A MODERN AND EFFICIENT FULL SCALE FATIGUE TEST FOR THE SWISS F/A-18

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After the redesign of the Swiss F/A-18, it was decided to launch a test and qualification program for the Swiss F/A-18 aircraft structure. A Full Scale Fatigue Test was designed and taken into operation to provide the knowledge in respect of the Swiss F/A-18 aircraft structure and to enable the qualification and validation of the modified and redesigned parts of the structure. A modern and efficient test concept was found permitting a most accurate loading of the test structure and supporting the execution of detailed inspections and measurements.

INTRODUCTION

In an early phase of the Swiss F/A-18 program an Aircraft Structural Integrity Program (ASIP) per MIL-STD-1530 was performed in order to evaluate the entire aircraft structure against the unique Swiss requirements. All structural elements which did not meet the given structural requirements were redesigned (material changes, local beef up's and fatigue life improvements). Most important structural modifications based on these structural evaluations were located in the centre fuselage (carry through bulkheads and the dorsal deck longeron) and in the wings. Detailed information on the ASIP results were already published in previous ICAF papers.

The Swiss Defence Procurement Agency (DPA) has chosen RUAG Aerospace to perform the Swiss F/A-18 Full Scale Fatigue Test (FSFT). RUAG Aerospace as the prime contractor decided to team with IABG during the definition phase, the test set-up phase and the commissioning phase in order to perform this fatigue test in an economical way with the most state of the art test set-up and equipment. This fatigue test is presently carried out at the RUAG Aerospace facility in Emmen.

This paper describes the outline of the test program, the test concept and the test set-up and points out the important engineering task to test the Swiss F/A-18 redesign: the development of a load introduction system to simulate a most accurate loading.

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F/A-18 TEST PROGRAM

The design of the new Swiss fighter aircraft F/A-18 was performed in order to meet the criteria, defined by DPA, (USN baseline criteria plus extended damage tolerance criteria) and based on the Swiss Air Force defined usage spectra (mission descriptions, mission mix, external stores configurations, etc.). Basically the same procedure was performed to elaborate the whole test and qualification program to reach the required goals of this project. The Full Scale Fatigue Test on the Swiss F/A-18 was designed to provide the knowledge in respect of the Swiss F/A-18 aircraft structure and to establish the basis for a safe and economic operation and maintenance plan of the entire Swiss F/A-18 fleet. Furthermore this Full Scale Fatigue Test is indispensable for the qualification and validation of the modified and redesigned structure for the design service life of 5,000 flight hours. Therefore the comparability of the test results to the in-service-life with respect to the structural modifications of the aircraft was one of the most important factors during the development of the test program for the F/A-18 FSFT.

A scatter factor of 2 is used to demonstrate compliance with the aircraft service life. An additional 400 spectrum flight hours (SFH) of testing are performed to demonstrate compliance with the residual strength capability according to the USAF damage tolerance specification. Therefore 10,400 SFH have to be simulated in total during this Full Scale Fatigue Test. An adapted Master Event Spectrum for this fatigue test (Test-MES), which was already published in earlier ICAF papers, was generated. All fatigue load cases applied in the test were derived from manoeuvre events based on component loads at specific reference stations. The Test-MES, representing a block of 200 flight hours, consists of 26,990 lines with 2,009 unique flight load cases (excluding cockpit pressure).

To gather in time all necessary data resulting from the fatigue cycling a detailed inspection- and measurement program is a very important issue. As the Swiss F/A-18 structure is not a complete new one but a redesigned aircraft, a test program was developed based on the Swiss ASIP study and the Boeing test results. Especially all redesigned and critical locations will be inspected in pre-defined inspection intervals. Beside daily walk around inspections during the test performance closed visual and instrumental inspections (NDI) will be performed every 1,000 SFH. This procedure leads to a meaningful statement about the required goals of this Full Scale Fatigue Test.

TEST CONCEPT

For the Swiss F/A-18 FSFT a modern test concept was developed which fulfils all given requirements. In total 68 hydraulic push/pull actuators are installed to the test set-up to simulate aerodynamic and inertia loads of the aircraft structure. The loads are applied in the following structural areas:

- fuselage structure: 20 jacks
- L/H wing box and flaps: 16 jacks
- R/H wing box and flaps: 16 jacks
- LEX structures (L/H, R/H): 6 jacks in total
- tail structures (VT, HT): 10 jacks in total

One of the first steps during the test concept development was the definition of suitable load introduction points, which were capable to apply the required loads without any structural overloading of the test article and with a minimized effort in structural reinforcements in the area of the load introduction devices. Whiffle trees are used to distribute the loads to several load introduction points and to limit the number of hydraulic jacks.

