently in terms of both fuel consumption and service life.*

III. Full-power altitude is the altitude at or above which the engine is permitted to run with the throttle fully open when at normal atmosphere. However, except for short bursts of power, the full power possible at this altitude can only *be fully utilised for engine speeds below this level with a freely variable propeller.*

IV. *Take-off engine speeds are those speeds which are reached in horizontal flight at altitudes below the short-burst power altitude at the relevant stipulated charging pressures and normal atmosphere with a fixed-pitch propeller."*

A1.6.10.2 Performance data from the engine manufacturer

The BMW 132 A3 engines are designed as high-altitude engines with enlarged air nozzles. Operation of the engine with fully opened butterfly valve and at 2,050 rpm is only permitted starting at an altitude of 900 m AMSL and for a maximum period of five minutes when using a fixed-pitch propeller. This is called short-burst-power operation. As the engine is subject to excessive thermal stress when the butterfly valve is fully opened at altitudes below 900 m AMSL, it may only be operated in this range with a fully-opened butterfly valve in exceptional cases (see table 2). The engine manufacturer has defined corresponding limit values for the maximum engine speeds in the different operating modes depending on the flight altitude (see figure 18).

	Engine speed [rpm]	
	Below 900 m AMSL	Above 900 m AMSL
Short-burst increased power up to 1 minute	2,050	
Short-burst power up to 5 minutes	1,965	2,050
Increased continuous power up to 30 minutes	1,890	1,975
Continuous power	1,850	1,930
Cruise power	1,785	1,860

Table 2: Power limits according to engine manufacturer.

According to the engine manufacturer's specifications, the engine's power output is 725 PS at 2,050 rpm. This is valid at a fully opened butterfly valve and CINA normal atmosphere at sea level (760 mm Hg, 15 °C). This power is called short-burst increased power and may be used in urgent cases for take-off as a short burst of increased power for up to a maximum of one minute.

The engine delivers 660 PS with the butterfly valve fully open at an altitude of 900 m AMSL at normal atmosphere (684 mm Hg, 9 °C). For this, the engine speed is 2,050 rpm. This output is referred to as short-burst power.

The engine manufacturer has defined the permissible deviations for power and engine speeds as follows:

Power: + 4 % to – 2 % Speed: +/- 2 %

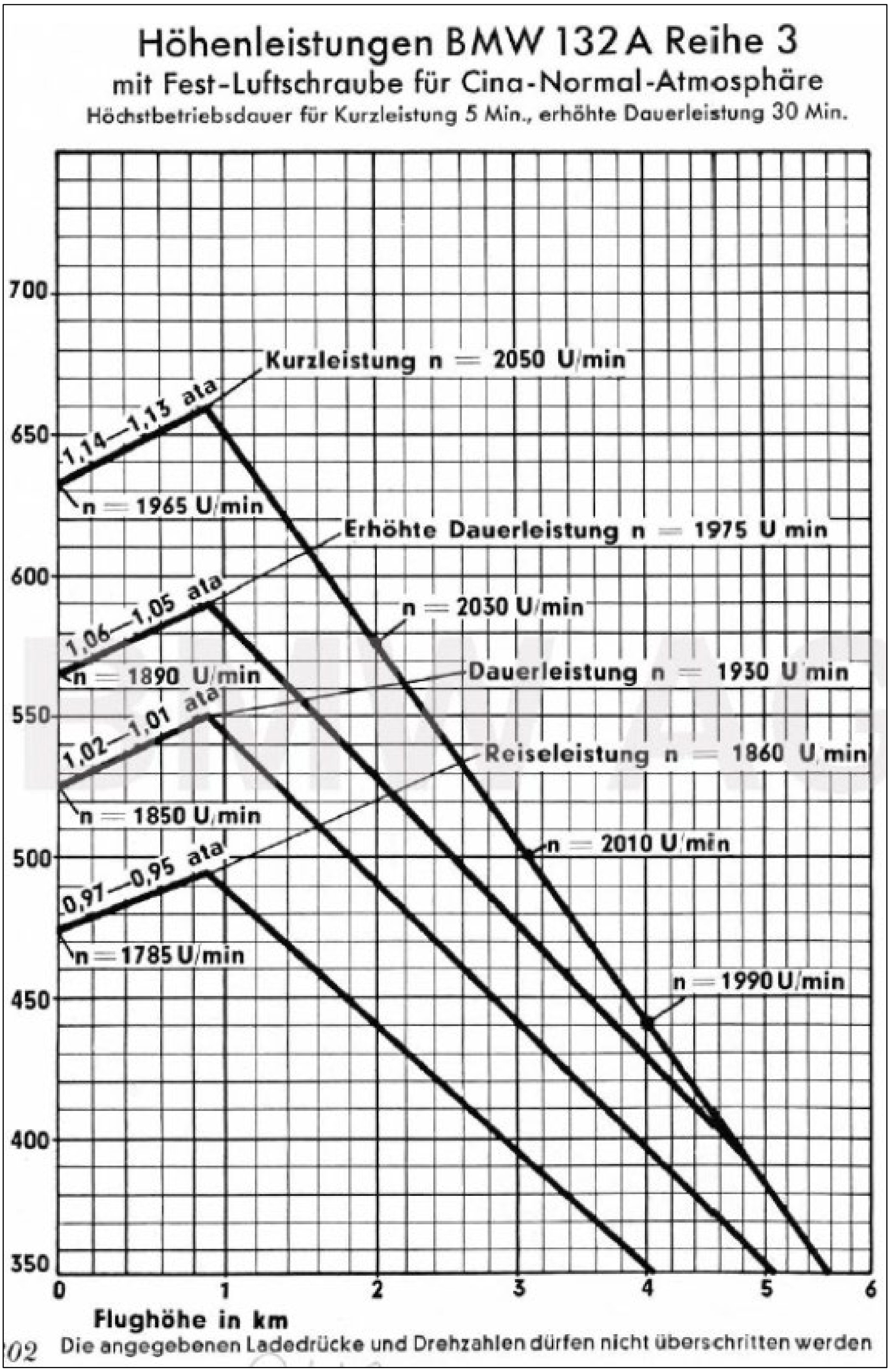


Figure 18: Altitude performance for the BMW 132 A3 aircraft engine. Source: "*Betriebsanleitung des BMW-132-A3-Motors*" (instruction manual).

A1.6.10.3 Guidelines for the inspection of engines

In 1937, the then Reich Minister of Aviation published the test data for the BMW 132 A3 engine via the aircraft testing institute on an engine test stand. According to these specifications, the following must be demonstrated when testing the engine on the test bench:

Power description	Power	Duration
Short-burst increased power	725 PS at 2,050 rpm	5 minutes
Short-burst power	660 PS at 1,990 rpm	15 minutes
Increased continuous power	590 PS at 1,925 rpm	105 minutes
Continuous power	520 PS at 1,850 rpm	–

Table 3: Engine test data for use in verification inspections.

During this test, the charging pressure, the specific fuel consumption and, for increased continuous power, the specific amount of lubricant consumed should also be measured. Limit values were defined for the measured data.

The above performance data refer to performance at CINA standard atmosphere. In places where the above values are not achieved despite a fully opened butterfly valve, the measured value can be calculated based on normal conditions.

For full power – which in the above list corresponds to the short-burst increased power of 725 PS – the aircraft testing authority specified a power tolerance of +/- 2.5 % and an engine speed tolerance of + 100 to - 60 rpm.

A1.6.10.4 Performance data from the aircraft manufacturer

A1.6.10.4.1 Operating data table

On the left-hand side of the fuselage in the cockpit, there was an operating data table with the permissible operating values (see table 4). These were supplied by the aircraft manufacturer in 1939.

	Engine speed [rpm]	
	Below 900 m AMSL	Above 900 m AMSL
Short-burst increased power up to 1 minute	2,050	
Short-burst power up to 5 minutes	1,950	2,050
Increased continuous power up to 30 minutes	1,900	1,975
Continuous power	1,850	1,930
Cruise power	1,775	1,850

Table 4: Values from the Junkers operating data table from 1939.

A1.6.10.4.2 Engine speeds in flight operation

In section 10, 'Flight operation', of the operating instructions for the Ju 52/3m g4e, the following information is given regarding engine speeds during the various flight phases:

"Take-off

[…]

Stop lever for main throttle on the left-hand side of the control panel set to 'on'.

Accelerate at a good pace until the 'up' stop.[33]

1-minute power, engine speed n = 2,050 rpm.[34]

[…]

After 1 minute back off the throttle to 30-minute power:

Engine speed n = 1,950 rpm[35] *at alt. = 0–900 m*

n = 2,050 rpm[36] *at alt. = over 900 m.*

Climb

[…]

After completing 1-minute power, switch to 30-minute power.

[…]

Cruise

Best altitude for cruising flight approximately 1,000 m

Engine speed at continuous power n =1,925 rpm

Engine speed in cruise flight n =1,850 rpm.

Cruising speed

V_a[37] *= 240 km/h at an altitude of 500 m*

V_a *= 220 km/h at an altitude of 2,500 m*

V_a *= 175 km/h at an altitude of 5,000 m*

[…]

I. Engine failure

In the event of one engine failing, there is enough power to continue the flight. Please note the following points:

[…]

3. *Open the main throttle levers of the healthy engines to full-throttle, regardless of altitude."*

The permissible operating values of the engines are marked on the display units by red lines or by luminous material.

---

[33] Here it is to be understood that the throttle levers must be moved 'up' until the full-throttle limit is reached.

[34] If necessary, the limit stop can be disengaged to use the maximum speed of 2,050 rpm for one minute.

[35] Short-burst power up to five minutes at an engine speed of 1,950 rpm, as per the operating data table.

[36] Short-burst power up to five minutes at an engine speed of 2,050 rpm, as per the operating data table.

[37] V_a: Indicated airspeed

A1.6.10.5 Verification flights during acceptance of the aircraft

In a total of four flights between 29 September and 4 October 1939, a Swiss delegation measured the performance of one of the three Ju 52/3m g4e aircraft ordered at the airfield in Dessau where Junkerswerke was based. Based on previous inspection flights with the two aircraft bearing serial numbers 6580 (later HB-HOS) and 6595 (later HB-HOT), the aircraft with serial number 6580, which was assessed as less powerful, was designated as the aircraft to be used during the performance measurements.

The performance flights were carried out with a mass of 10,000 kg. The three propellers had the following pitches:

Left propeller	Centre propeller	Right propeller
21°	20.5°	21°

The performance flights included in particular:

- Horizontal speed close to ground level
- Climb to service ceiling
- Take-off and landing measurements

In summary, the following performances were measured:

Altitude [m AMSL]	Climbing time [min.]
0–1,000	4.7
0–2,000	9.3
0–3,000	15.2
0–4,000	24.6
0–5,000	42.2

Table 5: Logged climbing times during acceptance.

Climbing measurements with flap position set to 11 degrees:

Flying altitude	Indicated airspeed	Climbing speed	Engine speed left engine	Engine speed centre engine	Engine speed right engine
[m AMSL]	[km/h]	[m/s]	[rpm]	[rpm]	[rpm]
1,000	155	3.55	1,760	1,835	1,790
2,000	153	3.10	1,770	1,840	1,790
3,000	152	2.25	1,770	1,835	1,800
4,000	145	1.40	1,760	1,830	1,760
5,000	142	0.60	1,760	1,820	1,760

Table 6: Logged climbing measurements during acceptance.

Maximum speed at 1,000 m AMSL:

- v_{max} 271 km/h

Take-off and landing measurements:

- Length of take-off run until lift-off: 293 m
- Distance required to standstill after landing: 351 m

Further informative performance data taken from the extensive flight logs are listed below.

Speed measurements taken at 150 to 180 m AMSL with various engine speeds:

Engine speed [rpm]	V_a [km/h]
1,450	160
1,650	200
1,860	250

Table 7: Logged speeds at different engine speeds

A1.6.10.6 Performance data in the aircraft flight manual

A1.6.10.6.1 General

The aircraft flight manual *(*AFM) written by Ju-Air was based on the manufacturer's operating instructions for the aircraft. At the time of the accident, the AFM with revision 11 dated 1 June 2017 was valid.

A cover sheet dated 1 December 1997 had been inserted into section 10, 'Flight operations', of the operating instructions, stating:

"*The original information is purely informative. The mandatory procedures can be found in the current manuals, such as the AFM, FOM, MOE and the aircraft maintenance programme.*"

A1.6.10.6.2 Operating data table

The permissible operating values were published in section 5.8.2, 'Operating data table', of the AFM (see table 8).

	Engine speed [rpm]	
	Below 900 m AMSL	Above 900 m AMSL
Short-burst increased power up to 1 minute	2,050	
Short-burst power up to 5 minutes	1,950	2,050
Increased continuous power up to 30 minutes	1,900	1,975
Continuous power	1,850	1,925
Cruise power	1,750	1,850
Throttled glide	–	max. 2,250

Table 8: Values from the operating data table in the AFM.

A1.6.10.6.3 Engine speeds in flight operation

In sections 3, 4 and 5 of Ju-Air's AFM, revision 11 dated 1 June 2017, the following information regarding engine speeds in the various flight phases is given:

"*4.10.6 Take-off*

[…]

After the brake is released by the PIC, the pilot flying (PF) pushes the throttle levers forward slightly, so that all 3 engines develop power evenly without stuttering.

He then increases the output smoothly up to max. 1,800 rpm.

[…]

4.10.7 Climb

After lift-off, increase speed V_2 (flaps at 10 degrees) and reduce engine speed to 1,750 rpm (PIC) at the same time. For light aircraft or noise sensitive areas (e.g. Dübendorf) 1,700 rpm is sufficient.

[…]

The PF instructs the PNF to retract the flaps and to set the desired engine speed (1,700–1,750 rpm). The PNF retracts the flaps and synchronises the desired engine speed.

[…]

5.7 Cruising flight

The best altitude for cruising flight is approximately 3,000 ft AMSL

Engine speed at continuous power	*1,850 rpm*
Engine speed at cruise power	*1,750 rpm*

Cruising speed

V_a = 200 km/h at an altitude of 500 m

V_a = 170 km/h at an altitude of 2,500 m

V_a = 140 km/h at an altitude of 5,000 m

4.11.9 Cruise flight check

1.	*PNF*	*Engine speed as per PF's instruction*	*1,650–1,750 rpm set and synchronise*

[…]

3.7.4 Engine failure in flight

1.	*PF*	*Throttle lever of the failing engine*	*Idle*
2.	*PF*	*Engine speed of engines still running*	*Increase, 1,750–1,800 rpm (depending on requirements)*

[…]"

A1.6.10.7 Inspection of engines after major overhaul

A1.6.10.7.1 General

Between 2010 and 2016 the three engines, which were mounted on HB-HOT at the time of the accident, had been subjected to a major overhaul, carried out by Naef Flugmotoren AG. After an overhaul, the engine was brought to a company in Germany for inspection on the test bench. The measured values from the test run, which lasted several hours, were recorded in a test log and evaluated by the tester.

The test run carried out did not meet the specifications listed in section A1.6.10.2.

The test log was not self-explanatory, units were incorrect or missing. The log was not filled out completely.

In parts, the evaluation of the measured data was incomprehensible or wrong.

The logs did not contain any references or information on test requirements or tolerances.

The test results did not indicate whether the test requirements were met.

A1.6.10.7.2 Test results of the engines

After the respective major overhaul at Naef Flugmotoren AG, a performance test with fully open butterfly valve was carried out on the engines by a company in Germany. For the test of the right engine dated 28 June 2016, the engine was fitted with a different carburettor. From the logged measurements, the STSB has determined the following performance values based on the calculation formulas (modalities) given by the engine manufacturer:

	Actual engine speed1) [rpm]	Actual power2) [PS]	Actual power3) [PS]	Test run date
Left engine	1,996	666	606	12 Oct. 2010
Centre engine	2,030	711	647	17 April 2013
Right engine 1st test run 2nd test run	 2,038 2,027	 708 698	 644 635	 27 June 2016 28 June 2016

Table 9: Determined performance values for the engines during the test run after the respective major overhauls.

1) Target engine speed: 2,050 rpm

2) Target power: 725 PS at CINA standard atmosphere (760 mm Hg, 15°C)

3) Target power: 660 PS at 900 m AMSL (684 mm Hg, 9°C)

A1.6.10.8 Static test runs before and after maintenance work

During the period from 14 May 2018 to 26 July 2018, Ju-Air carried out maintenance work on HB-HOT's three engines on several occasions; this included static engine test runs. Prior to the work commencing, all three engines were subjected to a static pre-inspection test run (see table 10). After completing the work, the engine on which maintenance work had been carried out was subjected to a static post-inspection test run.

The engine speeds were measured with the main throttle lever in the following positions.

- Position until full-throttle limit, i.e. full-throttle limit 'on'
- Full-throttle position, i.e. full-throttle limit 'off'
- Idle position

The values measured during the respective static test runs were recorded in a static test log. The target values and their tolerances of the variables to be measured were neither stated on the test log nor in other static test documents.

Depending on the habit of the person, the engine speed values were read and recorded using the digital values indicated on the tachometers or the dials. Below are the engine speeds recorded during the static test runs with the full-throttle limiter set to 'on' and 'off'.

		Engine speed [rpm]		
Date	**Full-throttle limiter**	**Left engine**	**Centre engine**	**Right engine**
14 May 2018 Pre-inspection test	On	1,750	1,760	1,730
	Off (full-throttle)	1,880	1,870	1,840
25 May 2018 Post-inspection test	On	1,770	1,760	1,740
	Off (full-throttle)	1,900	1,880	1,860
18 June 2018 Pre-inspection test	On	1,750	1,770	1,750
	Off (full-throttle)	1,880	1,880	1,880
22 June 2018 Post-inspection test	On	–	–	1,710
	Off (full-throttle)	–	–	1,820
23 July 2018 Pre-inspection test	On	1,770	1,760	1,710
	Off (full-throttle)	1,890	1,860	1,810
26 July 2018 Post-inspection test	On	1,800	–	–
	Off (full-throttle)	1,910	–	–

Table 10: Recorded static-test engine speeds from the last three months before the accident.

A1.6.10.9 Technical inspection flights

A1.6.10.9.1 General

The Ju-Air maintenance organisation exposition (MOE) contains the following provisions regarding technical inspection flights:

"*2.24.2 Technical inspection flights with aircraft*

Technical inspection flights shall be arranged by the operations manager or their deputy, either using a standard flight programme or establishing a separate programme for specific checks.

Only persons directly involved in the purpose of the flight may be carried on inspection flights involving exceptional risks or flight manoeuvres."

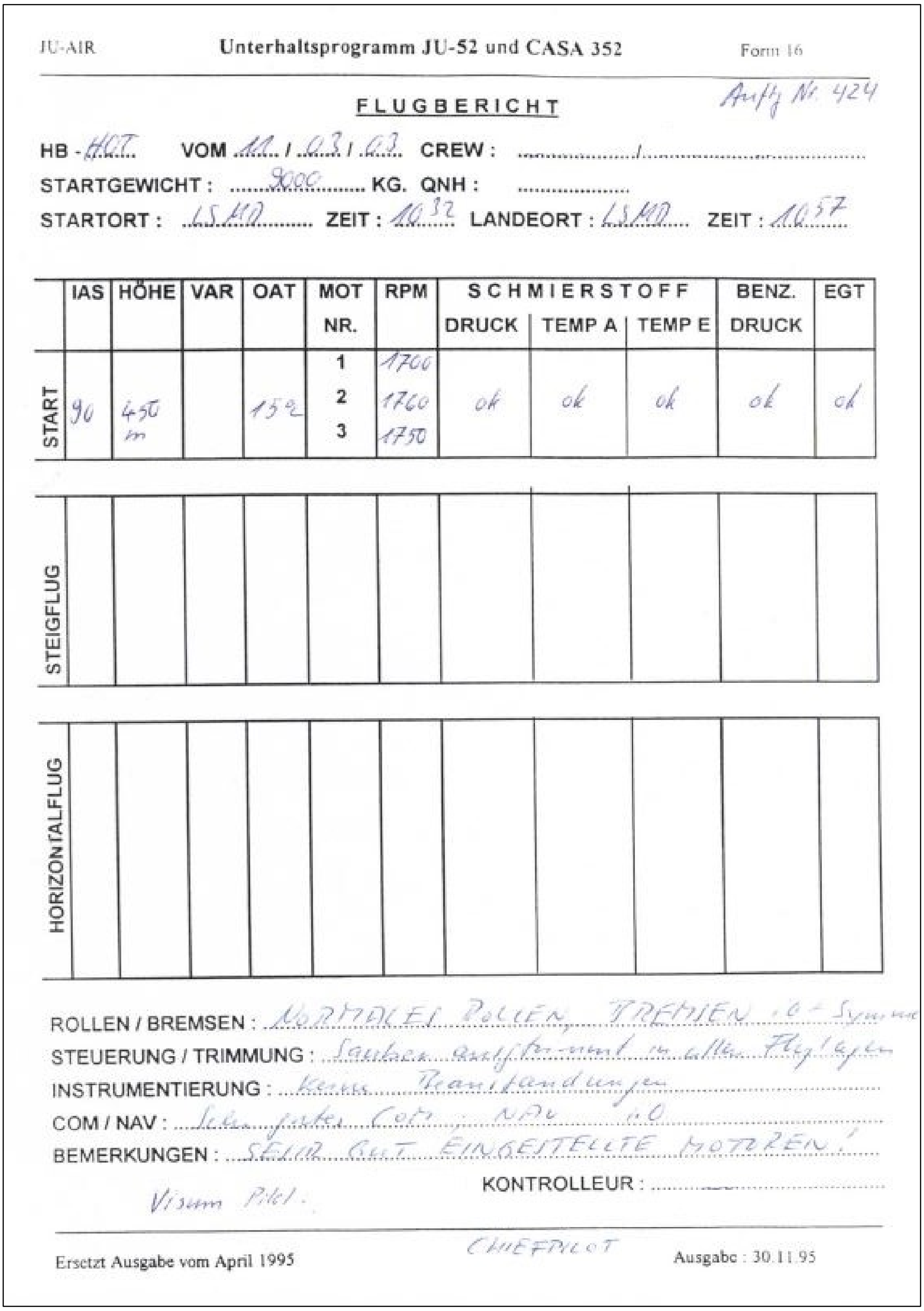
Under work preparation on the cover sheet of the maintenance checklists for the interval inspections, "*C. AVOR, 5th test flight*" is listed. Over the last few years, the cover sheets have usually had a check mark for 'test flight', 'n/a' or nothing at all.

The technical files only included two HB-HOT inspection flight reports for the last 15 years. These test flights were carried out after major repair work.

A1.6.10.9.2 Inspection flight on 11 March 2003

This inspection flight was performed after repair work on the horizontal stabiliser (see section A1.6.16.2.4). The flight lasted 25 minutes, essential parameters were not recorded during this flight (see figure 19).

The pilot had written the following under 'Remarks' on the flight report: "*Very well-tuned engines!*"



JU-AIR Unterhaltsprogramm JU-52 und CASA 352 Form 16

FLUGBERICHT Auftr Nr. 424

HB - HOT VOM 11 / 03 / 03 CREW : /

STARTGEWICHT : 9000 KG. QNH :

STARTORT : LSMD ZEIT : 10.32 LANDEORT : LSMD ZEIT : 10.57

	IAS	HÖHE	VAR	OAT	MOT NR.	RPM	SCHMIERSTOFF DRUCK	SCHMIERSTOFF TEMP A	SCHMIERSTOFF TEMP E	BENZ. DRUCK	EGT
START	90	450 m		15°	1 2 3	1700 1760 1750	ok	ok	ok	ok	ok
STEIGFLUG											
HORIZONTALFLUG											

ROLLEN / BREMSEN : NORMALES ROLLEN, BREMSEN i.O. + Symm

STEUERUNG / TRIMMUNG : Sauber ausgetrimmt in allen Fluglagen

INSTRUMENTIERUNG : Keine Beanstandungen

COM / NAV : Sehr gute Com, NAV i.O.

BEMERKUNGEN : SEHR GUT EINGESTELLTE MOTOREN!

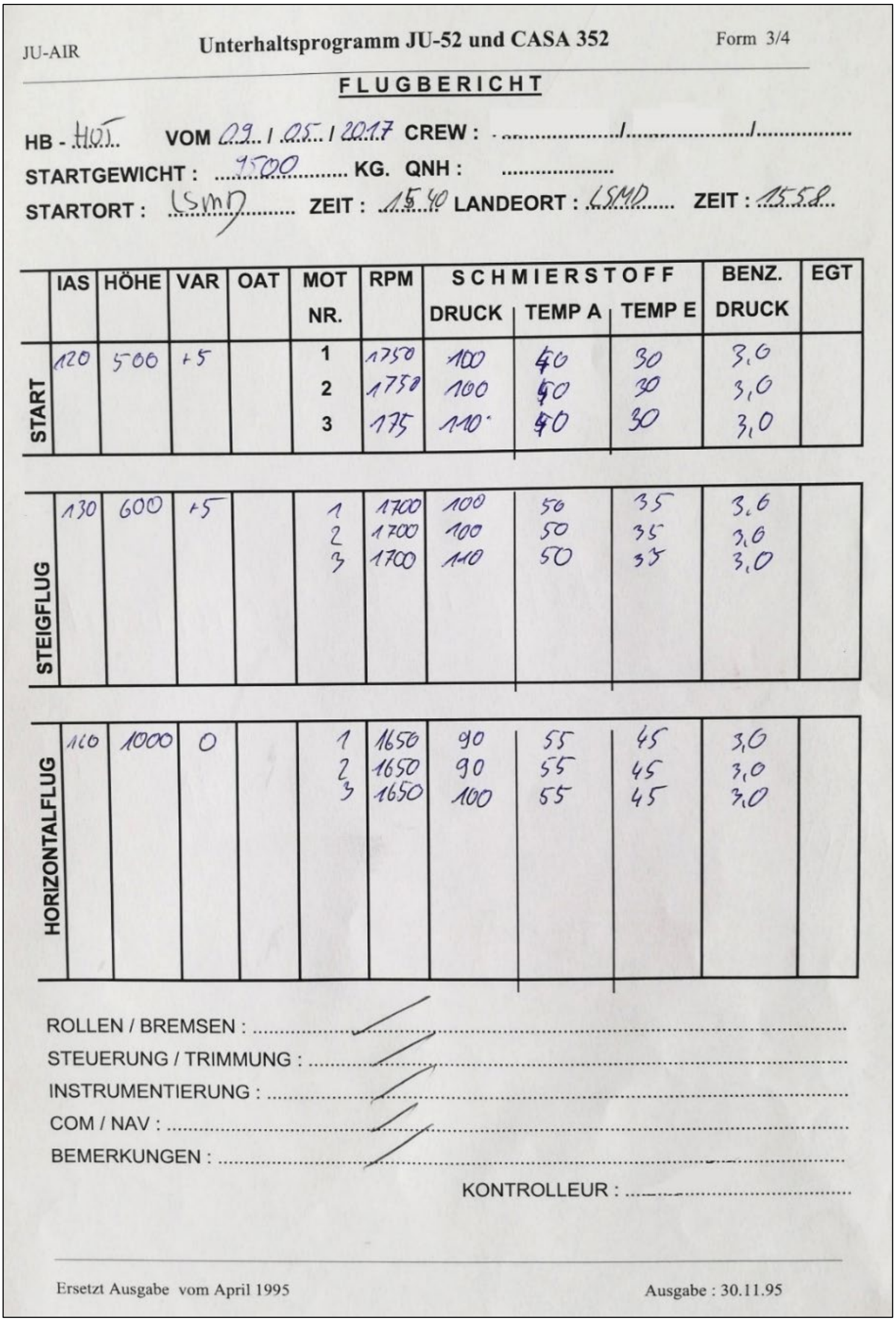
Visum Pilot. KONTROLLEUR :

Ersetzt Ausgabe vom April 1995 CHEFPILOT Ausgabe : 30.11.95

Figure 19: Test flight report from 11 March 2003. Names of persons removed by the STSB. Source: Technical records HB-HOT.

A1.6.10.9.3 Inspection flight on 9 May 2017

This inspection flight was performed after repair work on a wing spar (see section A1.6.16.2.3). The flight lasted only 18 minutes and essential parameters were not recorded (see figure 20). According to the log, relevant systems such as the flight controls, trim, brakes, etc. were not checked.



JU-AIR **Unterhaltsprogramm JU-52 und CASA 352** Form 3/4

FLUGBERICHT

HB - HOT VOM 09 / 05 / 2017 CREW : ..../........../..........

STARTGEWICHT : 9500 KG. QNH : ....

STARTORT : LSMD ZEIT : 15.40 LANDEORT : LSMD ZEIT : 15.58

	IAS	HÖHE	VAR	OAT	MOT NR.	RPM	SCHMIERSTOFF DRUCK	SCHMIERSTOFF TEMP A	SCHMIERSTOFF TEMP E	BENZ. DRUCK	EGT
START	120	500	+5		1	1750	100	40	30	3,0	
					2	1750	100	50	30	3,0	
					3	175	110	50	30	3,0	
STEIGFLUG	130	600	+5		1	1700	100	50	35	3,0	
					2	1700	100	50	35	3,0	
					3	1700	110	50	35	3,0	
HORIZONTALFLUG	160	1000	0		1	1650	90	55	45	3,0	
					2	1650	90	55	45	3,0	
					3	1650	100	55	45	3,0	

ROLLEN / BREMSEN : ....

STEUERUNG / TRIMMUNG : ....

INSTRUMENTIERUNG : ....

COM / NAV : ....

BEMERKUNGEN : ....

KONTROLLEUR : ....

Ersetzt Ausgabe vom April 1995 Ausgabe : 30.11.95

Figure 20: Test flight report from 9 May 2017. Names of persons removed by the STSB. Source: Technical records HB-HOT.

A1.6.10.10 Evaluation

A1.6.10.10.1 General

This section analyses the development in performance of the BMW engines from the Ju 52/3m g4e aircraft delivery to the Swiss air defence corps in 1939 up until the time of the accident. The effects on flight performance were also examined.

A1.6.10.10.2 Available engine power

In order to create a basis for the following consideration, the performance measurements that were determined at the Junkerwerke airfield in Dessau (57 m AMSL) during four flights between 29 September and 4 October 1939 were used. Among other things, the horizontal speed at ground level was determined.

The performance flights were carried out with a mass of 10,000 kg. The three BMW 132 A3 engines were practically new and the propellers had a pitch of 21 degrees.

In horizontal flight at 150 to 180 m AMSL, the following values were achieved at that time:

Engine speed [rpm]	Speed [km/h]
1,450	160
1,650	200
1,860*	250*

Table 11: Logged speeds at different engine speeds.

The values marked with an * are comparable with the values for cruise flight mentioned in section 10, ‘Flight operations’ of the operating instructions for Ju 52/3m g4e aircraft:

“At an altitude of 500 m, at 1,850 rpm, speed V_a = 240 km/h”.

Between 2010 and 2016 the three engines, which were mounted on HB-HOT at the time of the accident, had been subjected to a major overhaul, carried out by a maintenance organisation. Afterwards, a company in Germany carried out a performance test on the engines with the butterfly valve fully open. On the test stand, the engine was operated with a brake propeller.

As the test results show, none of the three engines reached the target speed of 2,050 rpm during the test runs. For full power – which corresponds to the short-burst increased power of 725 PS – the aircraft testing authority specified a power tolerance of +/- 2.5% and an engine speed tolerance of + 100 to - 60 rpm. Thus, all of the engines were within the speed tolerance during the test run after the major overhaul, but only the centre engine was within the power tolerance.

