Review of Aeronautical Fatigue Investigations in Switzerland

May 2023 – February 2025

Swiss National Review

of the International Committee on Aeronautical Fatigue

and Structural Integrity

ICAF

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and Structural Integrity

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Summary

This document reviews the work that has been done in Switzerland in the field of aeronautical fatigue. Contributions to the document were made by Zurich University of Applied Sciences (ZHAW), Lucerne University of Applied Sciences and Arts (HSLU), RUAG AG and Pilatus Aircraft Ltd. This document represents a chapter of the ICAF National Reviews document that is published online on the ICAF website. The format of the review conforms to ICAF requirements.

Prepared and approved for the presentation for ICAF website www.icaf.aero

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1. Introduction

The present review gives a summary of the work performed in Switzerland in the field of aeronautical fatigue in the period from May 2023 to February 2025. Contributions were made by the following organisations:

- **Zurich University of Applied Sciences (ZHAW)**; Centre for Aviation of the School of Engineering
- **Lucerne University of Applied Sciences and Arts (HSLU)**; Department of Engineering and Architecture
- **RUAG AG**, Emmen; Business Area Air
- **Pilatus Aircraft Ltd**

The many interesting contributions are gratefully acknowledged, especially the effort of Xinying Liu, Cyrill Kalberer, Nicola Schneider, (ZHAW), Markus Gottier (Gottier Engineering), Dejan Romančuk (HSLU), Ingrid Kongshavn (RUAG AG) and Milian Seiler and Vincenzo Rossi from Pilatus Aircraft Ltd.

The financial support by the Swiss Federal Office of Civil Aviation (FOCA) is gratefully acknowledged for the activities of the Ageing Aircraft project. The Swiss Federal Office for Defence Procurement, armasuisse, is gratefully acknowledged for the supervision and funding of work carried out for military aircraft at RUAG AG, Emmen.

2. Swiss Aviation Activities

Kopter – a Leonardo Company

The Kopter Group based in Switzerland, a Leonardo Company since April 2020, is developing a new generation of single turbine helicopter – the AW09 – that delivers best in class performance, the largest cabin and cargo volumes, outstanding modularity, the highest safety levels and modern design and avionics.
Positioned in the 2.8 metric ton class, the AW09 stands out as the only all-new single-engine helicopter design introduced in the last four decades, see figure 1. Engineered with cutting-edge technologies and advanced materials, it sets a new benchmark in its category. Key features include a crashworthy composite structure and fuel tank, an IFR-capable Garmin G3000H avionics suite, a low-vibration main rotor, a shrouded tail rotor for reduced noise, and exceptional cabin flexibility to accommodate a range of mission profiles.

The cabin's modular design maximizes the flat floor, class-leading cabin volume, and innovative high-ceiling concept, allowing for versatile configurations. It accommodates up to eight individual crash-worthy passenger seats and provides unobstructed rear access for equipment and medical stretchers via clamshell doors. Leveraging its adaptable layout, the AW09 serves as a highly versatile vertical lift platform, ideal for a wide range of missions.

The AW09 offers outstanding payload and sling-load capabilities, driven by the reliable Safran Arriel 2K 1,000 shp class turbine. The engine's fuel efficiency, combined with the helicopter's crashworthy fuel tank, enables the AW09 to achieve a maximum range of over 800 km (432 nautical miles) or a maximum endurance exceeding 5 hours. With its dependable engine performance and extended operational reach, the AW09 delivers versatility for a wide range of missions. First certification flights for EASA were conducted in 2024. There are still some challenges but hopefully bey end of 2025 the Kopter Aw09 will be certified and afterwards delivered to first customers.

Figure 1: Kopter AW09 Flight Testing in Mollis CH

The Kopter Group is also working on an innovative hybrid electrical solution based on the AW09 for developing a very sustainable helicopter. The ultimate goal is to offer lower emissions, simplified emergency procedures with efficient operation and high safety standard. These new technologies will provide new operational scenarios for operation in congested hostile areas, simplified training procedures, and improved public acceptance.

Aviation Research Center Switzerland (ARCS)

Switzerland, unlike other European countries, did not have a national competence center for aviation research until mid-2017. The Swiss aviation sector, though, requires greater innovation if it intends to further improve its efficiency, safety and environmental performance. That's why the Swiss Federal Council, in its aviation policy report published in 2016, called for the creation of such a center that would work in close cooperation with the aviation industry and public authorities. The ZHAW School of Engineering's Centre for Aviation (ZAV), the University of St. Gallen's Center for Aviation Competence (CFAC) and the Chair of Management of Network Industries (MIR) at the Swiss Federal Institute of Technology in Lausanne (EPFL) founded the Aviation Research Center Switzerland (ARCS) on June 30, 2017. The University of Zurich (UZH) and the Swiss Federal Institute of Technology in Zurich (ETHZ) joined the organization shortly thereafter, and ARCS today is open to other colleges and universities that can provide scientific contributions. In 2024 the Swiss Material Science and Technology also become a member of ARCS with expertise in material testing, emission, and energy technology, and DroneHub for aerial innovation and sustainable future.

ARCS's objectives are:

- to coordinate aviation research activities at universities and to promote training and continuing education pursuant to the Swiss Federal Council's aviation policy report (Lupo 2016)
- to plan and execute value-adding research and development projects in close cooperation with the aviation industry and the FOCA with the aim of positioning Switzerland as an important center for aviation research (Lupo 2016)
- to enable participation in international projects such as HORIZON 2020 and Clean Aviation as well as in projects with EU partners for the purpose of increasing Switzerland's attractiveness.

The above objectives are to be pursued in close cooperation with the aviation industry and Switzerland's Federal Office of Civil Aviation (FOCA) with the aim of strengthening Switzerland's status as an innovative research site.

To cope the challenges of the Swiss Aviation System we launched two strategic initiatives:

- Sustainable Aviation Fuel
  With its goal to support the Swiss Aviation System to reach Net Zero emission by 2050 for sustainable aviation

- Swiss Single Digital Sky
  With its goal to support the Swiss aviation infrastructure with a new design of the airspace for a more efficient operation and for the integration of drones (Swiss u-space) and the new players of urban air mobility.

The biggest effort so far was the development of the Swiss “Road Map Sustainable Aviation” which was released in May 2021. Climate change is one of the greatest challenges of our time. There is now a broad consensus that greenhouse gas emissions must be reduced to avoid serious environmental problems. Like all other sectors, aviation is also called upon to make its contribution to reducing greenhouse gas emissions. The Aviation Research Center Switzerland (ARCS) has therefore launched the project of a Swiss "Road Map Sustainable Aviation" and, together with the company Ecoplan, has prepared the present study. A working group with representatives from SWISS, the Swiss Business Aviation Association, the national airports of Zurich, Geneva and Basel, the federal offices FOCA and FOEN, as well as ETH Zurich and the Zurich University of Applied Sciences ZHAW accompanied the study. In the final phase of the project, easyJet was added to the group. This Sustainable Aviation Road Map shows how aviation to and from Switzerland can reduce its greenhouse gas emissions and climate impact in line with the goals of the Federal Council's long-term climate strategy.
Building on the work of global, European and Swiss umbrella organisations in the aviation sector, a Swiss "Road Map Sustainable Aviation" has been developed, which is based on the following four packages of measures (see figure 2):

- SAF market development: As a central and most important package of measures, fossil kerosene is to be replaced by biogenic and synthetic fuels (Sustainable Aviation Fuels SAF). The measures for SAF market development start on the demand side as well as on the supply side. International, transnational measures have priority but can be effectively supplemented by independent Swiss measures.
- Promoting more efficient aircraft: Promoting and incentivising the use of more fuel-efficient aircraft, especially on long-haul routes, as well as the use of electric aircraft for short-haul and hydrogen aircraft for short- and medium-haul flights in the medium to longer term.
- Operational measures: More fuel-efficient handling of air traffic on the ground and in the air.
- Offsetting: Short- to medium-term CO2 offsetting through voluntary offsetting and participation in the European emissions trading scheme and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), medium to long-term development of global markets for negative emission technologies (NET) to reduce the remaining climate-relevant emissions.

In June 2024, the first assessment of the current situation was carried out by ARCS and the participants of the study. To date, some progress has already been made. However, there is still a long way to go to achieve climate neutrality by 2050. This is partly since aviation in Switzerland has not yet fully overcome the losses of the COVID crisis. An important milestone is the first use of SAF. However, it should also be noted that air transport is still far below the new mandate of a blending quota of 2% in 2025. In addition, however, it can be seen as positive that the use of newer and more economical aircraft of the last generation has enabled a CO2 reduction of 2%. Progress has also been made in reducing CO2 emissions from ground infrastructure. However, compared to airside emissions, they make a smaller contribution (around 5%) to net-zero emissions in aviation.
The assessment of the current situation made it possible to determine the most important current challenges:

- The relatively high price and limited availability of SAF.
- Lack of willingness on the part of major energy companies to invest in the production capacity of new fuels such as SAF.
- The high complexity, the lack of clarity of the regulation of the implementation of the blending requirement for SAF in the coming years.
- The high investment requirements, some of which must be coordinated.

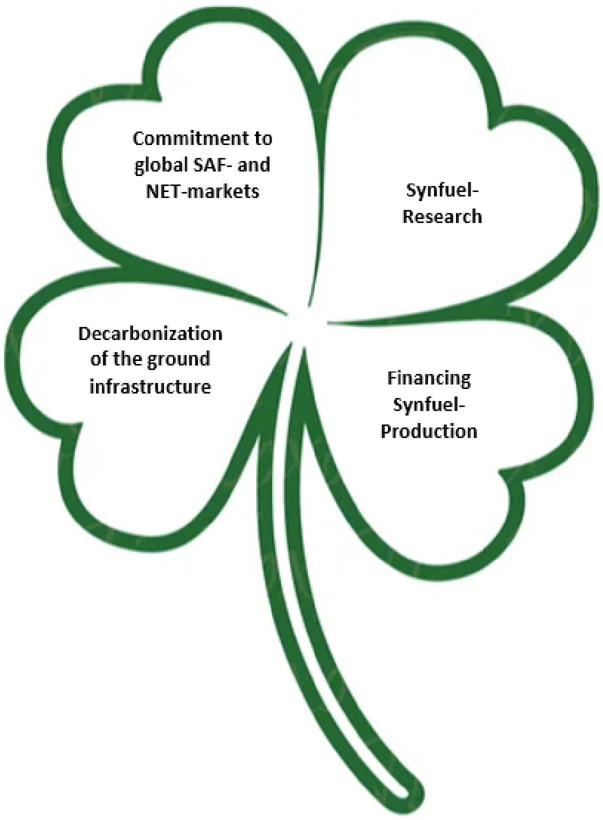


Figure 2: The four main action directions of the Swiss “Road Map Sustainable Aviation”

3. Ageing Airplanes (ZHAW)

Gottier Engineering GmbH, Markus Gottier; ZHAW, Michel Guillaume, Cyrill Kalberer, and Nicola Schneider

Switzerland just had several Hunter MK 58/68 see figure 3, and Vampire DH110/115 which were flight worthy, and which were maintained by private organizations. Flight Prop Heritage at Altenrhein Airport was able to maintain this aircraft with small professional maintenance team and engineering support from Centre for Aviation of Zurich University of Applied Sciences. The supplemental structural inspection documents were developed with the help of Bachelor and Master student projects. With the new EASA requirements for continuous airworthiness the National Authority (FOCA) requested for this complex ageing airplanes a Part 145 organization to maintain this ex Military Jet Aircraft. This was truly not a business for Swiss private organization for the Hunter or Vampire association. All the Hunter MK58 and MK68 were sold to interested organizations like Lortie Aviation Inc. in Canada. Some of this Hunter Jets exceed 9'000 flight hours without any detrimental structural damage. Damage tolerance analysis based on US Air Force standard using AFGOW crack growth software proved the good and reliable structural design with quite long inspection intervals under civil usage spectrum.

Figure 3: Ageing airplanes Hawker Hunter (left), and De Havilland Vampire (right)

De Havilland Vampire DH.110 / DH.115

The main objective of the structural analysis is to perform fatigue calculations at the critical locations of the De Havilland Vampire DH-100 (figure 4) and DH-115, especially at the main connection of the wing. Several critical areas have been identified at this site during the Swiss military service life, which also have been revealed by fatigue testing by De Havilland. The goal is to set a new maintenance interval according to the damage tolerance philosophy of the US Air Force. To achieve this goal, several simulations were carried out using modern methods. First, a Computational Fluid Dynamics (CFD, figure 5) simulation were done with Fluent software to determine the aerodynamic loads, because no suitable aerodynamic data from De Havilland was available. A Finite Element (FE) model of the Vampire aircraft was then developed with ANSYS mechanical software tool to identify the stiffness and stress at the critical locations, see figure 6. The two simulation models are then validated with data from De Havilland. Finally, crack propagation calculations were performed with AFGROW code to determine the service life. The FALSTAFF spectrum was modified according to the usage for the calculations. By using modern methods of damage tolerance, a new maintenance interval could be determined for the two most critical locations on the wing main connection. Due to the lower use and lower stress level for civil operations of the Vampires, the lifespan has increased significantly, resulting in a 4.5-fold increase in lifespan through the crack propagation calculations, see figure 7. The results of the simulations show that the Vampires can still be operated under civil environment to meet the structural integrity. Nevertheless, further research is needed, and the engineering models must be verified against the original engineering data and tests.

