

**Review of Aeronautical Fatigue**  
**Investigations in Switzerland**

March 2017 – April 2019

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### **Summary**

The Swiss review summarizes fatigue work in Switzerland. It includes main contributions from the Zurich University of Applied Sciences (ZHAW) and RUAG Switzerland Ltd. (RUAG Aviation). This document forms a chapter of the ICAF conference minutes published by the conference host nation. The format of the review reflects ICAF requirements.

Prepared and approved for the presentation at the 36<sup>th</sup> ICAF Conference

Krakow Poland, 2<sup>th</sup> and 7<sup>th</sup> June 2019

## Inhalt

<b>Summary .....</b>	<b>- 2 -</b>
<b>4.1 Introduction .....</b>	<b>- 4 -</b>
<b>4.2 Swiss Aviation Activities .....</b>	<b>- 5 -</b>
<b>4.3 Junkers Ju-52/3m from JU-AIR.....</b>	<b>- 8 -</b>
<b>4.4 Hunter MK58/68 .....</b>	<b>- 23 -</b>
<b>4.5 Fatigue Test of Minimally invasive repaired sandwich core .....</b>	<b>- 25 -</b>
<b>4.6 F/A-18 C/D Structural Refurbishment Program (SRP).....</b>	<b>- 27 -</b>
<b>4.7 F/A-18 C/D Service Life Assessment Program (SLAP).....</b>	<b>- 30 -</b>
<b>4.8 Patrouille Suisse Fleet Management.....</b>	<b>- 32 -</b>

## 4.1 Introduction

The present review gives a brief summary of the work performed in Switzerland in the field of aeronautical fatigue, during the period from April 2017 till March 2019. The various contributions to this review come from the following sources:

- Zurich University of Applied Sciences (ZHAW); School of Engineering, Institute of Material Processing & Centre for Aviation
- RUAG Switzerland Ltd., RUAG Aviation; Structural Engineering

All the interesting contributions are gratefully acknowledged, especially the effort of Paul Gerards (ZHAW), Markus Gottier (Gottier Engineering), Silvain Michel (EMPA Materials Science and Technology), Gregor Peikert (ZHAW), and Andreas Uebersax (RUAG Aviation).

The financial support from the Swiss Federal Office of Civil Aviation (FOCA) is gratefully acknowledged for the activities of the Ageing Aircraft project. Personal thanks to Mr. Rolf Meier and Mr. Hamid Hampai from FOCA for supporting the project and the Zurich University of Applied Sciences, ZHAW in Winterthur.

## 4.2 Swiss Aviation Activities

Zurich University of Applied Sciences

The Swiss Aviation industry made considerable progress in the last two years. Pilatus has certified the new super versatile business jet by the end of 2018. Already 80 aircraft are sold, and the pace of delivery is increasing. The order book was opened at EBACE in Geneva again and hopefully, a lot of orders will follow. Pilatus is investing a lot into the production line of the PC-24 in Stans, the goal is to produce all the parts of the Pilatus PC-24 in Switzerland to demonstrate Swiss quality.



Figure 1 PC-24 in flight

The Swiss helicopter company Marenco got new management with experience in helicopter design and manufacturing. The name was also changed to kopter which has now its engineering office in Wetzikon. The 3<sup>rd</sup> prototype P3 is flying now most test flights are done in Italy. The prototype P3 showed in detail considerable improvements compared to the previous prototypes. The 4<sup>th</sup> prototype is under development and showed will be the configuration of the first production models. The goal is to certify the kopter helicopter in 2020.



Figure 2 P3 kopter prototype during flight testing

Swiss International Airlines introduced the Boeing 777 on long haul flights. More challenging was the introduction of the Bombardier C Series which replaced the aging Avro jets from BAE Systems. The Bombardier C Series now belongs to Airbus A220 is a new radical airplane with aluminum/lithium fuselage with a composite wing with the new PW geared turbo fan. Bombardier developed a new fly by wire system which provides force feedback. The aircraft had more than two years delay but the performance is much better than predicted but the advanced technology caused real operational challenges with a lot of engine replacement and delayed software updates. Overall the Airbus A220 is a great plane and the support with the experience of Airbus is very beneficial.



Figure 3 Bombardier C-series with geared turbo fan

The small airline Helvetic which also provides a lot of wet leasing to Swiss International Airlines will get brand new Embraer E 190 E2 jets by the end of 2019. It will be interesting to compare the Embraer E 190 E2 with the Airbus A220. A first comparison was already done by the Bachelor Aviation students in their thesis in Winterthur.

The year 2018 was a tragedy for the Swiss aviation, in the first weekend of August the Junkers Ju-52 the only original configuration crashed near the mountain and 20 people were killed. The preliminary investigation showed some cracks and corrosion at locations which could not be inspected. The structural integrity was not the cause of this tragedy. On the same day, the Pilatus test pilot crashed with his family on a holiday trip to France.

The Swiss Foundation of Technology (TA-SWISS) launched a study to assess the impact and future potential of drone technology and business development. This study entitled "Remote-controlled flying machines" was presented to the public in March 2018 and got a lot of attention. The study was performed by the Zurich University of Applied Sciences (ZHAW) and the University of Zurich (UZH).

In Switzerland, a lot of Drone start-ups are doing business also the Federal Office of Airworthiness is very active in JARUS and EASA to promote the new field of unmanned aircraft systems. Switzerland has the lead in the process of Specific Operation Risk Assessment (SORA) which will be mandatory for beyond visual line of sight operations (BVLOS). The World Economic Forum (WEF) together with the Federal Department of Energy and Environment organized the Home of Drones Event at the ETH in Zurich with a demo of the Swiss solution for Unmanned Traffic Management called Swiss U-Space. Skyguide together with AIRMAP started the operation of the Swiss U-space in Lugano and Geneva in April 2019. The Swiss Post has performed more than 2500 flights in collaboration with Matternet for blood delivery in Lugano and over the lake of Zurich under BVLOS operation. The Swiss Aviation Research Center (ARCS) founded in June 2017 to coordinate the research activities among the Swiss Universities. This initiative was motivated by the Federal Office of Airworthiness (FOCA) to increase the research activities in novel technologies in the Aviation. An innovation board with the stake holders (CEO and CTO) of the Swiss Industry ensure that the industry will benefit from the research results in the future.

## Aviation Research Center Switzerland



Figure 4 Layout of Aviation Research Center Switzerland ([www.arcs.aero](http://www.arcs.aero)).

In June 2017 a study was completed for using mobile network infrastructure BVLOS drone operation in collaboration with Swiss Air navigation Service provider Skyguide and Swisscom the biggest mobile network company in Switzerland.



### 4.3 Junkers Ju-52/3m from JU-AIR

Zurich University of Applied Sciences, Gottier Engineering GmbH, and EMPA Materials, Science and Technology

The Swiss Air Force operated from 1939 till 1982 three original Junkers Ju-52/3m with BMW 132 engines. Since 1983 these Ju-52/3m (immatriculation HB-HOP, HB-HOS, and HB-HOT) were operated as Annex II aircraft by JU-AIR, an association in Dübendorf near Zurich. From April till October JU-AIR was operating passenger flights to the Alps as well as local pleasure flights. Most flights are fully booked with 17 passengers. Each aircraft Ju-52/3m makes about 250 FH per year. Until the end of 2018, the total flight duration of each aircraft has passed 10'000 flight hours. The fleet leader has accumulated 11'386 FH.



Figure 5 JU-AIR Ju-52/3m flying over the alps

Since 2011, JU-AIR, the Federal Office of Civil Aviation (FOCA) and the Centre of Aviation (ZAV) of the Zurich University of Applied Sciences (ZHAW) have been running a long-term ageing aircraft campaign for continuous structural airworthiness.

This campaign was organized in three phases:

**Phase I:** Survey of fleet information and data collection

- fleet information
- inspection documents
- reports
- identification of fatigue critical locations



**Phase II:** Performance of inspections and structural analysis

- analysis of critical locations with respect to local stress levels, local geometry, and material
- development of a load spectrum based on theoretical assessments of  $n_z$ -occurrences, mass distribution, flight altitude profile, etc.
- fatigue life analysis, crack initiation and crack growth life calculations
- determination of safety limits or inspection intervals

**Phase III:** Development of SSID

**Phase I – a survey of fleet information and data collection**

Regarding Ju-52/3m, the ZAV started in 2015 reviewing all the available documents from the JU-AIR, including information from the German “Lufthansa Berlin Stiftung” (a foundation) which operates a Ju-52/3m, called D-AQUI. The goal was to assess the continuous airworthiness of the Swiss Ju-52/3m regarding material fatigue.

The German Ju-52/3m has a history which is very different from the Swiss aircraft: First operated with Lufthansa then converted to a seaplane flying during second world war in Norway, and finally operated in South America for local flights. Compared with the Swiss Ju-52/3m, the D-AQUI had accumulated much more flight hours - more than 25'000 flight hours. D-AQUI showed first cracks in a spar at 12'949 flight hours and 25'495 flight cycles in 2003. Therefore a refurbishment of the primary wing structure was necessary after this crack finding.

The wing structure consists of truss and beams with four spars, see Figure 1 and 2 below.