The engine manufacturer, however, stated a power tolerance of + 4 % to – 2 % and an engine speed tolerance of +/- 2 %. Thus, the left engine was outside the speed tolerance during the test run after the major overhaul. Only the centre engine was just within the power tolerance.

During the period from 14 May 2018 to 23 July 2018, Ju-Air carried out maintenance work on HB-HOT’s three engines on several occasions. After completing the work, the engine was subjected to a static test run.

With the butterfly valve fully open, the engine should reach a speed of 2,050 rpm.

	Test runs after major overhaul			Static test run measurement (HB-HOT)	
	Date	rpm[1)]	PS[2)]	Date	rpm
Left engine	12 October 2010	1,996	666[3)]	23 July 2018	1,890
Centre engine	17 April 2013	2,030	711[3)]	23 July 2018	1,860
Right engine	28 June 2016	2,027	698[3)]	23 July 2018	1,810

Table 12: Comparison of the test run and static-test values.

1) Target speed = 2,050 rpm under CINA standard conditions (760 mm Hg, 15°C)

2) Target power at 2,050 rpm = 725 PS under CINA standard conditions

3) Power determined by the STSB from the logged torque measurements

As can be seen from the table above, this speed was not achieved on the three HB-HOT engines during the test runs after the major overhauls, nor during the static test run on 23 July 2018. The engine speeds determined during the static test runs are markedly below the target value of 2,050 rpm.

There is quite a large period of time between the test runs after the major overhauls and the static test run on 23 July 2018. In the meantime, the maintenance team had carried out several repairs on the three HB-HOT engines (see section A1.6.16.3). The factors listed below may have had an influence on the different measurement results:

- Condition of the engines;
- Adjustment of the control linkage between the main throttle lever and the carburettor;
- Properties of a brake propeller versus an aircraft propeller;
- Different atmospheric conditions;
- Different engine speed measuring devices.

A1.6.10.10.3 Available flight performance

Table 13 below compares the flight performance of the Ju 52/3m g4e in 1939 with that in the years 2017 and 2018. In each case the airspeeds in cruising flight were compared. It stands out that HB-HOT was able to reach higher airspeeds at comparable engine speeds in 1939 than it was prior to the accident. The following variables may potentially explain the difference:

- Lower engine power than when originally tested;
- Propeller pitch of 21 degrees as opposed to 19 degrees;
- Propeller efficiency of the reproduction propellers;
- Increased aerodynamic drag of the aircraft.

Operating instructions from 1939		Acceptance flights dating September/ October 1939		Ju-Air AFM, rev. 11, dated 1 June 2017		Inspection flight on 9 May 2017		Flight past Mount Rigi on 3 August 2018		Comparative HB-HOS flight in October 2017	
Cruising speed at 1,850 rpm		Cruising speed at 1,860 rpm		Cruising speed at 1,750 rpm		Cruising speed at 1,650 rpm		Cruising speed at ~1,750 rpm		Cruising speed at ~1,700 rpm	
Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h	Altitude m AMSL	km/h
500	240	< 500	250	500	200	500	–	500	–	500	–
1,000	–	1,000	–	1,000	–	1,000	160	1,000	–	1,200	150
2,500	220	2,500	–	2,500	170	2,500	–	1,800	150	2,500	–
5,000	175	5,000	–	5,000	140	5,000	–	5,000	–	5,000	–
Propeller pitch 21 degrees				Propeller pitch 19 degrees							

Table 13: Comparison of flight performance.

When comparing the cruising speeds from the inspection flight on 9 May 2017 and the cruising speeds from the comparative flight of HB-HOS in October 2017, with the indicated airspeed during the flight past mount Rigi, it can be seen that the figures shown are in fact plausible.

A1.6.11 Propellers

When the Ju 52/3m g4e was delivered in 1939, the engines were fitted with two-blade fixed propellers made of Duralumin labelled with Ju-PAK. These propellers rotate clockwise. They had a diameter of 2.9 m and were set at a pitch of 21 degrees.

The original pitch for the propeller blades of 21 degrees changed over the years. Ju-Air's AFM, rev. 0 dated 1 October 1982, mentions a setting of 17 degrees. According to Ju-Air's documentation, the propellers were operating at a pitch of 19 degrees at the time of the accident. This was also indicated in the current version of the AFM.

Due to corrosion and wear, the original propeller blades had to be replaced. However, as original blades were no longer available, new blades based on service bulletin no. 1045 (see section A1.6.17.2.6) were produced from 2000 onwards. The original hubs have been reconditioned for reuse several times (see section A1.6.16.3.5).

A1.6.12 Systems

A1.6.12.1 Fuel systems

A1.6.12.1.1 General

In each outer wing there is a group of fuel containers, consisting of seven aluminium cells that are connected to each other by branch lines. Cells no. I to VI are connected in series and installed between spar II and spar III, the additional cell no. VII is installed between spar III and spar IV (see figure 21). The contents of each group of containers is indicated by a mechanical display. According to the operating instructions, the total capacity is 2,400 litres. In contrast, the AFM lists a volume of 2,500 litres.

The fuel is delivered by fuel pumps, which are driven by the respective engine via a bevel gear and a remote shaft.

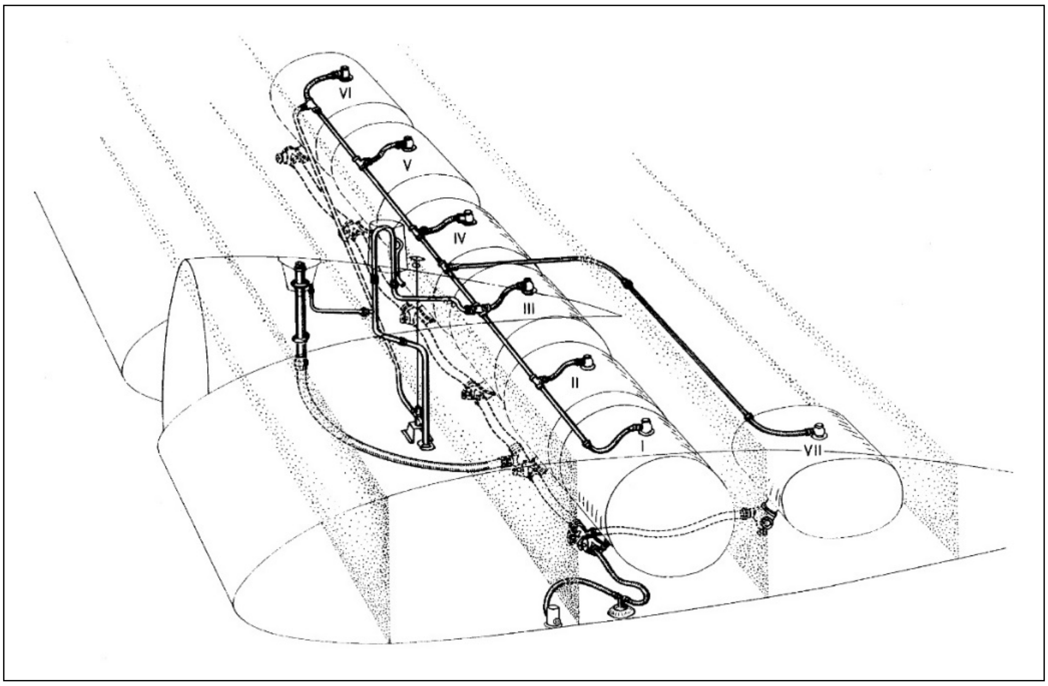


Figure 21: Fuel cell assembly in the right-hand outer wing. Source: Ju-Air AFM from 2017.

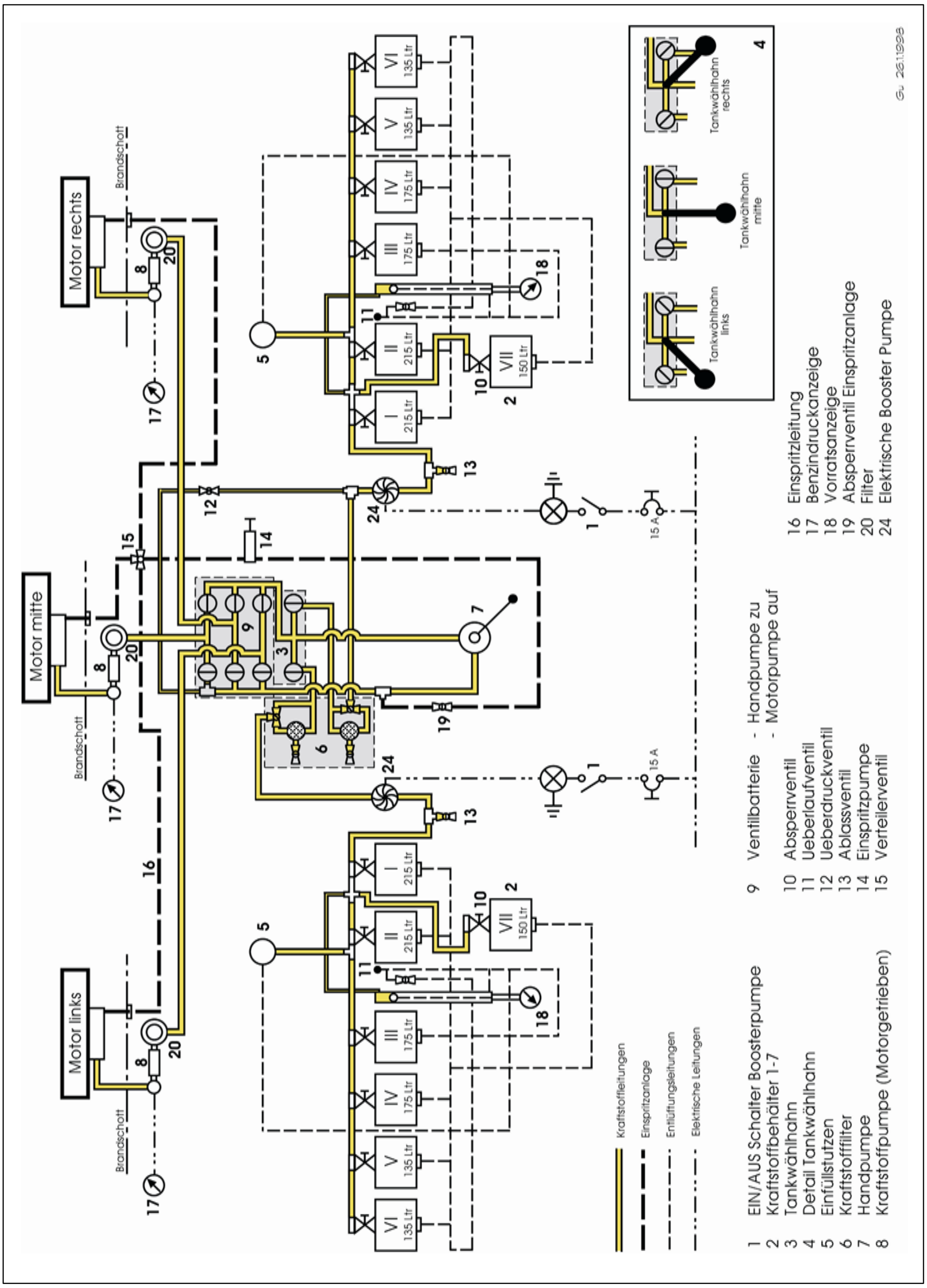


Figure 22: Diagram showing the fuel system. Source: Ju-Air AFM from 2017.

A1.6.12.1.2 Fuel filter

Each outer wing is fitted with a fuel filter (see figure 22, (6)). After the fuel has passed the filter, it is fed to the engine by an engine-driven fuel pump (8). The pressure is measured using a fuel pressure indicator (17). If necessary, the injection line (16) is activated when the engine is started.

A1.6.12.1.3 Fuel valve battery

A valve battery with seven connections between the lines is connected to distribute the fuel coming from the fuel cells to the engine systems (see figure 22).

The valve battery consists of a housing divided into four chambers. Each of these chambers feature two spring-loaded valves. These can be adjusted using a cam disc. All of the line connections and five valves are labelled on top of the housing. The fuel flow is regulated using control levers located in the cockpit. The levers allow the valve for fuel flow from the cells or fuel flow from the hand pump to be selected for the respective engine. The cam disc’s third position results in these two valves not being actuated, or closed.

A1.6.12.1.4 Installation of electric fuel pumps

Based on service bulletin no. 1043, two electric fuel pumps (booster pumps) were installed in HB-HOT in August 1997 due to the use of MOGAS. These pumps were switched on when the outside air temperature reached 25 °C or more, in order to counteract the potential for fuel vaporisation. According to the hold item list (HIL), MOGAS was no longer used as of 15 February 2007 and the electric fuel pumps were deactivated. However, these remained installed in the fuel system. As such, the fuel flowed through a bypass integrated in the pump. The only measure taken was to lock the circuit breakers (CBs) in the off position using a cable tie and label the switches for the respective electric fuel pumps on the control panel as “*Inop.*”.

Among other places, the electric fuel pumps have continued to be mentioned in the system descriptions and instructions for normal and abnormal operation in the current version of the AFM as if this system were still active. Furthermore, the pumps were listed in the minimum equipment list (MEL) as well as in the checklist for pilots of Ju-Air’s Ju 52 aeroplanes dated 6 March 2017.

For example, the electric pumps were mentioned in section 9, “*Low fuel pressure*”, of the checklist (see figure 23).

LOW FUEL PRESSURE / DREHZAHLABFALL

1. PNF Boosterpumpen LH und RH .... ein
2. PNF Gemischregulierungen .... auf entsprechende (Höhengas) .... Höhe stellen

ACHTUNG ! Tankwählhahn-Stellung
Mitte .... Boosterpumpen LH und RH ein
Rechts .... nur Boosterpumpe RH ein
Links .... nur Boosterpumpe LH ein
Bei Ausfall einer Boosterpumpe werden auf Stellung Mitte von der noch laufenden Boosterpumpe pro 10 Minuten ca 100 Liter Treibstoff in den anderen Flügel transferiert. (Der Ausfall einer Boosterpumpe trotz funktionierender Stromversorgung ist nur durch die entstehende Unbalance der Treibstoffanzeige feststellbar).

BOOSTERPUMPENWARNLAMPE LH/RH resp Treibstoff UNBALANCE

1. PNF Tankwählhahn .... auf Seite der noch laufenden Boosterpumpe resp den Flügel mit tieferem Benzinstand stellen
2. PNF Ausgefallene Boosterpumpe .... aus

falls sich Fuel press wieder normalisiert hat (unter 5000 ft resp OAT < 25 °C)

1. PNF Boosterpumpen .... aus
2, PNF Gemischregulierung .... zu (ganz nach unten)
3. PNF Tankwählhahn .... auf Seite mit höherem Treibstoffvorrat (Vorrat ausgleichen)

Figure 23: Extract from section 9 of Ju-Air's checklist.

The fact that maintenance was no longer carried out on the pumps meant that there was a risk that the fuel flow rate would be reduced. The condition of the pumps examined confirms that they had not been maintained for years (see annex A1.12). Components and systems installed in an aircraft must be maintained, otherwise the airworthiness of the aircraft can no longer be assured.

The files revealed that the two fuel pumps had been installed in HB-HOT for 4,239 operating hours since the last major overhaul. This means that the intended interval of 2,500 operating hours for a major overhaul was considerably exceeded. Therefore, these components were not airworthy.

The deactivation of the fuel pumps was not carried out consistently. The documents have not been adjusted to accurately reflect the state of the aircraft for over ten years. It is difficult to understand that this circumstance was accepted by both the flight crews and FOCA. The example indicates that the maintenance organisations and the flight operations team were not working in a coordinated manner.

In the HIL, the deactivation of the electric fuel pumps was mentioned as follows:

"*1 Aircraft to be fuelled with AVGAS 100 LL only*
Fuel test

2 LH + RH booster pumps have been deactivated due to AVGAS operation only"

This entry has existed since 2007. As a matter of principle, complaints noted in the HIL must be resolved within a defined period of time. For systems that are permanently deactivated, the HIL is the wrong instrument.

These processes indicate a lack of quality awareness and that Ju-Air staff obviously did not have the necessary expertise.

A1.6.12.2 Lubrication system

Each engine has its own lubrication system. The oil is circulated by a suction and pressure gear pump, which is driven by the engine. The lubricant is drawn from the respective engine's oil tank by the pump and fed under pressure to the individual points of lubrication. In each lubricant supply line, there is a shut-off valve which is coupled to the fire valves. In addition, there is an oil filter element (fine-mesh sieve), which – due to its design – is unable to filter the oil for fine particles and wear debris. A magnet is mounted in the filter housing cover. This magnet is intended to catch and hold magnetic metal particles. Such accumulated metal particles can provide valuable information on the condition of an engine. Nowadays cockpits are fitted with warning lights for these particle detectors, however, this was not the case with HB-HOT.

The oil filter has no bypass valve. This can lead to the oil circulation system failing if the filter element becomes blocked. There is also no system to indicate a clogged oil filter.

To regulate its temperature, the lubricant in the return line is led over the coolers via a changeover tap.

An electrical pressure gauge system, with display instruments incorporated into the cockpit's instrument panel, is installed to monitor the supply of lubricant.

Each engine has a built-in oil pressure warning light which lights up when the oil pressure drops below 3 bar.

The temperature of the lubricant is measured at the inlet and outlet using electrical thermometers and is displayed on instruments in the cockpit's instrument panel.

A1.6.12.3 Pitot-static system

The airspeed indicators, the altimeters, the variometers and the altitude encoder for the transponder are connected to the pitot-static system. All of these devices are connected in parallel. This means that the system is not redundant.

The airspeed indicator system consists of the pitot tube, the airspeed indicators and the associated lines.

To prevent the risk of icing, the pitot tube is electrically heated. However, there was no warning indicator for pitot tube heating failure.

HB-HOT had only one pitot tube system. The airspeed indicators for the pilot and the co-pilot were connected to the same pitot tube, without any redundancy. It was therefore not possible to identify any inaccurate readings through cross comparison.

The basic principle of operation of the airspeed indicator system is as follows (see figure 24): The pitot tube (1) transmits the dynamic pressure via the pressure line (2) to the display unit's measuring cell (6). The measuring cell links to the needle via a mechanism, which gauges the respective dynamic pressure and thus indicates the speed of the aircraft in relation to the surrounding air on the dial. The display unit has a second connection to the port for static-pressure compensation (4).

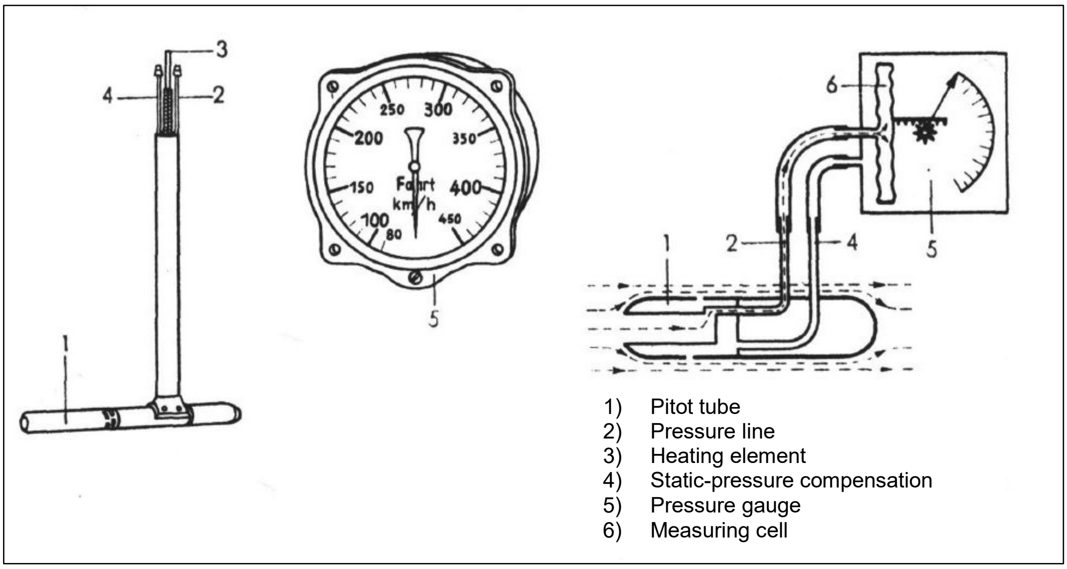


Figure 24: Airspeed indicator system. Source: "*Betriebsanweisung Ju 52/3m g4e*" (operating instructions).

Dynamic pressure is taken from the pitot tube, which on Ju 52/3 g4e aircraft extends from the leading edge of the left outer wing (see figure 25).

Figure 25: Arrangement of the pitot tube with red cover on sister aircraft HB-HOS.

The static pressure is also taken from the pitot tube (see figure 26). In the cockpit, there is also an emergency intake for static pressure.

In the rearmost part of the pitot tube, the pressure line has a diameter of only 2 mm. This is where it is possible for foreign objects (dust, insects, etc.) to clog the pitot tube, which can lead to inaccurate readings on the air speed indicator.

Figure 26: Pitot tube of HB-HOT. The openings for the static pressure are circled in black.

A1.6.12.4 Indicators and warnings

A1.6.12.4.1 Tachometers

Ju-Air's Ju 52 aircraft are equipped with one HRC 02 electronic tachometer per engine. This type of tachometer has an analogue and a digital display (see figure 27). The digital display for the centre engine shows the measured engine speed, while the displays for the two outer engines show the deviation in speed from the centre engine. This allows the engines to be synchronised with each other as precisely as possible. The electronic tachometers were installed in February 2002 based on the revised service bulletin no. 1025 (see section A1.6.17.2.7).

Figure 27: Type HRC 02 tachometers with analogue and digital displays. Photograph from private individual.

The electronic tachometer processes the pulses generated by a proximity switch. The number of pulses is proportional to the speed of the engine. The read-outs on the analogue display for all three engines and the digital display for the centre engine are calculated based on the above-mentioned pulses. The read-out on the digital displays for the left and right engines is based on the difference between the speed of the relevant engine and the digital display for the speed of the centre engine.

A1.6.12.4.2 Exhaust gas temperature measuring system

The aircraft is equipped with an exhaust gas temperature measuring system that measures the temperature at the exhaust pipe for cylinder no. 1 of each engine. One dial per engine is incorporated into the instrument panel. The scale of the dial is in °F (degrees Fahrenheit), the temperature indications given in the AFM are in °C.

A1.6.12.4.3 Stall warning system

A stall warning system warns the flight crew when the aircraft approaches a critical angle of attack and, thus, warns of an imminent stall. The Ju 52/3m g4e aeroplane was not equipped with such a system.

A1.6.12.5 Transponder

A1.6.12.5.1 General

The aircraft was fitted with a Garmin GTX 330D mode S transponder. This meets the requirements of level 2. The transponder transmits on 1090 MHz and receives on 1030 MHz. The transponder meets the requirements for mode S enhanced surveillance.

On request from ground radar, the transponder automatically transmits the 'squawk' assigned by the ATC[38] and entered by the crew, as well as the pressure altitude, the aircraft address, the ground speed (GS) and the true track (TT). The transponder also communicates with the TCAS[39] of other aircraft. The transponder therefore meets the requirements for aeroplanes licensed to fly under visual flight rules.

The transponder is equipped with an antenna, which is located on the underside of the nose of the aircraft.

A1.6.12.5.2 Altitude encoder

In Ju-Air's Ju 52 aircraft, the transponder is connected to a type SAE 5-35 altitude encoder. This supplies the pressure altitude in feet (standard pressure 1,013.2 hPa) in 10-foot increments via a serial interface. The encoder is connected to the existing static pressure system in parallel to the altimeters. In HB-HOT, it was positioned below the left-hand instrument panel.

A1.6.12.5.3 Ground speed and true track

In Ju-Air's Ju 52 aircraft, the transponder was connected to a Garmin GNS 430[40] navigation computer. This provides the ground speed parameter via a serial interface (A429, label 312) and the true track parameter via label 313. Both of these parameters are calculated using GPS[41].

During the flight to Locarno on 3 August 2018, the GNS 430 was in operation. The ground speed was transmitted to ATC when the aircraft was within radar coverage.

[38] ATC: Air traffic control

[39] TCAS: Traffic alert and collision avoidance system

[40] The GNS 430 is a navigation system that allows pilots to enter a flight route. Deviations from the route are indicated on the corresponding instruments.

[41] GPS (global positioning system) is a satellite system with which an exact position can be determined worldwide. GPS is integrated in the GNS 430 for this purpose.

A1.6.12.5.4 Aircraft address

The 24-bit ICAO mode S address, which is allocated individually for each aircraft by the relevant authority, is entered into the transponder by the responsible technician during installation as a hexadecimal code.

A1.6.12.5.5 Periodic inspection of the transponder system

According to FOCA technical communication TM 20.100-20, the periodic inspection of the ATC transponder system must be carried out every 24 months. For HB-HOT, this inspection was last carried out on 19 December 2017.

A1.6.12.6 On-board battery

During the Ju 52 aircraft's military service, the original on-board batteries (lead batteries) had already been replaced by nickel-cadmium batteries (NiCd batteries). A NiCd battery was installed in HB-HOT at the time of the accident. However, it was not clear from the technical files what model of battery this was. In 1983, due to a FOCA stipulation, the NiCd batteries of every aircraft were retrofitted with an overheating warning system. According to the files, the temperature sensors used for this purpose were used exclusively on the Ju-Air Ju 52 aeroplanes. There were no documents in the files relating to this warning system.

A1.6.13 Maintenance instructions supplied by the aircraft and engine manufacturer

A1.6.13.1 Airframe

A1.6.13.1.1 Operating instructions

For operation of the Ju 52 3m/g4e, the aircraft manufacturer issued operating instructions (*Betriebsanweisung*) in 1939 which serves as a reference book for operation, maintenance and inspection as well as for the training of maintenance personnel.

The table of contents for these operating instructions merely indicates the title of the individual main sections and their reference numbers. The further structure and subdivision of the instructions can be seen on the introductory tables of contents for each of these sections. Sections 1 to 9, including the reference number, correspond to the structure of the aircraft. Sections 10 and 11 contain instructions for the operation of the aircraft and section 12 contains, among other things, equipment descriptions and test sheets. The main sections are titled as follows:

0 General (gives an overview of the whole aircraft)

1 Fuselage

2 Landing gear

3 Control surfaces

4 Controls

5 Wing

6 Engine frame

7 Engine system

8 Engine containers

9 Equipment

10 Flight operations (covers practical flight operations including daily maintenance)

11	Transportation	(shows how to load and transport the aircraft)
12	Appendix	(device descriptions, test sheets, etc.)

Partial and major overhauls of the airframe are described in section 0, 'General', of the operating instructions under 'Partial and major overhauls' as follows:

"*Partial overhauls are to be carried out after approximately 300 operating hours*.

Partial overhauls include, after removal of all covers and hatches (see cover and hatch overview), the precise examination of all operationally important joints and connections, the rivets, and – in particular – the connections of the landing-gear spring struts, the control transmission linkages, the engine system, etc. The controls must be checked for their setting dimensions (see setting diagrams in section 4, 'Controls').

Depending on the findings, it may be necessary to dismantle large structural elements such as the outer wings, empennage, landing gear, etc. in exceptional cases.

Particular attention must be paid to the surface protection conforming with specifications.

Major overhauls are to be performed after approximately 1,500 operating hours.

For this, all larger parts, such as the outer wings, empennage, controls, engine parts, etc. are to be dismantled and thoroughly inspected; in addition, the surface protection and all equipment are to also be overhauled. Any necessary repairs are to be made so that the final condition of the aeroplane is as close to factory-new as possible.

After a major overhaul, the time interval for 'partial overhauls' starts from zero as of the same date, unless the final findings indicate that a different interval would be appropriate. In addition to circumstances relating to weather and landings, the determination of the frequency primarily depends on the level of training of the persons entrusted with maintenance.

The calculation for time between inspections is therefore only connected with the calendar calculation to the extent that weathering can take place even without the aircraft being used."

Furthermore, the following relevant instructions are described in section 0, 'General', under 'Cleaning and paint care':

"*Lubricant and burnt-on exhaust residues adhering to cowlings, the wing, fuselage and empennage must be carefully removed with cleaning solvent*.

The engines as well as the inside of the cowlings are to be cleaned of any adhering lubricant using cleaning solvent.

[…]

Components that are difficult to access and yet exposed to the elements must be cleaned particularly carefully and protected against weathering.

Steel parts which are unprotected for reasons of fit must be regularly re-greased with acid-free grease after the removal of dust and dirt. Rust spots must be removed beforehand using sandpaper.

[…]

At certain intervals, the entire coating must be carefully inspected inside and out for damaged areas, flaking, blistering and cracking, etc. caused by weathering. Any damage must be repaired in accordance with the information given in the 'Junkers repair instructions'."

A1.6.13.1.2 Repair instructions

There is a 1939 repair instructions (*Ausbesserungsanleitung*) for Junkers metal aircraft written by the manufacturer. According to the manufacturer, these instructions are intended to provide all persons entrusted with the repair and maintenance of the aircraft with the necessary information for workshop and flight operations and to eliminate faults (which put the safety of the aircraft at risk) as a matter of principle.

In section 5, 'Surface protection', 'preliminary remarks', the manufacturer provided the following information:

"*Surface protection (corrosion-proofing) is intended to protect the material against all kinds of corrosion and thus increase the service life of the aircraft*.

[…]

In aircraft, corrosion is mainly caused by atmospheric influences (condensation), seawater and the electrical currents triggered when parts of different potential are connected (placed on top of each other).

The protection used must be easy to apply, durable, attractive and easy to repair or renew.

[…]

The decision as to whether the surface protection is to be repaired or renewed depends on whether or not sufficient protection is guaranteed during continued operation. Any increase in weight due to extensive paint application can also be a deciding factor. If the paint is not cracked or flaked off, it is usually not necessary to apply a new coat.

Before painting, the parts or areas concerned must be thoroughly cleaned with detergents (see 1a, 2a, 3a) as specified, avoiding sanding bare aluminium alloy with steel wool, sandpaper or a wire brush as far as possible. The cleaned surfaces must be free of paint residues, oils, greases, dirt, scale, oxides, hand perspiration, etc."

A1.6.13.2 Engines

A1.6.13.2.1 Description and operating instructions

There is a 1938 description and set of operating instructions (*Betriebsanleitung*) for the air-cooled BMW 132 A3 aircraft engine supplied by the manufacturer.

The maintenance and overhauls of the engines are described as follows:

"*V. Regular inspections*

The engine should be inspected before each flight and at regular intervals.

The following checks are to be carried out:

1. Before every flight

a) Check the fuel and oil level.

b) Check the ignition by switching on each magneto individually using the ignition switch.

c) Check that the oil and fuel pressure gauges give a reading.

d) Check that the engine is running at the correct speed at the permissible throttle opening.

e) Drain any water from the bottom of the fuel cells.

f) Check the propeller blades for play before and after the first flight, then every 10–20 operating hours.

g) Check the engine mounting bolts.