Figure 4: Vampire DH-110 with civil registration HB-RYN by FOCA

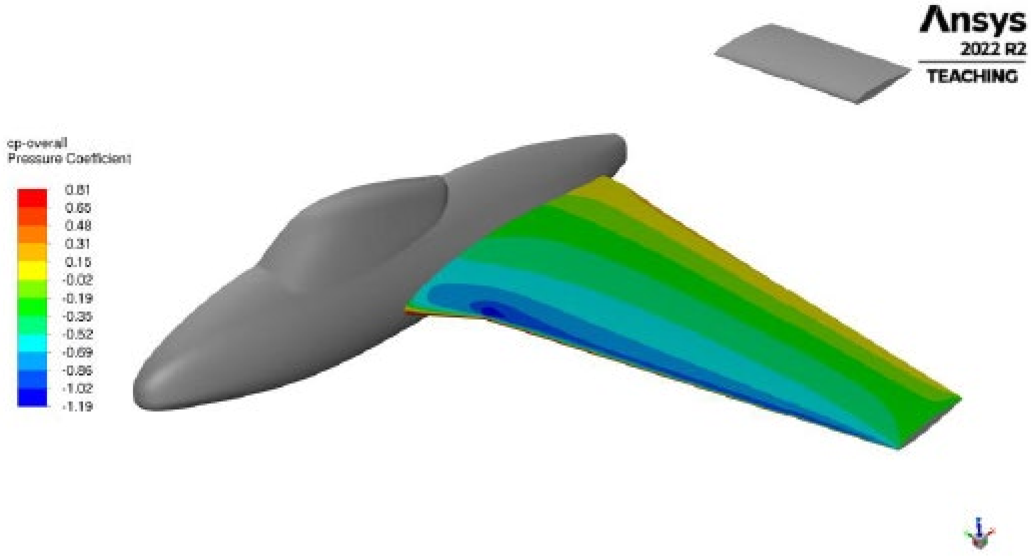


Figure 5: CFD Ansys calculation, cp plot of pressure coefficient

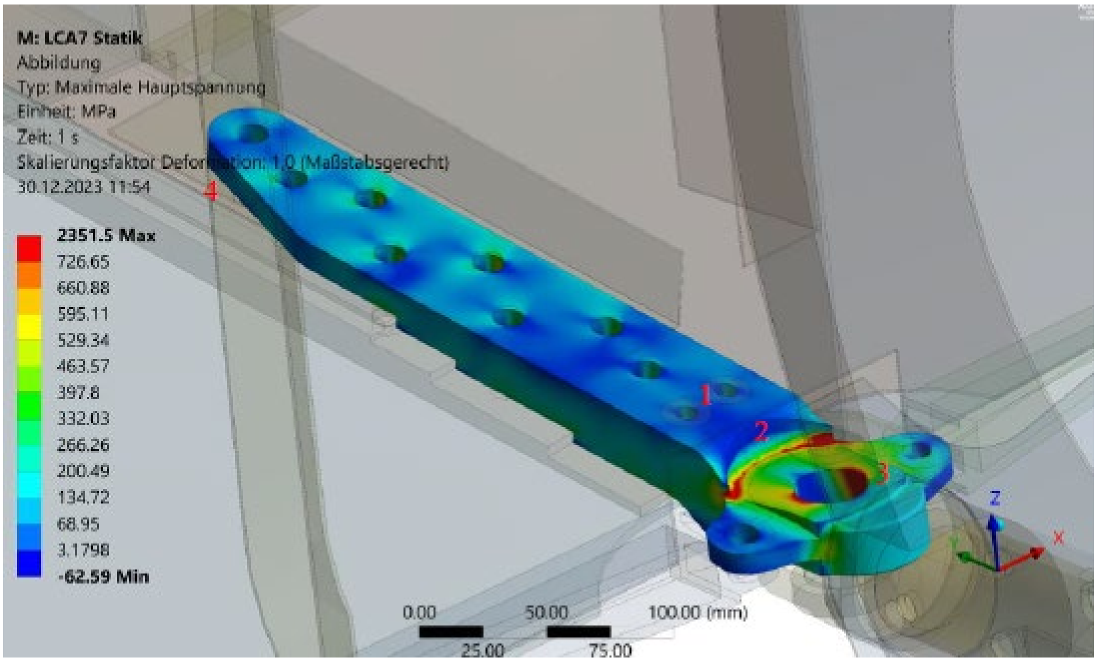


Figure 6: Detailed FE model with local stresses at the critical locations

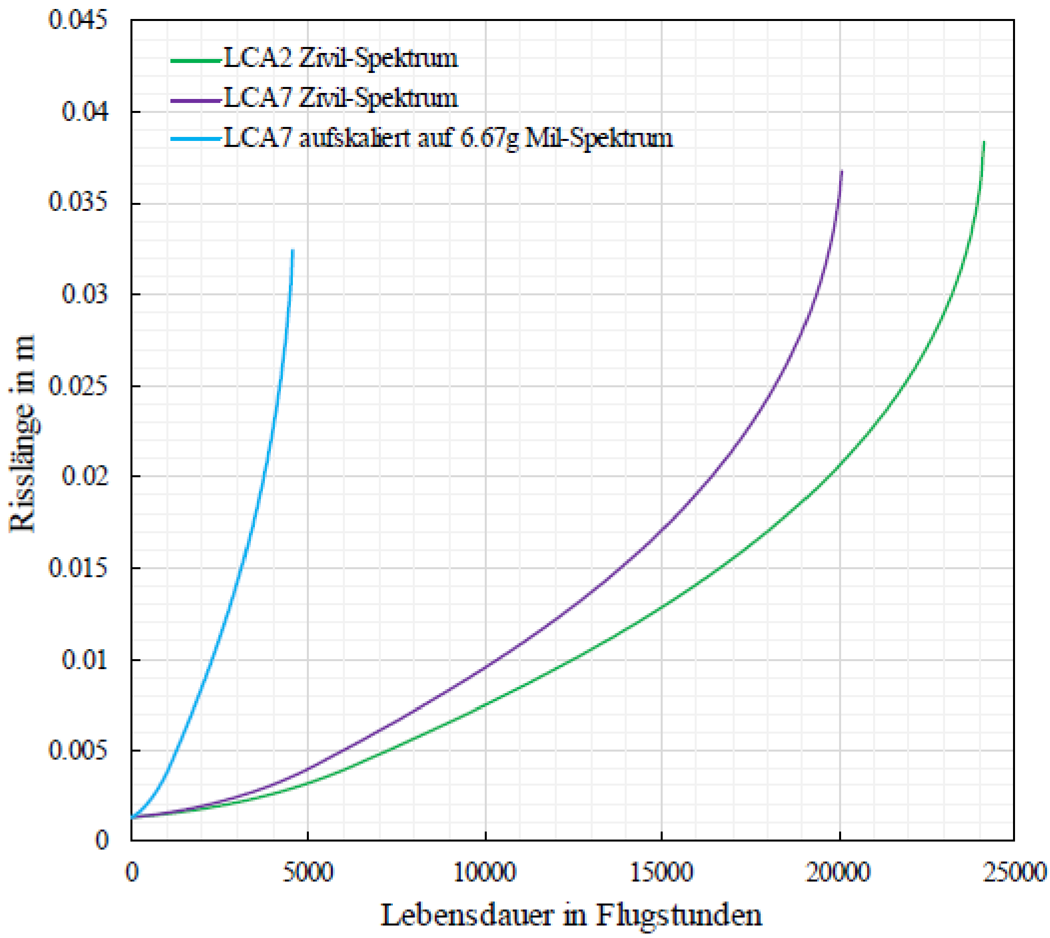


Figure 7: Crack growth calculations using AFGROW, difference of military (Mil-Spektrum) and civil (Zivil-Spektrum) usage

Structural Health Monitoring system for Corrosion Damage Assessment

Corrosion is a growing risk for aging aircraft. It is a major challenge and can affect structural integrity. The growing risk of stress corrosion cracking or corrosion fatigue becomes an increased safety hazard with the age of the aircraft. The growing risk leads to an increase in cost for corrosion maintenance and decrease of aircraft availability. This technology study was performed in collaboration with RUAG AG in Emmen to gain knowledge for structural health monitoring taking corrosion into account. The Boeing F/A-18 Hornet of the Swiss Air Force had its service life extended to fulfil its role until 2030. RUAG is responsible for maintaining the F/A-18 and must ensure safe operation up to its retirement. For this technology study we choose to use the F/A-18 which is a great platform for structural integrity. To ease this effort, emerging corrosion damage assessment tools may be used and applied for future aircrafts. Literature research was conducted to find tools fitting for use on the F/A-18. Two promising approaches emerged from it. The first were multiple modelling approaches, which use environmental or sensor data to estimate corrosion damage. These modelling approaches vary in

complexity and span from the use of environmental severity index based cumulative corrosion damage model to the use of weather and climate data to model the degradation processes due to corrosion of the airframe for predefined flight routes. The second was a corrosivity monitoring approach. Different corrosion measurement techniques were collected. For the two approaches, existing hardware and applied systems were found. The material collected was reviewed and the best suitable concept for use on the F/A-18 was identified. It was concluded that a corrosion monitoring system with a similar scope to the system NRL implemented on the NH90 using the Luna Labs Acuity LS provides the highest utility. An implementation roadmap for such a corrosion monitoring system on the F/A-18 was elaborated in the final step.
For corrosion measurement, a multitude of sensors exist. The most common ones are film sensors using the mass loss principle, such as those from BAE Systems used in the F35. A series of standalone measurement devices are best suited for this study, because a standalone system shortens the time dramatically needed to implement the system. To position node sensors, a corrosion hot spot database or similar methods to determine points of interest is used. A corrosion hot spot database gives an overview of areas susceptible to corrosion of the airframe. It stores information about the location, the type, the frequency and severity of corrosion and the criticality of the location in terms of safety, availability and cost. The database is developed using existing maintenance data.
Corrosion sensors or measurement equipment dedicated to aviation is sparse, but many sensors exist for other industries such as process industry, infrastructure and buried components. The Acuity LS system was developed by Luna innovations. Corrosion monitoring systems from Luna are featured in various presentations of ASIP-Con and AA&S-con from different operators, which means that they are widely applied in the industry. The Acuity LS is an autonomous corrosion and environment measurement system for long durations. The Acuity LS system is a development from the LS2A system, which is discussed in the next section. The Acuity Ls system was developed for autonomous on-board monitoring to improve corrosion prevention and control. TRL for the monitoring technology is 8 and the Acuity LS is used on several aircraft for long term testing. The analysis and classification of environment and corrosion severity for managing the aircraft is at a lower TRL.
Th Acuity LS records free corrosion rates, galvanic corrosion rates and environmental parameters such as relative humidity, surface contaminants, surface and air temperature. The device is powered by a replaceable Saft LS17500 primary-cell battery, which is a lithium-thionyl chloride battery with a voltage of 3.6 volt and a capacity of around 3600mAh. It must be noted that temperatures above 100°C can lead to battery fire or explosion. This allows the device to operate for 2 years with a measurement interval of 30 min or 4 years with a 60 min interval. The lid sensor panel is replaceable, such a lid sensor panel can be seen in figure 8. The black dot on the top left measures air temperature and humidity. The surface temperature is measured by the bottom case. The square gold interdigitated

electrode on top measures conductance. The conductance is used to determine the loading of salt contaminants. The two large sensors on the bottom can be configured as a galvanic corrosion sensor or a free corrosion sensor. The free corrosion sensor is using linear polarisation technique. It is highly correlated to mass loss with a coefficient of determination of R2 ≥ 0.95. The electrode material is customizable, so it can be matched to the alloy used in the aircraft. Aluminium AA7075 is the most used alloy used by the customers of Luna. The galvanic corrosion sensor utilizes a zero-resistance ammeter to measure the galvanic current. The electrode materials of the galvanic couple are customizable. The mostly used combination for the galvanic couple is aluminium AA7075 and steel A286, but also other electrode materials are possible such as carbon fibre or titanium alloys. Another feature of the Acuity LS system is that coatings can be applied over one or both corrosion sensors. Which leads to the benefit that measurements are comparable between the two systems. The lid sensor panel is oriented with 2 dowel pins, it is mounted with 4 screws and sealed with an O-ring. Electrical connection is achieved with 10 spring contacts. An explosion drawing of the Acuity LS can be seen in Figure 9.