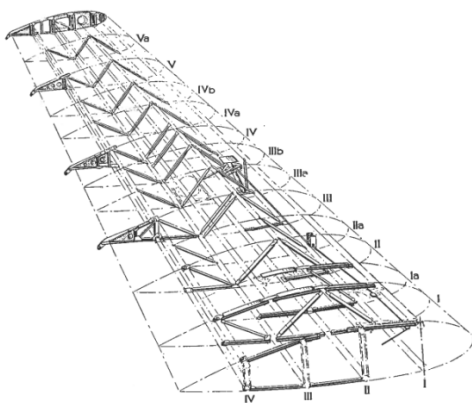


Figure 6 Wing structure of Ju-52



Figure 7 Disassembled Ju-52 wing showing the connection points

The “Deutsche Lufthansa Berlin Stiftung” has done several studies in cooperation with the Technical University Berlin and Hamburg University of Applied Sciences to determine the loads, loads distribution in the structure, usage spectrum and fatigue life of spars. Even strain gauge measurements were done, to get more information on local stresses in the main spars at the wing root, based on typical manoeuvres and gust loads. Conclusions were that ground-air-ground cycles and stochastic gust loads have a major impact on the fatigue life of the wing spars opposed to loads recorded during normal flight conditions. Furthermore, eigenfrequencies do not represent a factor for the structural integrity of Ju-52/3m. Another important result was, the wing construction was to be found as a fail-safe construction with significant damage tolerance potentials. In addition to this, the “Lufthansa Berlin Stiftung” provided some information and documents about the old German material standard “Flieg” which is relevant for the Ju-52/3m.

## **Phase II – performance of inspections and structural analysis**

### *Analysis of critical locations*

Due to the collected information, the FOCA identified fatigue critical locations which were the basis for the work done during phase II. The report showed the following elements as potentially critical with respect to material fatigue (see also Figure 8):

- four truss wing spars with the diagonal web (tube design)
- Horizontal tail single trim spindle for elevator control
- Horizontal and vertical tail spars and attachment points
- fuselage frames and spars
- control surface connections
- engine mounts and connections to fuselage or wing

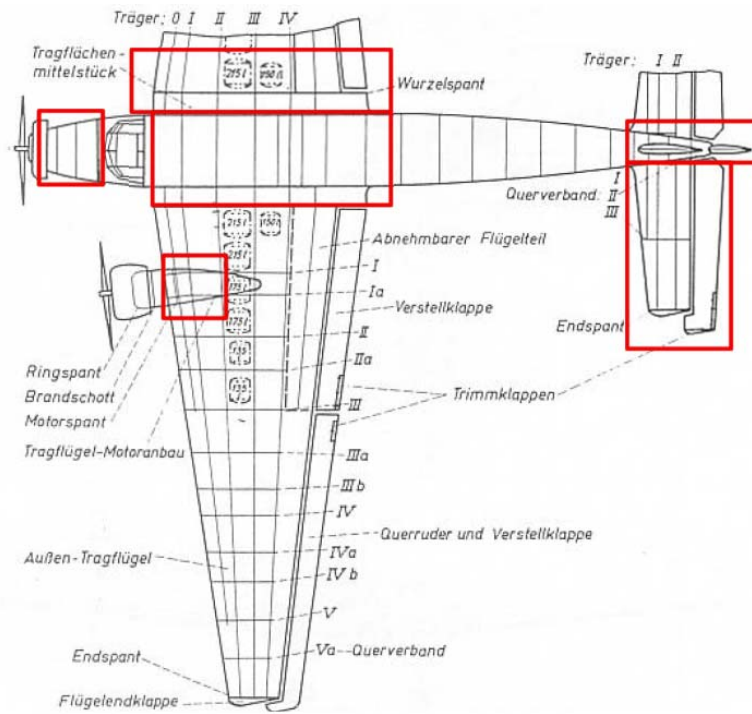


Figure 8 Locations of critical elements on the Ju-52/3m according to FOCA

### Wing

Besides the required structural analyses of the wing spars, a cracked spar on the HB-HOT in winter 2016/2017 led to further investigations regarding the wing structure. The cracked spar was found on the lower, forward spar of the central wing box (see Figure 4 and 5).

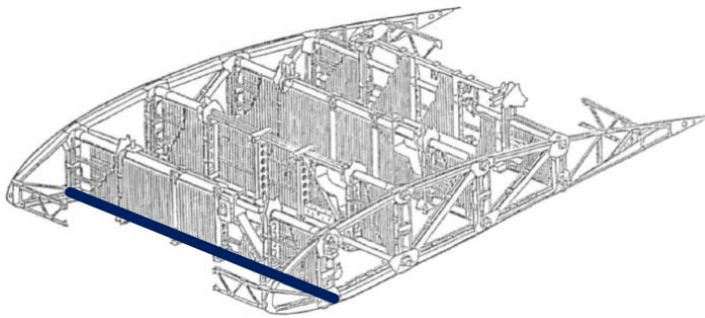


Figure 9 Blue line shows the lower, forward spar of the central wing box



Figure 10 Crack on the disassembled spar

Furthermore, additional borescope inspections (see Figure 11) on all. The possibility of further defect spars was ruled to ensure airworthiness.



Figure 11 Borescope inspections of the cracked spar II

To create a more detailed evaluation of the cracked spar tube, fractographical and material investigations were performed by the ZAV. It was found that the origin of the crack was a drain hole with poor production quality. Furthermore, the material investigations delivered information about the chemical composition and heat treatment of the spars. It was found to be comparable to today used 2014-T3 or 2024-T3. According to the history of the material standards published in the years before world war two, it was not possible to identify properly the material used in the German Ju-52/3m from 1936 (D-AQUI) and the three Swiss aircraft built in 1939. In addition, material parameters for fatigue evaluations or fracture mechanics calculations, such as crack growth life predictions are not available, because the material standard from then shows only classical static properties such as yield, strength and Young's modulus.

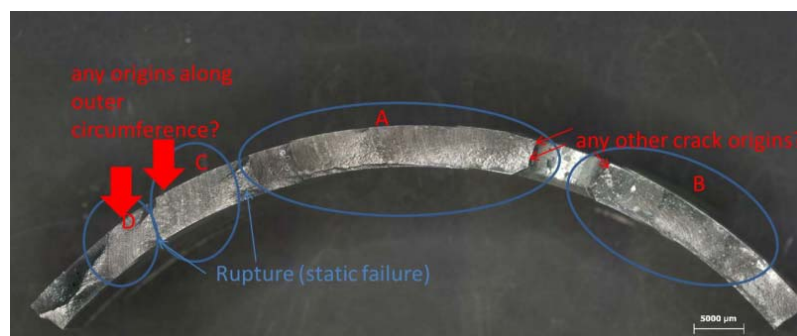


Figure 12 Fractographical analysis of the cracked spar tube

### Aerodynamic loads investigations on the outer wing of the Ju-52

For load calculation, in the first place, load cases need to be defined. Different critical load cases based on the developed flight envelope (based on CS23.333, see Figure 13), could be outlined. In this way, it was possible to determine the most loaded spar on each one of the defined load cases, which turned out to be Spar II.

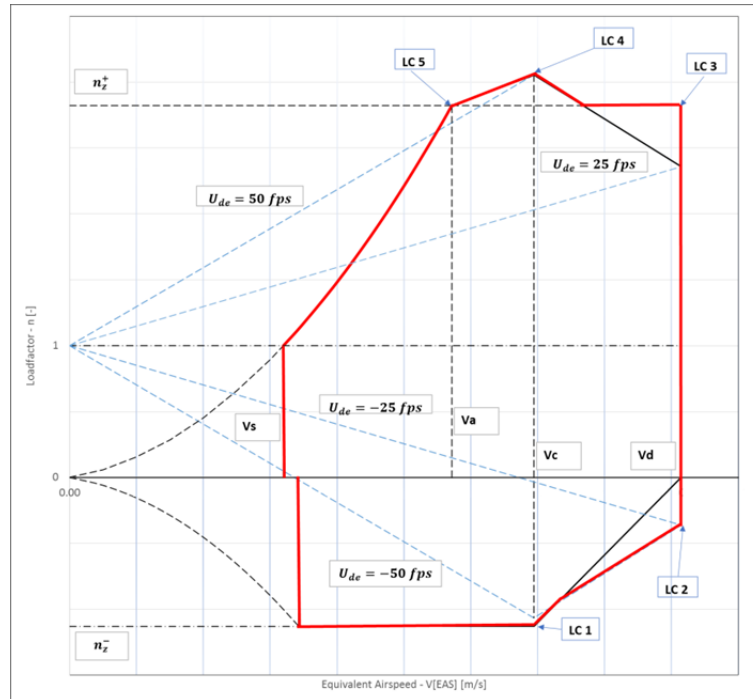


Figure 13 Flight envelope Ju-52

A single wing model of the Ju-52/3m was built in XFLR5. This software can analyze a 3D model of an aircraft (see Figure 14) based on panel methods (here Vortex Lattice Method). Not only the applied loads on the critical structural points (where ribs and spars of the outer wing cross) were studied, in fact, bending moment diagrams, shear forces diagrams and moments of torsion were calculated based on the data provided by XFLR5. On top of that, all these parameters were calculated on each of the spars of the wing separately.