2. After every longer flight

Check the compression while the engine is still warm. […]

3. In addition, every 10 hours

a) Check the valve clearance with the feeler gauge located in the on-board tool bag.

b) Check the valve springs by depressing them by hand.

c) Check the hemispherical pintle tips in the rocker arm pintle pins (pintle tips must not be stuck or displaced).

d) Brush the valve springs clean with oil.

e) Fill the oil compression nozzles for the rocker arm shafts and pintle pins with Gargoyle Mobil Compound 3 or Stanavo 2.

f) Clean the fuel filter installed in the aircraft.

g) Check the fuel-line connections for leaks.

4. In addition to the above checks, every 20 hours

a) Change the oil.

b) Clean the oil filters.

c) Test the engine for oil leakage.

d) Clean the spark plugs, check the insulation for fractures, adjust the electrode gap if necessary.

e) Clean the magneto breaker contacts with a non-fibrous cloth.
Note: a) Do not use emery cloth!
b) Do not change breaker settings!

f) Lubricate the magnetos as described in section IX, 2. 'Ignition' and the carburettor's butterfly spindle.

g) Check the rocker arms for lateral play and the oil holes in the rocker arm bolts for blockages.

h) Check whether the propeller hub is tight.

i) Check the fuel lines for blockages.

k) Check the carburettor and nozzles for sticking if benzene-petrol mixtures are used as fuel.

l) Clean the fuel filter in the carburettor.

[…]

It is important to always have the correct valve clearance, as excessive clearance can lead to valve breakage. The correct clearance when the engine is cold is 0.25 mm for both the intake and exhaust valves. […]

VII. Overhaul in the aircraft

The usual indication that an engine may require readjustment or possibly an overhaul in the aircraft is a decrease in engine speed on the ground with the permissible throttle opening. It should be noted that unusual conditions with regard to temperature and barometric pressure sometimes influence the propeller speed by 50 to 100 rpm without there being any defects in the engine.

First check that the control levers in the cockpit correspond to the actual position of the butterfly valve and altitude control levers. The magnet interrupters must also be checked using the feeler gauge supplied for this purpose. The gap should not be more than 0.3 to 0.4 mm.

[…]

After the above check and any necessary adjustments have been made, the engine is started and operated at low speed (800 to 1,000 rpm) until the temperature of the entering oil is at least 30°C. It should then be run with the throttle fully open and a 'full rich' mixture at full early ignition. The engine speed, the oil pressure, which should be between 5.8 and 7.0 kg/cm^2 and the fuel pressure, which should be 0.21 kg/cm^2, are to be monitored. The operation of the ignition should then be checked by running the engine first using one magneto and then the other. Any drop in engine speed must not exceed 50 rpm with only one magneto switched on. After the engine has been stopped and has cooled down a little, the compression in the individual cylinders is checked, for which purpose the engine has to be turned through by two revolutions. If the ignition and fuel pressure are okay and the engine does not run at the required speed on the ground, an overhaul is necessary."

"VIII. Major overhaul

A major overhaul should rarely be necessary prior to 200 to 300 operating hours."

A1.6.13.3 Propellers

A1.6.13.3.1 Operating and maintenance instructions

For Junkers metal propellers, the manufacturer issued operating and maintenance instructions (*Betriebsanweisung und Wartungsvorschrift*) in 1939. They describe the inspection of the propellers as follows:

"*Inspection during flight operations*

After the first workshop flight with a duration of 10 minutes, the shaft nut must be retightened. Likewise, the twelve-point nuts for the propeller blades must be retightened; in both cases the nuts have right-hand threads.

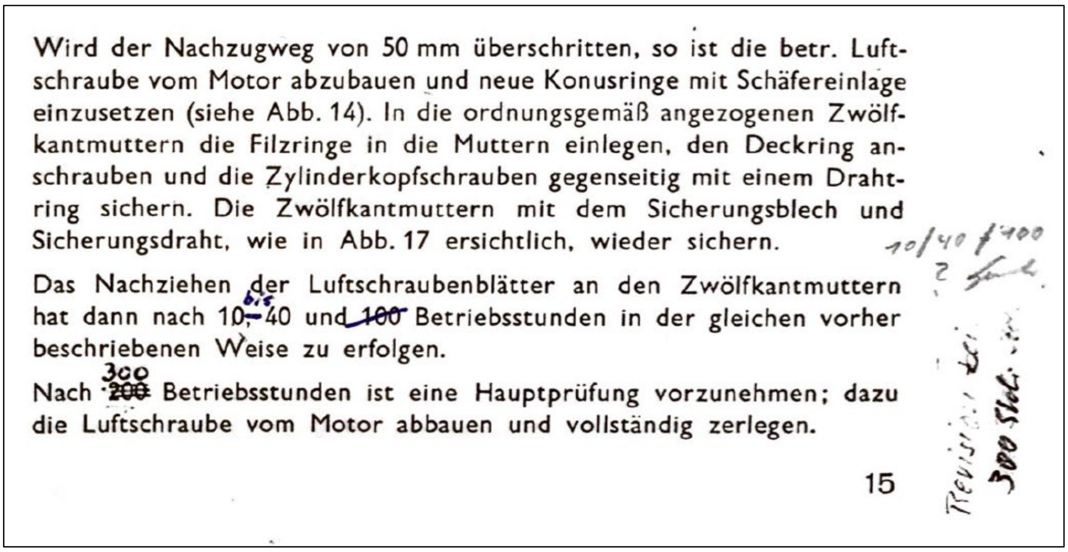
Remove the locking wire with locking plate from the twelve-point nuts. Remove the cover rings and felt rings from the twelve-point nuts. Using the W 9-20020-4 twelve-point nut wrench, tighten the twelve-point nuts with a tightening force of approx. 80 kg at a length of 1.200 m on the wrench arm. When tightening these nuts, it is advisable to support the blade in question with a wooden support in order to be able to tighten the nuts with the required force. When retightening the twelve-point nuts, make sure that the retightening distance measured on the outer circumference of the twelve-point nut after each retightening does not exceed 50 mm. To check this dimension, it is advisable to mark the nut and hub with a pencil before retightening the nuts.

If the retightening distance of 50 mm is exceeded, the propeller concerned must be removed from the engine and new conical rings with sleeves must be inserted. Insert the felt rings into the correctly tightened twelve-point nuts, screw on the cover *ring and secure the cylinder head screws with a wire clip. Re-secure the twelve-point nuts with the locking plate and locking wire.*

The propeller blades must then be retightened at the twelve-point nuts as described above after 10, 40 and 100 operating hours.

After 200 operating hours, a main inspection must be carried out; to do this, remove the propeller from the engine and disassemble it completely."

In the operating and maintenance instructions, the inspection intervals were corrected by hand and the inspection after 100 operating hours was crossed out (see figure 28). Likewise, the main inspection for the propeller was changed to 300 operating hours.



Wird der Nachzugweg von 50 mm überschritten, so ist die betr. Luftschraube vom Motor abzubauen und neue Konusringe mit Schäfereinlage einzusetzen (siehe Abb. 14). In die ordnungsgemäß angezogenen Zwölfkantmuttern die Filzringe in die Muttern einlegen, den Deckring anschrauben und die Zylinderkopfschrauben gegenseitig mit einem Drahtring sichern. Die Zwölfkantmuttern mit dem Sicherungsblech und Sicherungsdraht, wie in Abb. 17 ersichtlich, wieder sichern.

Das Nachziehen der Luftschraubenblätter an den Zwölfkantmuttern hat dann nach 10 bis 40 und ~~100~~ Betriebsstunden in der gleichen vorher beschriebenen Weise zu erfolgen.

Nach 300 ~~200~~ Betriebsstunden ist eine Hauptprüfung vorzunehmen; dazu die Luftschraube vom Motor abbauen und vollständig zerlegen.

15

Figure 28: Amended values in Ju-Air's copy of the operating and maintenance instructions. Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

Adjusting the blade pitch:

According to the operating and maintenance instructions, the propeller blades must be adjusted to the desired pitch by hand or by lightly hitting the blade with a wooden hammer. The pitch can be precisely adjusted either on the measuring bench or using a setting gauge.

When adjusting the blade on the measuring bench, the propeller blade is first properly aligned (see figure 29). The blade pitch is then adjusted using the inclinometer, from which the pitch can be read directly in degrees.

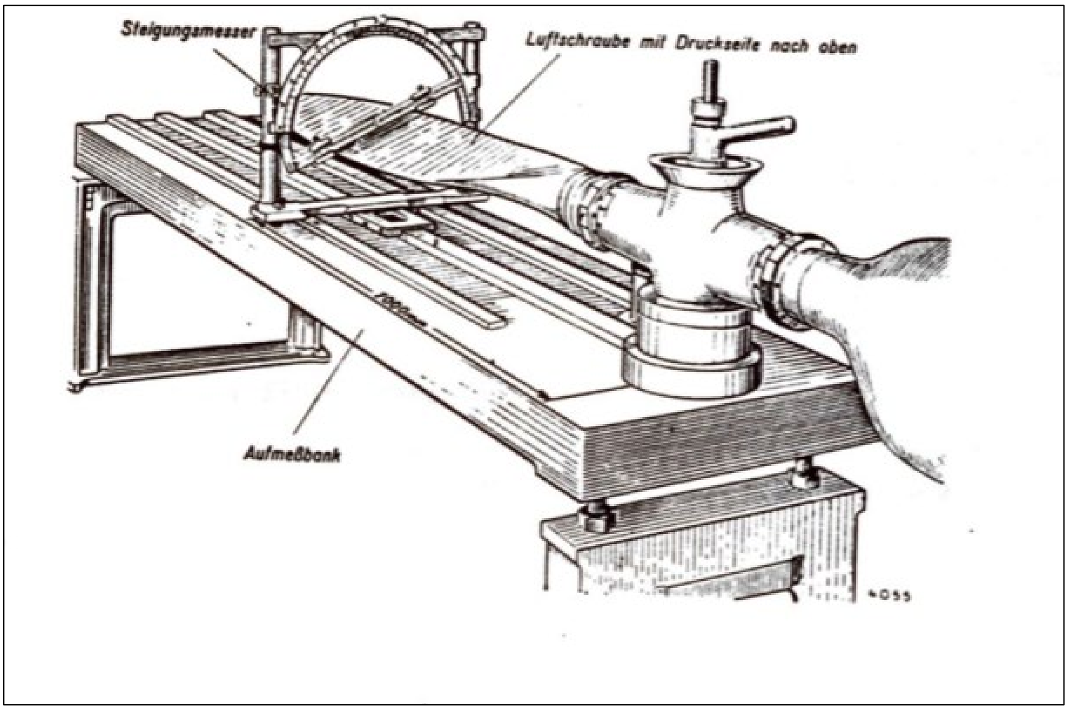


Figure 29: Adjusting the blade pitch on the measuring bench: Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

When using the setting gauge, the blade pitch is adjusted using only the setting scale on the hub and the mark on the root of the blade (see figure 30). Using this method, the propeller does not have to be removed from the engine. Ju-Air was not familiar with this method of adjustment.

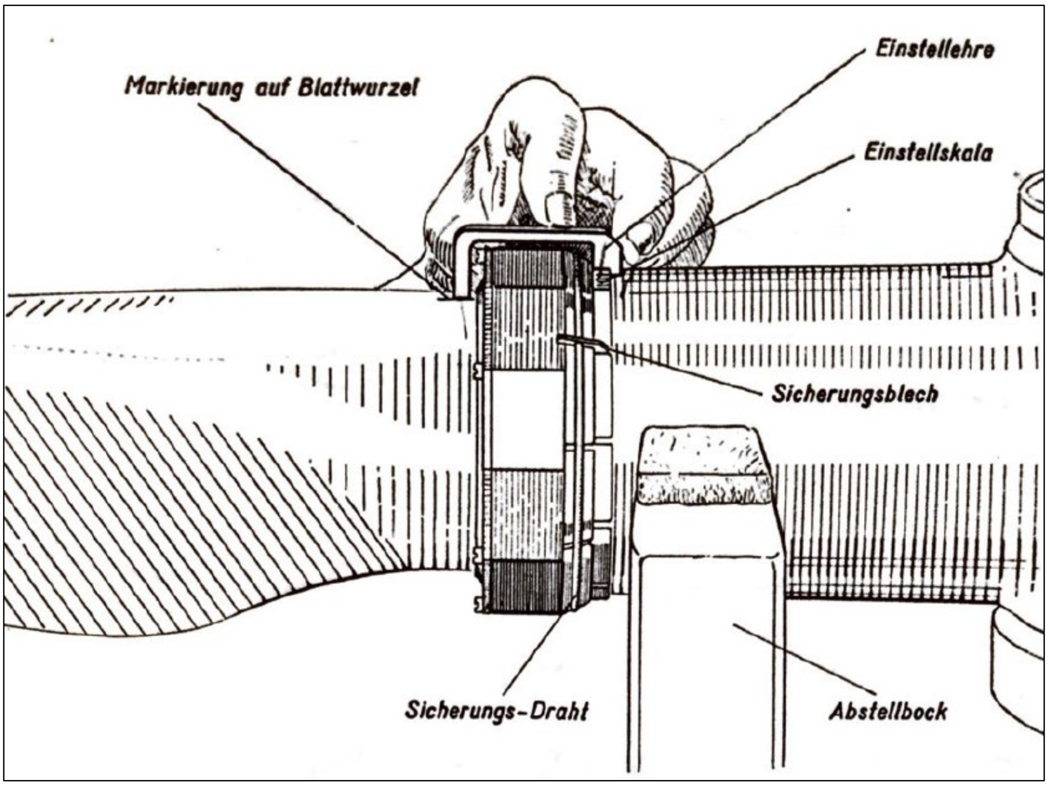


Figure 30: Inspection using the setting gauge. Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

After adjusting the blade pitch, each blade is to be checked for frictional resistance as per the operating and maintenance instructions. To do so, a bracket is placed on the blade 600 mm from the centre of the propeller and a weight of 50 kg is attached to a lever arm that has a length of 1,000 mm (see figure 31). With the weight in this position, lightly tap the tip of the blade with your hand. The blade must not twist.

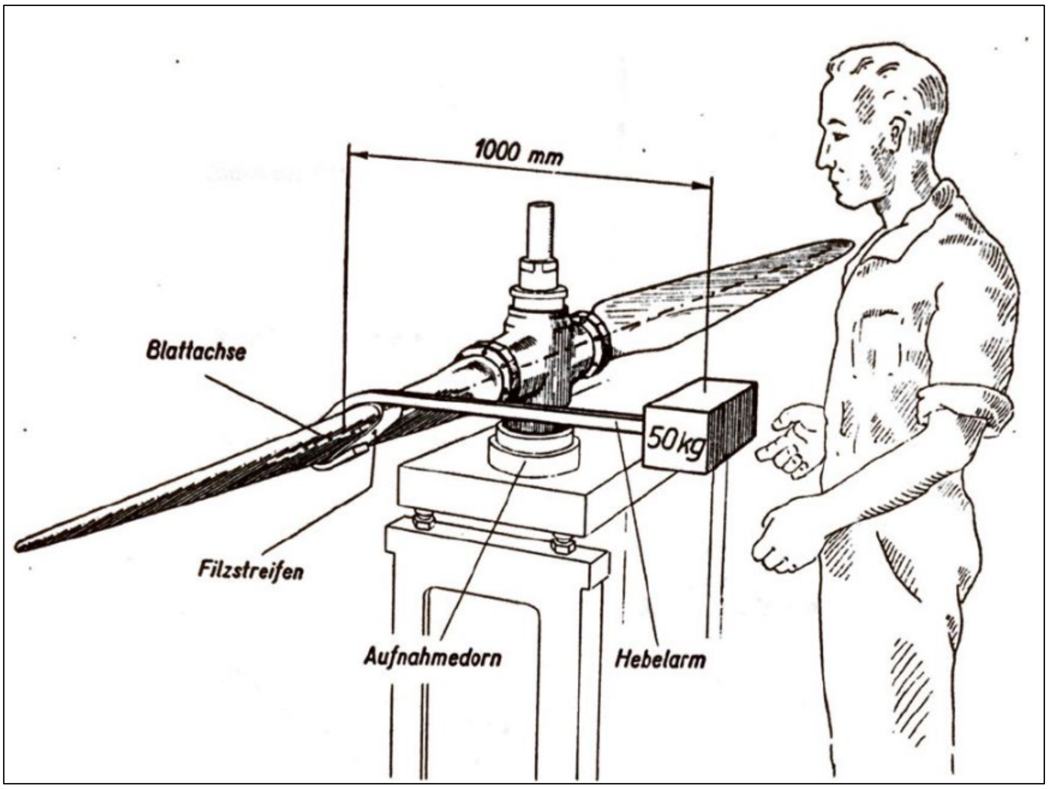


Figure 31: Checking the blade's frictional resistance. Source: "*Junkers Metall-Luftschrauben*" (Junkers metal propellers).

A1.6.14 Maintenance

A1.6.14.1 General

HB-HOT as well as its two sister aircraft have been maintained at Ju-Air's own maintenance facility since being taken over from the military. In the beginning, the engines were repaired and overhauled at Naef Flugmechanik AG in Fischenthal, just like they were during the aircraft's military service. In 1987, Naef Flugmotoren AG was founded and set up their business in the same hangar as Ju-Air. From 1988 onwards, work on the engines was carried out by this company.

A1.6.14.2 Legal basis

The following relevant paragraphs were listed in technical communication TM 02.020-35 'Handling of maintenance instructions and operating times published by the manufacturers'[42], which came into force on 1 January 2014:

"5. Maintenance programme for annex II aircraft [meaning: aircraft referred to in annex II of European Regulation 216/2008]

[42] Published in German as "*Handhabung der von den Herstellern publizierten Instandhaltungsanweisungen und Betriebszeiten*"

For annex II aircraft (aircraft which do not fall within the scope of Regulation (EC) No. 216/2008), there is no legal obligation to draw up an individual maintenance programme. As a matter of principle, all maintenance documents provided by the manufacturers / type certificate holders are binding for these aircraft (see article 25, paragraph 2 of the VLL[43]). However, exemptions in the sense of article 25, paragraph 2 (b and c) of the VLL can still be granted for annex II aircraft, but the possible exemptions are no longer generally published in individual TM technical communications. If the operator of an annex II aircraft wishes to deviate from maintenance documents or recommended operating times, they are also obliged to draw up an individualised maintenance programme for their aircraft in accordance with article 25, paragraph 2(e) of the VLL and to have it approved by FOCA (see technical communication TM 73.700-10). […]"

Technical communication TM 73.700-10 'Maintenance programmes for aircraft excluded from the scope of Regulation (EC) No. 216/2008'[44], which came into force on 7 March 2014, included, inter alia, the following paragraphs:

"3. *Maintenance programmes*

3.1 Aircraft with maintenance instructions from the manufacturer

In order to maintain their airworthiness, annex II aircraft are generally subject to the maintenance requirements stipulated in the Ordinance on the Airworthiness of Aircraft (VLL; SR 748.215.1). If maintenance instructions / maintenance documents from the manufacturer(s) are available, these are considered as binding maintenance requirements for the continued airworthiness of the aircraft as per article 25, paragraph 2 of the VLL:

- *The operating times specified or recommended by the type certificate holder (usually the aircraft manufacturer);*
- *The maintenance plans, maintenance instructions, work instructions, task cards and repair instructions, and airworthiness directives issued by the type certificate holder (usually the aircraft manufacturer).*

Based on article 25 of the VLL, the operator is fundamentally obliged to comply with all maintenance work and operating times recommended by the manufacturer / type certificate holder in order to maintain the airworthiness of their aircraft.

According to article 25, paragraph 2 (b and c) of the VLL, in individual cases the Federal Office of Civil Aviation (FOCA) may define exemptions from recommended operating times and recommended maintenance documentation (see TM 02.020-35) – provided it is not an 'airworthiness limitation'. If an aircraft operator wishes to make use of such an exemption or to deviate from recommended operating times or recommended maintenance work, a specific/individualised aircraft maintenance programme must be drawn up for the aircraft concerned. In this programme, they may specify deviations from recommended operating times (e.g. the operating times for engines), subject to the presentation of alternative/additional inspection or test procedures. In these cases, the design of the aircraft maintenance programme is largely based on the provisions listed under M.A.302 in annex I of Regulation (EC) No. 2042/2003. The corresponding aircraft maintenance programme must be approved by FOCA (see article 25, paragraph 2(e) of the VLL) and may

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[43] VLL: *Verordnung des UVEK über die Lufttüchtigkeit von Luftfahrzeugen* (DETEC Ordinance on the Airworthiness of Aircraft)

[44] Published in German as "*Instandhaltungsprogramme für Luftfahrzeuge die vom Geltungsbereich der Verordnung (EG) Nr. 216/2008 ausgenommen sind*"

only be used as a supplement to the maintenance instructions / maintenance documentation from the time of approval.

4. Formalities/communication

Any changes to the aircraft that have an influence on the aircraft maintenance programme, or changes to the aircraft maintenance programme itself, must be submitted to FOCA for re-approval prior to implementing the respective change."

A1.6.14.3 Aircraft maintenance programme

A1.6.14.3.1 General

According to their statements, Ju-Air had written an aircraft maintenance programme (AMP) after taking over the aircraft from the military. It could not be fully clarified at what point in time the maintenance work was based on this programme, neither could its structure nor what it contained.

The first record of FOCA's AMP approval is dated 4 March 1987.

On 30 November 1995, a completely new edition of the AMP marked as revision 0 was examined and approved by the Federal Office of Civil Aviation. At the time of the accident, the AMP with revision 5 dated 8 February 2011 was valid.

The following introductory text was written in the AMP under 'Organisation':

"*This aircraft maintenance programme for the JU 52/3m g4e and CASA 352 has been prepared for regular, civilian use of the aircraft, the programme lists all requirements to be performed during scheduled maintenance*.

These are historic aircraft and the aim is to ensure the continued airworthiness and operational readiness of the aircraft over the coming years. Continued airworthiness can only be maintained as long as airworthy spare parts are in stock, can be procured or manufactured.

The requirements have been determined taking the manufacturers' specifications into account and in accordance with current maintenance procedures as well as with regard to the age of the aircraft. Based on the experience gained during maintenance, this programme can and must be adapted or changed over time.

[…]

In the event of an increase in annual flight hours, low defect frequency and increasing experience, the annual cycle may be adjusted upwards (in the opposite case downwards) without changing the programme as such."

In order to reduce aircraft downtimes, maintenance work in the AMP was arranged to be progressive and cover nine areas of the aircraft. These areas were to be maintained successively at intervals of 35 operating hours. These nine intervals formed a cycle of 315 operating hours. Each engine was to be serviced every 105 operating hours and the respective areas of the airframe every 315 hours (see figure 32). The minimum annual maintenance was to consist of a complete cycle of these nine intervals. More in-depth maintenance stages, such as partial and major overhauls, are not defined.

The individual areas are based on the main sections of the operating instructions, as is the maintenance work.

JUNKERS JU-52/3mg 4e und CASA 352 Wartungsprogramm												
Intervall No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**2**	**usw.**
Arbeitsumfang	**Erster Zyklus (minimum jährlich)**									**2 Zyklus**		
Motor No 1	X			X			X			X		
Motor No 2		X			X			X			X	
Motor No 3			X			X			X			X
Cockpit	X									X		
Kabine		X									X	
Rumpf			X									X
Flügel				X								
Leitwerk					X							
Steuerung						X						
Ausrüstung							X					
Benzin- & Öl-System								X				
Fahrwerk									X			
Mängel	X	X	X	X	X	X	X	X	X	X	X	X
Flugbereitschaft	X	X	X	X	X	X	X	X	X	X	X	X
35 Std. Ergänzung	X	X	X	X	X	X	X	X	X	X	X	X

Figure 32: Maintenance intervals in Ju-Air's Ju 52 aircraft maintenance programme.

Except for one single checkpoint, the task cards for the airframe, engines and propellers as well as the checklists that were included in the AMP have not been changed since the AMP was drawn up in 1995.

Observations made when examining the AMP include:

- In four out of the five revisions to the AMP since the new edition in 1995, only the operating times (TBO[45]) for the components have been changed, or rather increased.
- For some inspection points, the task cards used by the maintenance organisation differ from those listed in the AMP.
- The manufacturers' instructions required for all maintenance and repair work were not listed.
- The generic term 'engine units' is listed, but not the individual components.
- The AMP does not contain information on the following points, despite them being published in the manufacturers' instructions (see section A1.6.13), for example:

  - Partial overhauls of the engines

[45] TBO: Time between overhaul (operating time until overhaul)

- Partial and major overhauls of the airframe
- Repair processes
- Surface protection

- Furthermore, the following points were missing from the AMP:
  - Recurring maintenance (e.g. service bulletins)
  - Deviations from the type (e.g. modifications)
  - Comprehensive list of component operating times
  - Maintenance of NiCd batteries
  - Supplemental structural inspection documents (SSID) (see section A1.6.19)

Section 2.8 of Ju-Air's maintenance organisation exposition (MOE), 'Application of and compliance with maintenance documentation' contained the following:

"*This paragraph shall apply to the following documents*:

- *Part 145 and EASA AD*
- *Maintenance and repair manuals from the manufacturers*
- *Manufacturer instructions (service bulletins, etc.)*
- *Aircraft maintenance programmes from the manufacturers*
- *Publications from the competent authorities (aviation law, technical communications, etc.)*

The operations manager is responsible for ensuring that the above-mentioned documentation is available for all maintenance work planned on-site. They shall periodically verify that the documentation is in line with the latest version and shall procure any necessary supplements."

In addition, the following was described in section 2.10 'Compliance with aircraft maintenance programmes':

"The operations manager is responsible for ensuring that the relevant documents to be used for this purpose are already specified when planning maintenance work. When carrying out this work, they shall ensure that only the manufacturer's updated maintenance programme is used and that all the tasks included therein are fully completed before release to service."

During inspections carried out by FOCA over recent years, the following complaints had been raised regarding the aircraft maintenance programme:

Date	**Complaint level 2**
13 February 2018	"*No procedure to develop the maintenance program and process of its approval in accordance with M.A.302 is available in the MOE (chapter 2.30).*"
25 November 2016	"*The checklist based on the maintenance program, used for aircraft maintenance, should be reassessed to highlight the tasks that need an independent check in order to minimize the risk of multiple errors during maintenance*."

04 July 2013	"*The procedure Maintenance Program periodical revealed, that the review was not performed and documented (at least annually the Maintenance Program shall be reviewed). The AMP is still the first issue and references to the MME*[46] *and the JAA*[47] *and applicability of AD*[48] *shall be corrected (CAME and EASA). A procedure on how Ju Air is performing a corrosion control program shall be added.*"

The following was recorded, not as a complaint, but as a comment, during an inspection that was carried out:

Date	**Comment**
16 May 2017	"*To improve the readability, the AMP is under review to highlight more precisely which task(s) need a duplicate inspection. Additionally, the CASA denomination has to be removed from the AMP as this aircraft has left the managed fleet.*"

A1.6.14.3.2 Operating times

Maintenance measures and operating times, which are specified to maintain the airworthiness of the respective component, are defined by the manufacturers. These are usually binding instructions or airworthiness limitations.

For airworthiness-related parts or components, the operating time between overhaul (TBO) or a life limit is specified by the manufacturer. For non-airworthiness-related components, the manufacturer may waive a limitation on operating time. Such components can be in operation as long as they are found to be good (what is known as 'on condition') by visual inspection.

The AMP for Ju-Air's Ju 52 aeroplanes only lists the maximum permissible operating time and its tolerances for a few components (see figure 33). The operating times listed have been steadily increased over time by Ju-Air (see section A1.6.14.3.3). It is not apparent in the AMP whether the maximum operating times listed are a life limit or a TBO.

Furthermore, components with calendar-based operating times are listed, however it is not clear from the AMP whether these components have a life limit or whether they are to be reconditioned.

All other components that are not listed in this table are only checked visually to assess whether they are on condition during the respective progressive inspections.

BMW engine	1,500 hours + 10 %
Ju-PAK propeller	1,200 hours + 10 % or 6 years (until next annual inspection max. 7 years)

46 MME: Maintenance management exposition. The MME has been replaced by the continuing airworthiness management exposition (CAME).

47 JAA: Joint Aviation Authorities. The JAA has been replaced by EASA (European Aviation Safety Agency).

48 AD: Airworthiness directive

Hoffmann propeller	See service bulletin 1
Engine units	Same as engine
Pallas carburettor	Bench test when reaching the engine TBO Major overhaul when reaching 2× the engine TBO
Mechanical fuel pump	Bench test when reaching the engine TBO Major overhaul when reaching 2× the engine TBO
Compressed air tank	10 years
Portable oxygen cylinder	10 years
Engine-fire extinguishers	20 years
Emergency location transmitter battery	6 years
Compass system and magnetic compass	2 years and after engine replacement
Electric fuel pump	Carbon inspection every 500 hours Overhaul, every 2,500 hours
Oil and fuel lines between engine and firewall	10 years (until next annual inspection max. 11 years)

Figure 33: The maximum operating times listed in the AMP for components in Ju 52 aircraft.

At the request of FOCA, a life limit of ten years was specified for oil and fuel lines between the engine and the firewall when the AMP was last amended in 2011. For all other fuel lines in the aircraft, no operating time limit was defined.

The electric fuel pumps, also referred to as fuel pumps or booster pumps in Ju-Air documentation, had been deactivated since 2007, but remained installed in the fuel system. The progressive inspection checklist includes the following inspection point under ‘Fuel and oil system’:

“*Check both electric fuel pumps for leaks, overall condition, mounting and operation*.”

This was amended with a handwritten note stating “*Electrically inop. see HIL*” and attested as “*n/a*”.

According to the component cards for both electric fuel pumps, the pumps were installed in HB-HOT after an overhaul on 7 July 1997. At this time HB-HOT had recorded 5,950 operating hours. Since then, the pumps had been installed for 4,239 operating hours without ever being overhauled.

Furthermore, no operating time limit had been defined in the AMP for the landing gear. According to information from Ju-Air, the landing gear as well as assemblies from the flight control system have never been completely overhauled, i.e. disassembled and crack-tested since the aeroplanes had been acquired from the military, which is backed up by the files.

The engine manufacturer did not specify any operating time limits for the magnetos; however, maintenance work had to be carried out on the magnetos every

20 and 50 hours. In the AMP, a TBO of 1,500 h (+ 10%) was specified for the magnetos and the following maintenance work had to be carried out every 105 operating hours:

- Check magnet interrupter for cleanliness, condition and distance 0.3 to 0.4 mm. If 0.5 mm, replace magnet.
- Refill magnet hinged-lid lubricator until wick is fully soaked.
- Grease magneto after TSO 650 h, grease distributor rotor arm with NBU30.

A1.6.14.3.3 Increase in operating time limit for the engines

According to the files, in 1985 the time between overhaul (TBO) for the engines was set at 1,000 operating hours. It could not be determined which value applied before.

At the request of Ju-Air, FOCA approved an increase to 1,200 operating hours in 1996, and an increase to 1,500 operating hours in 2004.

An attempt to increase the TBO to 1,800 operating hours was made between 2010 and 2014 following approval by FOCA. Two of five engines did not reach this operating time due to damage to supercharger bearings. One of these two engines, serial number 68842, was installed on HB-HOT at the time of the accident as the centre engine. After this unsuccessful attempt to increase the TBO to 1,800 operating hours, Ju-Air decided in 2014 to leave the TBO at 1,500 operating hours in order to preserve its engines.

The internal report for this attempt to increase the TBO concludes with the following remark:

“This concludes the attempt, the running time for the engines remains at 1,500 operating hours + 10 % in order to not place extreme stress on the engines.”