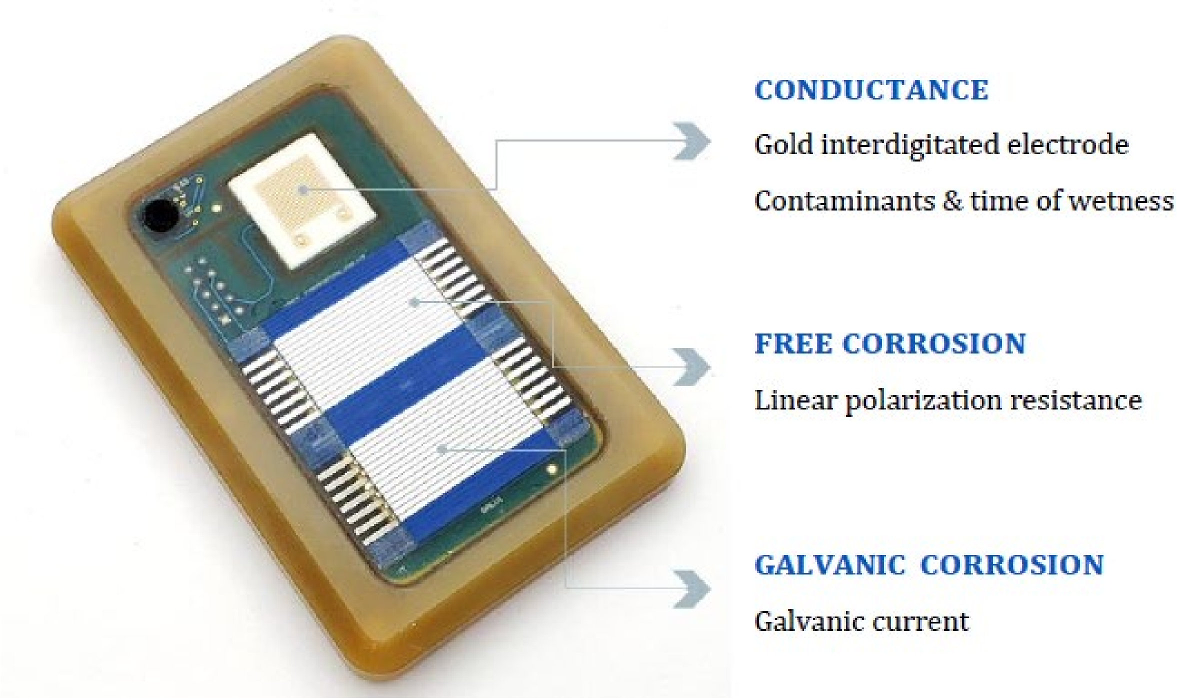


Figure 8: Luna Acuity LS Lid sensor panel

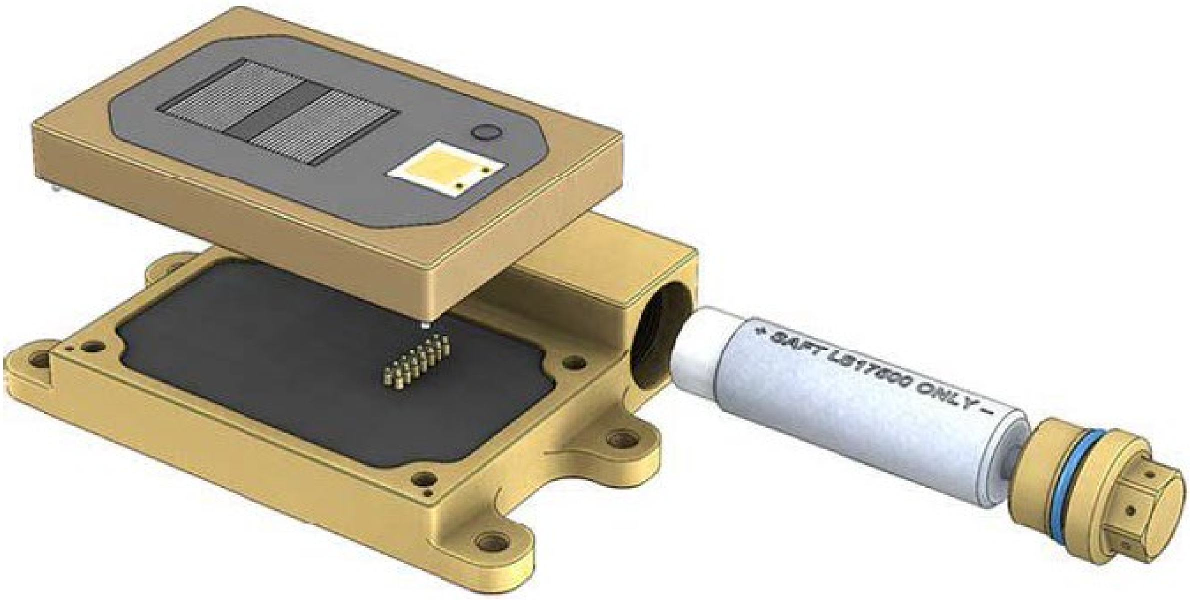


Figure 9: Luna Acuity LS explosion drawing

4. Structural Health Monitoring for Composites (HSLU & RUAG AG)

Lucerne University of Applied Sciences and Arts (HSLU): Dejan Romančuk, Andre Gut, Marco Schnidrig
RUAG AG: Mattia Lüchinger, Hakon Eijsermanns, Michea Ferrari, Mirko Figliolino (Armasuisse)

Activities in aeronautical structural integrity at the Lucerne University of Applied Sciences and Arts (Hochschule Luzern - HSLU) are carried out at the Institute of Mechanical Engineering and Energy Technology (IME) within the Competence Center of Mechanical Systems (CCMS). Main focus and relevant continued progress has been made in Structural Health Monitoring (SHM) for composite structures as part of the project "Piezoelectric Structural Health Monitoring for Composites in Aircraft Applications" which was funded by the Swiss Innovation Agency "Innosuisse" and RUAG as the implementation partner supported by Armasuisse.

Piezoelectric sensor-based SHM systems for composite structures are believed to have significant potential for enabling cost-efficient and safe operation of aging aircraft. This project focused on evaluating the damage detection capabilities of a system supplied by Acellent Technologies. A key objective was to develop a methodology for assessing the probability of detection (POD) of customized piezoelectric sensors for a specific design feature—a step-lap joint. The so called SMART layer sensor system is designed to be permanently mounted to any structure. It consists of a network of distributed sensors embedded in a thin, flexible dielectric carrier film with integrated wiring and connectors.

The same requirements of the existing non-destructive inspection (NDI) method used for this design feature and location of an aircraft in a fleet were established for the SHM system. Another requirement was to position the SHM sensors in a manner that allows inspections using the existing NDI method to be conducted without access restrictions of the bonded SMART layer sensors.

A methodology for POD testing has been derived and the corresponding POD evaluation was carried out. The damage detection focused on disbonds between bonded CFRP and the metallic parts of a the step-lap joint. The growth of disbond was controlled by careful specimen design, the introduction of pre-damage and fatigue cycling. The validation of the disbond area after detection by the SHM system showed to be challenging: different methodologies such as computed x-ray tomography, ultrasonic phased array and visual inspections by destructive tear down were put in place.

FIGURE 1 provides an overview of the POD experiment with the specimen, the applied sensors and the set-up of hardware and software. FIGURE 2 shows the resulting POD curve, which was determined using the one-sided tolerance interval (OSTI) method. The OSTI POD method is based on the assumption that there exists a normal distribution describing the detected crack lengths respectively disbond areas in this case. The POD curve is then the cumulative probability density function (CDF) of the normal distribution describing the distribution of the disbonds at first detection.

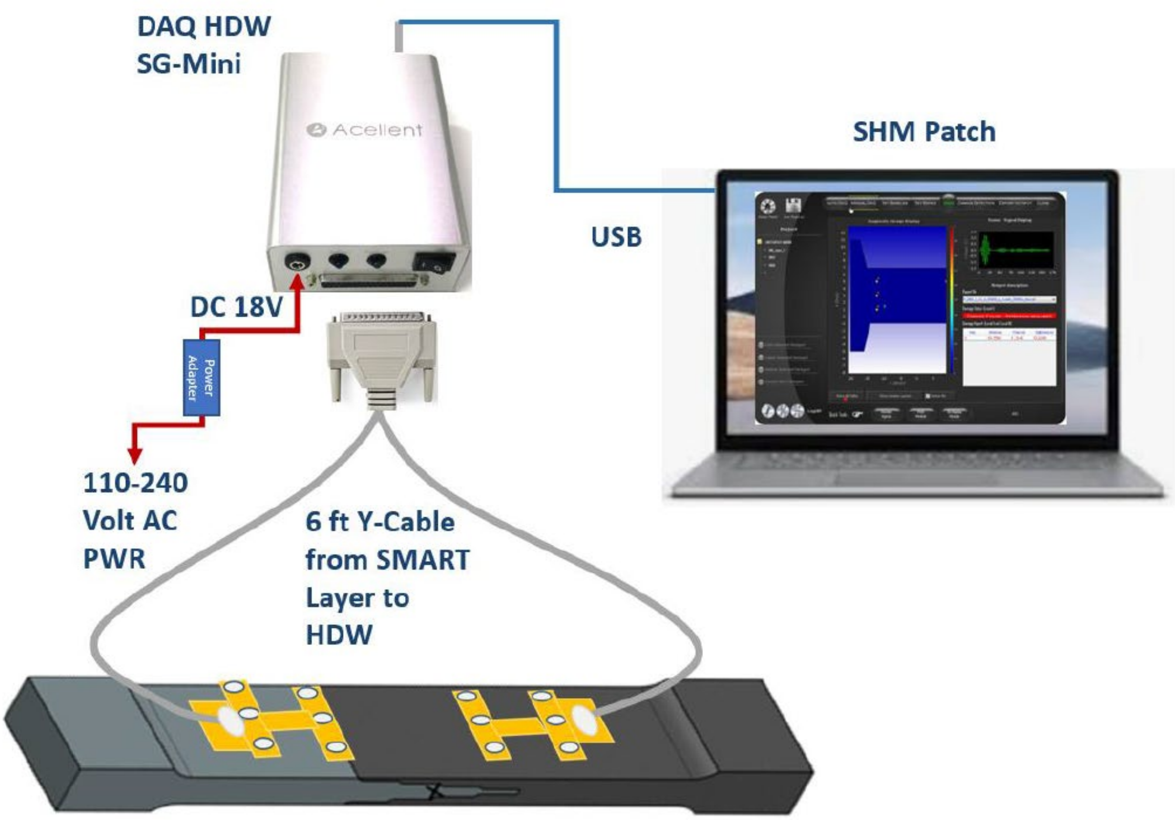


Figure 1 - SHM System Components for POD Testing

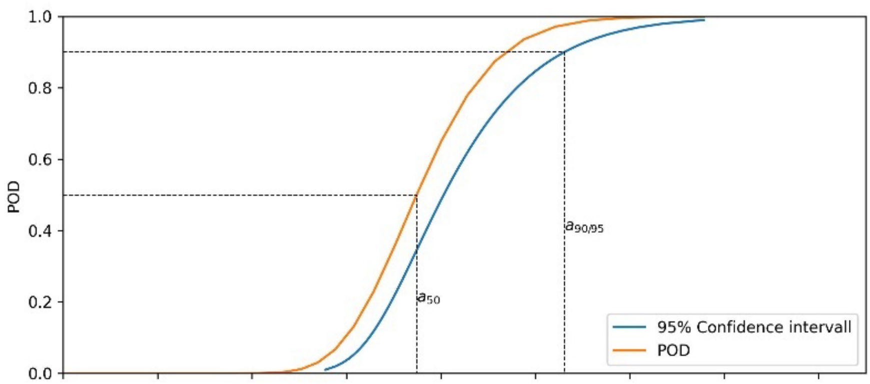


Figure 2 – Disbond Area POD Curve

The following project goals were met:

(1) demonstrate a path for the implementation of a piezoelectric sensor system for a specific aircraft composite structure for the detection of disbond damages
(2) Design of an experiment to determine a POD curve
(3) Determination of a specific POD curve for the particular application
(4) Determination of a SHM implementation concept

The high potential for the use of SMART layer sensors in a practical application was confirmed. Based on the testing result optimization to better capture damage location was identified. The indication threshold should be further optimized (lowered) to even further improve the detectability. For qualification testing, the POD experiment will require a robust validation with respect to correlation of damage type and signal response.

5. Structural Integrity Toolbox (HSLU)

Lucerne University of Applied Sciences and Arts (HSLU): Andre Gut, Dejan Romančuk

Activities in aeronautical structural integrity at the Lucerne University of Applied Sciences and Arts (Hochschule Luzern - HSLU) are carried out at the Institute of Mechanical Engineering and Energy Technology (IME) within the Competence Center of Mechanical Systems (CCMS). As part of various projects in the context of structural health monitoring and aeronautical fatigue a software tool box was developed, which comprises among other supporting tools used for curve fitting and optimal probability distributions the following main tools:

- ***CRINITY***: Strain-life crack initiation analysis tool which generates Kt x Design Limit Stress (KTDLS) curves for fatigue evaluation of metallic parts. CRINITY is built on the strain-life method, Neuber's rule and Masing's hypothesis. Key functionalities include the ability to load and manipulate variable amplitude spectra and print cycle-by-cycle damage results. Tabular material data can be loaded from a .csv file, or material data can be generated using Ramberg-Osgood and Coffin-Manson coefficients. The slope of the elastic strain-life curve (Basquin exponent) can be adjusted to accommodate surface treatment effects. The user interface is shown in Figure 3.

- ***LOSEA***: Tool for the assessment, handling and manipulation of loading sequences, e.g. processing from measured sensor data, rainflow counting for fatigue or crack growth analysis, etc.

- ***PODEX***: For determining the One-Sided Tolerance Interval (OSTI) Probability of Detection (POD). It utilizes the OSTI-POD methodology to provide a statistical approach to this determination by a user-friendly interface, see Figure 4, that verifies the compatibility of the provided data with the POD model assumptions.

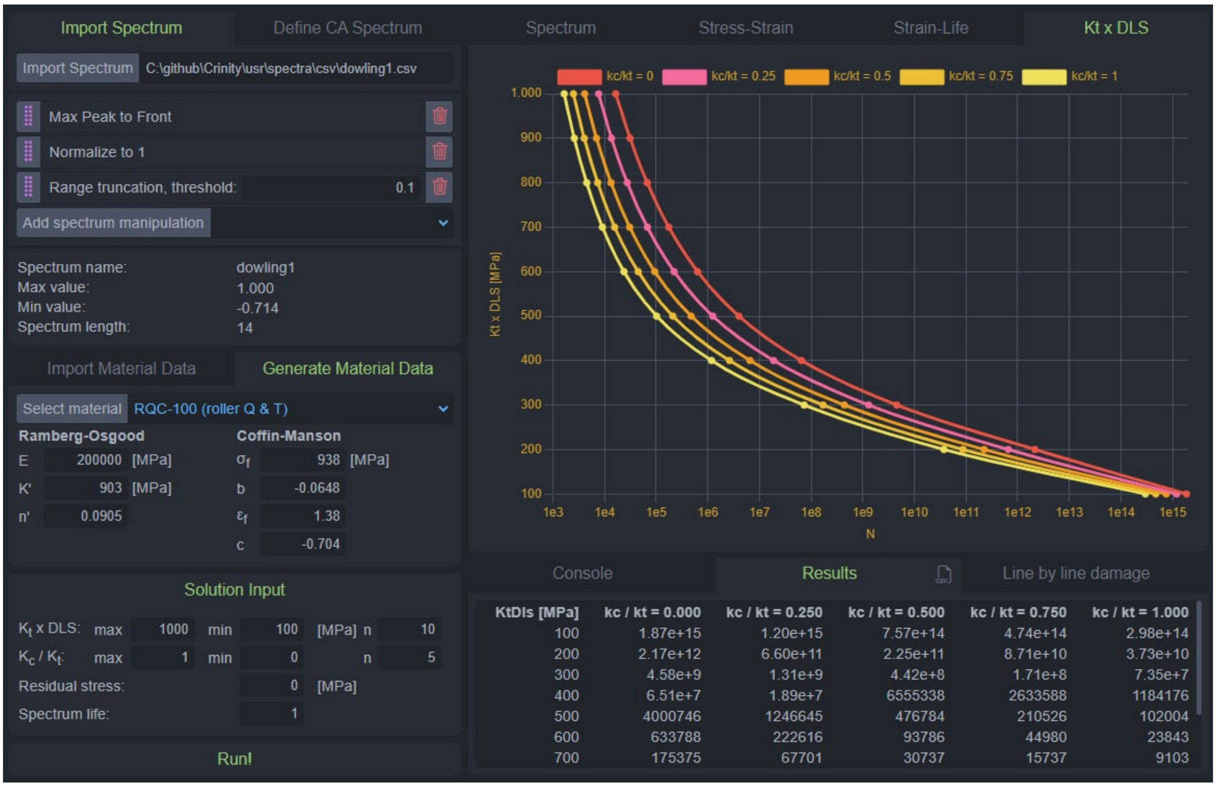


Figure 3- Crinity Crack Initiation Tool User Interface

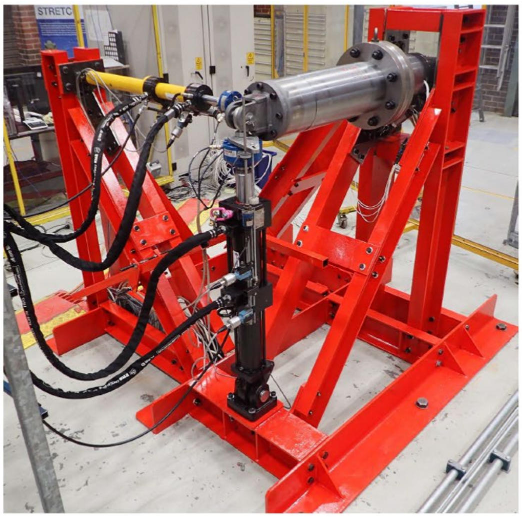
Figure 4: PODEX – POD Tool User interface

6. F/A-18 Spindle Component Test – FTS6 (RUAG AG)

RUAG AG, Ricardo Filipe do Rosario

Spindle Component damage tolerance fatigue test project is a collaboration effort between the Government of Australia, as represented by the Australian Department of Defence, and the Swiss Federal Council as represented by the Federal Department of Defence, Civil Protection and Sport. Where the Steering Committee for this joint project is comprised of ar (armasuisse, Switzerland) and DSTG (Defence Science and Technology Group, Australia). The project is supported by RUAG AG (Switzerland) and the Royal Melbourne Institute of Technology (RMIT, Australia).