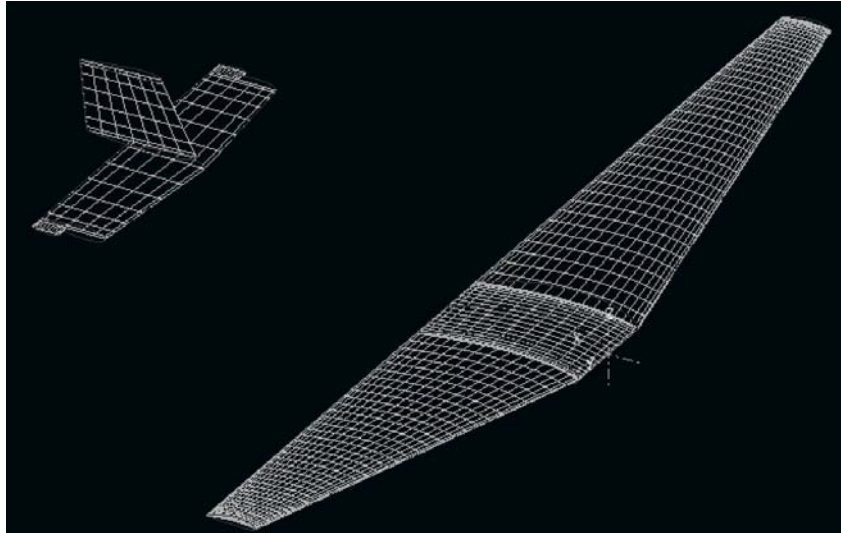


Figure 14 XFLR5 model for wing load distribution calculation

Further, in 2018 a master thesis was finished which focused on the aerodynamic loads on the outer wing. The study investigated the characteristic Ju-52/3m double-wing using CFD (ANSYS FLUENT), as it is thought to be important studying the airflow (see Figure 7) around the double-wing airfoil due to its impact on the wing loads. It was found that from a structural point of view the small wing of the double wing configuration of the Junkers Ju-52/3m does not play a key role.

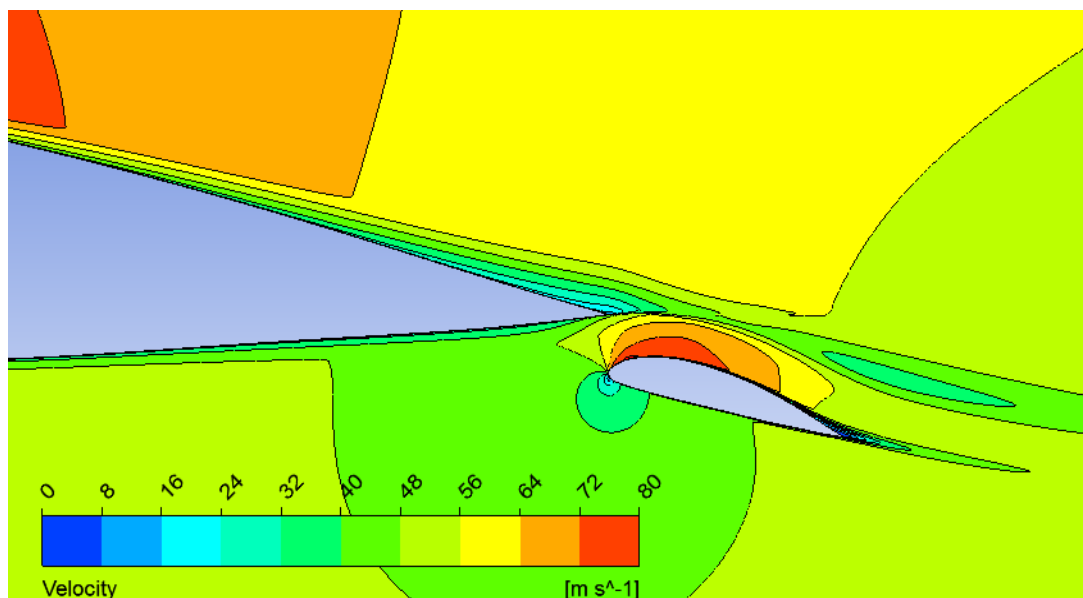


Figure 15 2D-CFD-model



*Special Case - Left wing modification HB-HOP*

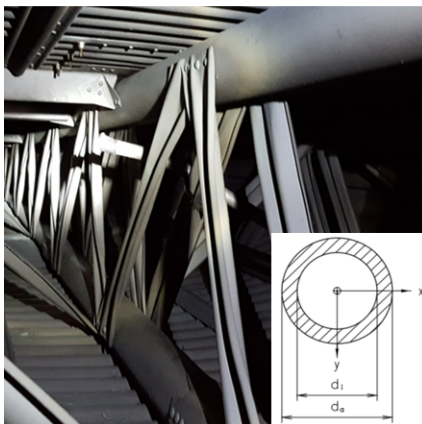
Due to further investigations of the wing structure, the special case of HB-HOP needed to be examined. In 1965 a crash on the ground caused a repair of the whole outer sections on the left wing.



Figure 16 Serious damaged left wing HB-HOP after a crash on the ground (1965)

The new structure is a modification of the original one. While the original construction's spars are tube-profiled, the modified version is based on hat-profiles (see Figure 17). Due to the required re-evaluation of all performed structural repairs, a new static strength verification was needed. The ZAV accomplished this with a conservative approach by a systematic comparison of equivalency for original and modified profiles on all affected wing areas. In addition to this, the used material 2024-T3 for the modification was found to have a higher strength of 7%. By these results, the wing's load capacity and structural integrity could be proven.

Original structure



Modification

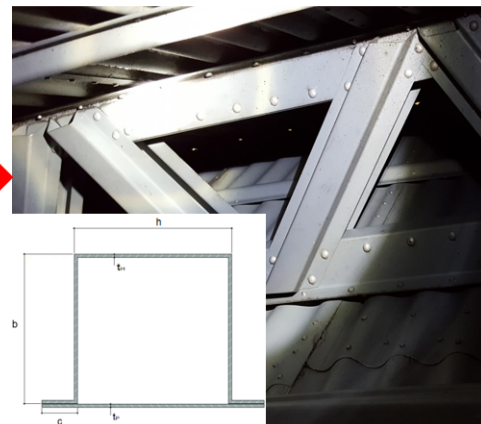


Figure 17 Difference between original (tube-profile) and modified wing structure (hat-profile) of the outer left wing HB-HOP



Nevertheless, further investigations are needed to assess the fatigue behaviour of the splices. Using the mentioned calculated aerodynamic loads a more detailed proof of strength for the splices between new and old structures needs to be verified by more detailed calculations and FEA (see Figure 18).

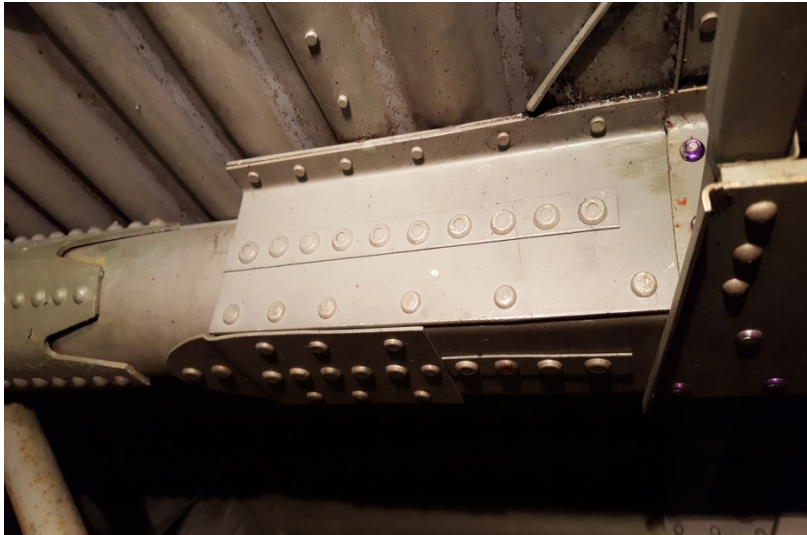


Figure 18 Splice between the modified and original structure

### *Elevator*

Due to the classification as a safe-life component, the elevator trim spindle needed a detailed analysis to ensure the continuous airworthiness of Ju-52/3m. This part is made of a special alloy (steel and bronze) and only static strength data is available from old data sheets of 1930 (“Flieg” standard). Even durability life data was not known.

Therefore, in 2016, the ZAV carried out safety and hazard analysis based on current standard CS23.1309. Further investigations focusing on the elevator, its attachment points and the elevator actuator spindle (see Figure 19) were performed.