The following was noted from FOCA in the respective approval to increase the TBO:

“If, during the course of maintenance work, problems with the condition of the engines become apparent for any reason as a result of the increased permissible operating time, the matter would have to be re-examined. The measures that may be necessary for this purpose are set out in the MOEs of the companies involved.”

Below is an excerpt from Naef Flugmotoren AG’s MOE as mentioned by FOCA concerning the necessary measures:

“2.18.2. Internal measures

All operational faults, incidents and any trends are analysed within the scope of monitoring as per NAEF MOE sections 1.2.2 and 2.18 and are integrated into the training programme if necessary.”

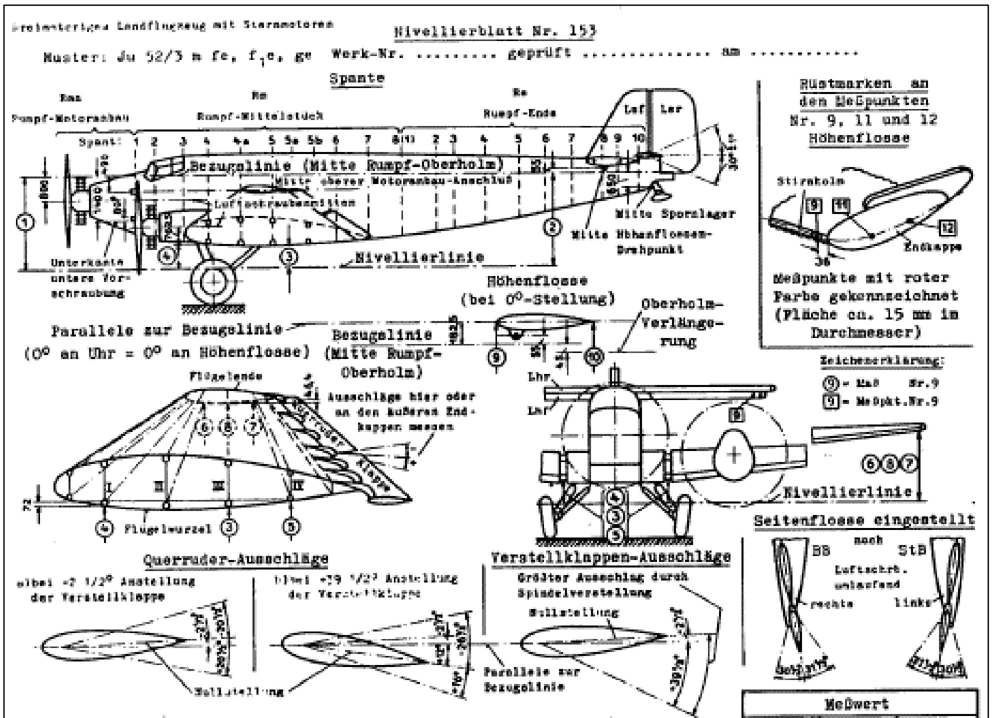
MOE section 1.2.2 describes the mandatory system for reporting faults and incidents (see annex A1.17).

This note from FOCA as a stipulation for the respective TBO increase was not followed up due to the lack of information regarding incidents and the non-systematic monitoring and safety management conducted by Ju-Air.

A1.6.14.3.4 Control settings

Section 4 of the operating instructions for the Ju 52, ‘Controls’, details the adjustment procedure, the necessary adjustment tools and the inspection intervals.

The nominal deflections for the control surfaces are listed on calibration sheet no. 153 from section 12 ‘Calibration and measurement sheets’ of the operating instructions, (see figure 34). This sheet was intended by the manufacturer as a log for entering the measured values.



Flugzeug in Waage gestellt, Bezugslinie (Rumpfoberholmmitte) liegt:

			Meßwert StB	Meßwert Mitte	Meßwert BB
Längs-lage	①	800 mm über Luftschraubenmitte bzw.			
		1400 mm über Unterkante untere Verschrbg. (80 ø) am Rm-Spant 1, oder			
		490 mm über Mitte oberen Motoranbauanschluß			
	②	55 mm unter Mitte Höhenflossendrehpunkt			
		650 mm über Mitte Spornlager			
Quer-lage	③	Maße bis Unterkante Verschraubung (136 ø) am Unterholm des Trägers III müssen BB und StB gleich sein			

Messung	Meßstelle	Meßwert mm StB	Meßwert mm BB	Unterschied soll StB u. BB	Unterschied ist StB	Unterschied ist BB	Abweichung StB	Abweichung BB
Anstellung am Spalt	④ Unterkante Verschrbg. (136 ø) Unterholm Tr. I			72				
	⑤ " " (104 ø) " " IV							
Anstellung am Ende	⑥ " Flügelendkappe beim " " II			46,4				
	⑦ (Dornnietreihe) beim " " IV							
V-Form	③ Unterkante Verschrbg. (136 ø) " " III			1612				
	⑧ " Flügelendkappe beim " " III							
Höhenflosse 0° Stellung	⑨ Meßpunkt Nr. 9 bzw.			0				
	Meßpunkt Nr. 11 (bzw. 14 mm darunter 1))							
	⑩ Mitte Auslaufspitze b. Ruß. Ruderlager bzw.							
	Meßpunkt Nr. 12 (bzw. 14 mm darunter 1))							

1) Meßpunkt 11 und 12 lagen früher 14 mm über Verbindungslinie Mitte Stirnholm (Meßpunkt 9) Mitte Höhenflossenauslaufspitze.

Messung	Ruder			soll StB u. BB		ist StB	ist BB	Abweichung StB	Abweichung BB
Ruder-Ausschläge	Seitenruder (aus Mitte Leitwerk) bei Einstellung nach	BB		31 ½°	30 ½°				
		StB		30 ½°	31 ½°				
	Höhenruder (bei 0°-Stellung der Höhenflosse)		oben	-30° ± 1°					
			unten	+30° ± 1°					
	Verstellklappe		oben	-2 ½°					
			unten	+39 ½°					
	Querruder (aus -2 ½° Nullstellung bei -2 ½° Klappenstellung)		oben	-20 ½°					
			unten	+20 ½°					
	Querruder (aus + 12° Nullstellung bei +39 ½° Klappenstellung)		oben	-26 ½°					
			unten	+16°					
Höhen-Flossen-Verstell-bereich	Landflugzeug		oben	+ 3 ½°					
			unten	- 2 ½°					
	Wasserflugzeug		oben	+ 3 ½°					
			unten	- 2 ½°					

Figure 34: Calibration sheet no. 153, which was intended by the manufacturer as a test log for control surface deflections. Source: “*Betriebsanweisung Ju 52/3m g4e*” (operating instructions).

The test logs in the technical files were incomprehensible (see figure 35). Practically no measured values were recorded. Moreover, the method of measurement was not apparent. Furthermore, the rudder deflections for right- and left-rotating propellers were listed, exactly as they had been written on calibration sheet no. 153 as a template. Ju-Air's Ju 52 aeroplanes had clockwise-rotating propellers. According to this, the rudder should be adjusted in line with "*Vertical stabiliser, left: 31.5°/30.5°*".

Inspection of the control surface deflections:

During the period from 30 October 2017 to 15 January 2018, progressive inspection nos. 6 to 9 were carried out. During progressive inspection no. 6, the control and control-surface settings were checked. The values of the settings for the controls recorded in the work report were incomprehensible. Of the 13 prescribed value entries, only one value was logged. The method of measurement and the time when this work was carried out were not apparent.

2	Überprüfe Ruderausschläge wie folgt (Nivellierblatt No 153) :		
	Ruder, Klappe oder Flosse	**Soll**	**Ist**
	Seitenruderpedale in 0-Lage Seitenruder (Seitenflosse links) (Seitenfl. rechts)	3° rechts 31,5°/30,5° 30,5°/31,5°	o.k.
	Höhenruder (Höhenflosse 0 Grad) auf ab	 30° + /° 30° - /°	30° + -
	Verstellklappe auf ab	2,5° 39,5°	✓ o.k
	Querruder (bei 2,5° Nullstellung und bei - 2,5° Klappenstellung) (bei 12,0° Nullstellung und bei 39,5° Klappenstellung	 auf 20,5° ab 20,5° auf 26,5° ab 16,0°	o.k.
	Höhenflosse	auf 3,5° ab 2,5°	o.k.

Figure 35: Extract from the work report for progressive inspection no. 6 with reference to calibration sheet no. 153.

Repainting:

According to the work report dated 23 October 2017, HB-HOT was repainted. For this purpose, the aircraft was flown to Altenrhein (LSZR). The elevators and rudder as well as the auxiliary wings were dismantled and reassembled after repainting. The operating instructions (see section A1.6.13.1.1) were used as the instructions when disassembling and reassembling the aircraft. According to the work report, the controls were checked "*for free movement and proper function*". Afterwards the aircraft was flown back to Dübendorf. The work report for the repainting was signed off after completion of the work on 5 December 2017. A weight sheet was prepared on 21 December 2017.

The exact process for the inspections of the controls and control surfaces as well as that of the inspection of the controls' settings could not be plausibly explained by the maintenance staff even with the help of the maintenance documents.

Based on the technical files and the information provided by the maintenance team, it is highly probable that not all control surfaces were checked or adjusted to the values specified in the operating instructions.

A1.6.14.3.5 On-board battery

A nickel-cadmium (NiCd) battery was installed in HB-HOT at the time of the accident.

According to statements made by Ju-Air, since their taking over of the Ju 52 aeroplanes in the 1980s, maintenance work on the NiCd batteries had been carried out by the Swiss Air Force's Logistics corps at Dübendorf Air Base. This was evident from the technical files for HB-HOT.

Ju-Air and Naef Flugmotoren AG were not authorised to carry out maintenance work on any batteries. They also did not possess the necessary infrastructure nor did they employ licensed personnel. No information about the NiCd battery was written in the AMP.

A1.6.14.3.6 Periodic inspections of the pitot-static system

For aircraft certified for VFR flights only, there is no requirement for periodic checks of the pitot-static system.

There is no information in the aircraft maintenance programme (AMP) regarding a periodic inspection of the accuracy of the airspeed indicator. For systems and functions that are not explicitly listed in the AMP, it is assumed that any faults are detected during operation. In the case of the air speed indicator, any obvious malfunctions can be identified by comparing two or more independent indicators. However, this is not possible in Ju-Air's Ju 52 aircraft, as the two speed indicators are connected to the same pressure source and there is no redundancy.

As ordered by Ju-Air, HB-HOT's pitot-static system was tested for leaks by an approved maintenance organisation in May 2017 but not for display accuracy. Although Ju 52 aircraft are operated by Ju-Air under visual flight rules, a full inspection, including speed indicators, would be appropriate for the reasons mentioned above, even if the regulations do not require it.

In order to be able to assess the accuracy of the indicated airspeed (IAS), HB-HOT's flight on 3 August 2018 was evaluated during the investigation. A comparison parameter, defined as IAS', was created for this purpose. The IAS' was calculated based on the true airspeed (TAS), taking into account the density altitude. The TAS was in turn calculated using the ground speed (GS) and the wind component (WK). The wind component (wind speed and wind direction) was determined along the flight path using the prevailing meteorological model.

The GS was transmitted from HB-HOT's mode S transponder to the radar system on the ground when radar coverage was possible. Due to the topography, this only occurred in certain locations. In table 14 below, these locations are designated as Rigi 1 to 5 and Lake Zurich.

Position	Altitude			IAS[1)]	TAS = GS-WK[2)]		TAS → IAS'[3)]		Δ = IAS - IAS'
	m AMSL	ft AMSL	ft AMSL	km/h	GS (kt)	TAS (kt)	km/h	km/h'	km/h
Lake Zurich	1,264[b)]	4,147[a)]	–	140	96	88	163	150.4	-10.4
Rigi 1	1,897[b)]	5,950[a)]	6,224[c)]	162.5	116	108.2	200.4	178.9	-16.4
Rigi 2	1,865[b)]	5,920[a)]	6,119[c)]	150	112	103.3	191.3	171.1	-21.1
Rigi 3	1,865[b)]	5,920[a)]	6,119[c)]	162.5	116	108.4	200.8	179.6	-17.1
Rigi 4	1,865[b)]	5,920[a)]	6,119[c)]	150	110	101.3	187.6	167.8	-17.8
Rigi 5	1,865[b)]	5,920[a)]	6,119[c)]	150	106	98	181.5	162.4	-12.4

Table 14: Comparison of the indicated airspeeds.

a) Altitude read-out on the altimeter in the cockpit, adjusted QNH 1,021 mbar

b) True altitude above mean sea level

c) Standard altitude, 1,013.2 mbar,15°C, from mode S transponder

1) Indicated air speed (IAS) read in the cockpit

2) Ground speed (GS) from the mode S transponder, wind component (WK) derived from the meteorological model

3) True air speed (TAS) converted to km/h and then indicated air speed (IAS') determined in km/h'

The above table reveals that the indicated airspeed (IAS) was 10 to 20 km/h lower than the reference IAS'. This may be due to the measuring accuracy of the indicator in the aircraft, but on the other hand, the calculated meteorological model is not completely accurate.

The evaluated radar data were mainly collected in the area around Mount Rigi. It can be assumed, however, that the indicated airspeed (IAS) in the area where the accident took place exhibited approximately the same deviation as described above.

The detected deviation is not regarded as critical because the actual airspeed is greater than the indicated airspeed.

A1.6.14.3.7 Oil change

According to the task cards for Ju-Air’s engines, the oil had to be changed every other progressive inspection for the respective engine, i.e. after 210 h (+/- 10 %). In contrast, the engine manufacturer’s operating instructions stipulate an oil change every 20 operating hours.

A1.6.14.3.8 Propeller

The task cards in the AMP include the following inspection points concerning the maintenance of the propellers:

35-hour inspection	*Clean propeller position 1/2/3 or polish with a suitable paste (especially the leading edge)*
105-hour inspection	*Check propeller for free play. Max. 3 mm (without spark plugs)*
	Check propeller blades for damage, hub for play. Check that pitch is correct. Secure propeller nut.

It was found that the inspection points listed on the task cards used by the maintenance team did not fully correspond with the inspection points listed in the AMP.

In Ju-Air's copy of the aircraft manufacturer's operating and maintenance instructions, an additional sheet had been inserted, which lists the intervals for blade- and hub-nut retightening (see figure 36). It also includes the tasks for a 100-hour inspection.

The torques used for tightening the nuts were in line with the manufacturer's specifications, however, the intervals were not. Also, according to the technical files, the propellers were never subjected to a main inspection after 200 operating hours.

Zusatz zu Betriebsanweisung JU PAK Propeller 05.12.2012

Prüfung während des Flugbetriebes

Blattmutter Anzug (Schlüssel 1,2m 80Kg max. 50mm)
Nabenmutter Anzug (Schlüssel max. 1,5m 80Kg)

1. nach Standlauf Blattmutter + Nabenmutter Nachzug
2. bei 10 Stunden Blattmutter + Nabenmutter Nachzug in HIL
3. bei 50 Stunden Blattmutter + Nabenmutter Nachzug in HIL
4. bei 100 Stunden Blattmutter + Nabenmutter Nachzug in HIL
5. bei 400 Stunden Blattmutter + Nabenmutter Nachzug in Laufzeit Liste
6. bei 800 Stunden Blattmutter + Nabenmutter Nachzug in Laufzeit Liste

Propeller wenn immer möglich in Waagrechte Stellung bringen, damit kein Wasser in die Nabe läuft.

Bei jeder 100 Stunden Kontrolle

Anzug der Nabenmutter kontrollieren.
Blätter auf verdrehen kontrollieren. (Holz 1m 50Kg Zuglast)
rote Blattmarkierung kontrollieren und wenn nötig ersetzen.
Blatt Abdichtung leicht mit Silikon Oel besprühen.

Figure 36: Intervals for blade- and hub-nut retightening. Signature removed by the STSB.

Propeller pitch adjustment on Ju-Air's Ju 52 aircraft was carried out by companies in Germany on their premises, in each case as part of a major overhaul.

After a major overhaul, Ju-Air applied a mark (line) on each twelve-point nut and the corresponding propeller blade using red nail polish (see figure 37). This marking was intended to aid in the detection of a loose or twisted propeller blade.

After retightening a blade nut, this marking had to be reapplied if necessary.

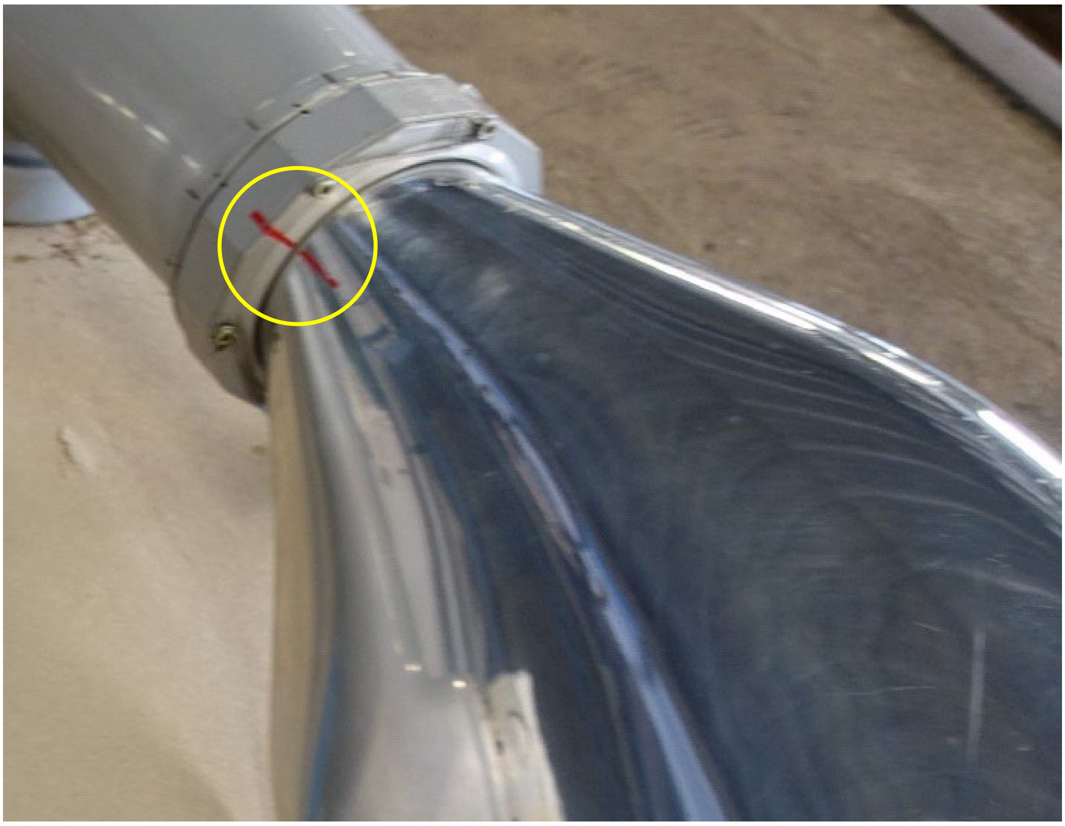


Figure 37: Red marking on the twelve-point nut and propeller blade (yellow circle).

From 2000 onwards, new propeller blades were manufactured based on pattern parts by a Czech aviation-approved company (see section A1.6.17.2.6). No release certificates[49] for the propeller blades mounted on HB-HOT were found in the files.

Due to the high degree of damage to the three propellers of HB-HOT, it was not possible to determine the pitch of the propeller blades.

There was no recorded data available for the overhaul of the propeller hubs. Nevertheless, the conical rings, which hold the propeller blades in the hubs, affected by corrosion were mechanically machined by a company not certified to provide parts for use in aviation. The propeller blades, which had either been manufactured based on pattern parts or had been reconditioned, were subsequently reassembled. Hubs were repeatedly overhauled in this way and as such, some of them exhibited the same defects again after short operating times. The responsible persons lacked the quality awareness necessary for this work. In some cases, the existing serial numbers on the hubs were removed and replaced by new numbers.

49 An authorised release certificate (EASA form 1) for a product, part or component shows that the product, part or component was manufactured, repaired or refurbished in accordance with approved design data and that it has been declared airworthy.

This is not permitted for aircraft parts. On HB-HOT, the serial numbers for the left and right hubs had been replaced.

The propeller blade's conical root is mounted into the propeller hub's corresponding conical ring; this is a frictional connection. Corrosion, wear or an inaccurate fit of the two conical surfaces can cause the frictional connection to weaken during operation and the propeller blades to become loose. This leads to changes in propeller pitch and vibrations.

Based on the poor technical condition of the connection between the propeller blades and the hub, and the resulting risk of a spontaneous change in the pitch of the propeller, it can be concluded that the propellers for the Ju 52 aircraft were no longer airworthy.

A1.6.14.3.9 Evaluation

At the time of the accident, the AMP with revision 5 dated 08 February 2011 was valid.

Ju-Air's AMP exhibited severe deficits in various areas and had not been adapted in line with the age of the aircraft and its use. For this reason, many defects in the aircraft and the engines remained undetected for long periods of time and the airworthiness of the Ju 52 fleet could not be guaranteed.

For the most part, the aircraft and engine manufacturers' maintenance instructions were not implemented in the AMP and were therefore never executed. This shows that the maintenance organisations did not follow the appropriate manufacturers' instructions.

The following important points were not defined in the AMP:

- Partial and major overhauls of the airframe according to the manufacturer
- Partial overhauls of engines according to the manufacturer
- Deviations from the manufacturers' maintenance instructions
- Corrosion protection programme
- Supplemental structural inspection document (SSID) (see section A1.6.19)
- Deviations from the type specification (STCs, modifications, etc.)
- Comprehensive list of component operating times
- Repair processes
- Recurring maintenance (e.g. service bulletins)
- Maintenance of NiCd batteries (see section A1.6.14.3.5)

Furthermore, the AMP has not been adapted to take into consideration the constant ageing of the aircraft structures, engines and systems over the last few decades. For example, no reliability programmes have been developed. Although various FOCA inspections raised complaints about this, Ju-Air's maintenance organisation did not comply with this request.

The intervals for the defined operating hours strongly deviated from the manufacturers' specifications. For these historic aircraft, which are approximately 80 years old, the intervals and cycles as defined in Ju-Air's AMP cannot meet all of the requirements for continued airworthiness. It is, for example, not appropriate to only change the engine oil at every other progressive inspection for economic reasons, i.e. after 210 operating hours, and this process should be reconsidered. Particularly in view of the BMW 132 A3 engine not being equipped with a modern oil filter system. The engine may have been equipped with a magnet with the intention of it being visually inspected for metallic abrasion debris, but was not fitted with a system that could trigger a warning in the cockpit.

Over the last 15 years, the AMP has not been adapted to reflect knowledge gained during maintenance. In four of the five revisions, only the operating times for components were changed, or rather increased. It is incomprehensible that the operating hours for components, especially engines, have been increased several times, and approved by FOCA, despite known engine faults or system malfunctions. At the time of the increase in the respective operating hours, the increase was, again, never questioned based on the age of the components and their reliability. This clearly shows a lack of understanding in terms quality as well as a lack of safety awareness among the two maintenance organisations.

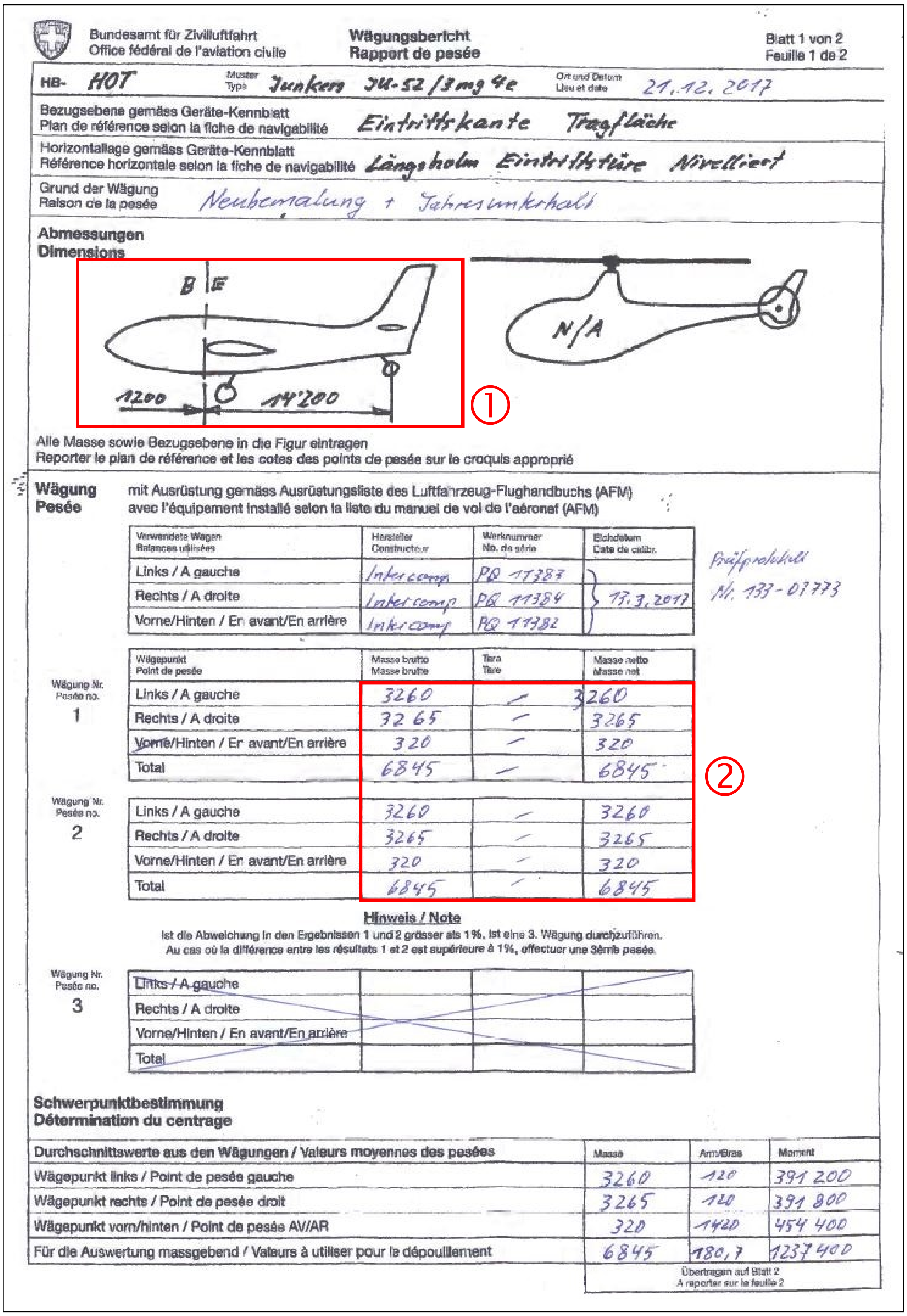
For maintenance work on the aircraft, task cards were used with inspection points that in places deviate from the task cards in the AMP audited by FOCA. This demonstrates that Ju-Air’s CAMO processes were not effective.

During inspections carried out by FOCA in the years leading up to the accident, several complaints had been raised regarding the aircraft maintenance programme (see section A1.6.14.3). For the most part, these were not remedied and FOCA did not take any measures in response.

A1.6.14.4 Aircraft weighing

HB-HOT was last weighed on 21 December 2017 after the entire aircraft had been repainted. FOCA’s weight sheet was used for this purpose. Observations made when examining the weight sheet include:

- The arm ‘reference datum – main landing gear’ was drawn incorrectly, the measured values (in mm) were correct (see figure 38, (1)).
- All measured values were given without units.
- It is mandatory and makes metrological sense to weigh the aircraft at least twice in succession. If the deviation in the measured values from the first and second weighing is greater than 1 %, a third weighing must be carried out. In HB-HOT’s weight sheet, the measured values entered for the first and second weighing were exactly the same (2).



Bundesamt für Zivilluftfahrt
Office fédéral de l'aviation civile

Wägungsbericht
Rapport de pesée

Blatt 1 von 2
Feuille 1 de 2

HB- HOT	Muster / Type: Junkers JU-52/3mg 4e	Ort und Datum / Lieu et date: 21.12.2017

Bezugsebene gemäss Geräte-Kennblatt / Plan de référence selon la fiche de navigabilité: Eintrittskante Tragfläche

Horizontallage gemäss Geräte-Kennblatt / Référence horizontale selon la fiche de navigabilité: Längsholm Eintrittstüre Nivelliert

Grund der Wägung / Raison de la pesée: Neubemalung + Jahresunterhalt

Abmessungen
Dimensions

Alle Masse sowie Bezugsebene in die Figur eintragen
Reporter le plan de référence et les cotes des points de pesée sur le croquis approprié

Wägung mit Ausrüstung gemäss Ausrüstungsliste des Luftfahrzeug-Flughandbuchs (AFM)
Pesée avec l'équipement installé selon la liste du manuel de vol de l'aéronef (AFM)

Verwendete Wagen / Balances utilisées	Hersteller / Constructeur	Werknummer / No. de série	Eichdatum / Date de calibr.
Links / A gauche	Intercomp	PQ 11383	13.3.2017
Rechts / A droite	Intercomp	PQ 11384	
Vorne/Hinten / En avant/En arrière	Intercomp	PQ 11382	

Prüfprotokoll Nr. 133-01773

Wägung Nr. / Pesée no.	Wägepunkt / Point de pesée	Masse brutto / Masse brute	Tara / Tare	Masse netto / Masse net
1	Links / A gauche	3260	–	3260
	Rechts / A droite	3265	–	3265
	Vorne/Hinten / En avant/En arrière	320	–	320
	Total	6845	–	6845
2	Links / A gauche	3260	–	3260
	Rechts / A droite	3265	–	3265
	Vorne/Hinten / En avant/En arrière	320	–	320
	Total	6845	–	6845

②

Hinweis / Note
Ist die Abweichung in den Ergebnissen 1 und 2 grösser als 1%, ist eine 3. Wägung durchzuführen.
Au cas où la différence entre les résultats 1 et 2 est supérieure à 1%, effectuer une 3ème pesée.

Wägung Nr. / Pesée no.	Wägepunkt / Point de pesée			
3	~~Links / A gauche~~			
	~~Rechts / A droite~~			
	~~Vorne/Hinten / En avant/En arrière~~			
	~~Total~~			

Schwerpunktbestimmung
Détermination du centrage

Durchschnittswerte aus den Wägungen / Valeurs moyennes des pesées	Masse	Arm/Bras	Moment
Wägepunkt links / Point de pesée gauche	3260	120	391 200
Wägepunkt rechts / Point de pesée droit	3265	120	391 800
Wägepunkt vorn/hinten / Point de pesée AV/AR	320	1420	454 400
Für die Auswertung massgebend / Valeurs à utiliser pour le dépouillement	6845	180,7	1237 400

Übertragen auf Blatt 2
A reporter sur la feuille 2

Figure 38: Weight sheet, page 1. Source: Technical records HB-HOT.

At the end of the weighing, the mass, the centre of gravity and the aircraft's moment when empty were calculated and entered on the weight sheet (see figure 39, (3)). These values have been verified by the STSB and were found to be correct.