The project was initialized under the umbrella of the F/A-18 SLEx (Structural life extension) activities triggered by very prohibitive SLAP (Service Life Assessment Program) results at some high strength steel hotspot locations leading to an ASI strategy mostly covered by acceptance of higher risks then on real sustainable mitigation actions. The final goal of the FTS6 project is to verify if there are conditions that can lower the accepted operational risk level.



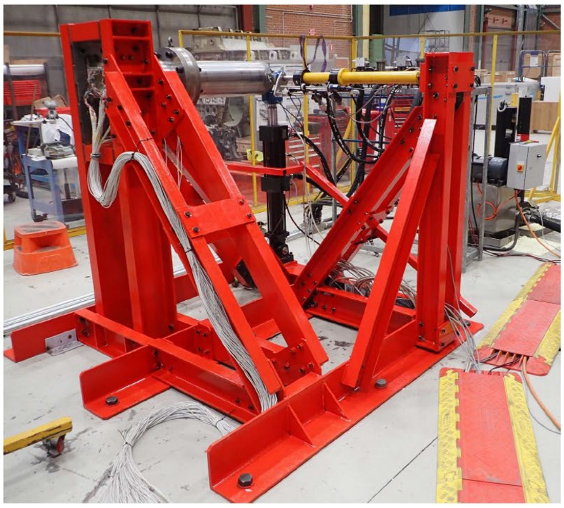


Figure 2 FTS6 – F/A-18 Spindle Component Test Rig

7. FTS3 Post-Test Activities (RUAG AG)

RUAG AG, Ricardo Filipe do Rosario

FTS3 Post-Test Activities project is the follow-on project to the FTS3 Centre Barrel Test, that now has the objective to conduct additional inspections to the aluminium components of the centre barrel, analysis and the logistical assessment of the test findings. These post-test activities have the main objective of providing input to the Swiss fleet End of Life strategy for the Centre Barrel components.

8. FTS4 Post-Test Activities (RUAG AG)

RUAG AG, Ricardo Filipe do Rosario

FTS4 Post-Test Activities project is the follow-on project to the FTS4 TEF Component Test, that now has the objective to conduct the test article full teardown and inspections, analysis and the logistical assessment of the test findings. These post-test activities have the main objective of providing input to the Swiss fleet End of Life strategy for the TEF components.

9. F/A-18 Usage Monitoring L/ESS Review (RUAG AG)

RUAG AG, Etienne Girard

An essential requirement of an Aircraft Structural Integrity Program (ASIP) is the ability to assess whether operational changes significantly impact aircraft loads and to verify that fatigue tracking systems and the structural verification basis remain valid throughout the service life. For the Swiss F/A-18 ASIP, this requirement is fulfilled by the Loads and Environmental Spectrum Survey (L/ESS) system.

The L/ESS system is an integral part of the Swiss F/A-18 ASIP Master Plan, serving as an additional tool within the Swiss F/A-18 ASI framework. This system enhances aircraft structural integrity and ensures long-term fleet availability.

As the Swiss fleet approaches its end-of-life phase, a pragmatic and feasible approach was selected for defining and developing the L/ESS system to maximize benefits in a timely manner. A key focus was placed on comparing fleet usage against the primary usage spectra used in life analysis, specifically the Swiss BOS (SAFOS14). This baseline operational spectrum, developed from in-flight measurements, represents average fleet usage between 2001 and 2012. However, as this was a one-time effort, continuous assessment through the L/ESS system is necessary for the fleet's remaining service life.

The primary objective of the L/ESS system is to detect operational changes and assess their impact on (1) aircraft loads, (2) the fatigue tracking system, and (3) the structural verification basis. As a data collection and reporting system, L/ESS enables the identification of operational variations and evaluates whether they significantly affect aircraft loads and structural integrity throughout the fleet's service life.

The Swiss F/A-18 L/ESS System task was carried out in three phases: (1) Definition, completed in 2022, (2) Development, completed in 2023, and (3) Execution, launched in early 2024. The development phase followed a structured workflow focused on assessing and verifying key operational parameters using readily available flight log records and historical fleet usage data from onboard tracking systems. This approach enabled full automation of processing and reporting efforts.

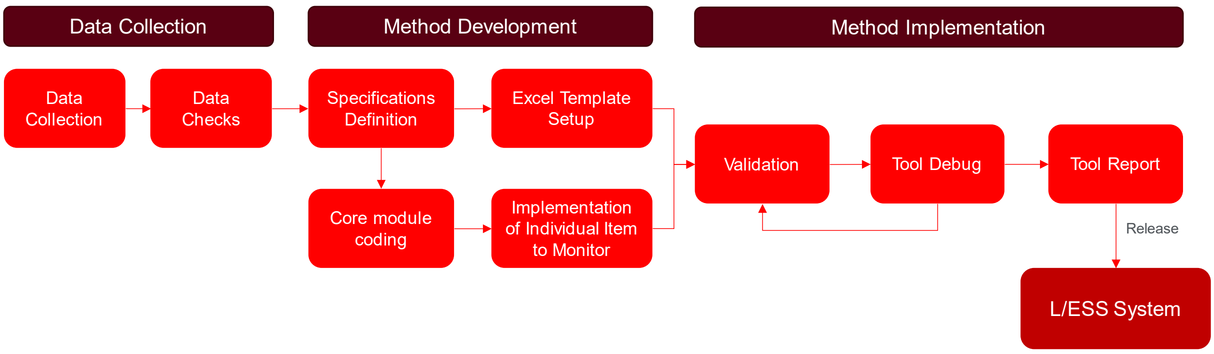


Figure 3 L/ESS System Development Phase Breakdown

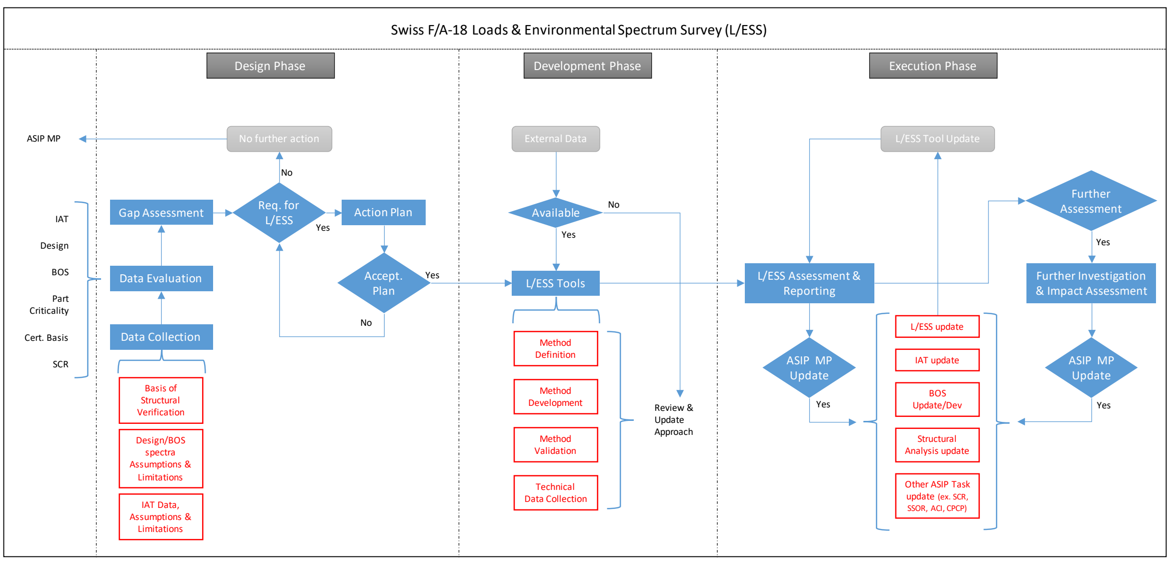


Figure 4 Swiss F/A-18 L/ESS Process Flow Chart

Over 120,000 flight hours of historical fleet usage data spanning 25 years of service were reviewed and assessed. A comprehensive range of parameters was analyzed to determine their impact on the Swiss BOS, categorized as follows:

- Flight Envelope (ex. Mach, Alt, Nz)
- Flight Parameters (ex. AoA, Dyni, Roll Rate, …)
- Supersonic Events
- Dynamic Vibration
- Abrupt Maneuvers
- Over-G Events
- Take-Off & Landing Events
- Operating Environment
- Miscellaneous Usage Parameters (ex. flight duration)
- Store Arrangement
- Aircraft Weight and Balance
- Flight Computer Upgrades
- Mission Mix

Based on the available parameters and historical usage data, no significant deviations were identified that would compromise the applicability or representativeness of the Swiss BOS (SAFOS14) for structural safe-life analysis. Consequently, the Swiss SAFOS14 BOS remains a valid representation of fleet usage for analytical purposes.

The L/ESS system will remain active for the remainder of the fleet's service life, ensuring continuous monitoring and capturing of potential operational changes that may arise in the future.

10. F/A-18 Leading Edge Extension Loads Development (RUAG AG)

RUAG AG, Etienne Girard

As part of the Swiss F/A-18 Service Life Assessment Program (SLAP), a detailed analysis was conducted on the Leading-Edge Extension (LEX) component of the F/A-18. This assessment raised concerns due to various factors, including numerous findings reported by other operators, limited available LEX load data, and the severe operational usage of the Swiss fleet, particularly during high-angle-of-attack maneuvers.

To address these concerns, a dedicated task was initiated to derive a comprehensive set of LEX loads for the Swiss Baseline Operational Spectrum (BOS) at all critical locations, such as the LEX attachment points. This approach was chosen to enhance analytical capability and reduce turnaround time for future fleet issue assessments and repairs.

A pragmatic methodology was employed for load development, balancing available simulation capabilities with expected accuracy improvements relative to task complexity and effort. The load derivation process was divided into two main components: simulation of inertial loads and simulation of aerodynamic loads, which were subsequently combined to determine the total maneuver LEX loads.

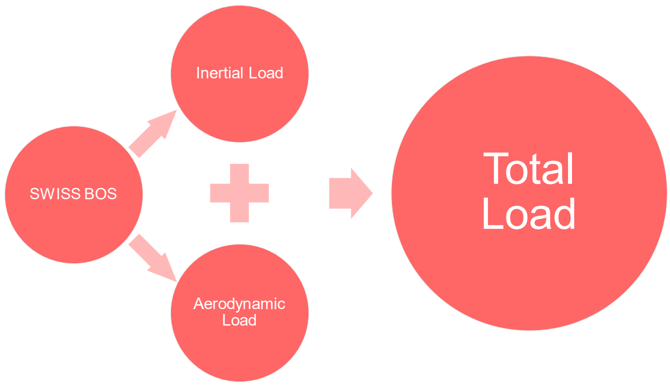


Figure 5 LEX Loads Development Approach

Inertial loads were computed using classical rigid body motion equations and the aircraft's inertial properties. A mass distribution model was implemented, accounting for variable mass items such as fuel quantity and external stores. Additionally, control surface deflections and relevant flight parameters (e.g., linear and angular rates and accelerations) were incorporated to simulate each condition in the Swiss BOS. A total of 550,000 simulation cases were analyzed to construct the Swiss BOS.

Aerodynamic loads were estimated using Computational Fluid Dynamics (CFD). To manage complexity, the approach assumed that aerodynamic loads were primarily governed by Angle of Attack (AoA) and Dynamic Incompressible Pressure (DYNI), while asymmetric influences played a secondary role (i.e., only symmetric cases were simulated). Over one hundred CFD cases were simulated intended to cover the full flight envelope in terms of AoA and DYNI. Interpolation of these simulated cases was used to calculate all conditions found in the Swiss BOS.

The resulting CFD pressure distributions were mapped onto the Swiss structural Finite Element (FE) model to compute the LEX component interface loads and internal reaction loads at the LEX-fuselage connections. This required the creation of non-structural components within the FE model to facilitate accurate mapping of the CFD results.