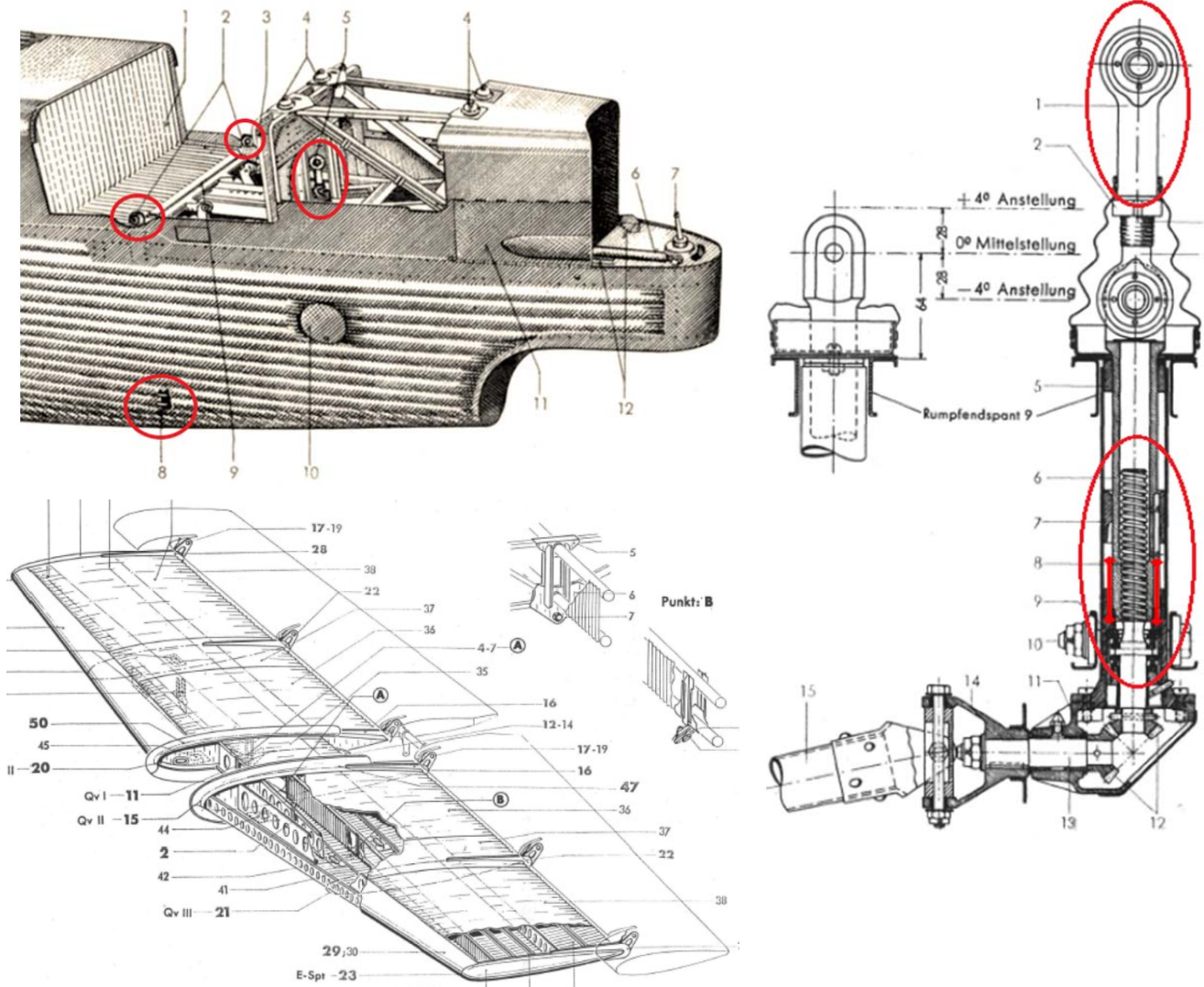


Figure 19 Overview of the Ju-52's rear section, the elevator, and its attachment points, as well as the spindle showing critical points

To do so, a conservative approach with higher loads than expected was used for the structural analysis to show that the elevator's safety is ensured. Nevertheless, in 2018 a more detailed theoretical approach was finished (CS23.421 to 23.427). In this study, aerodynamical analyses using XFLR5 (see Figure 20 ) were used to adapt the flight envelope load cases to the elevator. As expected the highest loads were found during abrupt pitch-up and pitch-down deflections (CS 23.423).

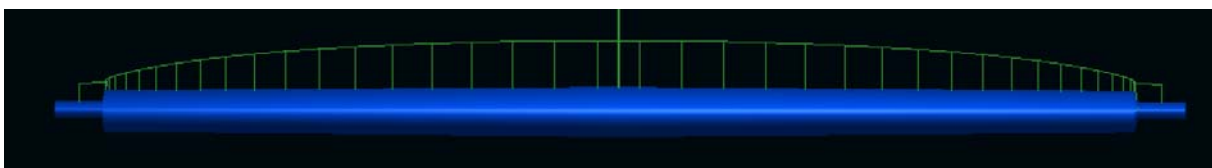


Figure 20 XFLR5 model of the Ju-52 elevator with 3° deflection

Those loads were applied on a developed truss model (in SkyCiv) of the elevator to assess distributed loads for all attachment points and to finally perform static strength analyses.

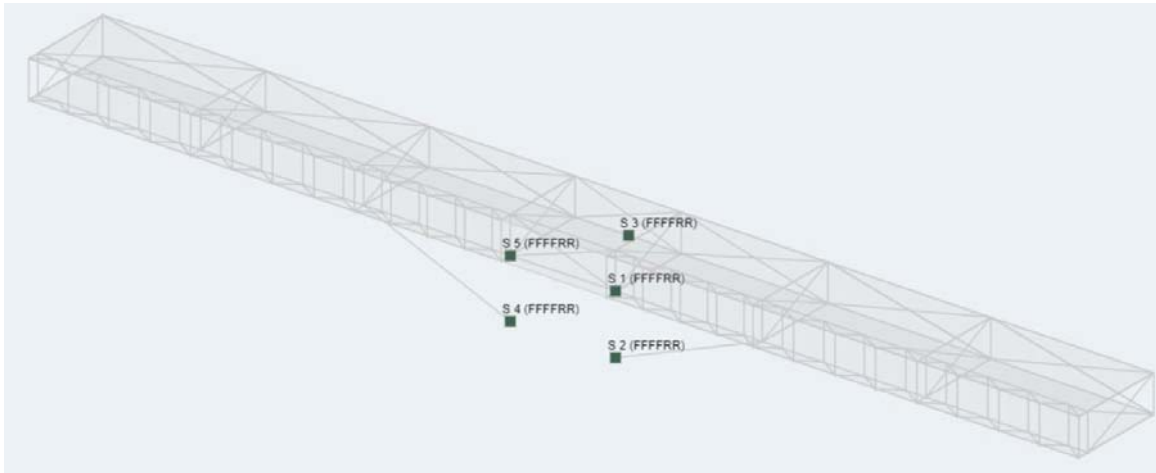


Figure 21 mechanical model of the Ju-52 elevator in SkyCiv

Nevertheless, due to its safe-life classification, further analyses in the form of instrumentation with strain gauges were necessary and accordingly integrated into flight test investigations in 2018. Not only measuring typical loads on the spindle during 23 flights were performed, but also a stress-to-load relation was determined. Firstly, loads acting on the spindle were generally low but showed higher pressure rates during start and landing. Secondly, it was concluded, that a detailed flight testing is necessary to derive the local stress histories due to the more dynamic loads acting on the elevator during take-off and landing.

Based on this study, the crack initiation life (CI-Life) was calculated in a follow-up report. Even with a conservative approach for materials and CI-life, the results led to the conclusion of a high margin of safety and a given safe life characteristic.

### *Spectrum*

Not only to validate all already theoretical approaches of this program but also to have a better understanding and finally establish a basis for all left investigations, flight tests adapted to the JU-AIR configurations and flight missions were performed.

In summer 2016, a Bachelor thesis was done to develop a first master event spectrum for the Swiss Ju-52 usage. This study showed not only that gust loads are important and will influence the fatigue life, furthermore, but the weight and especially the fuel level in the tanks also have an impact. Due to these conclusions, a more specific study was performed about the impact of different tank configurations. It was found that the Swiss Ju-52 can fly longer and with a different fuel sequence of the tanks. The Swiss Ju-52 has a total of 7 tanks whereas the D-AQUI only has 6 tanks. As a final

product of this project, a JU-AIR specific design spectrum with a stress sequence for 2 types of flight missions and 250 flight hours was defined.

To be able to estimate the lifetime as accurately as possible depending on the actual operating loads, a JU-AIR specific load spectrum based on flight tests needed to be developed. In spring 2017, a new study was launched to measure  $n_z$  spectrum and sequence for the whole season with MEMS loggers from MSR Electronics GmbH in Switzerland. While “MSR165” data loggers have the possibility to measure for temperature, humidity, pressure, and 3-axis acceleration, “MSR160” data loggers also have four additional analog inputs which can be used for strain gauges. The data logger was placed as close as possible in between the range of the calculated center of gravity (see Figure 22). All three aircraft were equipped in 2017.