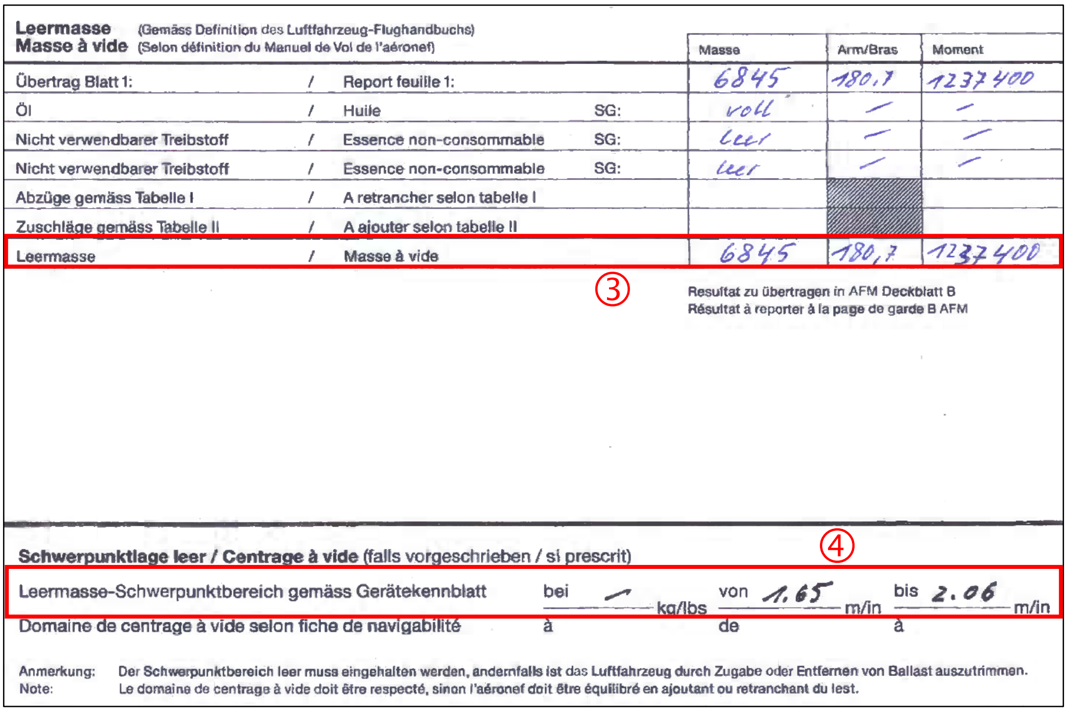
Furthermore, Ju-Air entered the values 1.65 (m) and 2.06 (m) under 'Centre of gravity range when empty according to the equipment data sheet'. No value was entered for the empty mass (4).

The values stated apply for the aircraft's centre of gravity range when laden.

In the operating instructions for the Ju 52/3m g4e, in the loading plans, the centre of gravity range was defined as follows:

"*Maximum permissible forward:* *1,650 mm*

Maximum permissible aft: *2,060 mm*"



Leermasse (Gemäss Definition des Luftfahrzeug-Flughandbuchs)
Masse à vide (Selon définition du Manuel de Vol de l'aéronef)

			Masse	Arm/Bras	Moment
Übertrag Blatt 1: / Report feuille 1:			6845	180,7	1237400
Öl / Huile	SG:		voll	–	–
Nicht verwendbarer Treibstoff / Essence non-consommable	SG:		leer	–	–
Nicht verwendbarer Treibstoff / Essence non-consommable	SG:		leer	–	–
Abzüge gemäss Tabelle I / A retrancher selon tabelle I					
Zuschläge gemäss Tabelle II / A ajouter selon tabelle II					
Leermasse / Masse à vide			6845	180,7	1237400

③

Resultat zu übertragen in AFM Deckblatt B
Résultat à reporter à la page de garde B AFM

Schwerpunktlage leer / Centrage à vide (falls vorgeschrieben / si prescrit) ④

Leermasse-Schwerpunktbereich gemäss Gerätekennblatt / Domaine de centrage à vide selon fiche de navigabilité: bei / à – kg/lbs, von / de 1.65 m/in, bis / à 2.06 m/in

Anmerkung: Der Schwerpunktbereich leer muss eingehalten werden, andernfalls ist das Luftfahrzeug durch Zugabe oder Entfernen von Ballast auszutrimmen.
Note: Le domaine de centrage à vide doit être respecté, sinon l'aéronef doit être équilibré en ajoutant ou retranchant du lest.

Figure 39: Extract from the weight sheet, page 2. Source: Technical records HB-HOT.

A1.6.15 Borescope inspection of the wing spars

On 9 January 2006, the inside of spars I and II of the two outer wings was inspected using a borescope[50]. According to the work report, neither cracks nor corrosion were detected and the condition of the spar tubes was judged to be visually faultless. Subsequently, spars I to IV were treated with the corrosion inhibitor ACF 50. According to the files, the centre wing's spars were not inspected. No other information was recorded in the files.

In 2015, a fracture was discovered on lower spar II from the centre wing of the Ju 52/3m operated by Deutsche Lufthansa Berlin-Stiftung (DLBS). On the basis of this information, an inspection of the wing spars was carried out on HB-HOT on 24 February 2017 shortly before reaching 10,000 operating hours. During this inspection, the outer wings remained mounted on the fuselage. For this work, a drainage maintenance company was commissioned to carry out an inspection of the eight spar tubes over the aircraft's entire wingspan, together with Ju-Air's responsible aircraft mechanic. However, neither the person from the drainage maintenance company nor the aircraft mechanic had the necessary experience and level of expertise in performing borescope inspections and damage assessments on aircraft. The inspection of the spar tubes began at the left- and right-hand wingtips respectively. Due to the length of the borescope, the spars in one outer

[50] A borescope is an optical device used to illuminate and inspect the inside of a structure that cannot otherwise be seen.

wing, the centre wing and up to approximately one metre of the opposite outer wing could be seen.

This inspection ultimately revealed a crack in lower spar I of the centre wing (see section A1.6.16.2.3).

When reviewing these recordings, the STSB detected large quantities of drilled-out rivets, swarf and rivets that had fallen out by themselves in the spar tubes (see figures 40 to 42). Dirt deposits and flaking anti-corrosion paint were present in places. In some places, small quantities of the ACF 50 corrosion inhibitor applied during the borescope inspection on 9 January 2006 were still visible in the tubing (see figure 40). The condition of the tubing under this layer could not be assessed. The borescope's camera lens was moved at relatively high speed through the spar tubes during the inspection on 24 February 2017. This led to insufficient image and video quality, meaning that it was not possible to assess the condition of the spar tubes more precisely.

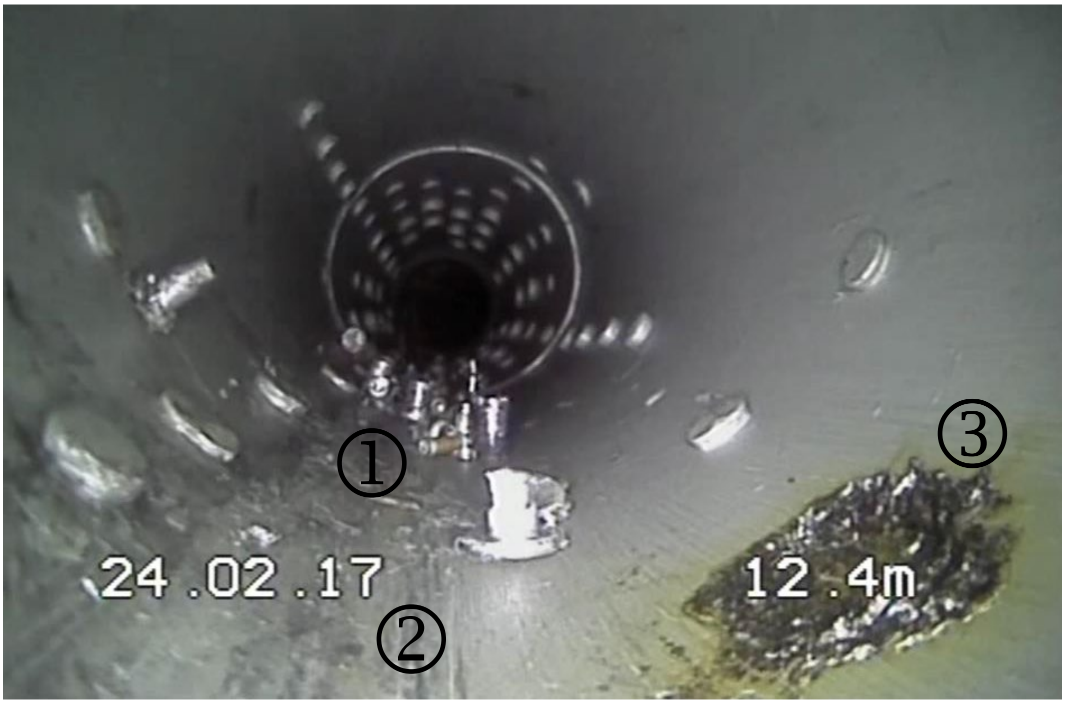


Figure 40: Left-hand outer wing, lower spar I – various rivets lying around (1), partly flaked off anti-corrosion paint (2) and dried ACF 50 corrosion inhibitor (3). Photograph provided by Ju-Air.

Figure 41: Left-hand outer wing, lower spar II – large quantity of rivets. Photograph provided by Ju-Air.

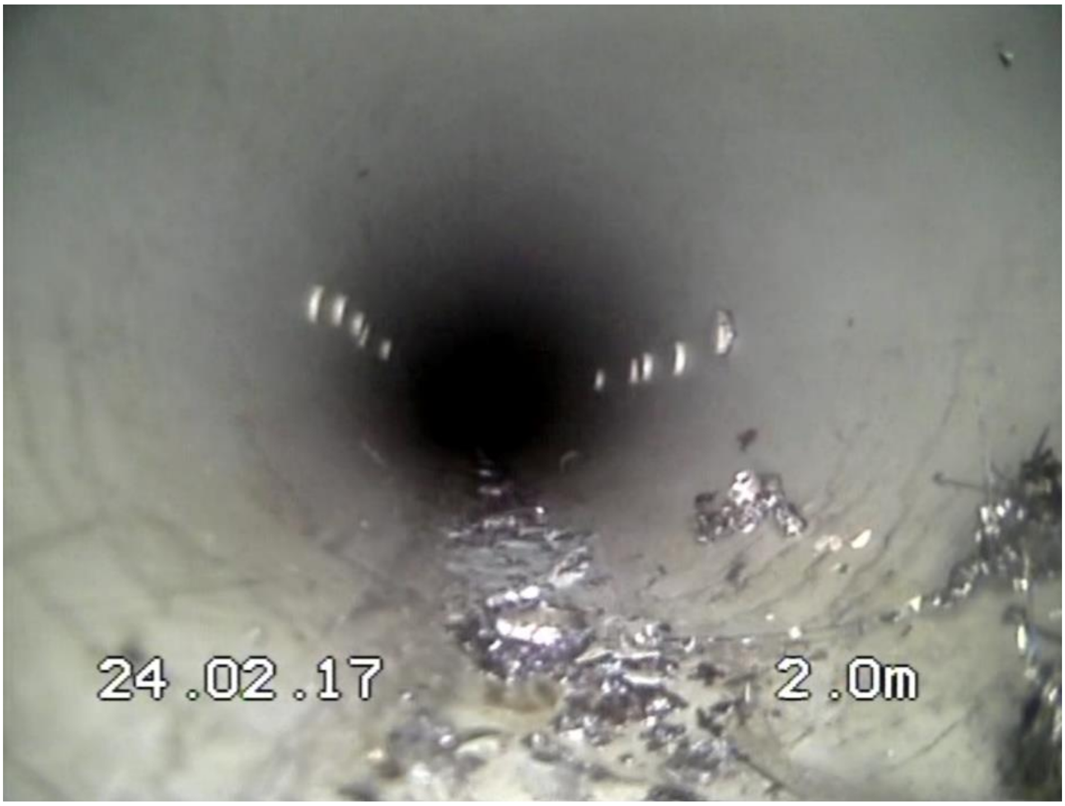


Figure 42: Right-hand outer wing, lower spar IV with swarf. Photograph provided by Ju-Air.

On 18 October 2017, another borescope inspection was carried out by Ju-Air. The following summary was written on the work report:

"*The spar tubes exhibit no signs of cracks, corrosion or other damage. However, some faulty rivets as well as several drilled-out rivets can be seen. In addition, the condition of the paint in some spar tubes is poor.*"

The review of these recordings by the STSB revealed that the situation in the spars on 18 October 2017 was the same as had been detected during the borescope inspection on 24 February 2017 (see figure 43). This shows that these deficiencies had not been remedied in the meantime.

Figure 43: Left-hand outer wing, lower spar II. Photograph provided by Ju-Air.

In the area where the spar had been repaired in May 2017, there were many loose rivets and large quantities of swarf in the spar tube (see figure 44). This is further indication of the poor quality of the repair work.

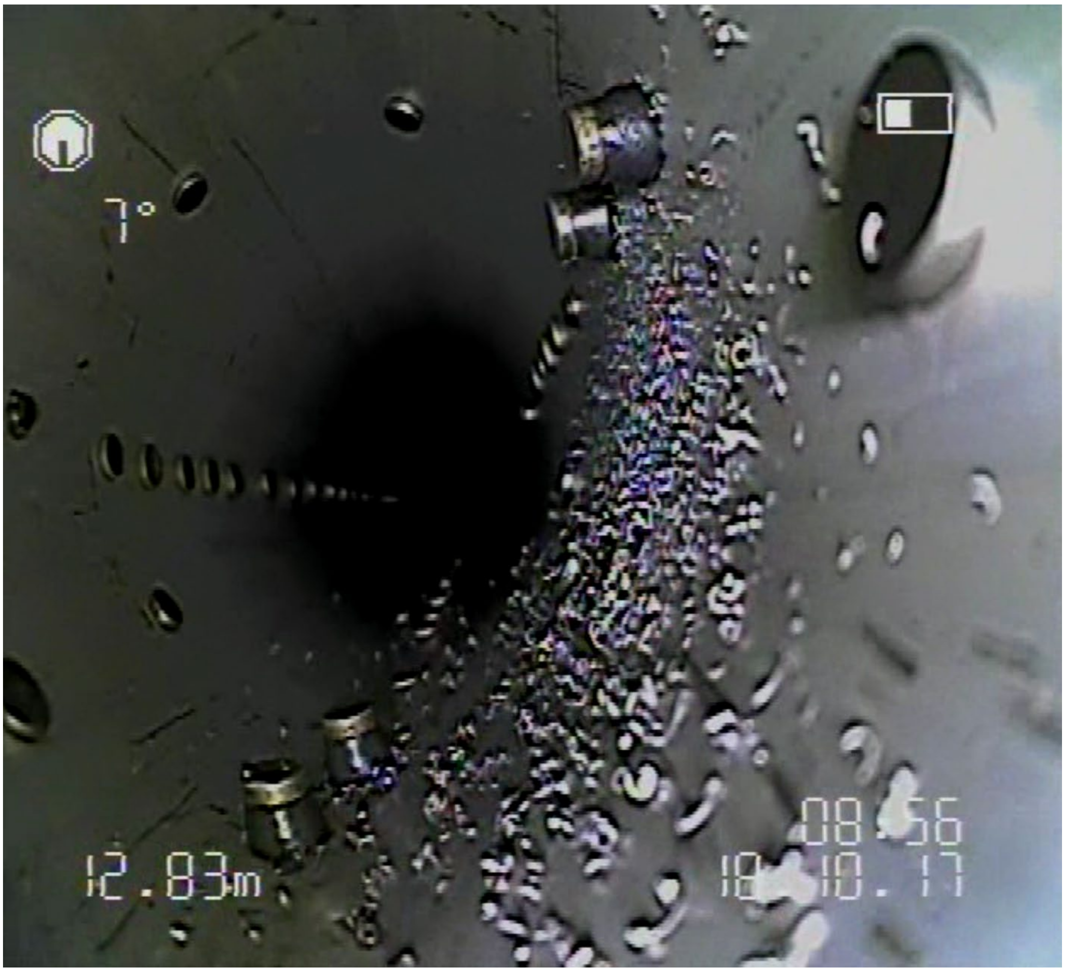


Figure 44: Centre wing, lower spar I, after repair. Photograph provided by Ju-Air.

The pre-existing crack in the spar (see annexes A1.12 and A1.16) identified as part of this safety investigation was not detected during the borescope inspections. This shows that borescope inspection on its own was an inappropriate and unreliable method in this particular case.

A1.6.16 Repairs and modifications

A1.6.16.1 Legal basis

Maintenance on Ju-Air's Ju 52 aircraft was required to be performed according to annex II (part 145) including annex I (part M) of European Regulation 2042/2003 (see section A1.6.5.3). However, according to FOCA, repairs and modifications were subject to the national DETEC Ordinance on the Airworthiness of Aircraft (VLL). Based on this ordinance, FOCA published Technical Communication TM 02.020-60, which specifies modifications to aircraft and aircraft parts in greater detail.

The VLL contains the following information regarding repairs and modifications:

"Art. 42 Obligation to obtain a permit

1 *Modifications to aircraft as well as to engines, propellers, aircraft parts and equipment must be approved by FOCA.*

2 *Relevant documents must be submitted to FOCA before any modification work may commence.*

3 Repairs that are not carried out within the scope of ordinary maintenance and require development work shall be considered modifications."

"Art. 44 Permit and approval of modifications

1 FOCA differentiates between major and minor aircraft-type modifications.

2 What type documents are required to be submitted is determined on a case-by-case basis.

3 In the event of major aircraft-type modification, FOCA shall confirm that airworthiness requirements are met by issuing:

a. An extended type certificate, provided the applicant is the type-certificate holder;

b. A supplemental type certificate, provided the applicant is not the type-certificate holder.

4 Minor modifications are approved by FOCA if the airworthiness requirements are met.

5 FOCA may accept extended or supplemental type certificates issued or minor modifications approved by a foreign aviation authority.

6 FOCA shall issue guidelines in the form of Technical Communications (art. 50) on the following:

a. Distinction between major and minor modifications;

b. Relevant procedures;

c. Type documentation required."

The Ju-Air and Naef Flugmotoren AG maintenance organisation expositions (MOEs) contain the following provisions regarding repair work:

"*2.9 Procedure for repair work*

[…]

The operations manager is responsible for ensuring that all repair work is carried out as per the applicable procedures stipulated by the authorities and the requirements laid out by the manufacturers of the aircraft or component concerned. Otherwise, the standard procedures and codes of practice used in aviation apply.

If the organisation is unable to carry out a repair itself, it will award a contract to an organisation approved for this purpose with a clear indication of the applicable regulations.

[…]

If the organisation needs to manufacture spare parts for a repair themselves, these must fully comply with the applicable airworthiness requirements. The manufacture of such parts and their conformity must be fully documented in each individual case. The competent authority must be informed using a 'notice of modification'."

A1.6.16.2 Performed repairs or modifications to the aircraft structure

A1.6.16.2.1 General

Various repairs or modifications to the aircraft structure were carried out on HB-HOT. This work was carried out by various companies, including Ju-Air itself. The period considered as part of this investigation dates from 2000 onwards.

Since 2000, FOCA received the following notices of modification across Ju-Air's entire Ju 52 fleet. These notices were all approved by FOCA.

Registration	Description	Classifi-cation	Activity	Approval by FOCA
All Ju 52 aircraft	Auxiliary fuel tank for ferry flights	Major	Change	05/09/2013
HB-HOP	Avionics upgrade	Minor	Change	28/02/2013
HB-HOT	Avionics upgrade	Minor	Change	08/05/2012
HB-HOT	New transponder	Minor	Change	08/05/2008
HB-HOP	New transponder	Minor	Change	04/04/2008

Table 15: List of notices of modification approved by FOCA.

For the avionics upgrades, the notices of modification were processed by the appropriate avionics company.

However, according to the files, various repairs and modifications were carried out during the same period which had not previously been approved by FOCA. The majority of the work carried out was noted in the form of a handwritten note on what is known as the 'complaint sheet'. Working processes and specifications of the material used were not listed. Tracing the repair and modification work performed proved difficult, and in parts even impossible. For some of the deficiencies that resulted in repair or modification work, no OCRs[51] were produced.

The following table lists repair and modification work carried out that had not been reported to FOCA as regards to their execution or process and consequently had not been approved by FOCA.

Date	Description	Work report
24/05/2018	Repair on the engine frame (centre)	Yes
23/10/2017	Repair on the airframe and the LHS aileron	No
24/08/2017	Repair on the RHS aileron	Yes
17/05/2017	Repair on spar I	Yes
10/05/2017	Repair on the engine frame (left, centre)	Yes
07/12/2015	Repair on the engine frame (left)	No
26/10/2009	Repair on the LHS aileron	No
13/06/2005	Repair on the tip of the left-hand outer wing	No
06/02/2004	Overhaul of the engine frame (left)	No

[51] OCR: Occurrence report, an incident report to be sent to FOCA or EASA.

11/03/2003	Repair on the elevators and ailerons	No
11/03/2003	Misc. work on the adjustment spindle	No
04/11/2002	Fitting a lubrication groove on the right-hand shock-absorbing strut	No
06/03/2002	Misc. substantial metal work on the cabin	No
27/02/2001	Repair on the tip of the left-hand outer wing	No

Table 16: List of repairs and modifications not reported to and consequently not approved by FOCA.

Due to incomplete record keeping, it must be assumed that this list is not exhaustive.

Since 2017, any more substantial metal work has been carried out by Kaelin Aero Technologies GmbH. There are work reports for the respective work.

The following sections provide illustrated descriptions for a few examples of the repairs and modifications that were carried out and for which no FOCA approval was available.

A1.6.16.2.2 Engine frame

During a progressive inspection of HB-HOT's centre engine at the end of May 2018, approximately two months before the accident, a crack was detected on the engine frame in the lower-right mounting frame attachment (gusset plates) (see figure 45). To allow the repair to be carried out with the engine frame in place, the corner tube between the engine mount and the firewall was cut through (see figure 46). The cracked gusset plate was replaced by a remanufactured part, welded aluminium sheets with subsequent heat treatment (see figure 47). The severed corner tube was reattached using a doubler consisting of two manufactured U-shaped wraps. Corrosion protection was not applied (see figure 48). The repair was carried out by Kaelin Aero Technologies GmbH. According to the work report, the repair was carried out based on the "*Reparaturanweisung Ju 52/3m*" (Ju 52/3m repair instructions)'.

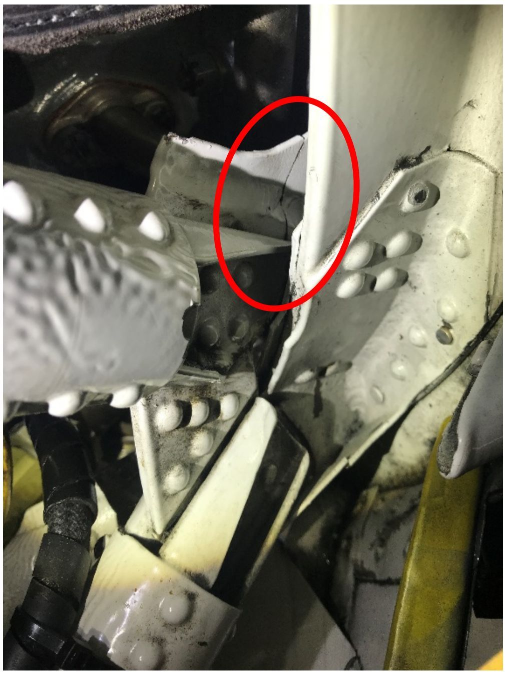


Figure 45: Crack in the mounting frame gusset plate (red circle). Photograph provided by Ju-Air.

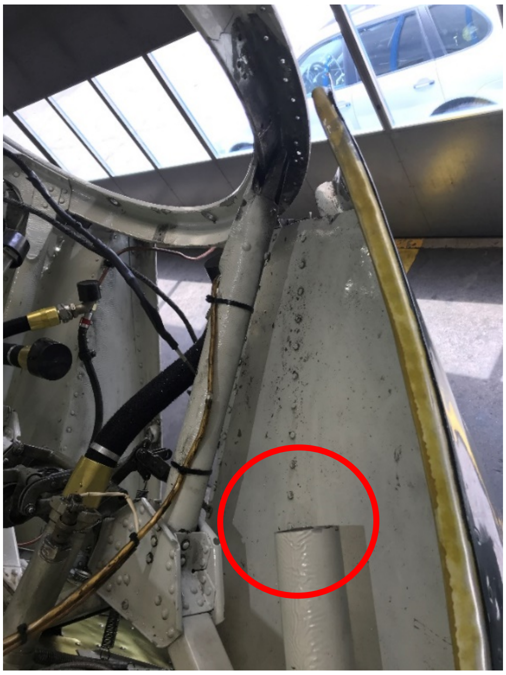


Figure 46: Cut strut tubing (red circle). Photograph provided by Ju-Air.

Figure 47: Remanufactured and assembled plate. Photograph provided by Ju-Air.

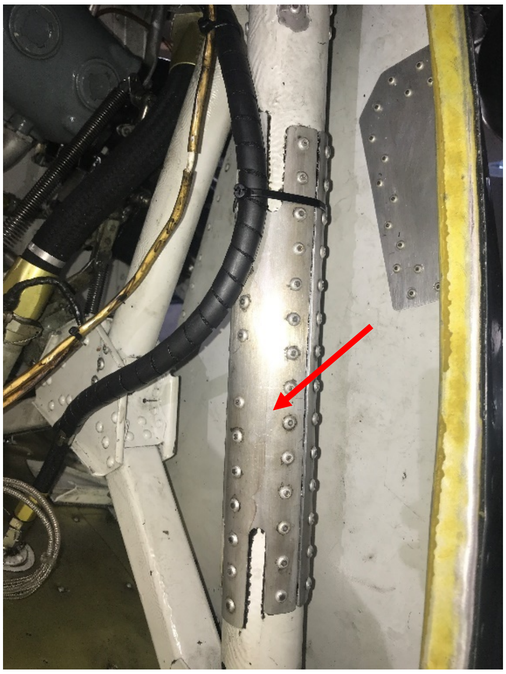


Figure 48: Tubular strut repaired with a doubler. Photograph provided by Ju-Air.

A1.6.16.2.3 Wing spar

In 2015, a fracture was discovered on lower spar II from the centre wing of the Ju 52/3m operated by Deutsche Lufthansa Berlin-Stiftung (DLBS). The extensive repair work was carried out by Lufthansa Technik in cooperation with the German company Kaelin Aero Technologies GmbH. The necessary processes and supporting documents were prepared by Lufthansa's own design organisation using an engineering bulletin to this effect. As there had been a constant exchange of information between Ju-Air and the DLBS for many years, Ju-Air was also informed about the crack detected in the spar.

During a progressive inspection on HB-HOT in February 2017 at 9,858:04 operating hours, the inside of the tubing for each spar was inspected for the first time using a borescope supplied by a drainage maintenance company (see section A1.6.15). A crack was found in lower spar I of the centre wing, immediately next to the left-hand joint and threaded piece to which the left-hand outer wing is attached (see figures 49 and 50). The crack originated from a borehole. The crack had an approximate length of half the circumference of the spar tube.

Figure 49: Interior view – crack in lower spar I of the centre wing, immediately next to the left-hand joint and threaded piece (borescope image). Photograph provided by Ju-Air.

Figure 50: Exterior view – crack in lower spar I of the centre wing. Photograph provided by Ju-Air.

This finding was reported by Ju-Air to FOCA using the intended form. Under ‘Analysis and follow-up’ the following was noted by Ju-Air with respect to this:

“*The crack was discovered during scheduled comprehensive maintenance. The maintenance programme has therefore proven to be effective. As FOCA has been conducting investigations into the service life of the Ju 52 for some time, the events are being discussed in this context. Apart from the replacement of the spar tube and other regular inspections, no further measures are necessary.*”

In Ju-Air’s ‘Hazard and occurrence report’, the possibility of the present problem recurring was assessed as very unlikely (see figure 51).

Your personal opinion:

Probabilty:	can it happen again?	*extremely improbable*	1☐	2☒	3☐	4☐	5☐	*may / has occurr(ed) frequently*
Severity:	or potential consequences?	no damage, injury or adverse consequences	1☐	2☒	3☐	4☐	5☐	**live threatening**

Figure 51: Extract from Ju-Air’s hazard and occurrence report.

Ultimately this major repair work was carried out by Ju-Air together with the metal worker from Kaelin Aircraftstructure GmbH. No FOCA approval was available for the repair of HB-HOT (see section A1.6.16.1).

Ju-Air was able to use the existing devices (jigs) and repair documents from the DLBS used in the earlier repair of the German Ju 52/3m. However, the jigs had to be modified for use in the repair work on HB-HOT, as the repair was not the same. In Ju-Air's work report, the following was written with regard to this:

"*For the spar repair, we're benefiting from engineering work performed by the DLBS, which had a similar repair on middle spar II*. *This repair was also performed by Kaelin Technologies.*

Elements from the DLH type certification report and the Lufthansa Technik design organisation's engineering bulletin 'Simplified aircraft repair' [...] were consulted for the repair [...].

Adaptation of the centre box jigs provided by the DLBS (Deutsche Lufthansa Berlin-Stiftung) to suit the centre box of HB-HOT."

According to the work report from Kaelin Aircraftstructure GmbH, the repair work on HB-HOT took place between 27 February and 3 May 2017. The individual tasks were all initialled to have been carried out on 7 September 2017. The entire order was also certified with this date.

At the end of the work report, the following was written:

"*All of the above-mentioned works have been completed according to SRM*[52] *instructions and drawings and were checked by*". No such SRM existed for the Ju 52/3m g4e at the time. The repair instructions of the aircraft manufacturer for type Ju 52/3m aeroplanes did not support this repair.

In the technical files for HB-HOT, the repair and maintenance work was certified by Ju-Air on 10 May 2017 and the aircraft was released to service. Due to incomplete record keeping, tracing this repair was difficult, and in parts even impossible. The following task was listed in the work report: "*Provisionally install new connection pieces LH + RH (manufactured according to DLBS drawing)*". No files were available with respect to this.

A1.6.16.2.4 Horizontal stabiliser

Between 4 November 2002 and 11 March 2003, a variety of repair and maintenance work was carried out on HB-HOT. Among other things, corrosion was found on the joints and the bearing bracket for the horizontal stabiliser's adjustment spindle. Thereupon the horizontal stabiliser and elevator were removed from the aircraft (see figure 52).