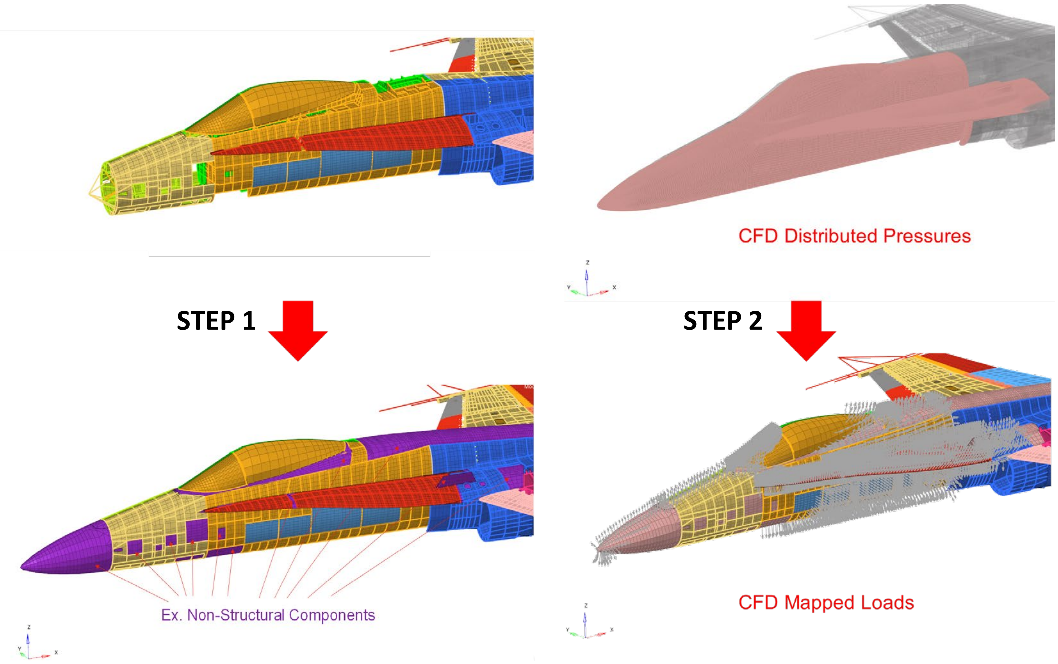


Figure 6 Steps to Map the CFD Results to the Structural FE Model

A complete set of LEX interface and internal reaction loads was successfully derived for the Swiss BOS, significantly enhancing the ability to support any future fleet issue assessments and repairs more efficiently. This project demonstrates RUAG's engineering expertise and innovative approach in leveraging its extensive experience and multidisciplinary technical knowledge in areas such as coding, FEM, loads, and CFD.

11. Cracks in Upper Wing Skin Metal Substructure (RUAG AG)

RUAG AG, Lubomir Castulik

During the Swiss F/A-18 full scale fatigue test (FTS1) TDI, multiple cracks were found in the spars of the inner wing (IW) structure. Surprisingly, a large number of these cracks were located in the upper spar caps which are subjected to compression dominant spectra. Since a satisfactory explanation of the crack initiation (CI) and the crack growth (CG) in the upper spar caps was missing, it was decided to assess whether the FTS1 cracks in the upper spar caps can be predicted using the standard analysis methods.

According to the assembly drawing, solid shims are used to obtain the best spline fit between the upper wing panel and the upper spar caps. It is also permitted to use a liquid shim to fill gaps of 0.030

in or less. The latter represents up to 32% of the thickness of the upper spar caps in the investigated locations. Subsequently, the fasteners are tightened using a prescribed torque.

In case some gaps between the upper wing panel and the upper spar caps exist and are not properly shimmed, the application of the prescribed torque is expected to lead to a local deformation and the corresponding manufacturing residual stresses around the affected fastener holes, as schematically depicted in the figure below.

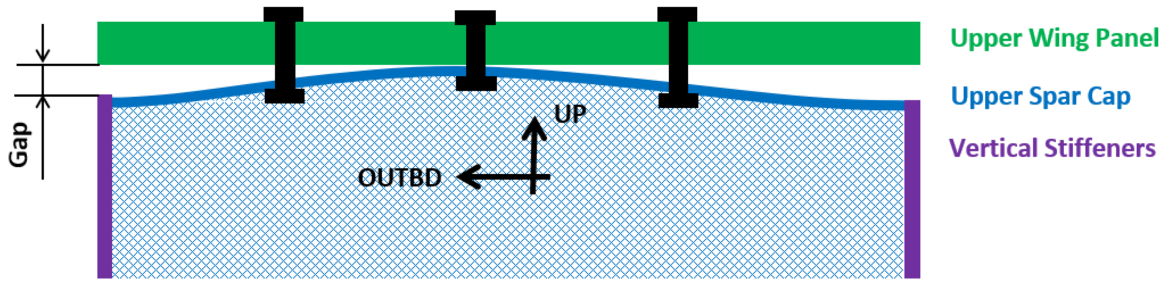


Figure 7 Model of the Fastener Holes

As shown below, the residual stress field around the affected fastener hole (Δσ) then results in a shift of the loading spectrum.

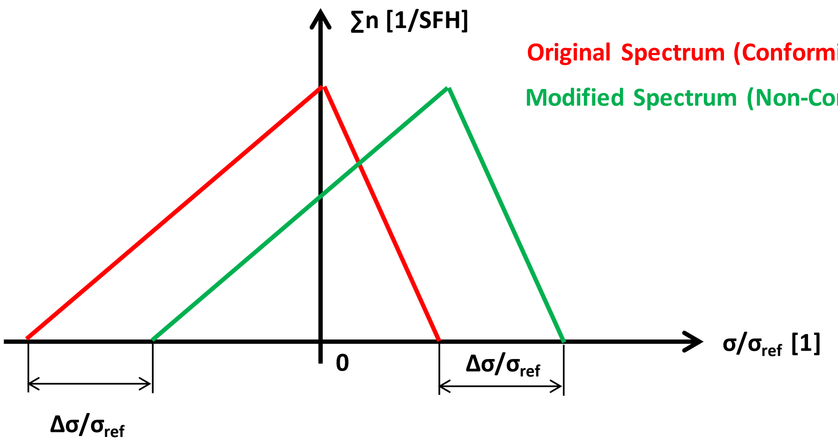


Figure 8 Effect of the Residual Stress Field on the Spectrum

In order to assess the impact of the manufacturing residual stress on the unfactored total life of the IW upper spar caps, total life analysis of the selected fastener holes in the upper spar caps was per-fomed. Altogether two analysis approaches were used in conjunction with short crack growth data for 7050-T7451 aluminum alloy:

- Combination of standard CI analysis and CG analysis starting at C_{init} = 0.254 mm

- CG analysis starting at C_{init} = EPS = 0.010 mm

In addition, the following two different methods for idealization of the residual stress effects were compared:

- Approach A   Usage of Modified (Preloaded) spectrum
- Approach B   Usage of Original spectrum in combination with Residual Stress (RS) option

It was found that the aforementioned analysis approaches are equivalent and provide consistent results in terms of CI and the initial phase of CG. Moreover, the residual stress levels required to match the FTS1 findings were not excessive with respect to the maximum stress levels in the spectrum. Hence, it was concluded that the FTS1 findings could be satisfactorily explained by manufacturing quality issues, which are also expected to affect the fleet.

In order to assess the unfactored total life of the IW upper spar caps installed in the Swiss F/A-18 fleet, it was decided to use the analysis approach B which is able to distinguish between various residual stress fields. Since the actual residual stress field due to an improper shimming is not known, the following assumptions about the manufacturing residual stress distributions were made (see the figure below):

- Distribution B02   Maximum residual stress back to 0% at 1·D
- Distribution B03   Maximum residual stress back to 0% at 2·D
- Distribution B06   Maximum residual stress back to 50% at 1/2·D

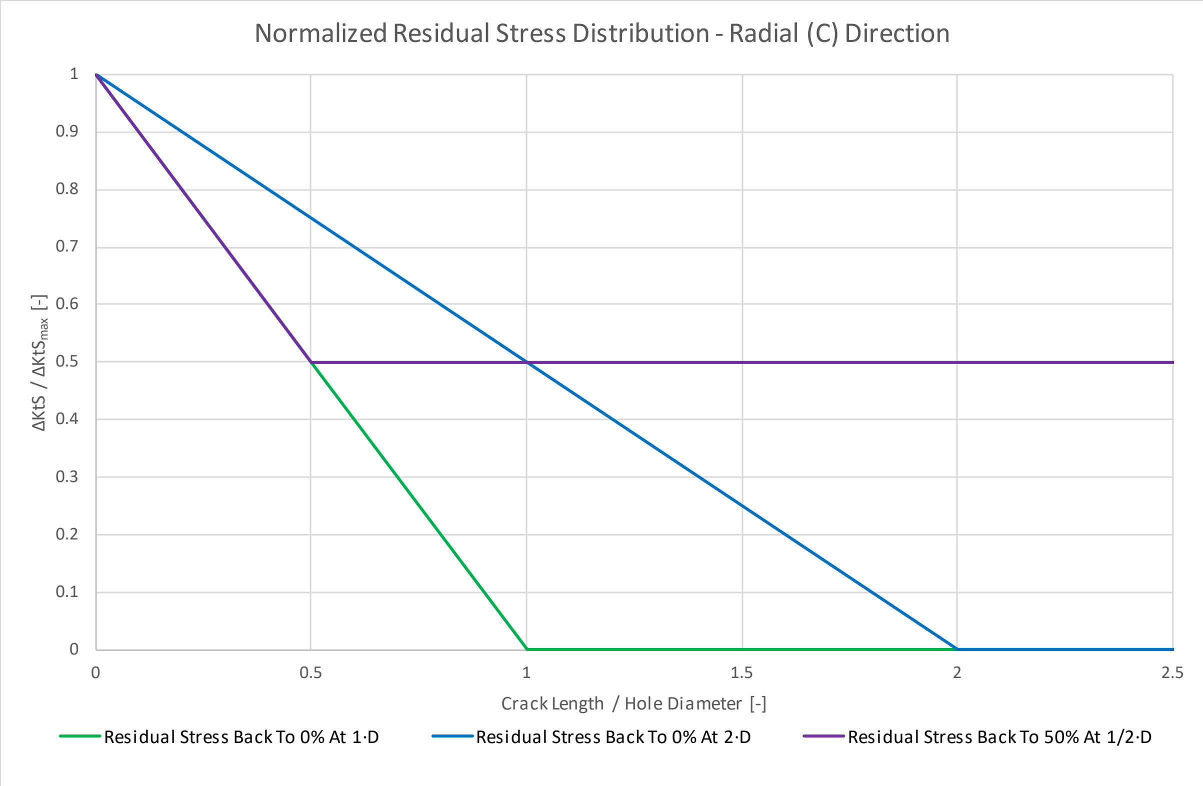


Figure 9 Normalized Residual Stress Distribution - Radial Direction

It was found that the residual stress distribution has an important impact on the CG behavior and the unfactored total life. The results suggest that the cracks propagating under the compression dominant spectrum do not stop and may reach full ligament length as a result of the residual stress field. At the same time, it was found that that the unfactored total life at the outboard fastener holes (ID 477 & 714) is approximately two times higher than the unfactored total life at the inboard fastener holes (ID 608 & 769). This is mainly attributed to the differences between the loading spectra at the respective locations.

12. Piano Hinge Optimized Repair Development (RUAG AG)

RUAG AG, Vincenzo Rotella, Marco Marinelli von Wartburg

Piano Hinges are common joints at several locations in an aircraft structure, e.g at the interfaces to the flight control surfaces. Lug roots are, due to their geometry, typical features leading to local stress concentrations which are therefore prone to develop fatigue cracks. In case of fatigue crack findings a blending repair at the lug root is often the only repair option.

The term "piano hinge" describes groupings of hinges in series, the radius between the hinge lugs is called lug root, see *Figure 10*.

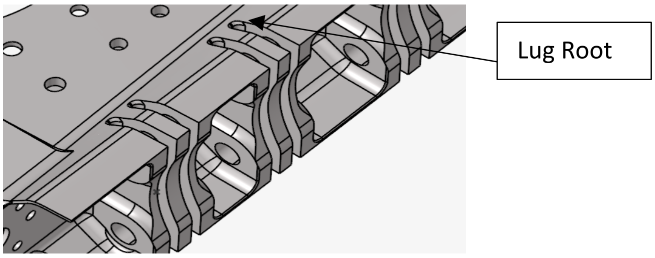


Figure 10 "Piano Hinge" and "Lug Root"

The "Piano Hinge Optimized Repair Development" project has the purpose to develop a tool which allows the sizing of blending repairs at piano hinge lug roots in a short turnaround time using structural optimization techniques and automation.

In the frame of this project the practical application of structural optimisation methodologies available in current state of the art finite element software is explored, such as topology optimisation, shape optimisation etc.

Within the tool development, the following steps were performed so far:

- Establishing of lug root sample models representing the appropriate stress state

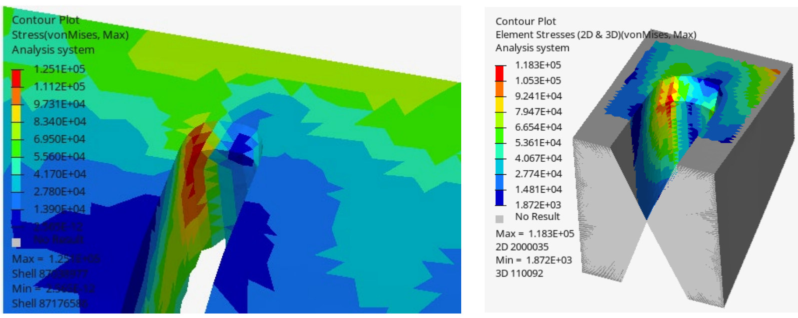


Figure 11 Stress Approximation in Sample Model

- Automation of initial damage introduction into the sample model

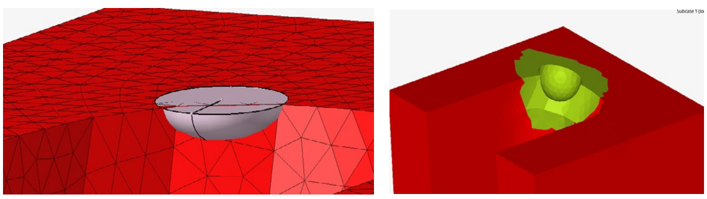


Figure 12 Automation of damage introduction using TCL script.