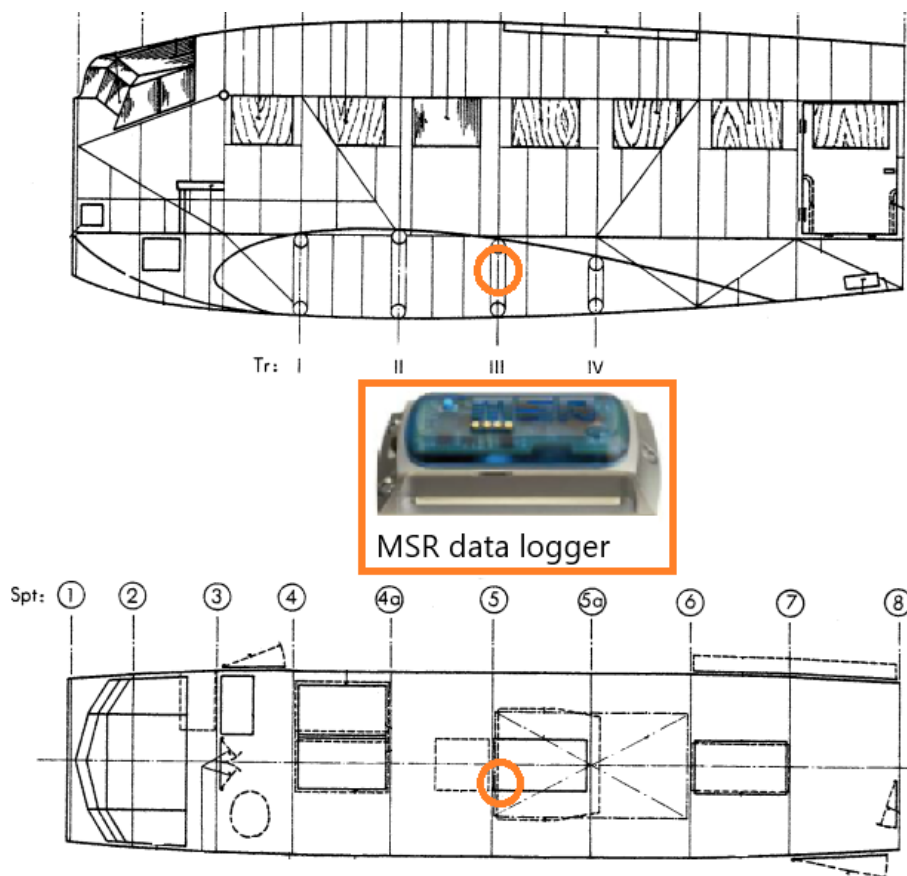


Figure 22 Placement of the MSR data logger with integrated IMU

Due to the broken spar found at HB-HOT and its needed replacement, the opportunity was given to instrument the wing spars with strain gauges in May 2017. The strain gauges were attached on the lower spar III and on the lower and upper spar II by the Transmetra GmbH (see Figure 23)



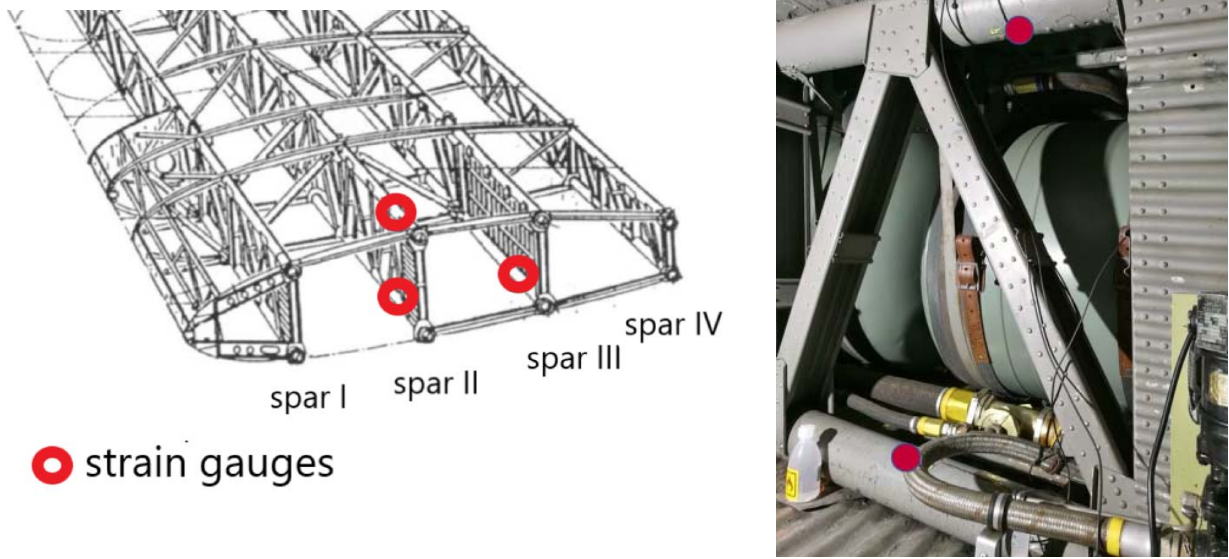


Figure 23 Strain gauge installations on wing spars II and III

During flight season 2017 data was collected for 260 flight cycles with a total flight time of 250 flight hours. A master thesis was finished in summer 2018 and statistically evaluated the generated data. Its investigations led to preliminary results which are pointing on a sharper flight spectrum in contrast to the previously created JU-AIR design spectrum and the MINITWIST spectrum (see Figure 24).

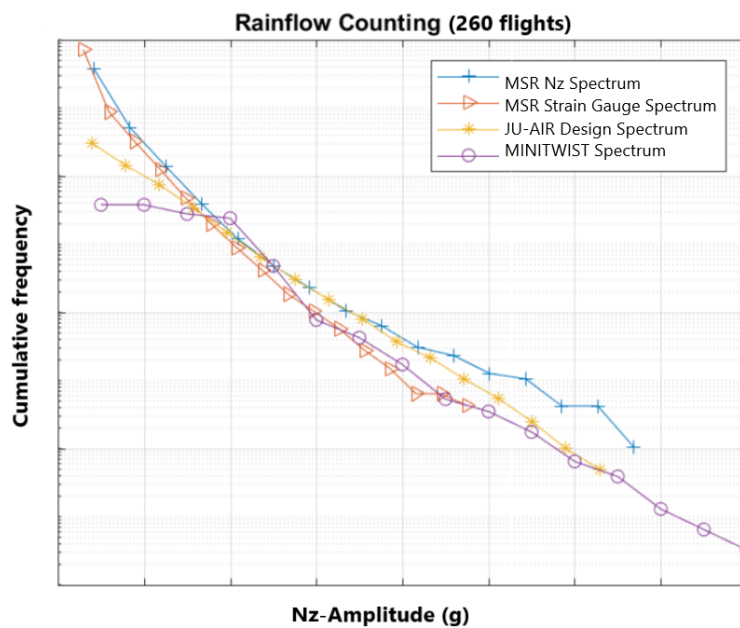


Figure 24 Comparison of the spectra: measured  $n_z$ , measured by strain gauge on wing root, theoretical JU-AIR design spectrum, and the MINITWIST spectrum

Overall, further investigations need to be performed for a better understanding and to create a profound stress-to-load ratio for different weight configurations (see Figure 25).

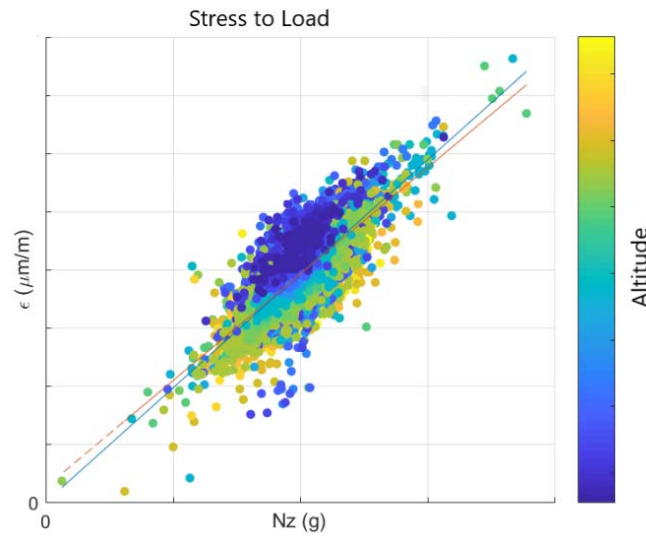


Figure 25 Stress-to-load correlation

Turning back to the cracked spar, a spar-specific spectrum was used to calculate the crack growth using AFGROW and by that NASGRO equations. In addition to this, it was compared with the MINITWIST. Due to the result of a sharper spectrum, the crack growth was way more accelerated. In Figure 26 you can see the outcome.