[52] SRM: Structural repair manual

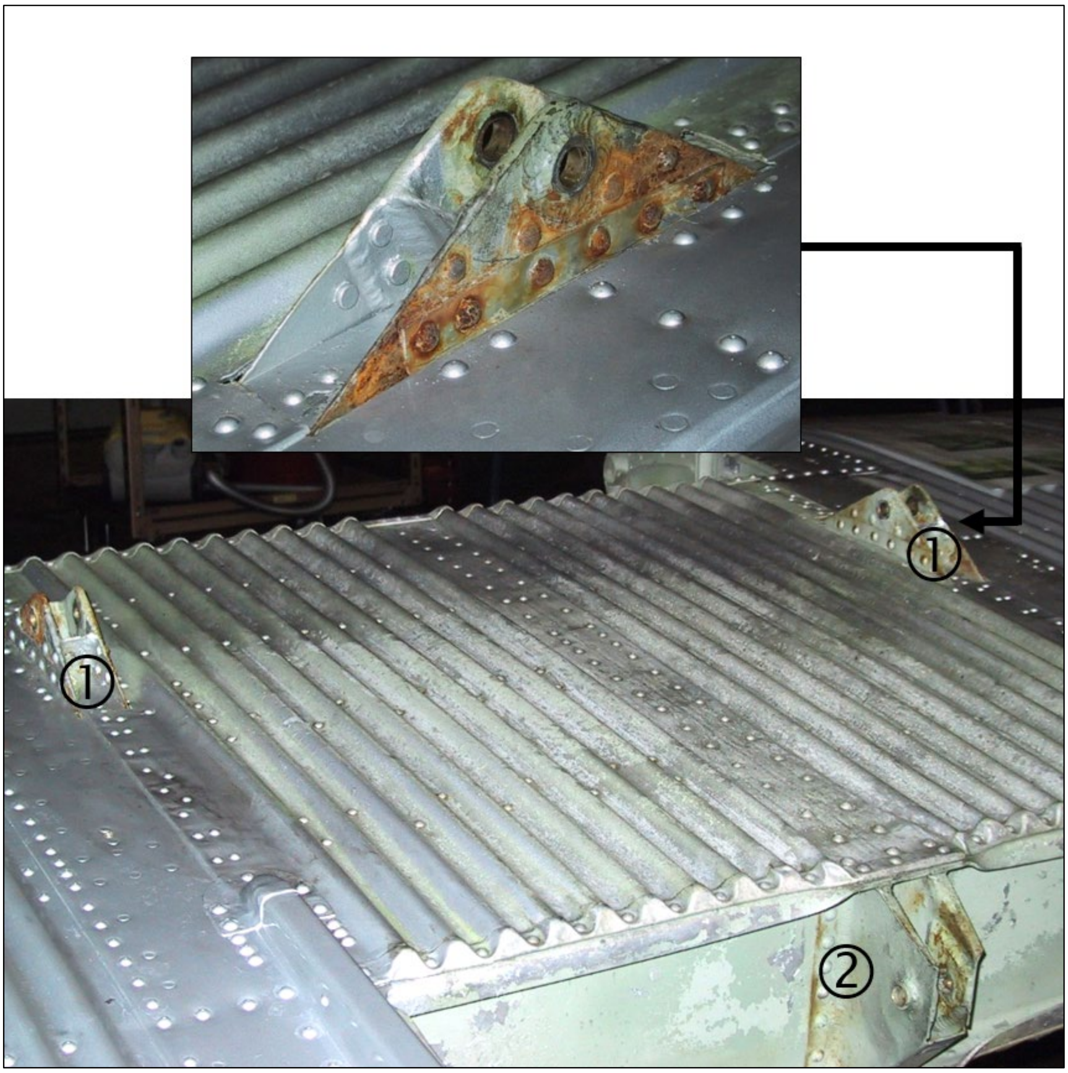


Figure 52: Horizontal stabiliser with severely corroded joints (1), bearing bracket (2) and panelling. Photograph provided by Ju-Air.

The panelling on the top of the horizontal stabiliser was then removed to expose the fittings. Afterwards the joints and the bearing bracket were removed by drilling out the rivets (see figure 53).

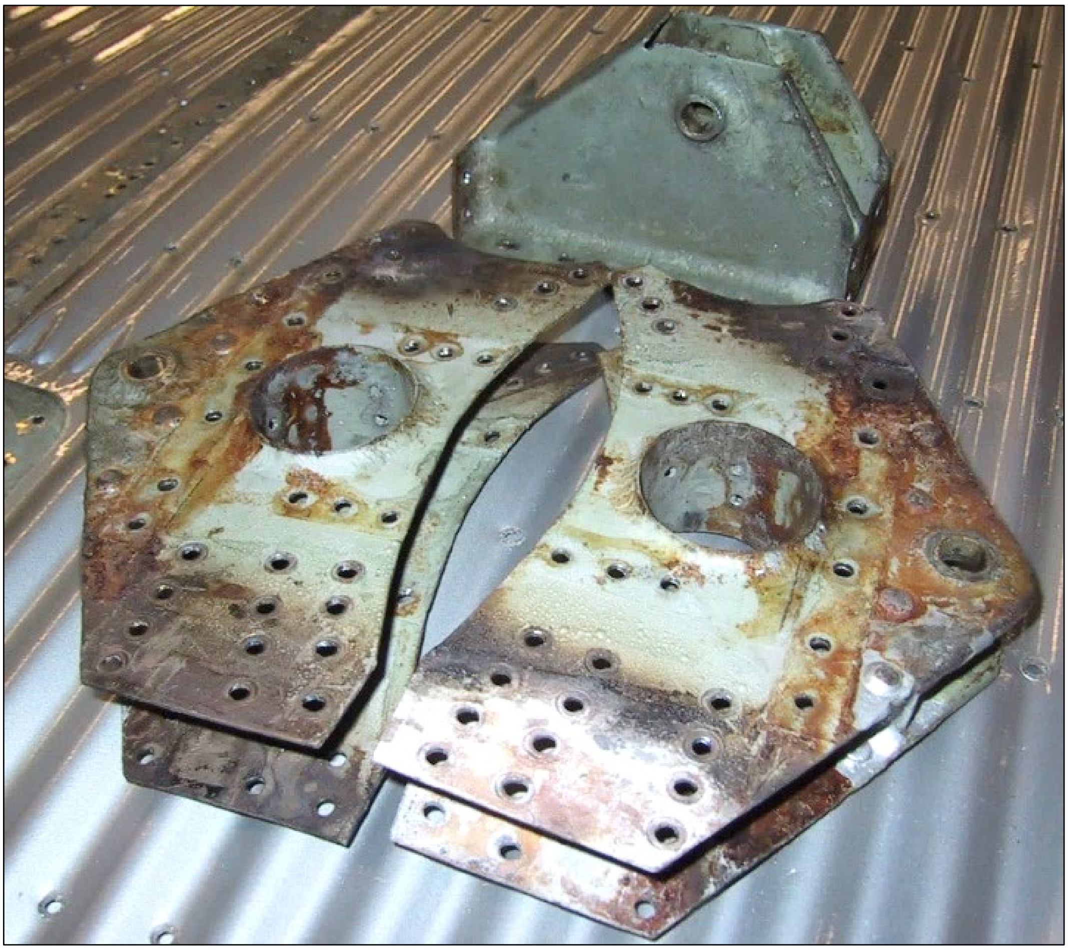


Figure 53: Removed, severely corroded components from the horizontal stabiliser. Photograph provided by Ju-Air.

According to the files, the joints and the bearing bracket were cleaned, inspected and the surface treated (cadmium-plated). As the spar tubing also exhibited corrosion in the area of the two joints, it was replaced with a new section of tubing. Afterwards the horizontal stabiliser's components were riveted back together again. As can be seen in figure 54, there were other severely corroded components in the area where the repairs were conducted which had not been treated or replaced.

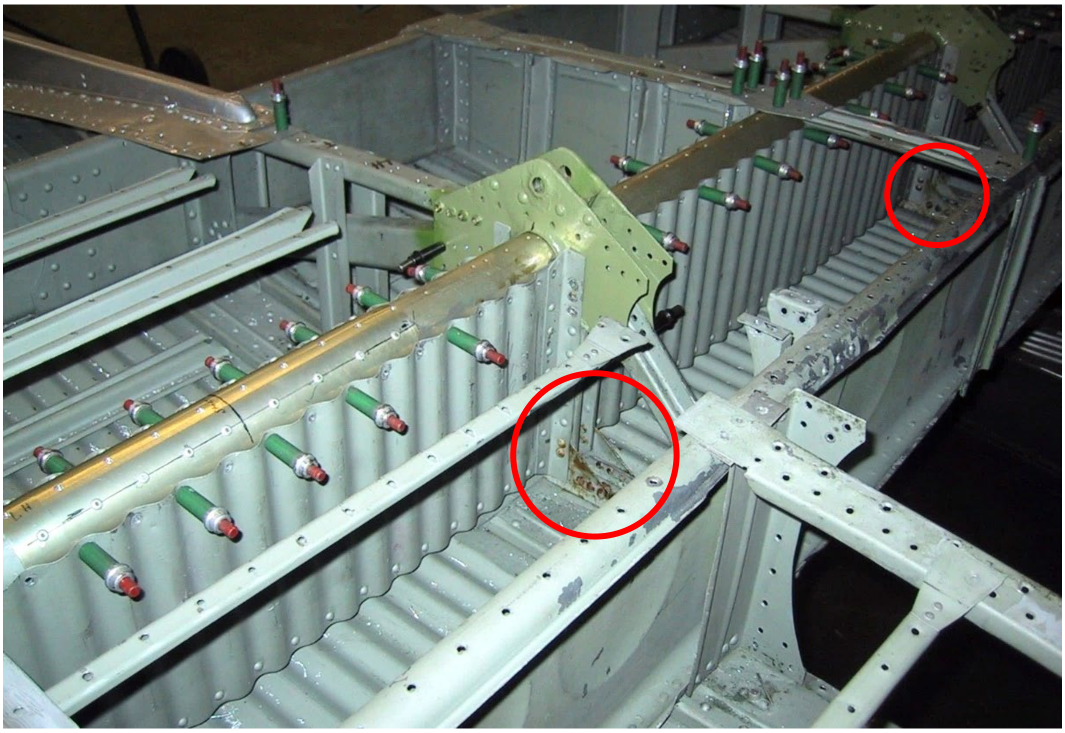


Figure 54: Reworked components in the horizontal stabiliser with new spar tubing. Circled in red are other severely corroded components that have not been treated or replaced. Photograph provided by Ju-Air.

This repair was carried out using a hand-drawn sketch only (see figure 55) and no work report could be found in the technical files, only a complaint sheet with minimal description of the work carried out (see figure 56).

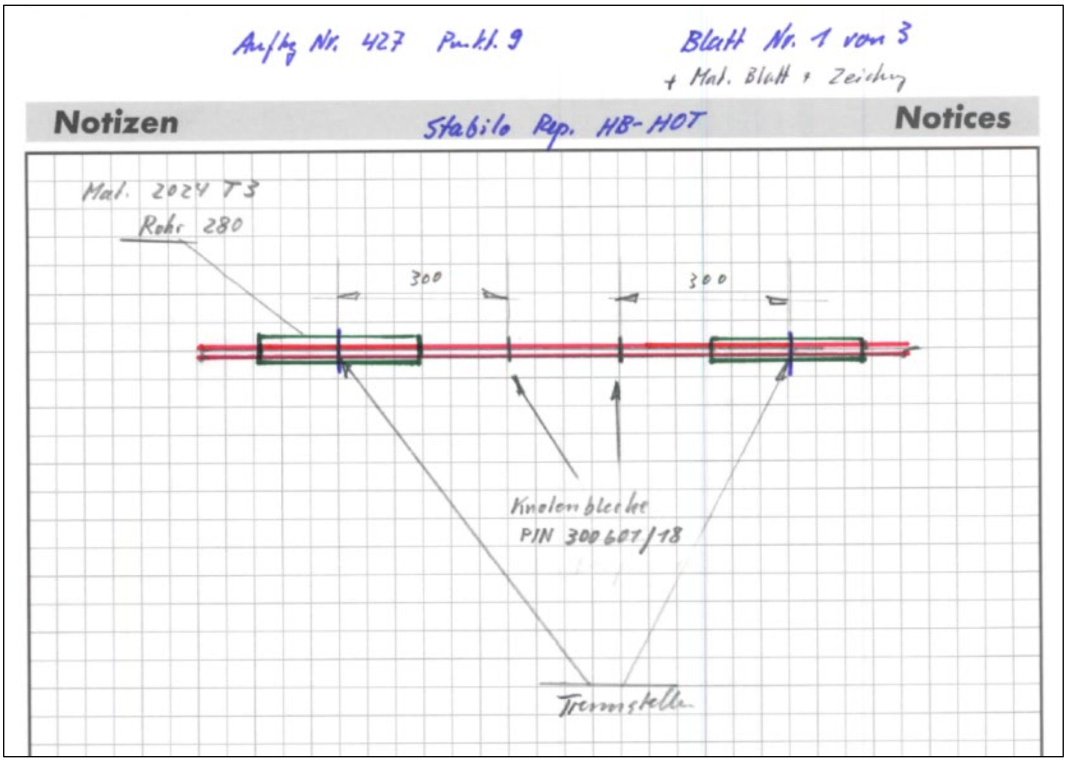


Figure 55: Repair work based on this hand-drawn sketch. Source: Technical records HB-HOT.

5.1.5 Auftragsformular JU-AIR, Interner Gebrauch

BEANSTANDUNGSBLATT Nr.: 3

Flugzeug: HOT Datum: 4.11.02 Auftrg. ~~oder LOG~~ Nr.: 424
Zellen Std.: 6957:33

Betrifft: Kontrolle, Reparatur, Unterhalt, Änderung			
Pt.	**Beanstandung und Behebung**	**Mech**	**T.K.**
9.	An Höhenstabilo Knotenstück am Unterholm (Lagerung) LH + RH stark rostig		
	- Seiten Steuer demontieren.		
	- Seiten steuer montieren		
	- Höhensteuer LH demont.		
	- Höhensteuer LH montieren		
	- Höhensteuer RH demont.		
	- Höhensteuer RH montieren		
	- Seitenstabilo demont.		
	- Seitenstabilo mont.		
	- Höhenstabilo Streben LH + RH demont.		
	- Höhenstabilo demont.		
	- Höhenstabilo montier		
	- Streben LH + RH montieren		
	- Elektr. Anlage siehe Pt. 8		
	- Alle Lager abschmieren		
	- Einstellungen nach BAW + Kontr. Blatt Intervall Nr. 6		
	- Am Höhenstabi die Lagerpunkte Knotenbleche LH + RH P/N 3006.01 / 78 ausbauen, reinigen, cadmieren, Kontr. und Grundieren		
	- Knotenbleche einbauen + vernieten nach Junkers Ausbesserungsanleitung (Spengler)		

Alle Arbeiten vor dem Einschalen der Kontrolle melden.
Komponentenwechsel notieren.

Figure 56: Complaint sheet with minimal description of the work carried out. Names of persons and initials removed by the STSB. Source: Technical records HB-HOT.

There were no basic conceptual explanations documenting the professional execution of the repair, and the required approval for the work had not been obtained from FOCA. There was also no adequate description of the findings nor an analysis of the damage that led to the repair. The actual repair of the corroded part could not be reproduced using the documents available. Nor is it apparent which methods were used to carry out the repair. Furthermore, the setting for the horizontal stabiliser after this repair could not be determined due to missing documentation.

A1.6.16.3 Performed repairs or modifications to the engines and propellers

A1.6.16.3.1 General

Since Ju-Air took over the three Ju 52/3m g4e aircraft from the Swiss air defence corps, the engines have had to be continuously repaired and modified. This work was carried out by Naef Flugmotoren AG and commissioned subcontractors. Some of the repairs and modifications were carried out on the basis of a service bulletin (SB) provided by Ju-Air (see section A1.6.17.2). No SBs existed for other repairs and modifications, nor were any notices of modification submitted to FOCA. Consequently, this work had not been approved by FOCA.

The following sections describe some examples of repairs and modifications to the respective engines.

A1.6.16.3.2 Left engine

HB-HOT's left engine last underwent a complete overhaul on 12 October 2010, performed by Naef Flugmotoren AG. After 180 operating hours, a cylinder had to be repaired for the first time. In the time between the major overhaul and the accident, the engine recorded 946 operating hours. During this time, a total of 13 cylinders had to be dismantled and repaired.

Cylinder nos. 1 and 9, which were sourced from an aircraft that had crashed on a glacier, were installed on 24 September 2015 (see section A1.6.17.4). On 28 January 2016, after 13 operating hours, Naef Flugmotoren AG subsequently issued a release certificate for each of these two cylinders. Cylinder no. 1 was repaired on 18 January 2017 at 108 operating hours, and on 30 July 2018 at 214 operating hours, a leak in the tappet tube was repaired. Neither of these pieces of repair were entered on the component card.

Before the 2018 Locarno adventure tour, three cylinders were repaired during the last progressive inspection on 31 July 2018.

A1.6.16.3.3 Centre engine

The centre engine last underwent a complete overhaul on 17 April 2013. At the time of the accident, the engine had recorded 1,153 operating hours. In addition to eight cylinders and the oil pump, the cam disc had to be replaced after 821 operating hours. The engine frame had to be repaired twice too.

The operating hours for cylinder no. 2 could not be traced because the entries were missing from the component card. Entries regarding a repair on 5 February 2016 could also not be found. As the cylinder had been used on various engines during its service life and these changes had not always been documented, it was not possible for the maintenance team to monitor the operating hours using their record keeping system.

In the time between this engine recording 556 and 1,079 operating hours, a total of eight cylinders had to be removed and repaired.

At 1,060 operating hours, the oil pump had to be replaced. The installed replacement had been in stock since the engine's last major overhaul (6 years).

A1.6.16.3.4 Right engine

Cylinder nos. 1 and 9 installed in the right engine were sourced from an aircraft that had crashed on a glacier (see section A1.6.17.4).

The right engine last underwent a complete overhaul on 1 June 2016. At the time of the accident, this engine had recorded 457 operating hours. 105 operating hours after the engine's major overhaul, the cam disc was found to be defective and was replaced.

During the 457 operating hours, four cylinders had to be repaired. Cylinder no. 2 was repaired at 299 and 416 operating hours (41 operating hours before the accident). Cylinder nos. 4 and 5 were also repaired after 416 operating hours, i.e. 41 operating hours before the accident.

A1.6.16.3.5 Propeller

According to the technical files, between February 2008 and September 2018, there were 23 occasions of a propeller undergoing a major overhaul at a company in Germany.

Following complaints about strong vibrations or insufficient performance being observed during flight operations, eight of these major overhauls were requested because the maximum permissible rotation was exceeded when retightening the propeller blade nut or because of loose propeller blades. In some cases, this was only a few operating hours after a general overhaul. FOCA was never informed about this recurrent problem (see annex A1.17).

This problem of loose propeller blades had not been solved by the time of the accident.

Among other things, Ju-Air repeatedly commissioned a company not certified to provide parts for use in aviation to repair conical rings and hub threads that had been damaged by corrosion. According to the description of the work processes, the following work was carried out:

- Removal of the damaged surfaces, layer thickness approx. 0.3 mm;
- Nickel-plating, layer thickness 0.3 to 0.5 mm; this work was carried out by a company certified to provide parts for use in aviation;
- Machining of the conical ring and thread to correspond to the original dimensions.

No records, such as technical drawings or process descriptions, were available for this work.

Afterwards the propellers with the reworked hubs were assembled at a company in Germany. The majority of the propeller blades had been manufactured based on pattern parts; some had been reconditioned (see section A1.6.17.2.6).

The hubs for HB-HOT's left and centre propellers were mechanically reworked in the same way.

The propeller blade's conical root is mounted into the propeller hub's corresponding conical ring; this is a frictional connection. Corrosion, wear or an inaccurate fit of the two conical surfaces can cause the frictional connection to weaken during operation and the propeller blades to become loose. This leads to changes in propeller pitch and vibrations.

On some hubs the serial numbers have been removed and replaced by new numbers (see table 17). This is not permitted for aircraft parts.

Original serial number	Newly applied serial number	Date of change	Remarks
31851	32026	December 1993	Hub for HB-HOT's right propeller
32015	3201	February 2000	Hub for HB-HOT's left propeller
32050	32018	November 1994	–
31865	31861	August 1995	–
32018	31851	January 2000	–

Table 17: Changed serial numbers on propeller hubs.

In summary, this type of repair work on propellers is not permitted.

Based on the poor technical condition of the connection between the propeller blades and the hub, and the resulting risk of a spontaneous change in the pitch of the propeller, it can be concluded that the propellers for Ju-Air's Ju 52 aircraft were no longer airworthy.

A1.6.16.4 Evaluation

During the last few decades, various repairs and modifications have been carried out on Ju-Air Ju 52 aircraft and their engines. For some modifications, service bulletins were drawn up concerning the procurement of spare parts and the reconditioning of components and were approved by FOCA. Furthermore, dozens of repairs and modifications were carried out, largely without approved technical bases and without approval from FOCA. For example, only five notices of modification were submitted to FOCA for approval between 2000 and the time of the accident. Four of these were submitted by an avionics company because of a modification to the avionics. In addition, non-aviation-compliant components were procured and installed. The procedures were defined, among other places, in Ju-Air's maintenance organisation exposition and in a European Regulation, but for the most part they were not applied.

During the examination of the maintenance work, various shortcomings were found, in particular in the documentation for carrying out major changes and in the management of spare parts. Such deficits represent a risk.

A1.6.16.5 Known, but not repaired damage to the aircraft

In December 2015, a broken stringer was found on the right-hand outer wing during maintenance work (see figure 57). The findings were recorded, but no repair was ever carried out.

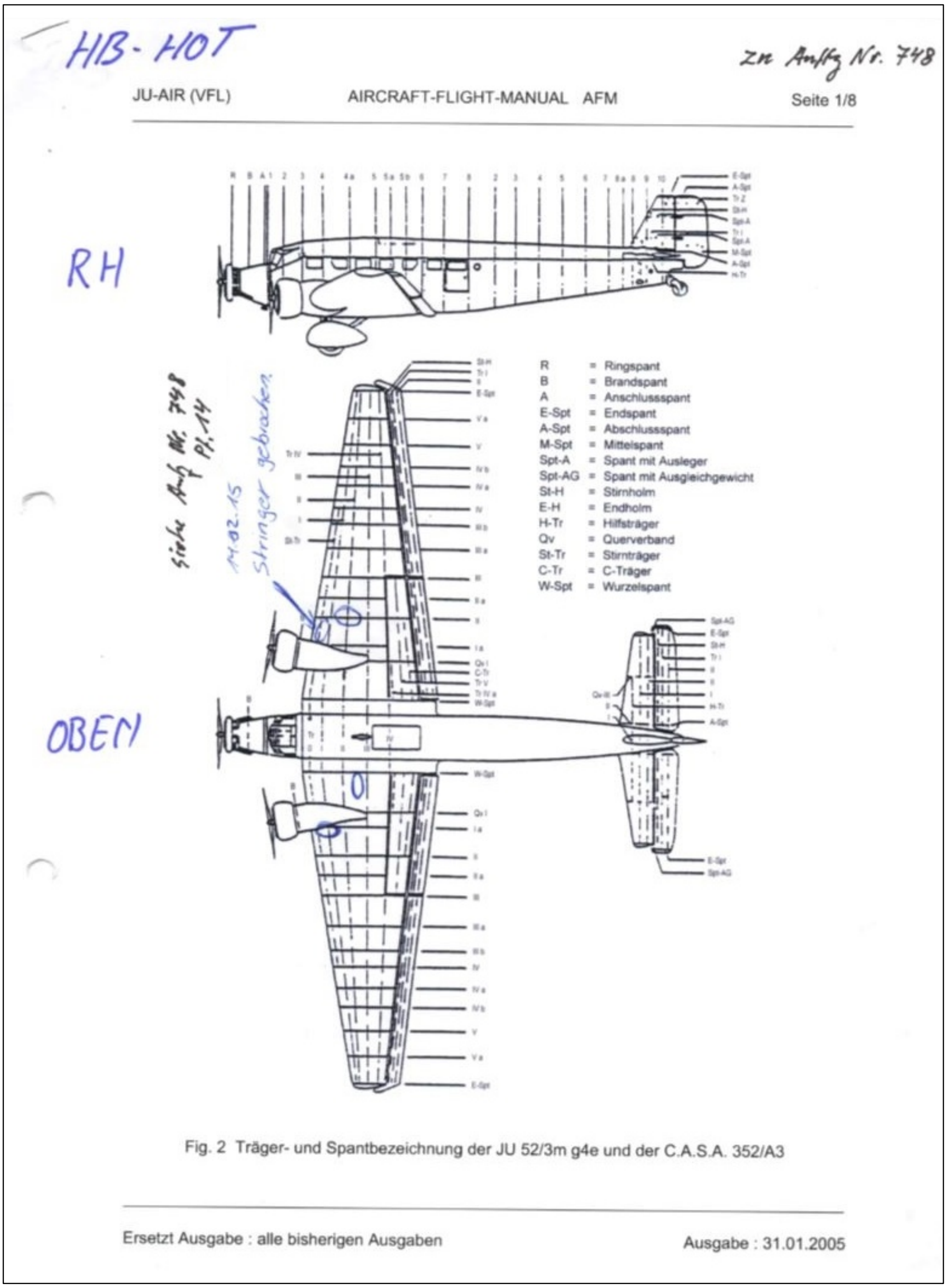


Figure 57: Ju-Air document where the broken stringer is noted. Names of persons and signatures removed by the STSB. Source: Technical records HB-HOT.

The files also contained a photograph from 2003 showing a section of damaged strut tubing (diagonal tube) that was part of an engine frame (see figure 58). Here too, there were no files regarding repair work or necessary clarifications.

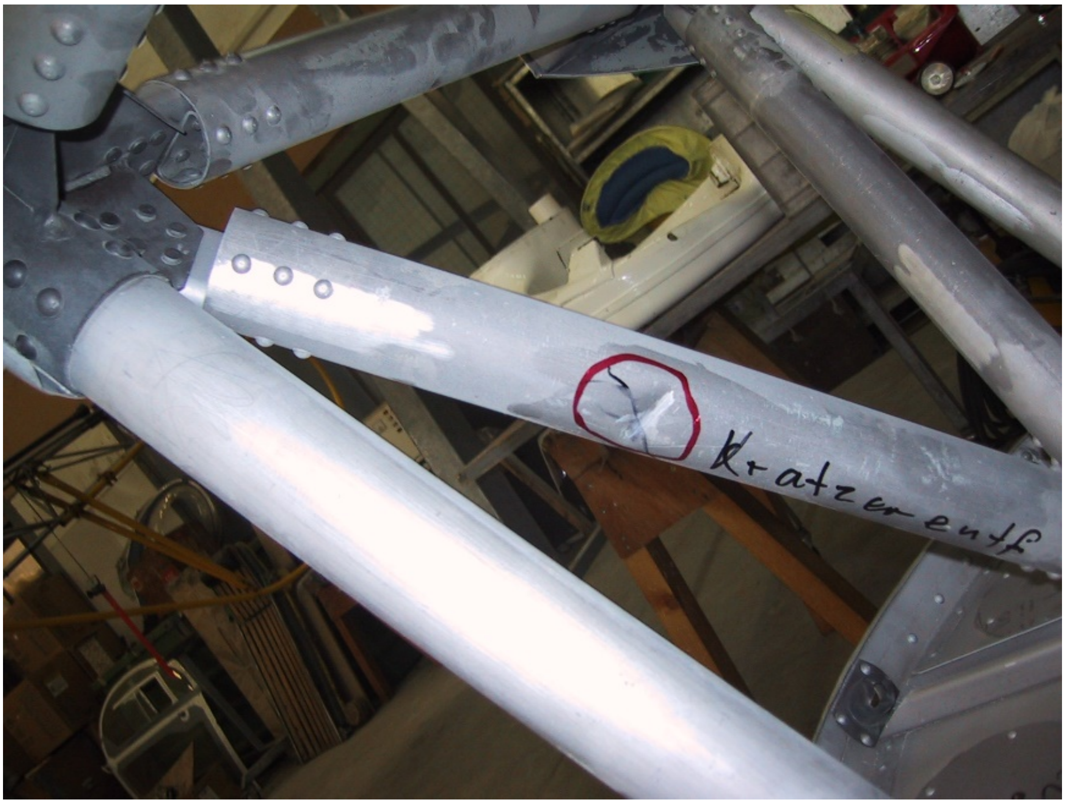


Figure 58: Damaged strut tubing (diagonal tube). Photograph provided by Ju-Air.

A1.6.17 Spare-part procurement

A1.6.17.1 General

As by the end of the Second World War the aircraft manufacturer Junkers had ceased to exist and BMW had ceased operating as an aircraft engine manufacturer, the flight operation and maintenance companies were dependent on the procurement of spare parts from other sources. Parts were remanufactured, reconditioned and non-certified standard components were also installed. Since the 1980s, service bulletins have been issued by Ju-Air for certain remanufactured components and manufacturing processes, and approved by FOCA. A release certificate was issued by Naef Flugmotoren AG for the remanufactured and reconditioned engine components.

A1.6.17.2 Service bulletins

A1.6.17.2.1 General

A service bulletin (SB) is a document that is published by an aircraft or engine manufacturer and contains changes, improvements or inspections that are recommended to be performed on an aircraft or engine. The decision to implement a service bulletin rests with the aircraft operator.

The aircraft manufacturer Junkers has not existed since the end of the Second World War, neither has BMW operated as an aircraft engine manufacturer since that time. Consequently, original spare parts could no longer be obtained from these two companies.

When Ju-Air took over the three Ju 52 aircraft in the 1980s, the company had to source spare parts for the engines so that it could continue to operate its aircraft.

A1.6.17.2.2 Service bulletins issued by Ju-Air

Ju-Air wrote a service bulletin (SB) for some of the remanufactured components, original parts to be reconditioned and the installation of components not certified for use in aviation. These SBs were subsequently examined and approved by FOCA. The majority of these SBs regarded engine components. Between 1984 and 2001, a total of 41 SBs were drawn up and approved by FOCA (see table 18). During this time, some SBs were replaced by a new version, and some SBs were repealed.

The last newly created SB no. 1047 was approved by FOCA in 2005.

The majority of the service bulletins lacked necessary information or supporting documents such as:

- Certification proof for components or materials with new manufacturer;
- Tool numbers when using special tools;
- Information on the set of drawings for design modifications or adaptations to the aircraft or engine;
- Information on drawings regarding their approval and official release as well as the respective revision status with date.

Most of the individual service bulletins were not accompanied by any technical files or documentation.

During its review of the records, the STSB identified that SB no. 1005 (engine piston), which was produced in 1989, was modified in 2018 and approved by FOCA. This SB was not included in the current version of the SB overview list dated 15 March 2013.

From 2002 onwards, apart for SB no. 1005, the SBs were no longer maintained, meaning that processes and subcontractors were no longer updated and thus no longer approved by FOCA.

The following sections present some service bulletins as examples.

For many other remanufactured components, an SB was not written or submitted to FOCA for approval (see section A1.6.17.3). As a result, these SBs did not undergo the review and approval processes with FOCA.