- Structural shape optimisation of initial damage to reduce stress level at repair blending

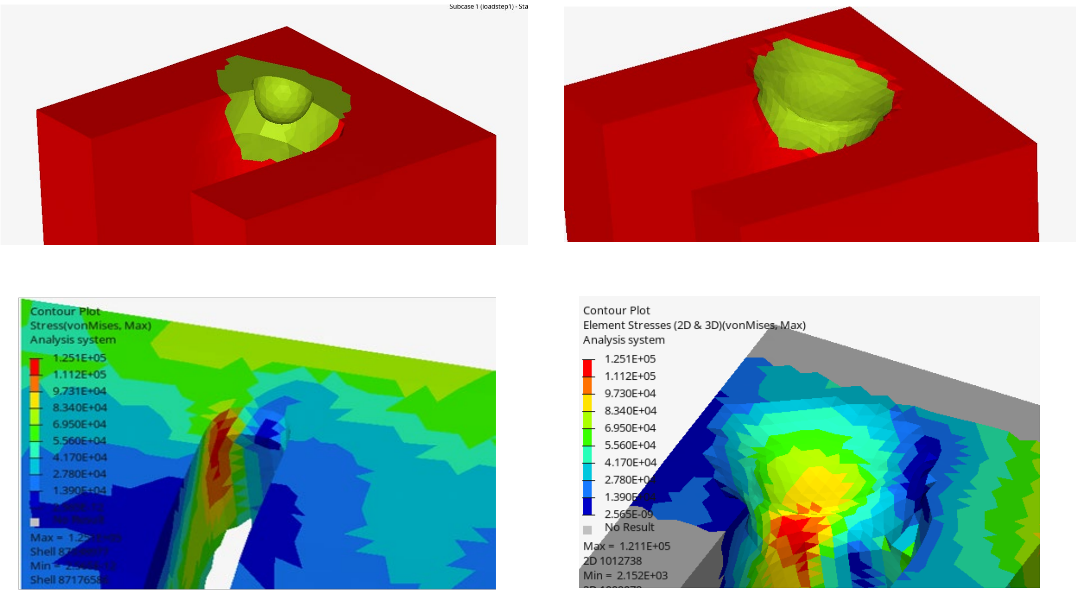


Figure 13 Shape Optimization

13. TEF Hinge Lug Repair Coupon Test (RUAG AG)

RUAG AG, I. Kongshavn, S. Argentero, B. Schmid, E. Dellenbach, W. Krummenacher, H. Eijsermans, Ricardo Filipe do Rosario.

This coupon testing project of a repaired TEF hinge lug is a collaborative project between armasuisse (ar, Switzerland), and the Finnish Air Force (FINAF), with support from RUAG AG and Patria Oyj. Additional support in failure analysis was provided by the Defence Science and Technology Group (DSTG Australia) and the Royal Melbourne Institute of Technology (RMIT, Australia).

Findings of in-service failures of the Swiss F/A-18 inboard TEF hinge lug have led to regular fleet inspections and repair. The TEF hinge lug is made of AA 7050-T7452 forging, is IVD coated, reamed and cold worked and is fitted with a neat fit monoball bearing. Several fleet operators have found in-service cracks in the bore of the lug (see *Figure 14*), and a repair has been developed consisting of milling the lug bore to remove the crack followed by a confidence cut, installing a monoball bearing inside a split bushing, then alodine coating and sealing. The repair may be performed with or without cold working.

NDT inspections of in-service cracks are challenging as the lugs fail inside the bore, thus requiring bearing removal for early detection. Eddy current (ET) can be used around the bore with the bearing still in place and ultrasonic inspections (UT) can be performed from the back faces, as shown below.

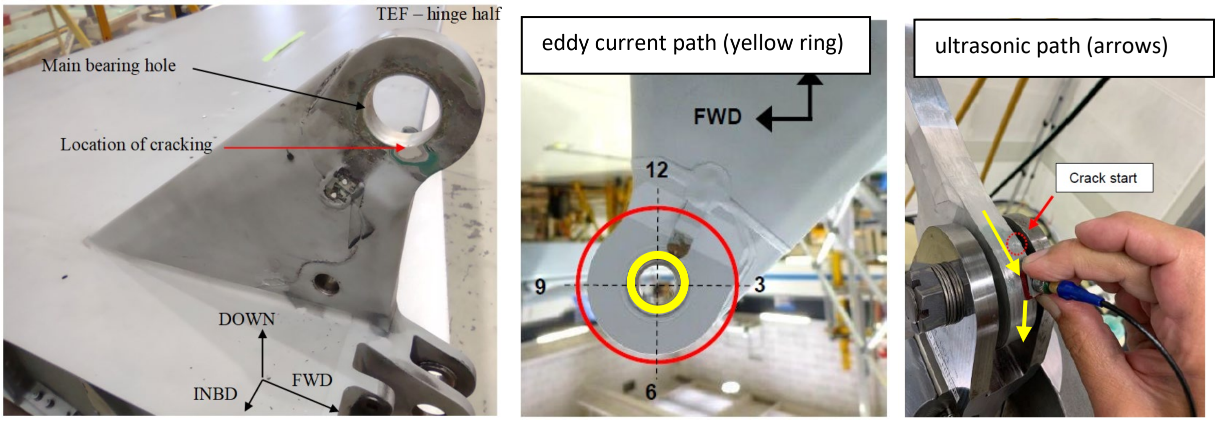


Figure 14 left: Inboard TEF hinge lug crack location, middle: ET inspection, right: ultrasonic inspection.

A coupon test program was initiated to evaluate the NDT inspection methods and to assess the fatigue lives of repaired configurations with and without cold working. Analytical predictions of the crack growth lives are highly dependent on representative modeling, which must account correctly for the local contact stresses, failure mechanisms such as fretting, corrosion and mechanical damages from the installation processes, as well as the effects of the cold work process. Thus the test data will be used to tune predictive models to better assess repaired lives. To properly capture the crack growth curves of each test specimen, marker loads are included in the test spectrum to aid in post-test quantitative fractographic analysis (QF).

Forged vs Plate Material Comparison

Coupons representing the TEF hinge lug hotspot were prepared by Patria and tested at RUAG. The lugs were made of AA 7050-T7451 plate material, however on-aircraft lugs are made of an AA 7050-T7452 forging. A forged vs plate correction factor was first determined by fatigue testing low Kt coupons made of excised TEF lugs (forged) and comparing their lives to coupons made of plate material.

TEF Lug Fatigue Test

The TEF lug coupon is shown in *Figure 15*. Cold worked and non-cold worked repaired lugs were tested with a typical in-service loading spectrum that included manoevre (hinge moment) and buffet flight loads. The load level was chosen to cause failure at similar lives as those observed in fleet components.

According to a detailed failure analysis of a Swiss TEF hinge lug from a full scale test (FTS4) by RMIT/DSTG, cracking initiates in the bore from fretting and surface tears (most likely from using blunt tooling), see Ref. *1*. For in-service aircraft, corrosion may also be present. It was also noted that growth at the origin was not perpendicular to the loading axis, but at an angle, making early detection by NDT more difficult. Failures in the TEF lug coupon campaign were also from fretting, at a similar location in the lug bore to cracks observed in the fleet and in the FTS4 test.

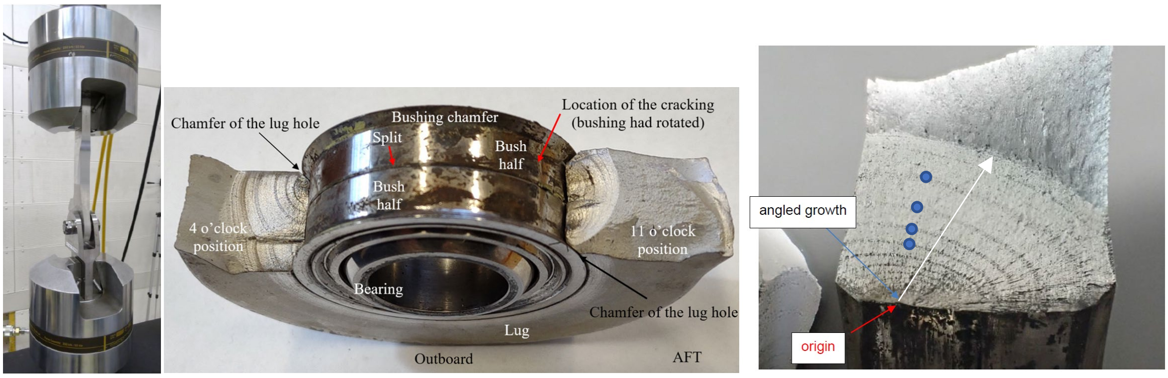


Figure 15 left: TEF lug coupon, middle: FTS4 lug failure, right: lug coupon test failure with some marker bands indicated in blue.

The growth between marker bands was measured by QF using high resolution optical microscopes with long working distance lenses. Near the origin there was much debris and rubbing, which removed some of the early markers. However, the lives and growth rates measured by QF indicated that cold working roughly doubles the life of the lug and reduces the growth rates of cracks greater than 1 mm by roughly one third. The first indications of cracking were found by ultrasound at a crack depth starting at approximately 0.6 mm for non cold-worked lugs and starting at approximately 3 mm for cold worked lugs. With eddy current the crack was first detected once it became a corner crack and grew along a side face. Inspection with phased array ultrasonic did not improve early detection.

Reference:

1 B. Main, S. Barter, I. Kongshavn, R. Filipe do Rosario, J. Rogers, I. Field, M. Figliolino, A Fractography Case Study of Full-Scale Durability Test (FSDT) vs Service Experience for a Combat Airfract Trailing Edge Flap (TEF) Hinge Lug Bore, *USAF ASIP Conference Presentation, 2024.*

14. Additively Manufactured Hinge Certification (RUAG AG)

RUAG AG, L. Barloggio, B. Bachmann, S. Bräutigam, J. Friedli

An F/A-18 aluminum alloy hinge is being developed for certification using additive manufacturing (AM). The hinge was chosen for the following reasons:

- Non safety-critical part, used only during maintenance
- The same geometry can be used
- Single part qualification

Figure 16 Hinge for AM Part Certification.

Fatigue testing is being performed at the coupon level on hinges made of Scalmalloy and another proprietary alloy. After machining, two versions are being tested, with and without hot isostatic pressing (HIP). The testing consists of both constant and variable amplitude loading, and marker bands have been added to the spectrum to aid in post-test quantitative fractography. Density measurements are also performed. For certification, the fatigue lives of the AM hinges are being compared to those of the original wrought alloy. Surface treatment is being evaluated between sulfuric acid anodizing and a chromate conversion coating by comparing the visual appearance and performing tests of thickness, salt spray resistance, coating weight, primer adhesion and rub tests.

Figure 17 AM-Hinges and Static Tensile Test Probe

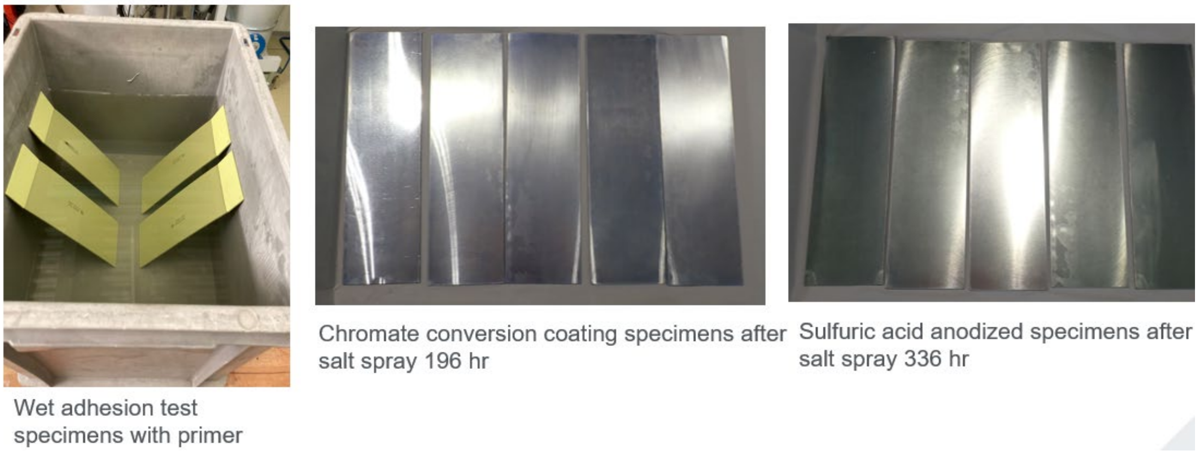


Figure 18 Comparison of Surface Treatments

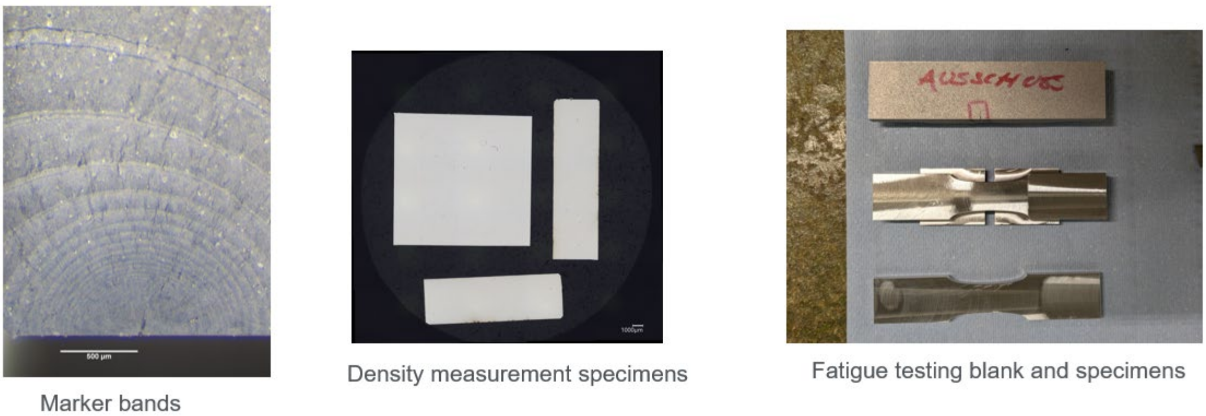


Figure 19 Left: Marker Bands in AM alloy Fatigue Coupons, Middle: Density Samples, Right: Fatigue Test Coupons

15. Fatigue tests on Scalmalloy coupons (RUAG AG)

RUAG AG, L. Barloggio, I. Kongshavn, S. Argentero, A. Dare

The aim of this project was to determine the fatigue strength of Scalmalloy, in terms of crack initiation (CI) and crack growth (CG), and compare it to other F/A-18 aluminum alloys. Variable amplitude fatigue testing was performed on Scalmalloy coupons extracted (machining) from blanks manufactured by Selective Laser Melting (SLM) by Sauber (Inwill, CH). After machining, no surface treatment was performed on the coupons.