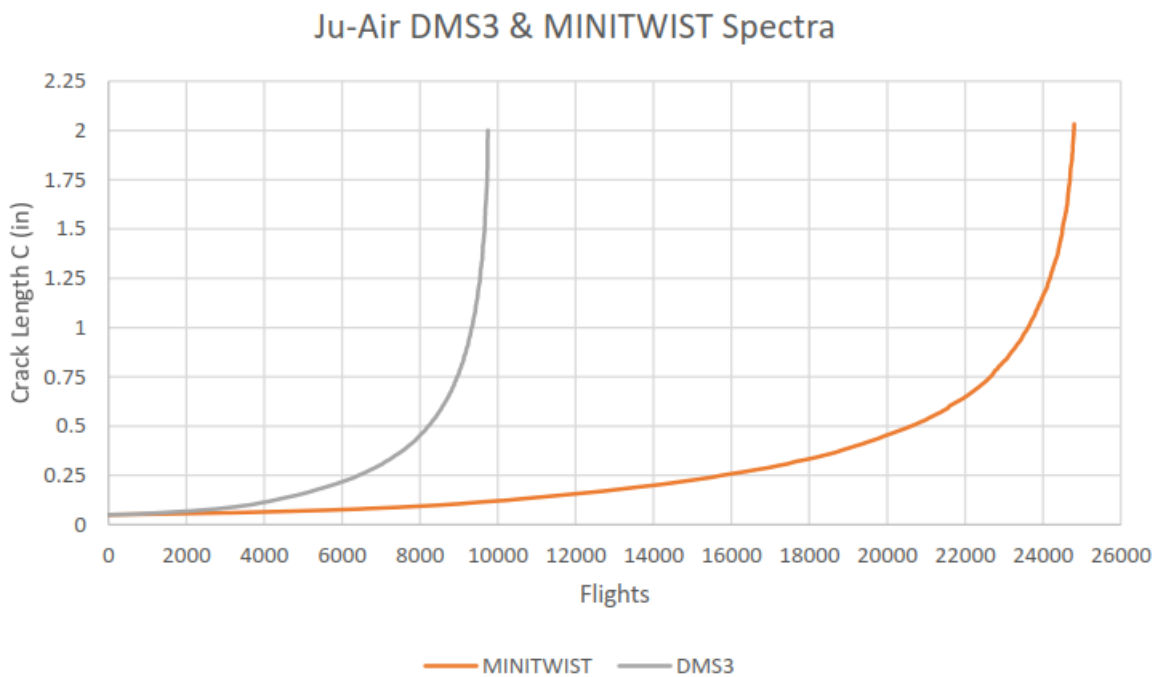


Figure 26 Crack Growth comparison between MINITWIST and the sharpest measured strain gauge (DMS3) for spar II

## **Next steps**

### *Complete Phase II and reconstruction*

To conclude, consecutive investigations belonging to phase II are required to create a profound Supplemental Structural Inspection Document (SSID) and approved by FOCA to ensure continuous airworthiness of Swiss Ju-52.

On August 4, 2018, the Ju-52 HB-HOT was destroyed in an accident in a mountainous area in Switzerland. The aircraft crashed into the southern slope of Piz Segnas at an elevation of 2540 m ASL. All 17 passengers and three crew members were killed. The ongoing accident investigation of this tragedy performed by the Swiss Transportation Safety Investigation Board (STSB) led to several additional regulations imposed by the FOCA. At this point, the remaining Ju-52 aircrafts are grounded until further inspections are carried out and for the time being, as various technical measures required by the FOCA have not yet been completely defined and implemented.

Nevertheless, the JU-AIR is preparing for the long-term continued operation of its historic Junkers Ju-52 and is investing in its future. For this purpose, today's 80-years-old aircrafts are completely dismantled and overhauled. Furthermore, the JU-AIR plans to establish the engineering capability to maintain the fleet for operation until the 100-years-anniversary.



## 4.4 Hunter MK58/68

Zurich University of Applied Sciences, and Gottier Engineering GmbH

In 1994 the Hunter aircraft were taken out of service from the Swiss Airforce. A few of these retired aircraft were purchased by a private organization. In order to get the permit to operate these aircraft on a civil basis a new maintenance concept, similar to an SSID (ref.1) was required.

In a first step, all available maintenance documents were reviewed and if necessary adjusted to the new operation status. As an example, the entire arming of the aircraft is removed from these privately-owned aircraft and thus no further maintenance for arming equipment is required. In addition, several maintenance positions were adjusted to the new much shorter operation times: Due to the fact that the number of flown hours per year is much smaller, the appropriate maintenance steps are now performed once a year and no longer after defined numbers of flying hours. In most cases this resulted in a more stringent maintenance program.

In a second step, additional locations were reviewed from their fatigue criticality point of view. It revealed that four locations had to be considered more in detail (see Figure 27).

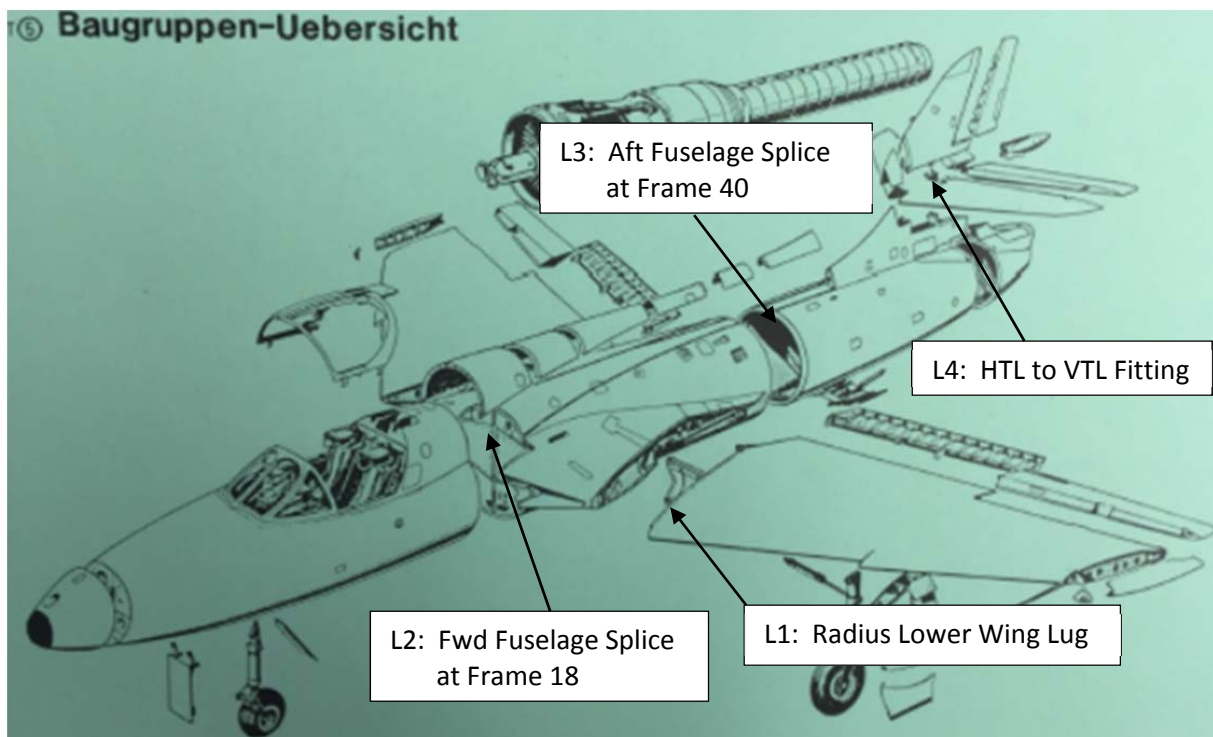


Figure 27 Four most critical locations

An in-depth investigation of these locations was performed. As a result of that following statements can be made:

L1: Radius at Lower Wing Main Spar Lug: The modification (increased radius at the lug) was established and as a result the inspection interval based on the crack growth life is drastically increased.

L2: Forward Fuselage Splice at Frame 18: The cockpit section was separated from the mid-fuselage section in order to perform an in-depth inspection of the four connection points. During this separation process, it was obvious that an additional joint in the upper part of the fuselage transfers a big portion of the fuselage bending moment. Based on this observation it can be concluded that the inspection intervals from the ref. 1 study are slightly conservative.

L3: Aft Fuselage Splice at Frame 40: This splice consists of 15 bolts and thus can be considered as a fail-safe structure. In addition, a thorough inspection of the 15 connection points was performed and no damage was discovered.

L4: Horizontal Tail (HTL) to Vertical Tail (VTL) Fitting: This part was replaced at the time the acquisition of the aircraft by the private organization. Thus, the fatigue life of this part is very long. Based on these results it can be concluded that these four locations can be considered as non-fatigue-critical and therefore additional inspections would not be justified.

Thus, the maintenance concept of the Hunter aircraft operated by the private organization consists of the adjusted maintenance documents mentioned above. No additional inspection is necessary for additional locations.

The appropriate documents for the aircraft maintenance are now in preparation.