SB no.	Description	Up-to-date version	Replaced version
1001	Exhaust valves	21/11/1995	15/11/1986
1002	Oversize steel cylinder	Repealed	–
1003	Oversize chrome cylinder	02/05/2001	07/04/1987
1004	Cam rings	Repealed	–
1005	Oversize pistons and piston rings	10/04/2018	25/01/1989
1006	Lubricant indicator	12/01/1984	–
1007	Propeller shaft bearings	05/03/1984	–
1008	Solenoid actuator	13/03/1984	–
1009	Inlet valve guides	21/11/1995	23/11/1988
1010	Galley	10/09/1984	10/07/1984
1011	Exhaust valve guides	21/11/1995	24/11/1988
1012	Cylinder and valve data	Repealed	–
1013	Spark plugs	25/02/1985	–
1014	Starter	26/02/1985	–

1015	Ball bearings for BMW 132 A3 engines	17/08/1992	25/06/1985
1016	Blank	–	–
1017	Blank	–	–
1018	Oil temperature gauge	14/02/1985	–
1019	Oil pressure indicator	10/08/1985	–
1020	EGT indicator	10/08/1985	–
1021	Extension of the NAV system and renovation of the instrument panel	27/09/1985	–
1022	Air brake instruments	10/09/1985	–
1023	Valve seats for BMW 132 A3 engines	01/02/1992	07/11/1988
1024	Intake valves for BMW 132 A3 engines	21/11/1995	26/01/1989
1025	Electronic tachometer	26/02/2002	10/01/1986
1026	Modification to the brake valves	15/03/1986	–
1027	Compressor system for the Ju 52's air brake system	26/01/1987	02/07/1986
1028	Cam disc for BMW 132 A3 engines	29/11/2001	31/08/1995
1029	Fuel pressure gauge	01/09/1986	–
1030	Oil pressure indicator	28/01/1991	01/10/1986
1031	Valve control for BMW 132 A3 engines	20/01/1989	21/04/1988
1032	PA system	15/03/1988	–
1033	On-board power supply monitoring	06/10/1989	–
1034	Blank	–	–
1035	Countershaft for BMW 132 A3 engines	31/08/1995	27/06/1989
1036	Threaded spark-plug bushing for BMW 132 A3 engines	27/01/1996	20/08/1989
1037	Blank	–	–
1038	Propeller bearings for BMW 132 A3 engines	Repealed	–
1039	GPS device	08/05/1991	–
1040	Generator voltage regulator	30/10/1991	–
1041	Starting ignition system	07/07/1992	–
1042	Upper loading hatch	25/10/1996	–
1043	Installation of electric fuel pumps	07/01/1998	22/05/1997
1044	Blank	–	–
1045	Replacement blade for Ju-PAK propellers	28/06/2000	–
1046	Replacement of the emergency location transmitter	10/11/1999	–
1047	Engine drain system	20/01/2005	–

Table 18: Service bulletin overview list, version dated 15 March 2013 valid at the time of the accident. The SB marked in yellow was not included in Ju-Air's list.

A1.6.17.2.3 Oversize chrome cylinder – SB no. 1003

The diameter of the bore when new is 155.56 to 155.60 mm, the wear limit is 155.80 to 155.90 mm. According to the 1939 operating instructions written by the manufacturer of the BMW 132 A3 aircraft engine, a cylinder must be replaced with a new component when the wear limit is reached. The manufacturer also states that it is not permitted to re-bore the cylinder.

As in 1984 most of the cylinders in the BMW 132 A3 aircraft engines had started to reach their wear limit, Ju-Air was looking for a solution. A company specialising in engine parts in Germany suggested honing the cylinder bore beyond the limit and then chrome-plating it to the wear measurement specified by BMW (see figure 59). Honing is a fine-machining process and chrome plating is a galvanic process.

In 1984, an initial batch of 15 cylinders were reconditioned at this company using this method. In 1988 and 1989 a further 18 cylinders were reconditioned by the same company. In 1994, this company informed Ju-Air that they were no longer chrome-plating cylinders.

Between 1998 and 2005, Ju-Air then commissioned two companies in the United States of America to chrome-plate another 33 cylinders.

In 2015 and 2017, a company in Switzerland plated a further 20 cylinders for Ju-Air. This company's method of plating cylinders is a process in which the powder is injected into a hot plasma, where it melts and is accelerated before then being applied to the surface to be coated. There was neither a SB for this procedure nor was it approved by FOCA. Naef Flugmotoren AG issued a release certificate for each of the cylinders reconditioned using this method. Cylinders with chrome-plated and plasma-coated bores were installed in HB-HOT's engines.

Figure 59: Example of a chrome-plated cylinder bore. The crack network typical for this method is clearly visible.

A1.6.17.2.4 Cam discs for BMW 132 A2 engines – SB no. 1028

As spare parts for BMW engines were no longer available from 1983, Ju-Air repaired and reconditioned worn cam discs.

1985 was the first time a larger number of cam discs were remanufactured. Various companies manufactured the individual components based on pattern parts, some of these companies were not certified to provide parts for use in aviation.

From 1985 onwards, manufacturing drawings and specifications for production were also created based on existing cam discs. These have been amended on several occasions over time.

A total of 38 cam discs were ordered and delivered between 1996 and 2013. The cam discs were manufactured based on pattern parts and drawings or sketches produced by Ju-Air. Individual parts were manufactured by companies not certified to provide parts for use in aviation.

A1.6.17.2.5 Ball bearings, roller bearings and rollers for BMW 132 A2 engines – SB no. 1015

From 1984 onwards, there were no original roller bearings, ball bearings and rollers for the BMW engine. They were therefore replaced by readily available, standard bearings. In some cases, the design was adapted with a spacer to accommodate the new bearing.

Service bulletin no. 1015, published in 1986, was last revised in 1992 and approved by FOCA. During engine overhauls from 1986 onwards, bearings were installed in accordance with this service bulletin. The supercharger shaft for the BMW 132 A3 engine rotates at up to 20,500 rpm. According to the bearing manufacturer, the maximum permissible speeds for the cylindrical roller bearings and deep-groove ball bearings newly installed on the supercharger shaft were considerably below this. The manufacturer of these bearings did not guarantee their use.

A1.6.17.2.6 Replacement blade for Ju-PAK propellers – SB no. 1045

Because the original propeller blades had to be replaced for operation due to corrosion, wear or damage, and because original propeller blades were no longer available, reproduction propeller blades had to be manufactured.

In order to continue using the original hubs, it was decided to produce new propeller blades that were identical to the originals and to issue a declaration of conformity (report no. E-657). In this, it was stated that the replacement blades were manufactured within defined tolerances of the original dimensions and original material specifications. The manufacturer was of the opinion that no type testing was necessary for the propeller or the aircraft. As no original drawings were available, new construction drawings were created from the average measurements of various used blades. The material composition of the original blades was determined via metallurgical analysis and then a suitable material was determined for the construction of the replacement blades. The data for the vibration tests during the static test and in flight were verified in the E-690 and E-654 reports.

There is no evidence to support a subsequent performance evaluation based on flight tests using the new blades was conducted. Consequently, there is no corresponding pool of data on which to base the data on flight performance in the AFM.

In July 2000, SB no. 1045, which regulates and permits the replacement of the old original propeller blades with a remanufactured part, was approved by FOCA.

In a letter dated October 1999, FOCA informed Ju-Air of the following information concerning a remanufactured propeller blade:

"[…]

- *The above application was reviewed internally by FOCA and approved in principle. The undersigned has been appointed for the detail work and as a point of contact.*

- *We have already stated on the phone that the present case only concerns the production of new metal blades, which are fundamentally the same as the original propellers. Consequently, neither a new type-certificate nor an STC is required, but only proof of conformity for the replacement blades.*
- *The processing can therefore take place in the context of a Ju-Air service bulletin, as has already been done on several occasions for the production of spare parts no longer available. Ju-Air is responsible for the preparation of the SB, naturally in collaboration with MT, and approval is to be granted by FOCA.*"

The propellers were manufactured based on pattern parts by a company in the Czech Republic. A company in Germany was responsible for construction management, supervision and quality control. Not every propeller installed in HB-HOT was issued with a certificate of release to service.

Due to the lack of an equipment data sheet, SB no. 1045 was entered in the certificate of release to service as the basis for approval. This was approved by FOCA.

In 2003, Ju-Air submitted an application to FOCA to increase the operating time for these propellers from 1,000 to 1,200 operating hours. This request was approved by FOCA.

A1.6.17.2.7 Electronic tachometer – SB no. 1025

Service bulletin no. 1025 was first written in 1986. This concerned the replacement of the mechanical tachometers for the two outer engines with electric tachometers. On 26 February 2002, the SB was revised and approved by FOCA. As per this revised SB, the mechanical tachometer for the centre engine and the electric tachometers for the two outer engines were replaced with electronic devices with analogue and digital displays.

According to the SB, the old indicators were showing different read-outs for the same engine speed. Furthermore, the mechanical and electrical systems were susceptible to faults.

When converting to the new system, four steel cams were soldered onto each of the coupling sleeves in the magneto drive system, whereupon this component received a new part number. The display instruments were developed and manufactured especially for Ju-Air. According to the SB, the built-in proximity switches, cabling and plugs corresponded to the industry standard and were commercially available. There was no indication that the parts used were aviation-certified material.

A1.6.17.3 New production of engine components without approval

A1.6.17.3.1 General

Until 2002, the service bulletins were maintained and mostly concerned the new production of components and reconditioning of original components. After 2002, dozens of components, mostly using an old and worn part as a template, were remanufactured or modified by subcontractors by order of Ju-Air (see table 19). Many of the components that were not certified for use in aviation were general, commercially available products.

Release certificates were issued by Naef Flugmotoren AG for each of the remanufactured engine components. No supporting documentation of any kind (strength, material, test runs, etc.) was available for these components.

The following sections describe some illustrative examples of remanufactured components.

Component	Component
Supercharger cover gasket	Discs for rocker-arm bearing
Aluminium seal, sump gasket	Rocker arm axle
Cylinder head screws for bearing cover	Dust caps, grease nozzles
Sealing groove supercharger housing	Rollers for rocker arm
Cover with bushing for mixture control	Valve control rollers
Gear for control drive	Set screws
Crankshaft bolts	Modification to the tappet housing
Washers	Modification to the valve tappet
Propeller bearings	Rocker arm, cover gasket
Locking screws	New production of a test cylinder
Roller bearings	Tappet springs
Crankshaft-bolt locking pin	Deep-groove ball bearings
Crankshaft	Bevel gears for tachometers
Pistons	Starter shaft
R-piston ring	Bearing
Gudgeon pin mushroom for gudgeon pin	Magnetic drive seal
Articulated-rod bushing	Starter pawls
Master-rod bearing bushing	Sealing ring for threaded connectors
M-piston ring, nos. 2 and 3	Cylinder head bolts
Gudgeon pin bushings	Magnetos
F-piston ring	Spark plug set
Master and articulated rods	Pallas carburettor
Outlet-flange gasket	Angle piece for atomizer nozzle
Stud bolts	Inlet flange gasket
Seals for tappet tubes	Gasket for supercharger tube
Union nut for fairing tube	Supercharger tube
Tappet tubes	Feather key insert
Rocker-arm cover gaskets	Oil pumps
Cylinder head screws for rocker-arm cover	Sealing ring
Screws for rocker-arm cover	Sealing rings for oil distributor
Inlet valves	Oil sump gasket
Inner and outer valve springs	Cylinder head screw for distributor sleeve
Bosch generator interference protection	Lower oil riser pipe
Inlet, outlet flanges	Oil filter seal
Cylinder locking pin	Lock nozzle for lubricant sump
Rocker-arm bearing shells	Elbow for oil return
Bendix starter	Oil return pipe
O-rings for cylinder base	Transverse bearing for dynamo drive
Leaf springs	Pump drive
Valve seats	Supercharger shaft
Countershaft with spur gear	Gear shaft with countershaft gear
Tappet guides	-

Table 19: Procured, commercially available components or those that have been remanufactured or modified. This list is most likely not exhaustive.

A1.6.17.3.2 Crankshaft bolts

In 1983, a sketch was made for the production of crankshaft bolts which were to be remanufactured. Subsequently, two bolts were manufactured by Naef Flugmotoren AG based on a pattern part and the sketch. It is not clear from the documents what material was used.

In 1985, material analysis of an existing bolt was commissioned. At the end of 1997, two more bolts were ordered from Naef Flugmotoren AG, manufactured according to sketches and templates. The material used was specified as 34CrNiMo6.

A1.6.17.3.3 Valve springs

In 1985, Ju-Air commissioned a company in Germany to provide 200 sets of valve springs to be manufactured based on pattern parts.

In 1989, a company in Switzerland invoiced Ju-Air for 560 inner springs and 530 outer springs.

Neither sketches or drawings for the production nor material specifications were found in the files.

A1.6.17.3.4 Supercharger shaft

On 8 March 2001, Ju-Air ordered five shafts and seven turbine wheels from a company in Switzerland for the superchargers of the Ju 52 engines. The order included the preparation of the manufacturing plans according to pattern parts and the preparation of operation plans. The choice of material was left to the manufacturer.

In 2012, this company delivered another six supercharger shafts.

A1.6.17.4 Cylinders from a wreck

On 4 January 1941, a Ju 52/3m had to make an emergency landing on the glacier on the Grossvenediger mountain in Austria. This wreckage was salvaged in 2002 and 2003, after the glacier released it from the glacier ice. The left and right engines were removed by Ju-Air and 16 cylinders were reconditioned from these engines for reuse. Release certificates were subsequently issued by Naef Flugmotoren AG for each of these cylinders. At the time of the accident, some of these cylinders were installed in the HB-HOT engines.

A1.6.17.5 Procurement of a flap

Following damage to the right-hand (inner) flap in May 1997, a replacement flap from a CASA 352[53] was purchased from a museum in Germany. A company in Switzerland, certified to perform aircraft repairs, was commissioned by Ju-Air to repair this flap. After the repair work was completed that same month, the flap was installed on HB-HOT; this flap was still installed at the time of the accident. It differs from the left-hand original Junkers flap mainly in the panelling on the underside of the flap, which was made of smooth and not corrugated sheet metal for a length of 2.33 m from the fuselage.

It could not be clarified whether the flap profile differs from the original flap, if for no other reason than because of the lack of drawings from the two aircraft manufacturers.

[53] CASA 352: The first series of the Ju 52 built under licence by CASA (Spain) from the end of the Second World War onwards.

The two flaps may exhibit different aerodynamic characteristics due to their design. However, no complaints from flight crews have been documented that would indicate an impact on flight operations.

A1.6.17.6 Evaluation

From 2002 onwards, SBs were no longer written for the new production and new procurement of spare parts and the reconditioning of original components.

Dozens of components were remanufactured or modified by a large number of subcontractors by order of Ju-Air, mostly using an old and worn part as a template. As a rule, the files did not contain any sketches, drawings or supporting documents (strength, material, test runs, etc.) for the remanufactured or reconditioned components. The technical records for the production of such components were missing. In many instances, the subcontractors contracted by Ju-Air were not certified to provide parts for use in aviation. In the majority of cases, no certification of airworthiness was available for these remanufactured components. Ju-Air also installed many commercially available, non-certified standard components.

A release certificate was issued by Naef Flugmotoren AG for each of the remanufactured and reconditioned engine components. With regard to the remanufactured or reconditioned aircraft components, there was no indication in the files that a certificate of release to service was available when these parts were installed.

The identified deficits in spare parts management led to many of the newly procured, reproduced or reconditioned components lacking a certificate of airworthiness.

The installation of such components in an aircraft is not permitted and, if the components are used, will result in an aircraft’s formal and material loss of airworthiness.

A1.6.18 Record keeping

A1.6.18.1 Guidelines issued by the Federal Office of Civil Aviation

A1.6.18.1.1 General

Matters relating to airworthiness are published by the Federal Office of Civil Aviation (FOCA) in the form of technical communications (TMs). These include the development, certification, production and maintenance of aircraft and aircraft components, as well as maintenance organisations and maintenance personnel.

The TMs are usually explanations or information from FOCA. They are not legally binding regulations. They represent the official interpretation of the underlying directives or laws.

A1.6.18.1.2 Keeping a record of technical files

Technical communication TM 02.010-50, ‘Keeping a record of technical files for aircraft and aircraft components’[54], includes the following information:

“*1. General and purpose*

Technical files (TAs) should be issued for each aircraft and for certain aircraft components (in particular engines, propellers and on-board equipment) to provide chronological evidence of all maintenance work carried out on an aircraft. In particular, the AMCs (acceptable means of compliance) for part M.A.305 should also contain information about keeping a comprehensible and complete record of technical files for an aircraft within the scope of the European Aviation Safety Agency

[54] Published in German as “*Führung der technischen Akten der Luftfahrzeuge und Luftfahrzeugteile*”

(EASA). In the interests of clarity and to ensure that records of these documents are kept as consistently as possible for all Swiss aircraft, the Federal Office of Civil Aviation (FOCA) issues the following notes, explanations and detailed definitions. The AMCs relating to part M.A.305 are complied with or are continued and their implementation is facilitated by providing templates.

2. Scope of application

This technical communication (TM) is applicable to aircraft falling within the scope of Regulation (EC) No. 216/2008 as well as to aircraft excluded from its scope as per annex II of said regulation (known as annex II aircraft).

3. Issuing and form of the technical files

The technical files are usually prepared by FOCA when the aircraft and its components (in particular the engines, propellers and on-board equipment) are registered in Switzerland. As a general rule, one corresponding folder is issued per aircraft.

Component cards represent a short form of technical files that briefly summarise the data relevant for the monitoring of airworthiness for individual aircraft components. It is important that the component card applies to a specific part with a defined serial number and accompanies this part from when it is issued until it is taken out of service.

[…]

4. Records in the technical files

In line with M.A.305(a), all maintenance work carried out shall be recorded and certified in the tech log or flight log immediately after completion by appropriately authorised maintenance personnel (the technical files shall be updated within no later than 30 days).

The records shall be legible and signed. Erroneous records shall not be erased or deleted but shall be crossed out in a way that the incorrect text can still be seen (as per M.A.305(g)).

5. Scope of records

The records shall be clear and complete, and document the type and scope of the work carried out in a transparent manner.

[…]

7.1 Maintenance record (form 52.02)

All maintenance work carried out shall be recorded chronologically in a logbook. Each log shall be accompanied by an attestation issued by the appropriately authorised maintenance personnel or organisation.

[…]

7.4 Component cards (forms 52.09 and 52.091)

The completion of component cards is not mandatory, but recommended. Component cards can be used to considerably simplify the overview, e.g. for aircraft components with their own airworthiness directives. Component cards are usually not issued by FOCA, but by the operator or the person/organisation tasked with the maintenance of the aircraft (completion of component cards as per M.A.305(e) 1 – 4).

There should be a directory of the currently applicable component cards, which shall be updated by the person/organisation tasked with the maintenance of the aircraft. From this, it should be apparent which parts of the aircraft are monitored using component cards.

As an attachment to the directory, the individual component cards should be kept in the technical files.

7.5 Work reports, test reports and certification documents

The test reports for the initial and final inspections of aircraft shall be filed and stored in the 'airframe' technical files.

TM 02.010-30 provides information on the preparation, structure and content of work reports accordingly.

Work reports shall be stored in the technical files or attached to the component cards. At the very least, these shall be kept as follows:

A) Until existing work reports and their annexes are replaced by equivalent ones.

B) For as long as the aircraft or aircraft component is in service/use and for at least 12 months after the aircraft or aircraft component has been permanently taken out of service."

A1.6.18.1.3 Work reports

Technical communication TM 02.010-30 'Work reports' includes the following information:

"*1. General and purpose*

Work reports provide supplementary information to the maintenance records of an aircraft. This communication/directive specifies when a work report is required, what it should contain, to whom it should be addressed and how it should be stored.

2. Scope of application

This directive applies to all aircraft on the Swiss aircraft register. For aircraft falling within the scope of Regulation (EC) 216/2008 (EASA aircraft), M.A.305 of annex I of Regulation (EC) No. 2042/2003 also applies.

3. Preparation of a work report

3.1 When is a work report required?

- *If a brief description in the maintenance record is not sufficient to describe the work carried out.*
- *For maintenance work that is not included in existing aircraft maintenance programmes (AMPs), such as engine and propeller replacements which must be reported to FOCA as per article 28, paragraph 2 of the VLL.*
- *For repairs, overhauls and modifications.*
- *If, for particular reasons, information is to be recorded in the technical files or at the request of the Federal Office of Civil Aviation (FOCA).*

3.2 Scope of a work report

A sample work report is provided in the annex to this technical communication. This contains all of the desired information that a report should contain at the very least. Separate reports for the engine and propeller shall only be prepared if the work was carried out on uninstalled units. Separate reports shall be prepared for *work carried out on the on-board equipment (electrical equipment, instruments, and avionics). Where necessary, the reports must also include the required information regarding the change in empty mass and centre of gravity.*"

A1.6.18.2 Maintenance organisation exposition (MOE)

Section 2 of Ju-Air's MOE, revision 9 dated 5 June 2018, 'Maintenance procedures' includes the following information:

"2.13 Maintenance records and their preparation

Aircraft or component cards for the individual parts recorded. Work on the entire aircraft (such as inspections) is only recorded in the aircraft files.

For work on components that are not intended to be installed immediately into an aircraft operated by the organisation or are to be supplied to third parties, [a release certificate] *must be issued in addition to the records on the component card.*

If components are removed from, repaired and then reinstalled in the same aircraft, [no release certificate] *shall be issued. The corresponding records on the component card will be sufficient.*

Over the course of the maintenance work, staff log the individual steps in the worksheets, based on which the work report is later prepared if such a report is required by the competent authority (i.e. FOCA).

If specific inspections or measurements are required within the work documents, the operations manager is responsible for ensuring that the results of these are provided in clear language in the work documents."

"2.16 Procedure for maintenance work certification

The purpose of the release certificate for parts/components is:

1) *To identify a part, a component or entire units, hereinafter referred to as 'part', after manufacturing or assembly.*
2) *To release the parts following maintenance work carried out on them within the framework of part 145.*
3) *To confirm that the required maintenance has been carried out professionally in line with procedures as per our MOE."*

In the corresponding section of Naef Flugmotoren AG's MOE, revision 10 dated 4 July 2018, stated the following:

"*All documentation concerning maintenance work is to be recorded in the aircraft files or on the component cards for the individual components. Work on the entire aircraft (such as inspections) is only recorded in the aircraft files.*

For work on components, a [release certificate] *is issued in addition to the records on the component card, provided that the part in question is not intended to be immediately installed in a component within the organisation or is to be supplied to third parties.*

Over the course of the maintenance work, the staff record the individual steps in the worksheets, based on which the work report is later prepared if such a report is required by the competent authority. If special inspections or measurements are required within the work documents, the technical manager is responsible for ensuring that the results of these are provided in clear language in the work documents.

Maintenance documentation for aircraft maintenance in line with the VLL annex must make reference to the current revision of the AMP in at least the relevant *work report. Before the relevant component or aircraft can be released, a final check must be carried out to ensure that no tools or parts have been left in the aircraft or component.*"

"2.16 Procedure for maintenance work certification

The purpose of the release certificate for parts, components and aircraft is:

1) *To identify a part, a component or entire units, hereinafter referred to as 'part', after manufacturing or assembly.*
2) *To release the parts following maintenance work carried out on them within the framework of part 145.*
3) *To confirm that the required maintenance has been carried out professionally in line with the procedures as per our MOE.*
4) *To release the parts in line with VLL annex, section 11.6, for maintenance of annex II aircraft."*

A1.6.18.3 Record keeping by maintenance organisations

A1.6.18.3.1 General

Ju-Air was responsible for the maintenance of its Ju 52 aircraft through its own maintenance organisation, which was approved according to annex II (part 145) of European Regulation 1321/2014, and kept a record of all of the aircraft's maintenance files (see annex A1.17).

Naef Flugmotoren AG, which was also certified as a maintenance organisation in line with part 145, carried out repair work and major overhauls on the engines and their components. Naef Flugmotoren AG kept a record of the files for this work.

The record keeping by these two maintenance organisations showed severe deficits. The sections that follow illustrate some of the shortcomings in their record keeping.

A1.6.18.3.2 Ju-Air technical files

The cover pages of the maintenance records were not prepared by FOCA, but initially by the VFMF[55] and later by Ju-Air, and were signed by a Ju-Air mechanic.

All maintenance work carried out on the airframe, engine, propeller or on-board equipment must be logged in the maintenance record upon completion, including the date and the relevant operating hours, and certified by an authorised person (certification of release to service). It must also be recorded which maintenance documents were used as the basis for the relevant work carried out.

The handwritten records in the technical files were at times difficult to read. Until 2012, the work carried out was certified only by the mechanic's initials and licence number. It was only possible to identify the person authorised to certify the work using their licence number. In the release certificates, there was never any reference to the maintenance documents that formed the basis for the work carried out. On numerous occasions, the documents in the technical files on work carried out were incomplete and tracing the work was difficult, in parts even impossible.

The task cards for the progressive inspections of the flight controls' settings listed the desired values. The inspection of these figures or settings was certified in the

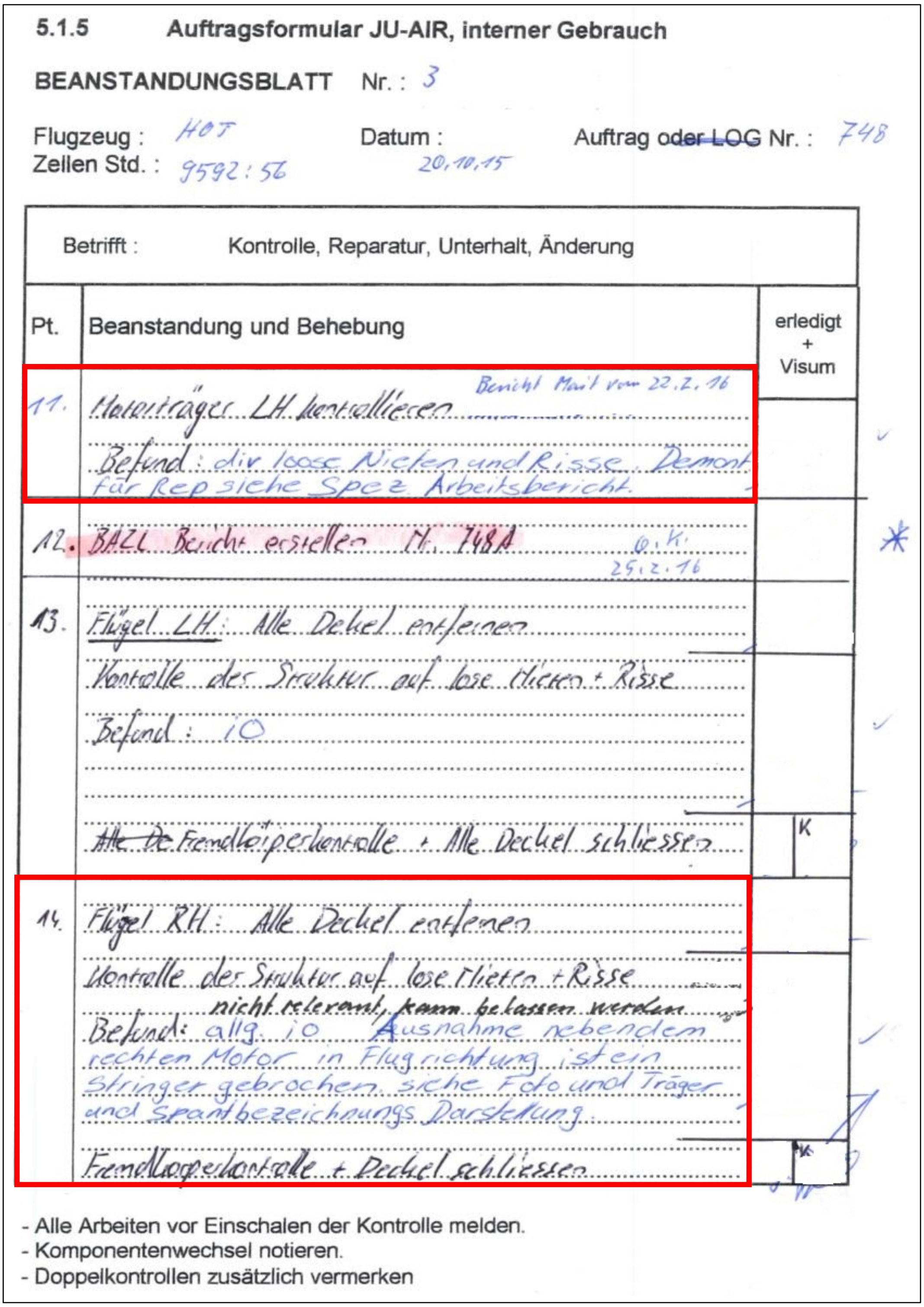
[55] *Verein der Freunde des Museums der Schweizerischen Fliegertruppen* (association of the friends of the Swiss air corps museum)

relevant work report using initials, whilst in most instances the actual values had not been noted (see section A1.6.14.3.4).

In addition to the task cards for the progressive inspections, there was also a ‘complaint sheet’. Additional work, such as repair work or modifications to the airframe or engines, was also recorded in shorthand notes on this sheet (see section A1.6.16.2.4). A rectified complaint was certified using initials. It was not clear whether this was someone who was authorised to certify the work carried out. The work carried out was largely documented in an incomplete and incomprehensible manner (see figures 60 and 61). Where work carried out was also logged in the maintenance record or other lists, it was described differently (see section A1.6.18.3.3). Categorically, no work reports were prepared in compliance with TM 02.010-30.

Since new propeller blades were produced, the cover pages of the propeller maintenance records were no longer correct in terms of part and serial numbers. Only the operating time of the hub was listed, not that of the blades. As the hub and the blades of a propeller did not have the same operating times, it was difficult, or even impossible, to trace the operating hours of the blades.

The information in section 2 of Ju-Air’s MOE and FOCA’s guidelines were not implemented.