Quantitative fractography (QF) was also performed in order to assess the detectability of the marker bands for the Scalmalloy and support the comparison activity. The qualification of the process was out of the scope of this project.

Following the test results, the Scalmalloy in the condition tested (machined surface, no HIP) showed lower CI lives when compared to 7050 and 7075 in both raw and anodized condition. This behavior is a consequence of the presence of defects found on the surface that originated during the SLM process (lack of fusion/porosities, as shown in the figure below). Those defects are spread upon the entire volume of the blanks and, after machining, show up at the surface of the machined coupon. The application of HIP at suitable parameters before machining could close or shrink these defects and improve the total lives of the Scalmalloy.

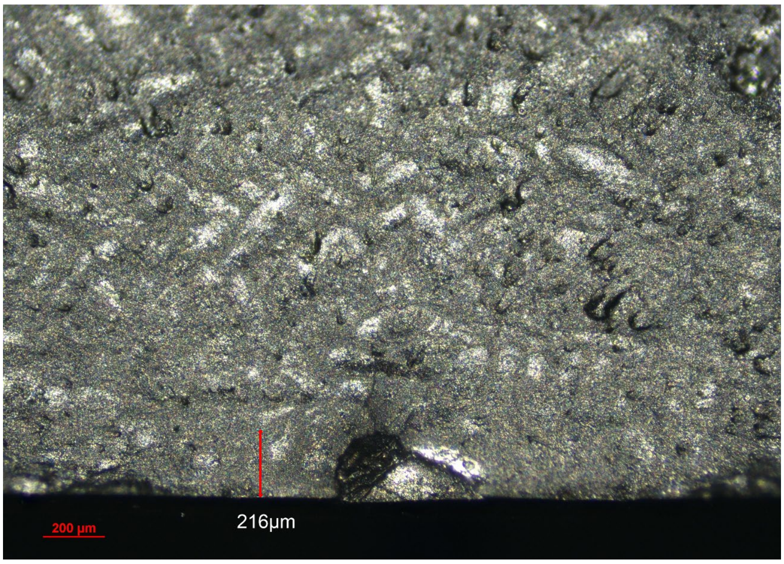


Figure 20. Surface Defect Found on Scalmalloy Coupon

Although a poor readability of marker bands (MB) - under optical and stereographic microscope - was found on all observed coupons (*Figure 21*), as a consequence of the extreme variability of grain size and texture, the Scalmalloy showed a higher crack grow rate for most of its life when compared to wrought alloys.

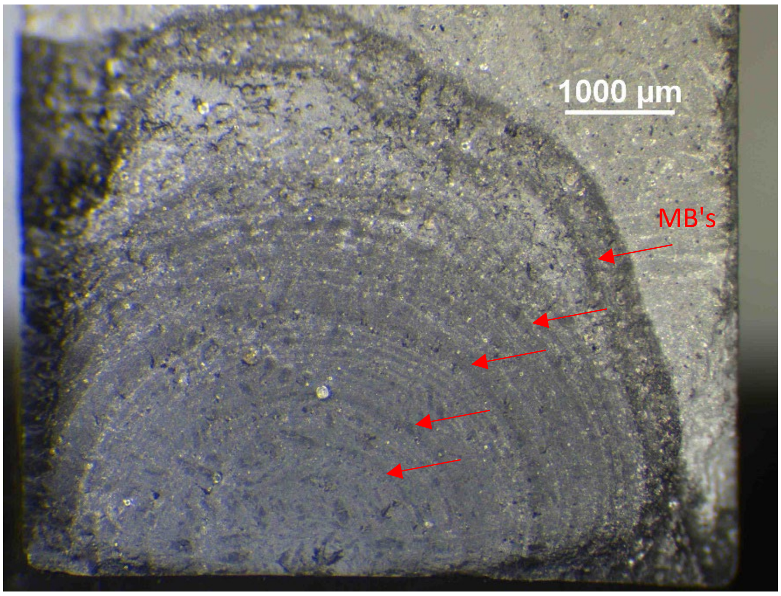
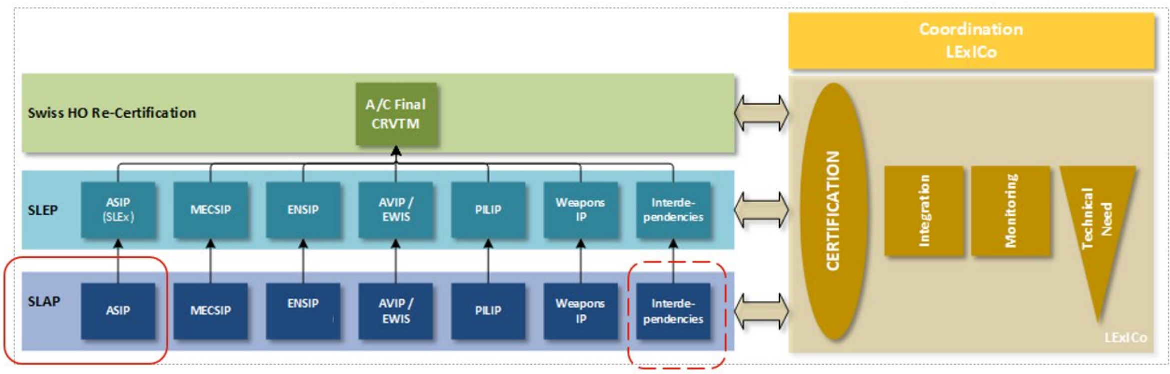


Figure 21. Crack Surface of Coupon with MB in Evidence

16. Recertification of an In-Service Aircraft Fleet (RUAG AG)

RUAG AG L. Sorensen

The Structural Service Life Assessment Program (SLAP) was executed to support the recertification of the Swiss F/A-18 C/D fleet to 6000 FH. Structural integrity is one of many aspects that need to be coordinated to ensure overall recertification, and structural integrity investigations are required to ensure that primary systems will continue to function safely.



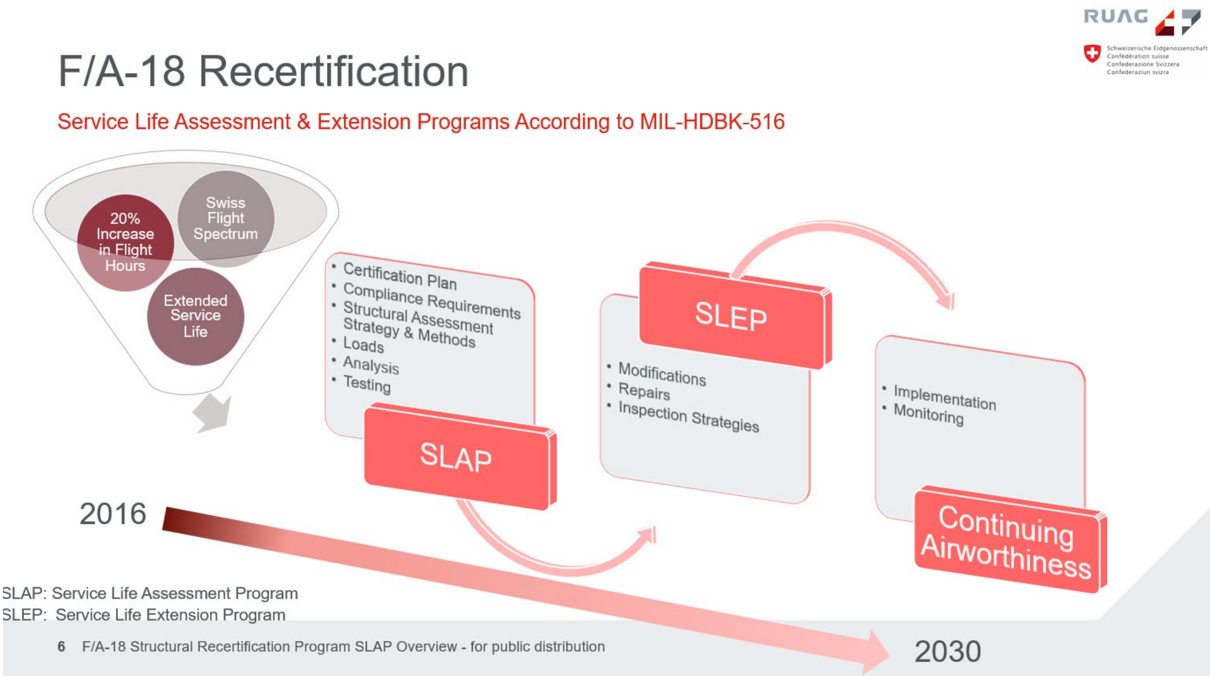


Figure 22. Structural Service Life Assessment Program and Recertification

The SLAP project consists of methods development, analysis, testing and the identification of mitigation options, as well as project management and documentation. Methods development includes review of the current lifing policy and scatter factors, as well as the determination of appropriate loads, spectra, crack initiation and crack growth analyses, life improvement factor policy and statistical evaluations. Since the Swiss F/A-18 is certified using a combination of crack initiation and crack growth requirements, a Swiss-specific methodology and lifing policy were developed.

Top Level

- Lifing Policy (requirements, acceptable risk level, use of test data, use of fleet data, pegging, model calibration, etc.)
- Scatter Factors (worst fleet aircraft, analysis factor, material factor, tracking factor, dynamic factor)

"Standard" Analyses

- Loads / spectrum derivation / summation of static & dynamic effects
- Crack initiation / crack growth
- Life improvement factors
- Statistics (baseline for: fleet findings processing, airworthiness/logistical risk assessment and mitigation option assessment)

"Non-Standard" Analyses (Swiss specific)

- Simplified Total Life approach (extrapolation of crack initiation results to a pre-defined crack length)
  - Conservative but quick analysis of SSE parts (no need to develop crack growth model !)
  - Estimation of expected crack size at DSG
  - Repeat inspection interval derivation for mitigation option "Safety by Inspection"
- Hybrid Crack Growth
  - Deal with threshold issues in crack growth analysis starting with initial crack size < 0.05" (<1.27mm)
  - Perform simplified probabilistic analyses

Figure 23. Swiss Methodology for Recertification

The requirements of the lifing policy are shown below:

Safe Life (SL)
- Crack Initiation at 6'000FH plus scatter factors

Damage Tolerant Life (SDTL)
- Crack Growth from a_{ini}=0.05" until failure at 6'000FH plus scatter factors

Total Life (TL)
- Crack Initiation plus Crack Growth from a_{ini}= 0.01" until failure at 6'000 FH plus scatter factors
  - Implementation of Total Life (crack initiation + crack growth up to ligament failure) concept on SSE parts as a relief to the Safe Life (crack initiation) requirement

Fracture Critical (PSE):
- SL & SDTL requirements

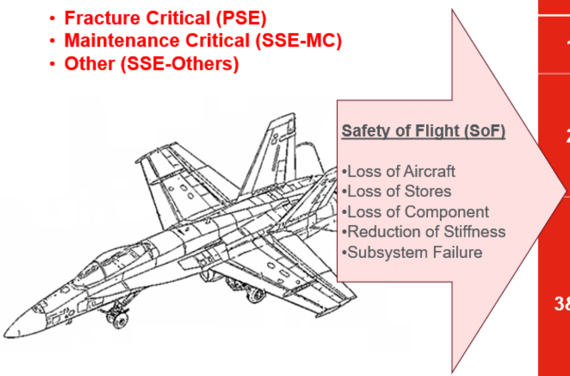
Maintenance Critical (SSE):
- SL requirement
- TL allowed

Figure 24. Swiss Lifing Policy

Parts were categorized as fracture critical (PSE), maintenance critical (SSE-MC) or other (SSE-Others) to prioritize the analyses.

What parts need review?

- **Fracture Critical (PSE)**
- **Maintenance Critical (SSE-MC)**
- **Other (SSE-Others)**



SoF Level	Assessment Priority	Comment
1	1	Parts categorized as PSE will be analyzed with the highest priority. Some SSE-MC parts are included.
2	2	Within this SoF level, the parts categorized as SSE-MC will be analyzed with the highest priority. The parts categorized as SSE-Others may be grouped together for analysis.
3&4	3+	Parts with low SoF, driven by systems or fleet findings. Structural analysis may be performed to support system assessment or within a grouped assessment of other parts. Low SoF parts may be assessed without analysis/test.

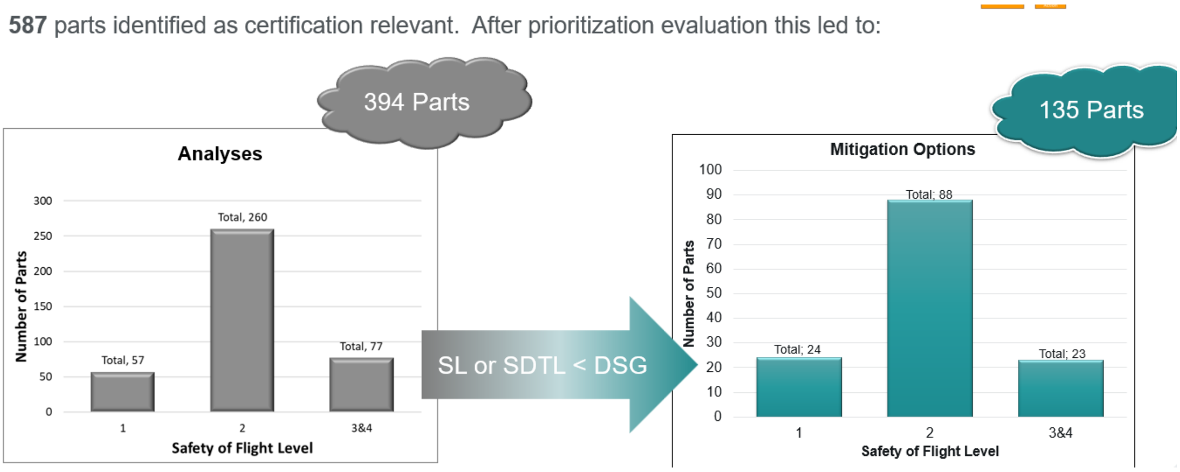


Figure 25. Part Prioritization

The decision to analyse a location / part is based on multiple factors. The main inputs for this justification include:

- in-service data
- comparisons of loads and spectra with respect to original certification or tests (i.e. Swiss ASIP or Swiss Full Scale Fatigue Test)
- part criticality

Each identified Hotspot represents a unique geometric location on a part. Risk mitigation options include part modifications, inspections or replacement.