#### **References:**

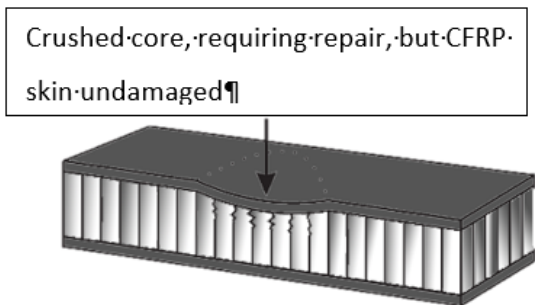
Ref.1 SSID stands for "Supplemental Structural Inspection Document"

Ref.2 "Structural Integrity Study for the Ageing Hawker Hunter Fleet", Master Thesis, 2016

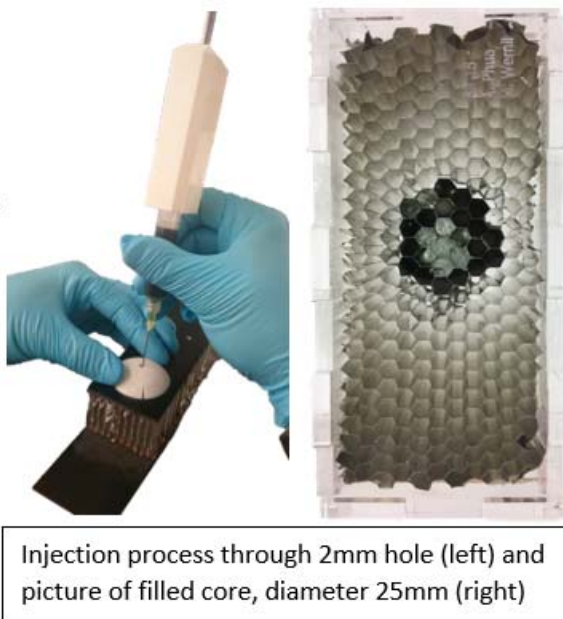
## 4.5 Fatigue Test of Minimally invasive repaired sandwich core

Zurich University of Applied Sciences, and RUAG Switzerland Ltd.

**Goal:** Temporary stabilization of the impacted and crushed core



**New concept:** Minimal-invasive approach by injecting repair resin through very small 2mm hole. The process has been developed at ZHAW, Institute of Materials and Process Engineering and demonstrator had been manufactured.



**Current task:** demonstrate that the filled core cells do not act as a crack inhibitor during fatigue testing.

**Performed test:** Sandwich samples filled with resin to simulate partial filling with and without adherence to core cells.

Results: No crack initiation at repaired section observed after 120'000 cycles (70% of ultimate strength)



Fatigue test of sandwich sample under shear loading. Core cells continually checked for cracking, yet no cracks detected near partially filled core cells

## 4.6 F/A-18 C/D Structural Refurbishment Program (SRP)

RUAG Switzerland Ltd.

As described in the 2017 Swiss National Review, RUAG Aviation is currently performing a second Structural Refurbishment Program (SRP 2) to ensure the operational availability of the Swiss F/A-18 for its required service life of 5'000 FH. Due to the decision to increase the service life from 5'000 FH to 6'000 FH, the SRP 2 modifications are being developed in accordance with the new service life requirement of 6'000 FH. The recertification itself of the aircraft to 6'000 FH is not covered by this Service Life Extension Program (SLEP).

For the SRP 2, around 250 structural locations are being assessed, 209 locations inspected and 54 modifications developed. The modifications and inspections are divided into two packages and will be implemented in the fleet sequentially.

After successful completion of the prototype of the first refurbishment package SRP 2.0 in 2018, the serial implementation of modifications for the fleet is in progress and shall be finished by 2022. The focus of the modifications are blendings of the Center Fuselage formers in the vicinity of the Leading Edge Extension, replacements of fracture and maintenance critical parts with an improved design, such as the bootstrap and speed brake longeron, as well as the modification of other maintenance critical parts, such as several locations of the lower outboard longeron in the aft fuselage.



Figure 28 Blending of two critical locations on Former 395 with the help of a robot

The work of the prototype aircraft of the second refurbishment package called SRP 2.1 began in autumn 2018 and will continue until mid-2019. In a first step, about 100 inspections and 29



modifications will be performed. Locations currently being addressed include the inner wing at the rear spar/kick rib, engine air inlet former Y419, aileron outboard hinge, fuselage center section former Y395, nacelle strut attachment former, inner wing forward spar lugs, and the outer wing forward spar.

Challenges of the serial fleet modifications are existing non-conformances from the manufacturing and blueprint deviations.

Before the end of the program, definitions and substantiations for potential periodic follow-on inspections of the considered locations are required. In order to show a sufficient structural life, depending on inspection findings during the refurbishment program, damage tolerance analyses are expected to be required for 50% of the locations which are inspected only but not modified. Additional damage tolerance analyses are required for aircraft specific repairs.

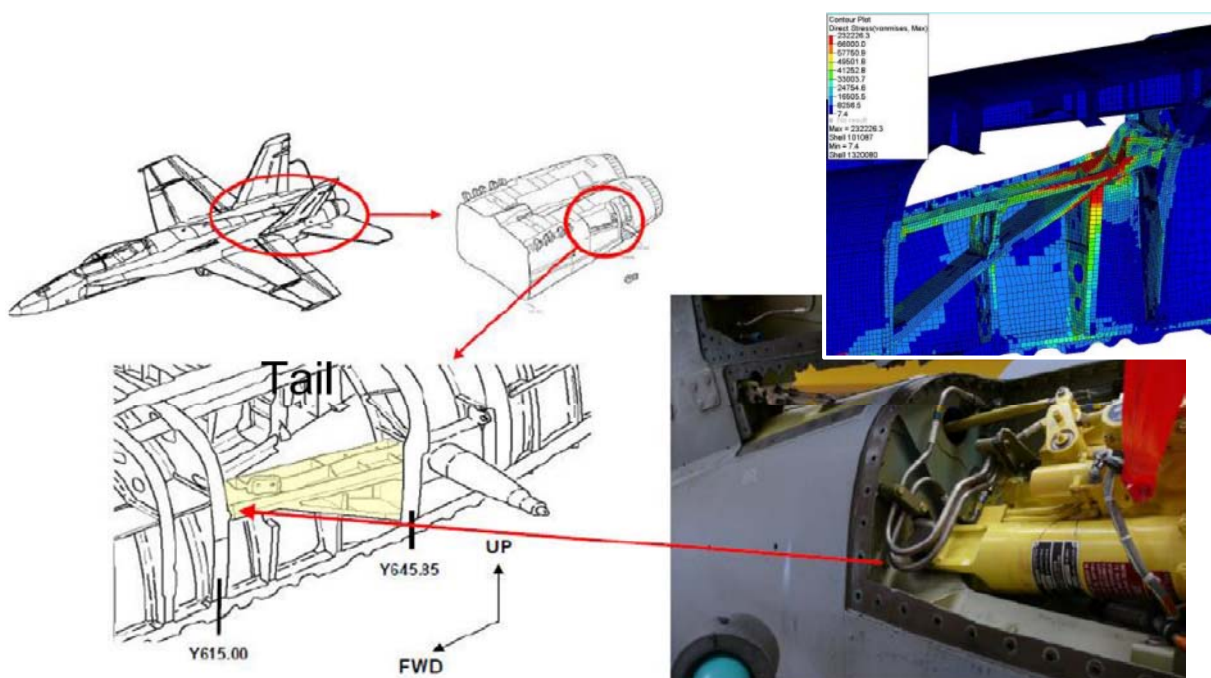


Figure 29 Horizontal stabilizer bootstrap replacement by modified part

### Periodic Pre-Refurbishment Inspections, Fleet Repairs, Preparation for Inspection Findings

The assessments of several locations showed that some of these locations will already have experienced too much fatigue damage at the time of implementation of SRP 2. This may lead to either potentially large cracks, prohibiting the planned modification for which full life could be shown. To ensure the fleet safety and availability, periodic inspections of these locations were initiated to find issues as early as possible, avoiding difficult repairs and the risk of long ground time

during SRP 2. Furthermore, due to the late implementation, a theoretical full life can't be shown since a life reset won't be achieved. This requires the program to be concluded in the range of certain service life of each aircraft which proves a logistical challenge.

An exemplary issue to ensure flight safety before SRP 2 is the inner wing inboard Trailing Edge Flap (TEF) Hinge for which a recurring inspection program and a robotic reblending of three zones is underway to reduce the stress concentration. As in-service cracking occurred on several parts and locations, multiple strategies to achieve full life solutions are required besides the development of the actual modification. Another example of a location at which cracks occurred in the inspections prior to the SRP 2 is the lower outboard longeron, where the installation of the planned modification has been performed as a repair. Hence an advanced modification will be developed to achieve a full life.

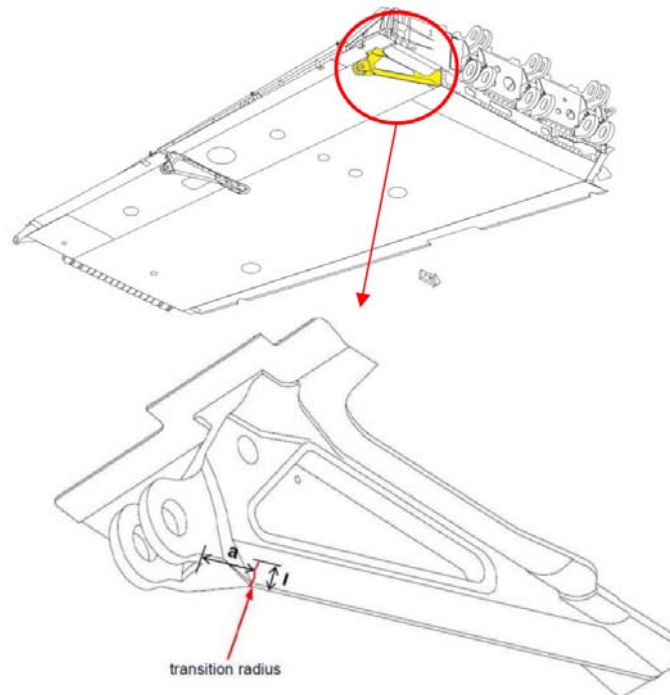


Figure 30 Inner wing inboard Trailing Edge Flap Hinge modification

In order to reduce the aircraft ground time for the performance of the SRP 2 program, standard repair schemes are being developed to accelerate repair development for specific damages.