5.1.5 Auftragsformular JU-AIR, interner Gebrauch

BEANSTANDUNGSBLATT Nr. : 3

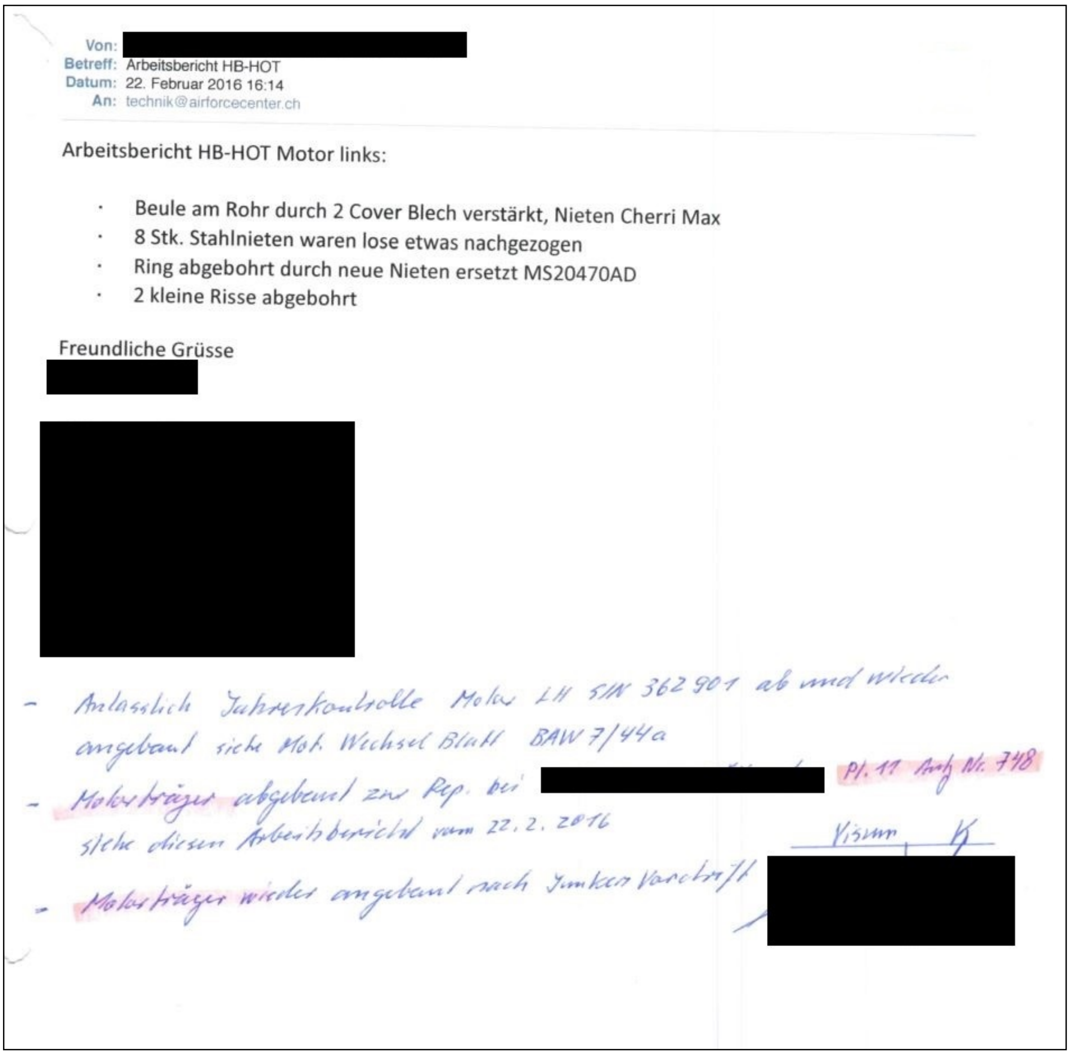
Flugzeug : HOT Datum : 20.10.15 Auftrag ~~oder LOG~~ Nr. : 748
Zellen Std. : 9592:56

Betrifft : Kontrolle, Reparatur, Unterhalt, Änderung

Pt.	Beanstandung und Behebung	erledigt + Visum
11.	Motorträger LH kontrollieren (Bericht Mail vom 22.2.16) Befund: div. lose Nieten und Risse. Demont. für Rep. siehe Spez. Arbeitsbericht.	✓
12.	BAZL Bericht erstellen Nr. 748A (o.K. 25.2.16)	*
13.	Flügel LH: Alle Dekel entfernen Kontrolle der Struktur auf lose Nieten + Risse Befund: iO ~~Alle De~~ Fremdkörperkontrolle + Alle Deckel schliessen	✓ K
14.	Flügel RH: Alle Deckel entfernen Kontrolle der Struktur auf lose Nieten + Risse Befund: allg. iO Ausnahme nebendem rechten Motor in Flugrichtung ist ein Stringer gebrochen, siehe Foto und Träger und Spantbezeichnungs Darstellung. (nicht relevant, kann belassen werden) Fremdkörperkontrolle + Deckel schliessen	✓ K

- Alle Arbeiten vor Einschalen der Kontrolle melden.
- Komponentenwechsel notieren.
- Doppelkontrollen zusätzlich vermerken

Figure 60: Complaint sheet no. 3 dated 20 October 2015. Initials and subcontractor removed by the STSB. Relevant work items are framed in red. Source: Technical records HB-HOT.



Von: [redacted]
Betreff: Arbeitsbericht HB-HOT
Datum: 22. Februar 2016 16:14
An: technik@airforcecenter.ch

Arbeitsbericht HB-HOT Motor links:

- Beule am Rohr durch 2 Cover Blech verstärkt, Nieten Cherri Max
- 8 Stk. Stahlnieten waren lose etwas nachgezogen
- Ring abgebohrt durch neue Nieten ersetzt MS20470AD
- 2 kleine Risse abgebohrt

Freundliche Grüsse
[redacted]

- Anlässlich Jahreskontrolle Motor LH S/N 362 901 ab und wieder angebaut siehe Mot. Wechsel Blatt BAW 7/44a
- Motorträger abgebaut zur Rep. bei [redacted] Pl. 11 Anf. Nr. 748
siehe diesen Arbeitsbericht vom 22.2.2016 Visum K
- Motorträger wieder angebaut nach Junkers Vorschrift [redacted]

Figure 61: Work report by the Ju-Air subcontractor for item 11, complaint sheet no. 3 dated 20 October 2015. Names, signatures and subcontractors have been redacted by the STSB.

A1.6.18.3.3 Horizontal-stabiliser adjustment spindle

According to the technical files, work on the horizontal-stabiliser adjustment spindle was certified on 11 March 2003. Due to records being incomplete, it is not possible to provide precise details about the work carried out and ultimately about the final condition of the horizontal-stabiliser adjustment spindle. The following table lists the different descriptions for the work from the relevant files. A complete work report was not available.

Complaint sheet no. 5, item 18 (job no. 424)	"*Chronological record of replaced components*", sheet no. 13	Maintenance record
• "*Höhenstabilo*[56] *adjustment mechanism P/N 460502/21*" • "*Remove from aircraft*" • "*Remove, clean, inspect, re-grease*" • "*Install in the aircraft and secure*" • "*Check setting and function*"	• "*Components: Höhenstabilo gears and Stabi*[57]" • "*Reason: overhaul*"	• "*Höhenstabilo repaired*"

Table 20: Different descriptions for the same piece of work carried out on the same part.

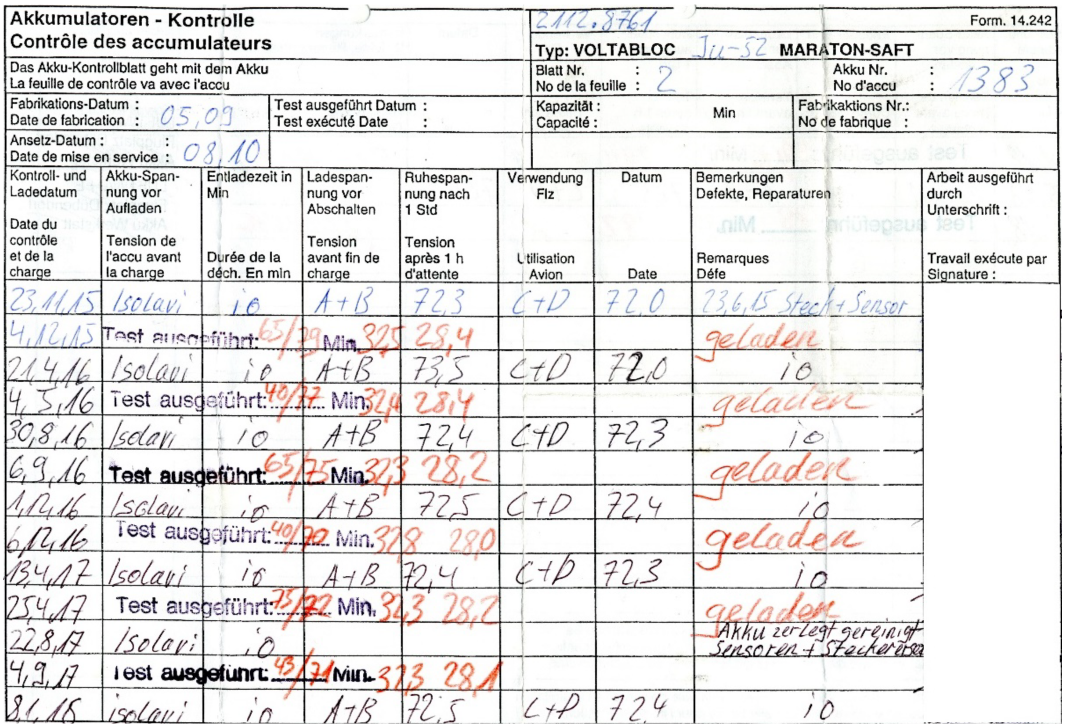
A1.6.18.3.4 On-board battery

An NiCd battery was mentioned in HB-HOT's equipment list, but neither the model of battery (part number) nor the serial number were recorded. The files did not contain a release certificate for the battery.

The Air Force continued to carry out the maintenance of the NiCd batteries at Dübendorf Air Base, even after Ju-Air had acquired the Ju 52 aircraft in the 1980s. For certification of the work, the 'Battery inspection' military form was used, in which the inspection results were noted. The form was filled out incorrectly in parts (see figure 62). In addition, the technical files included an on-board battery log, in which inspection findings were also written. The information in the form and the on-board battery log for the same period of time did not match, even though the two documents were marked with the same serial number.

56 Record keeper's shorthand note meaning 'horizontal stabiliser'

57 Another shorthand note meaning 'horizontal stabiliser'



Akkumulatoren - Kontrolle / Contrôle des accumulateurs		2112.8761 / Typ: VOLTABLOC Ju-52 MARATON-SAFT	Form. 14.242
Das Akku-Kontrollblatt geht mit dem Akku / La feuille de contrôle va avec l'accu		Blatt Nr. / No de la feuille : 2	Akku Nr. / No d'accu : 1383
Fabrikations-Datum / Date de fabrication : 05,09	Test ausgeführt Datum / Test exécuté Date :	Kapazität / Capacité : Min	Fabrikaktions Nr. / No de fabrique :
Ansetz-Datum / Date de mise en service : 08,10			

Kontroll- und Ladedatum / Date du contrôle et de la charge	Akku-Spannung vor Aufladen / Tension de l'accu avant la charge	Entladezeit in Min / Durée de la déch. En min	Ladespannung vor Abschalten / Tension avant fin de charge	Ruhespannung nach 1 Std / Tension après 1 h d'attente	Verwendung Flz / Utilisation Avion	Datum / Date	Bemerkungen Defekte, Reparaturen / Remarques Défe	Arbeit ausgeführt durch Unterschrift : / Travail exécute par Signature :
23,11,15	Isolavi	io	A+B	72,3	C+D	72,0	23,6,15 Steck+Sensor	
4,12,15	Test ausgeführt: 65/29 Min.		32,5	28,4			geladen	
21,4,16	Isolavi	io	A+B	73,5	C+D	72,0	io	
4,5,16	Test ausgeführt: 40/37 Min.		32,4	28,4			geladen	
30,8,16	Isolavi	io	A+B	72,4	C+D	72,3	io	
6,9,16	Test ausgeführt: 65/75 Min.		32,3	28,2			geladen	
1,12,16	Isolavi	io	A+B	72,5	C+D	72,4	io	
6,12,16	Test ausgeführt: 40/70 Min.		32,8	28,0			geladen	
13,4,17	Isolavi	io	A+B	72,4	C+D	72,3	io	
25,4,17	Test ausgeführt: 75/72 Min.		32,3	28,2			geladen	
22,8,17	Isolavi	io					Akku zerlegt gereinigt Sensoren + Steckerersa	
4,9,17	Test ausgeführt: 43/71 Min.		32,3	28,1				
8,1,18	isolavi	io	A+B	72,5	C+D	72,4	io	

Figure 62: Air Force form including inspection results for the NiCd battery. Signatures removed by the STSB. Source: Technical records HB-HOT.

In HB-HOT's 'on-board equipment' maintenance record and on the relevant complaint sheet, the maintenance work carried out on the NiCd battery was certified by Ju-Air mechanics E and G, who did not hold the required licence for this (see annex A1.17).

A1.6.18.3.5 Naef Flugmotoren AG technical records

Naef Flugmotoren AG carried out repair work and major overhauls on engines and their components. Upon conclusion of this work, a work report had to be written, the component cards had to be updated and, if necessary, a release certificate had to be issued. The handwritten records in the technical files were at times difficult to read. The component cards were not completely updated and were not transparent, meaning there was often no precise information available regarding operating hours or work carried out. There was no directory of the currently valid component cards.

The work reports were handwritten in shorthand, were incomplete and in some places barely or not comprehensible. Furthermore, the release certificates contained no reference to the documents that formed the basis for the repairs or major overhauls carried out. As of 2018, work reports were typed and their content and structure were slightly modified. On various occasions, however, the work reports were certified by a person who was not authorised to do so.

The overhaul reports for the engines are not transparent. According to the report, virtually every dismantled component was reworked. Other information was missing (see figure 63). There were also no test reports available for bench-tested components.

The specifications in Naef Flugmotoren AG's MOE and FOCA's guidelines were not implemented into the company's working processes.

NAEF FLUGMOTOREN AG
CH - 8600 Dübendorf

Baumuster BMW 132 3
Werk Nr. 67438
NAEF Auftrag Nr. 7/2003

Befundbericht : Triebwerk
Baugruppe : 03 Kolben und Pleuel
Ersatzteil-Best.

TSN: 4740.41
TSO: 0.00
Blatt : 4
von : 11

ck.	Teilebezeichnung	Teil-Nr.	*	LTA/TM SI/SB	Stck	Neuteil bzw. Austauschteil	**	Bemerkungen	*** M	*** Z
3	Kolben Zyl.1,2,9	43M-1600-U3	N	SB 1005				Reinigen Kolbenring nuten		
6	Kolben	43M-1601-U3	N	SB1005				Reinigen Kolbenring-Nuten		
9	Kolbenbolzen	43M-1610	N							
18	Pilz	43M-1611	N							
8	Nebenpleuelbüchsen	43M-1619	N							
8	Schlammbüchsen	43M-1620	N							
1	Hauptlagerbüchse	43M-1621	N							
9	Kolbenbolzenbüchse	43M-1627-1	N	TM-134						
1	Hauptpleuel	43M-1645	N							
8	Nebenpleuel	43M-1646	N							
8	Anlenkbolzen	43M-1640	N							
	-Lösedruck: i.O									
9	Kolbenringe	43M-1626-U3	A	SB 1005	9	43M-1626		Stoss-Spiel Kontrolle		
18	Kolbenringe	43M-1605-U3	A	SB 1005	18	43M-1605		Stoss-Spiel Kontrolle		
9	Oelabstreifringe	43M-1628-U3	A	SB 1005	9	43M-1628		Stoss-Spiel Kontrolle		

Code :
*
J = auswärts
A = Ausschuss
F = Fehlteil
K = Kreislauf
N = Nacharbeit
U = Wiederverwendung
**
1 = Grundüberholung
2 = i.O.
3 = lt. Aenderung aussondern
4 = Aenderung durchführen
5 = Laufbuchse riefig (honen)
6 = Ventilführung ausgeschlagen
7 = Sitzfläche eingeschlagen
8 = Buchse/Führung wechseln
9 = nachschleifen Korngrösse...
10 = Masse ausser Toleranz
11 = Gewinde beschädigt
12 = Oberflächenbehandlung
13 = Risse / gerissen
14 = allg. Korrosion
15 = allg. Verschleiss
16 = Riefen/Kratzer/Kerben
17 = Galling / Fretting
18 = eingewalzte Fremdkörper
19 = Materialausbruch
20 = Materialüberhitzung/Abbrand
21 = reinigen/Funktionsprüfung
22 = Federdruck zu schwach
23 = ...
***
Z = Rissgepr. ZYGLO
M = Rissgepr. MAGNETISCH
2 = i.O.
13 = gerissen/Risse

Figure 63: Overhaul report from July 2009, sheet 4, pistons and connecting rods. Source: Technical records HB-HOT.

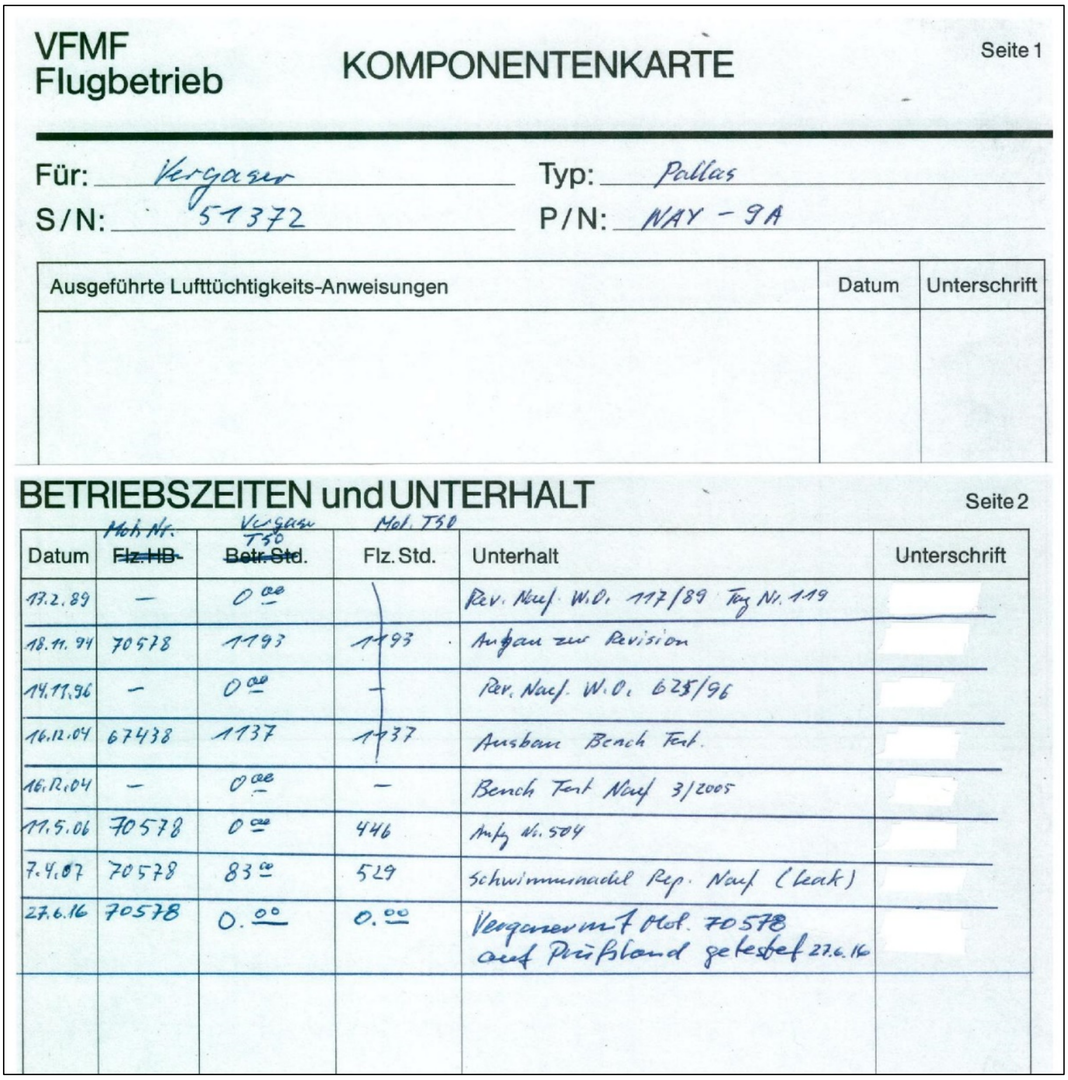
A1.6.18.3.6 Carburettors

The previous operating time was not apparent in the maintenance organisation's records.

Maintenance work carried out on the carburettor was not consistently recorded on the component card and could sometimes only be found in the engine logbook. During this investigation, it was difficult to trace updates to the operating hours following work or inspections.

The carburettor with serial number 60930, installed on the centre engine, was overhauled in June 2003. The test run performed in April 2013, after 1,772 operating hours, is listed as the next inspection. The aircraft maintenance programme stipulated the maximum operating time between test runs or overhauls as 1,500 hours. This limit was thus exceeded by 272 operating hours.

For the carburettor with serial number 51372, installed on the right engine, the first entry on the component card was dated February 1989 (see figure 64). An overhaul was carried out in November 1996. In December 2004, after 1,137 operating hours, the maintenance team carried out a test run. Thus, based on the Ju 52's maintenance programme, an overhaul would have been due no later than after another 1,500 hours. In June 2016, after a total of 1,611 operating hours instead of 1,500 hours since the last test run, another test run was carried out instead of an overhaul. According to the records, the carburettor had exceeded the limit for the next overhaul by 569 operating hours at the time of the accident.



VFMF
Flugbetrieb

KOMPONENTENKARTE

Seite 1

Für: Vergaser　　Typ: Pallas
S/N: 51372　　P/N: NAY - 9A

Ausgeführte Lufttüchtigkeits-Anweisungen	Datum	Unterschrift

BETRIEBSZEITEN und UNTERHALT

Seite 2

Datum	Mot. Nr. (~~Flz. HB~~)	Vergaser TSO (~~Betr. Std.~~)	Mot. TSO Flz. Std.	Unterhalt	Unterschrift
17.2.89	–	0.00		Rev. Naef W.O. 117/89 Tag Nr. 119	
18.11.94	70578	1193	1193	Aufbau zur Revision	
14.11.96	–	0.00	–	Rev. Naef W.O. 625/96	
16.12.04	67438	1137	1137	Ausbau Bench Test.	
16.12.04	–	0.00	–	Bench Test Naef 3/2005	
11.5.06	70578	0.00	446	Aufg Nr. 504	
7.4.07	70578	83.00	529	Schwimmernadel Rep. Naef (leak)	
27.6.16	70578	0.00	0.00	Vergaser mit Mot. 70578 auf Prüfstand getestet 27.6.16	

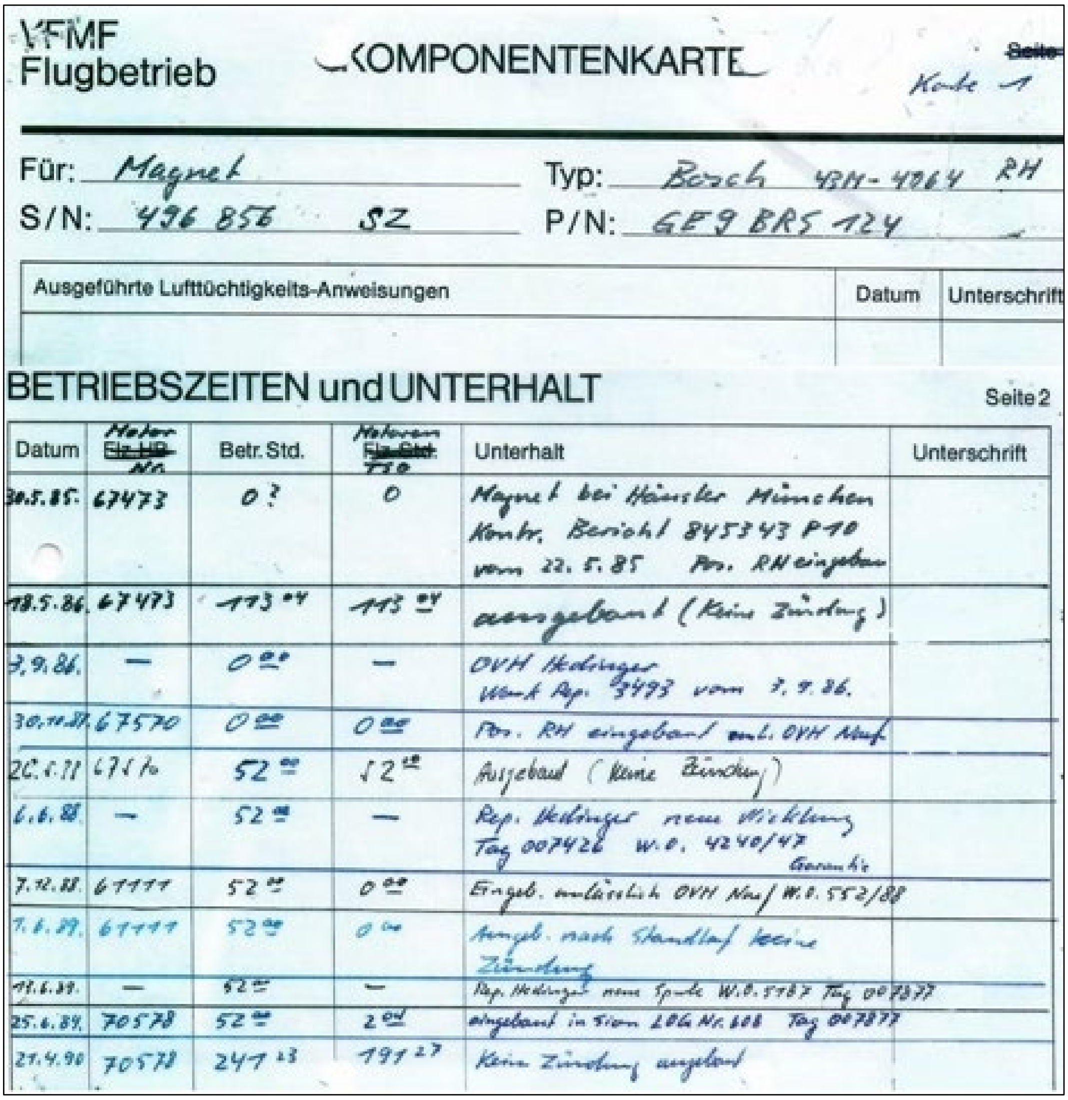
Figure 64: Component card for the carburettor with serial number 51372. Signatures of mechanics removed by the STSB. Source: Technical records HB-HOT.

According to Naef Flugmotoren AG, the carburettors were bench-tested following repair work or overhauls. During this process the carburettor was only checked for fuel flow and leaks. There were no records of test logs or work reports.

A1.6.18.3.7 Magnetos

The magnetos' previous operating times were not apparent from the technical files. Maintenance work carried out on the magnetos was not consistently recorded on the component card and could sometimes only be found in the engine files.
The magnetos were used in both positions, in various engines and in various aircraft. During this investigation, it was difficult to trace updates to the operating hours following repairs, inspections or overhauls. For example, the position of the magneto (serial number 496856) on the right engine could not be determined using the component card.

The first log on the component card is dated 30 May 1985 and shows 0 operating hours following an inspection (see figure 65). By the time of the accident, a total operating time of 3,644 hours had been recorded. During this period of operation, the magneto had been overhauled three times and repaired five times without achieving the expected operational life. The 650-hour inspection was never recorded on the component card. This magneto had been used in seven different engines.



VFMF Flugbetrieb — KOMPONENTENKARTE — Seite: Karte 1

Für: Magnet — Typ: Bosch 4BH-4064 RH

S/N: 496 856 SZ — P/N: GE9 BRS 124

Ausgeführte Lufttüchtigkeits-Anweisungen	Datum	Unterschrift

BETRIEBSZEITEN und UNTERHALT — Seite 2

Datum	~~Flz. HB~~ Motor Nr.	Betr. Std.	~~Flz. Std.~~ Motoren TTO	Unterhalt	Unterschrift
30.5.85.	67473	0 ?	0	Magnet bei Hänsler München Kontr. Bericht 845343 P10 vom 22.5.85 Pos. RH eingebaut	
18.5.86.	67473	113 04	113 04	ausgebaut (Keine Zündung)	
3.9.86.	—	0 00	—	OVH Hedinger Werk Rep. 3493 vom 3.9.86.	
30.11.87.	67570	0 00	0 00	Pos. RH eingebaut anl. OVH Mot.	
20.5.88	67570	52 00	52 00	Ausgebaut (Keine Zündung)	
6.6.88.	—	52 00	—	Rep. Hedinger neue Wicklung Tag 007426 W.O. 4240/47 Garantie	
7.12.88.	67777	52 00	0 00	Eingeb. anlässlich OVH Mot./ W.O. 552/88	
7.6.89.	67777	52 00	0 00	Ausgeb. nach Standlauf keine Zündung	
19.6.89.	—	52 00	—	Rep. Hedinger neue Spule W.O. 5787 Tag 007877	
25.6.89.	70578	52 00	2 00	eingebaut in Sion LDG Nr. 608 Tag 007877	
27.4.90	70578	247 13	197 27	Keine Zündung ausgebaut	

Figure 65: Component card for the magneto with serial number 496856. Signatures removed by the STSB. Source: Technical records HB-HOT.

A1.6.18.3.8 Cylinders

A cylinder’s serial number, its relative position on the engine and operating hours since the last service were not consistently recorded on its component card. Information regarding the cylinder’s installed position was not consistently updated. After a cylinder had been replaced or repaired, the serial number of the relevant cylinder was not declared in the technical files and work report. This approach meant that the documentation on engine maintenance was incomplete and not transparent.

A1.6.18.3.9 Evaluation

The vast majority of the technical files of both maintenance organisations were handwritten. In places these were barely legible, sometimes even illegible. For the most part, the work carried out was not transparent and it was extremely difficult, in most cases even impossible, to trace the work carried out on components. Records were not kept as specified in FOCA's technical communications and the companies' MOEs.

Work reports for the repairs carried out by Naef Flugmotoren AG were certified by an unauthorised person in 2018.

A1.6.19 Ageing aircraft programme

FOCA recognised the need to gain an overview of the operation of ageing aircraft. In many instances, these were aircraft that had previously been operated by the military and now required maintenance in accordance with civil regulations. In particular, aspects of material fatigue or ageing, and the maximum permissible operating time of aircraft needed to be assessed with the aim of continuing to ensure their airworthiness. Often, the manufacturers' maintenance programmes had not been designed to check critical areas of the structure. As can be seen from the example of Ju-Air's Ju 52 aircraft, such areas can barely or not at all be seen or inspected without extensively dismantling the aircraft. Furthermore, data on the maximum permissible operating time was missing.

To this end, in 2010 FOCA launched the ageing aircraft programme for models of aircraft on the Swiss register that were referred to in annex II of European Regulation 216/2008. In October 2011, the respective operators were contacted in writing and informed about this project.

The project was divided into three phases:

Phase I: - Situation analysis and collecting data

Phase II: - Evaluating existing reports

- Conducting a special inspection of the fleet-leader aircraft
- Performing or studying various analyses

Phase III: - Creating supplemental structural inspection documents (SSID)

In phase I, the following operating data was requested in order to carry out a risk assessment:

- Year of manufacture
- Total flight hours and landings
- Total flight hours and landings of the oldest aircraft (fleet leader)
- Executed repairs and/or changes, such as weight increases, etc.
- Service life tests carried out
- Problems arising (AD, SB)
- Load on and/or stress level in the critical components

Ju-Air's Ju 52/3m g4e aircraft were also part of this programme. In the beginning, FOCA had to ask Ju-Air several times to submit the operating data for phase I. In a statement dated 30 September 2015, Ju-Air informed FOCA of the status of the investigation and further action. Ju-Air stated that an extended special assessment programme, tailored to the aircraft's operating conditions, was to be developed. The statement did not include a concrete action plan and timeline. FOCA subsequently asked Ju-Air several times to develop an action plan for phase II, complete with deadlines. Ju-Air had not complied with this request at the time of the accident.

In early 2017, Zurich University of Applied Sciences (ZHAW), who had been commissioned for the project, suggested to FOCA that the forces acting on the horizontal-stabiliser adjustment spindle during flight be measured using strain gauges. At the time of the accident, this project had not yet been completed.

A supplemental structural inspection document (SSID) had not been developed by the time of the accident.

A1.6.20 Condition of HB-HOT's sister aircraft

HB-HOT's two sister aircraft, HB-HOS and HB-HOP, exhibited the same poor condition as HB-HOT. In particular, the anti-corrosion paint prescribed by the manufacturer had severely flaked off (see figures 66 to 70). This surface protection is necessary for Duralumin, as otherwise intergranular corrosion can occur (see annex A1.16). The aircraft also featured overaged fuel lines (see figure 68).

Figure 66: Surface flaking and a lack of anti-corrosion paint on the inside of HB-HOS's left-hand horizontal stabiliser.

Figure 67: Surface flaking and a lack of anti-corrosion paint on the inside of HB-HOS's right-hand outer wing.

Figure 68: Flaking anti-corrosion paint and severe contamination on the inside of HB-HOP's left-hand outer wing, and fuel line from 1989.

Figure 69: Lack of anti-corrosion paint on a spar tube in HB-HOP's left-hand outer wing.

Figure 70: Corroded components and a lack of anti-corrosion paint on the inside of HB-HOP's left-hand outer wing.