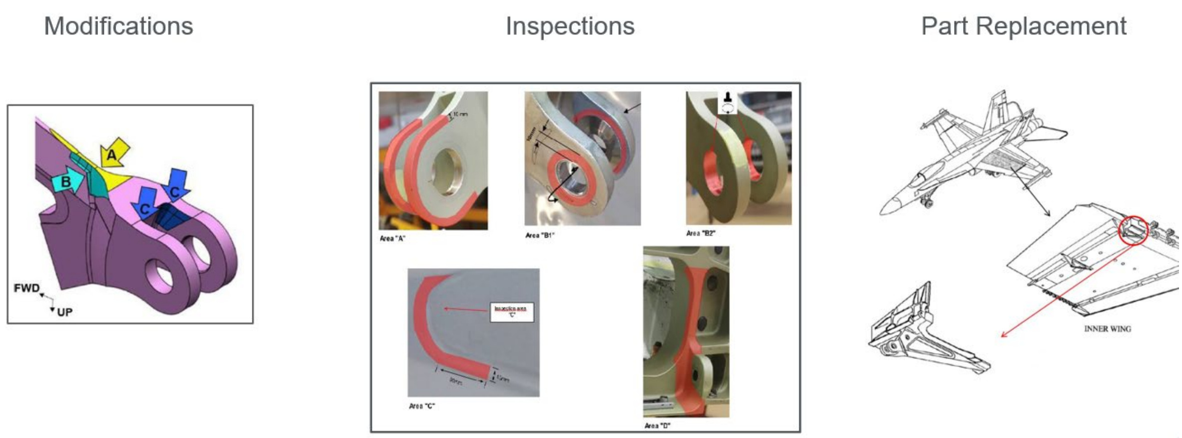


Figure 26. Risk Mitigation Options

Component tests using Swiss spectra were performed on the H-stab and the trailing edge flap, with was tested at the test facilites of the NRC in Canada. These tests have been described in previous Swiss ICAF National Reviews.

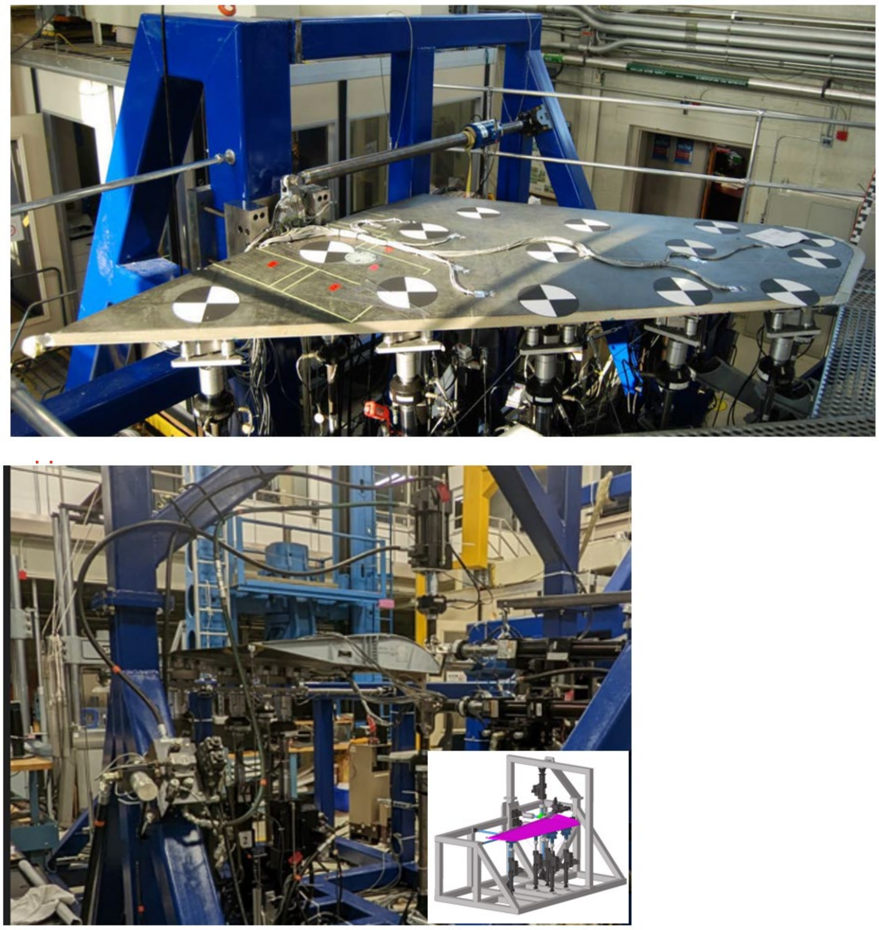
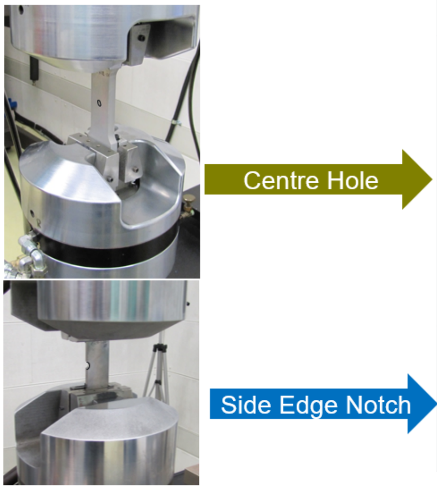


Figure 27. Top: H-Stab Component Test, Bottom Left: Trailing Edge Flap Test

A center barrel and horizontal spindle test were performed in collaboration with DSTG and RMIT.

Figure 28. Center Barrel and Horizontal Spindle Tests

To develop the analysis methodology and for spectrum truncation studies, coupon tests on AA 7050, AA 7075 and Ti6Al4V were performed on spectra containing various amounts of dynamic loading and symmetry, as shown below.



Material Type	Spectrum Type	Load Levels
Al-7050	Wing Root Bending Moment (WRBM)	High & Low
	Truncated Full Scale Test (WRBM)	
	Asymmetric Dynamic	
	Symmetric Dynamic	
Al-7075	Wing Root Bending Moment (WRBM)	High & Low
	Truncated Full Scale Test (WRBM)	
	Asymmetric Dynamic	
	Symmetric Dynamic	
Ti6Al4V	Wing Root Bending Moment (WRBM)	High & Low
	Truncated Full Scale Test (WRBM)	
	Asymmetric Dynamic	
	Symmetric Dynamic	

Figure 29. Coupon Testing with Various Materials and Types of Spectra

The coupon tests showed that in general, CI analyses provide conservative estimates of fatigue life with respect to the test data. Crack growth analyses of the safe damage tolerance life (SDTL), where an initial crack length of 1.27 mm is assumed, would provide similar or even conservative growth prediction with respect to the test data. However, for highly dynamic spectra, the crack growth calculated using standard material data at small crack lives can be overly optimistic. In such cases, RUAG used alternative methods for total life calculations.

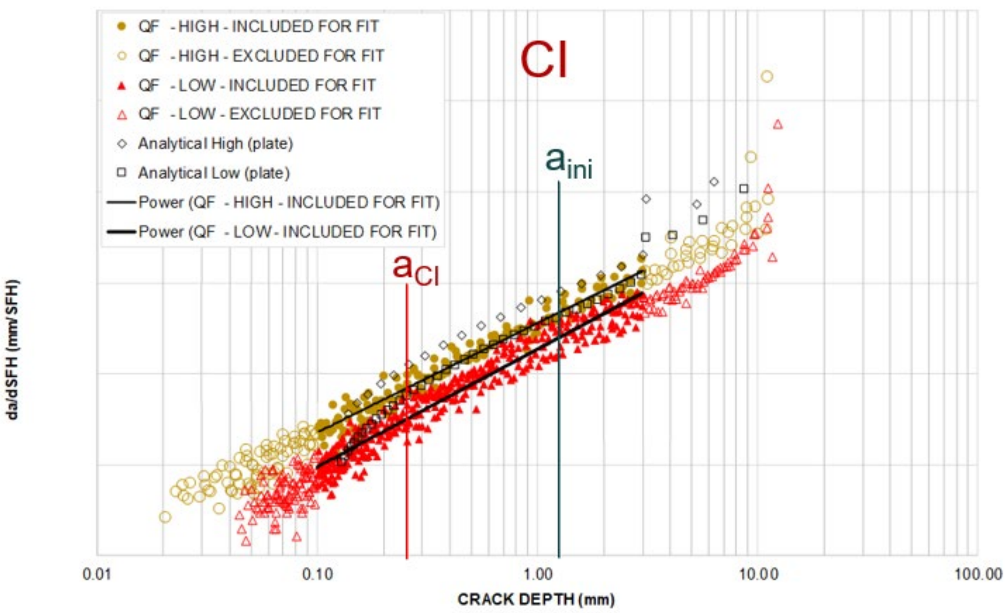


Figure 30. Growth Rates Measured Using Quantitative Fractography Compared to Predictions.

17. PC-24 Full Scale Fatigue Test (Pilatus Aircraft Ltd)

Pilatus Aircraft Ltd, Milian Seiler, Vincenzo Rossi

The PC-24 is a business aircraft in the light jet class with the cabin size of a midsize jet and a large cargo door, able to land on unimproved runways and to cruise at 45,000 ft above sea level. It was certified in the commuter category of CS 23 and 14 CFR Part 23, with a design life of 30,000 flight hours or landings, whichever comes first.

The airframe of the PC-24 aircraft is designed to damage tolerance criteria. The Full-Scale Fatigue Test (FSFT) is used to demonstrate that the airframe can sustain three design lives and survive the Residual Strength Test (RST).

Spectrum & Loading. The standard mission corresponds to an average flight profile (taxing, take-off, climb, cruise, landing) derived based on usage data. Combined with the statistical distribution of gusts and other events, a Master Design Spectrum (MDS) is derived. The MDS is the baseline for fatigue analysis and testing. For test efficiency, the MDS was reduced to the Master Test Spectrum by truncating all load cases that are below the fatigue threshold, resulting in a remaining 195,000 load cases. The load cases were mapped to 34 actuators, which further distribute the loads to 144 load introduction points using linkages and whiffletrees.

Test Article & Rig. The test article is a representative PC-24 airframe omitting parts structurally not relevant and/or not to be tested such as the horizontal stabilizer or the flight control system. Dummy structures were designed for the landing gear, the engines, and the horizontal stabilizer, to enable load introduction at these interfaces. Test instrumentation comprised of 500 strain gauges. The hydraulic actuators are combined with a pneumatic system able to simulate a climb from sea level to service ceiling in 15 seconds.

Test Performance. A block of 1,000 flight hours is completed in 38 hours on average and followed by structural inspections. After simulating two design lives, artificial damage was introduced in the test article at critical locations to demonstrate slow crack growth behaviour. The Residual Strength Test, performed after the third simulated design life, has shown that limit load can be sustained without catastrophic structural failures. The subsequent Tear Down Inspection was used to identify previously undetected damage and to demonstrate that no wide-spread fatigue damage has occurred.

Figure 1: Overview of the full-scale fatigue test rig.

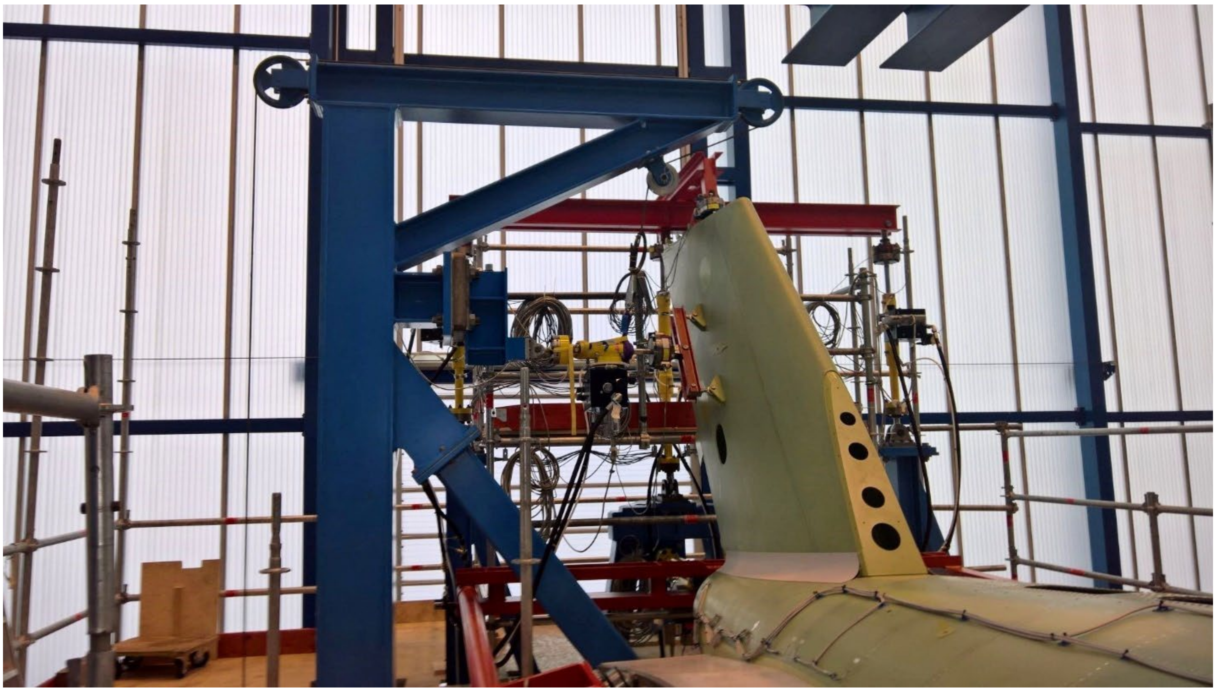


Figure 2: Load introduction details on the empennage.