## 4.7 F/A-18 C/D Service Life Assessment Program (SLAP)

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A service life assessment program was initiated in 2017 and is planned to continue until 2023, with the intent to recertify the operational aircraft service life from 5000 FH to 6000 FH. The program that covers the structural recertification will address in priority PSE (Primary Structural Elements). In the second phase, the evaluation of SSE (Secondary Structural Elements) will be conducted. Due to the volume of work, this represents, not all SSE will be reviewed in detail. Alternative methods will be investigated to determine how other parts can be substantiated.

The design spectrum used to size and justify the aircraft structure in fatigue is known to be more severe with respect to maneuver loadings than the current fleet usage spectrum for some areas on the A/C. However, the buffeting environment flown by the Swiss Air Force is much more severe than assumed during the original certification of the aircraft. This situation, in some cases, increases the substantiation effort to extend the life of the aircraft because the recertification effort needs to account for the more severe fleet usage in addition to an extension of 1000 FH.

As a result, it is expected that some actions will be required on the aircraft to extend the life of specific locations or to mitigate the airworthiness risk till to the service goal of 6000 FH. These actions could include a part replacement, a preventative modification or a new periodic inspection to monitor the safety of the aircraft.

In special circumstances, it is maybe logistically advantageous to conduct additional testing in order to demonstrate the new requirements by test. This is because some areas on the Swiss Full Scale Fatigue test (called FTS1) were not tested sufficiently to fulfill the new life extension requirements. This approach was considered for the Horizontal Stabilator structure which was subjected to 36'000 FH of simulated Swiss fleet usage. The Horizontal Stabilator is categorized as a Fracture Critical structure which is subjected to severe maneuver and buffeting usage in the Swiss fleet. This component test (called FTS2) was performed with the collaboration of the National Research Council Canada (NRC) and was completed in November 2018.

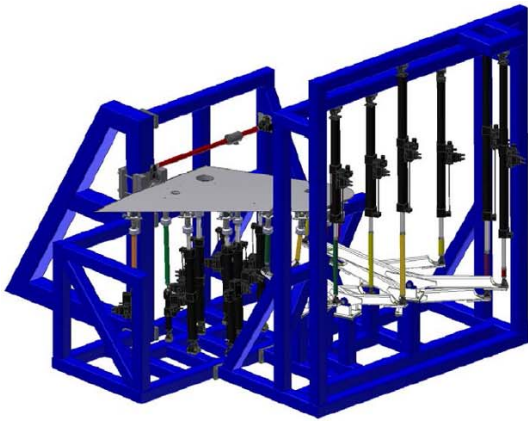


Figure 31 Test Configuration of FTS2 Fatigue Test

## 4.8 Patrouille Suisse Fleet Management

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### Patrouille Suisse

The Patrouille Suisse was established in 1964 as the Swiss Air Force display team, flying at this time the Hawker Hunter aircraft. Since 1995 the team flies standard Swiss Air Force F-5E, painted in a specific red and white paint scheme. Beneath the air display usage, the same aircraft are used for regular Swiss Air Force operations as well.

Today the Patrouille Suisse consist of a 6 aircraft formation, whereas two aircraft are used for solo routines. In total, 9 red and white F-5E are specifically used for the Patrouille Suisse displays.



Figure 32 Patrouille Suisse (Picture © Yannik Barthe Films / VBS-DDPS)

### Swiss Air Force F-5E/F Fleet

The Swiss Air Force fleet size of originally 110 acquired F-5E/F decreased to a total of 26 aircraft, whereas 21 are F-5E single-seaters and 5 are F-5F double seaters. Usage tracking of the Swiss Air Force F-5E/F fleet is done by a mix of single  $N_z$  exceedance counters and electronic data recorders, recording  $N_z$ ,  $N_y$ , altitude, and Mach time-history data.

Inspection intervals are defined according to the damage tolerance approach. Therefore a fleet reference spectrum was established based on usage data. This reference spectrum is used to

calculate the inspection intervals. The actual usage is checked on a yearly basis: it should not show a higher severity than the reference spectrum to guarantee conservative inspection intervals.

### Patrouille Suisse Usage

Through individual aircraft tracking it was noticed that the two aircraft flying the solo routines (position 5 and 6) show a significantly higher severity  $N_z$ -wise than the rest of the formation. The severity is highly dependent on the flown routine and maneuvers. The usage severity of the solo aircraft can reach the double of the general average fleet usage severity. Whereas the rest of the aircraft used in the formation, show even a lower severity than the fleet average.

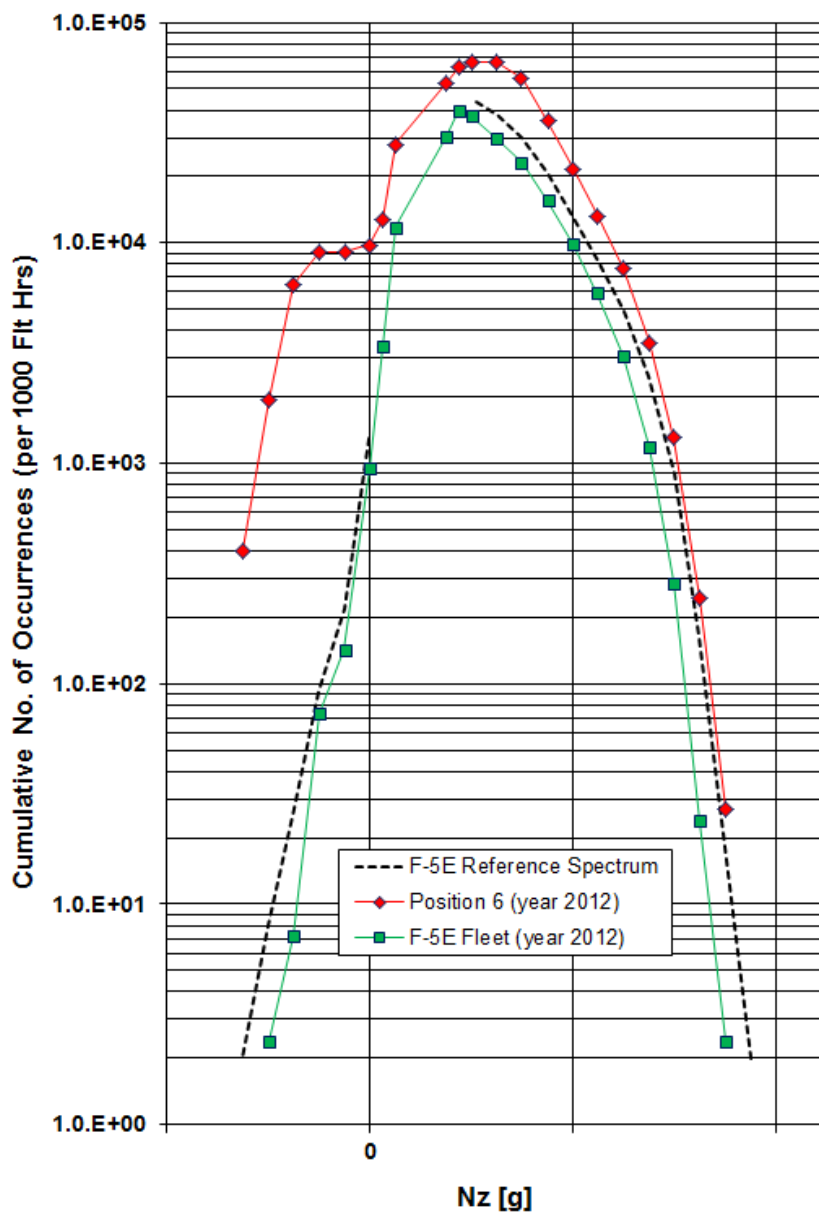


Figure 33 Typical  $N_z$  exceedance curves of the solo routine aircraft compared to fleet usage. The fleet showed a severity of 0.7, whereas the aircraft used for the solo routine (position 6) showed a severity of 1.7 compared to the F-5E reference spectrum. Typical

## **Fleet Management**

The usage tracking of Patrouille Suisse aircraft consist of the fleet-wise  $N_z$  and  $N_y$  tracking and additionally of the number of solo routine seasons and flight hours flown on each position.

Since 2003 the positions of Patrouille Suisse aircraft in the formation rotate each year. For aircraft flying the solo routines, it is imposed that they have not flown on these positions for at least 2 preceding years. This simple rule results approximately in an equal overall usage severity for each of the Patrouille Suisse aircraft that does not exceed the severity of the reference usage spectrum.

Additionally, each aircraft flying solo routines has a special inspection program defined to take into account faster crack growth during this period on locations with recurring inspection intervals less than twice the hours flown in the season. Thus taking into account a possible severity twice as high as the reference spectrum.

Up to now, this simple approach proved its effectivity. Some fatigue damages were detected prior to regular scheduled inspection within the special inspection programs for solo routine aircraft.