To develop a most accurate loading system all jack positions and whiffle tree details (concept, geometry and distribution to the prior defined load introduction points) were calculated and optimized on basis of 30 fatigue relevant balanced load cases of the test spectrum. For each of these load cases the shear force, bending moment and torque moment distribution was calculated using the test concept configuration and compared to the corresponding given values of the cross section design loads. The requirements for the load match accuracy were defined at 20 reference locations distributed all over the aircraft structure. A maximum calculated deviation of no more than 2.0% depending on the applied reference load at each reference point was allowed. With the final loading concept, all the above mentioned requirements could be met and approved for the 30 evaluated load cases.

The development of a suitable test concept for the Swiss F/A-18 FSFT was also driven by various special requirements. As the test program has a focus on the redesigned aircraft structures, the development of the test concept had to concentrate mainly on the centre fuselage and the inner wing including the fold rib. Therefore most jacks are located in the centre fuselage and the wings in contrast to the distribution of jacks in the not redesigned structures like the vertical tails, the forward and aft fuselage where only the interface loads had to be matched. An example of the calculated load over the fuselage structure with the discrete load steps can be seen in FIGURE 1.

With the use of hydraulic push/pull actuators which all are arranged below or beside the test article a test concept was developed which enables an easy access to all parts of the test article. This test concept also has the advantage to provide good access to the test for inspections.

TEST ARTICLE

The test article used for this fatigue test is a Swiss redesigned two-set F/A-18D Lot XVIII (FY94) airframe, designated as FTS1 which was manufactured together with the same manufacturing quality as the entire fleet. It consists of the complete airframe with all structural components. Most subassemblies and subsystems as well as some non structural items are not part of the test article. Some of the omitted components are replaced by dummy structures and are used for load introduction or load reaction purposes. These components are:

- nose radom
- nose and main landing gear
- drag brace
- gun mount
- fuselage centre pylon, fwd & aft attachment
- missile launcher, L/H & R/H, fwd & aft attachment
- arresting hook
- engines, L/H & R/H
- horizontal stabilizer, L/H & R/H
- inboard and outboard wing pylon, L/H & R/H
- wing tip missile launcher, L/H & R/H

During aircraft production of the Swiss configuration several problems occurred. Mainly the wing was affected by gaps between different structural parts, misoriented plate nuts, short edge distances of fasteners and escaped fastener hole improvements. Most of these non-conformances could not be retrofitted in early aircraft production. Detailed fatigue analyses were therefore needed to demonstrate the compliance with the Swiss requirements. Despite of these results, it was decided to leave some of these non-conformances on the right hand wing of the FTS1 test article.

A comprehensive FE Model of the test article with the complete test configuration was developed as described in earlier ICAF papers. This model was used for the validation of the structural integrity due to load introduction and for the prediction of global structural displacements. Therefore the test equipment which had to be procured (hydraulic jacks, etc.) could be exactly specified for the Swiss Full Scale Fatigue Test. This results in an advantage of an improvement in the load simulation accuracy and gives also an economic benefit.

All non structural doors and covers as equipment bay doors, dorsal deck covers, wing and fuselage fairings, flap and aileron shrouds etc. were omitted in order to gain additional access to the test structure and to some important fatigue critical locations during daily walk around inspections.

TEST SET-UP AND EQUIPMENT

Structural Test Floor

The entire test set-up and test equipment is supported by the “structural test floor”, a stiff steel construction. 13 nearly identical modules (11 identical ones and two ones adopted in size) are connected together to form a platform of 18 m x 15 m with a height of nearly 900 mm by high-tensile screws. The total weight of the structural test floor is about 115 tons.

This construction was necessary because the concrete floor at the test hall in RUAG Emmen was not strong enough to sustain all the reaction loads during fatigue cycling. It was a requirement to the stiffness of the structural test floor that no significant deformations (< 2 mm) should occur during the test performance. The height of the structural floor was limited because the complete test set-up and the integrated test article had to fit in the test hall with a height of only approx. 7.5 m.

Restraint System

The test article is supported by six single struts in a statically determined manner. These struts are fixed to the test article at defined load introduction points. They permit on the one hand a safe mounting of the test article and on the other hand they are used to be able to introduce loads during the test performance.

The restraint struts are connected to the nose and main landing gear dummy structures (3x Z-direction), to a load introduction fitting at the forward fuselage and to the arresting hook dummy (2x Y-direction) and the engine dummies (1x X-direction) as shown in FIGURE 2. In case of an emergency shutdown of the test a passive controlled unloading is performed. The arising reaction loads have to be sustained by the restraint system and the related load introduction points.

Test Rig and Inspection Platforms

The mechanical test rig consists of a number of steel structures supporting the loading system (68 hydraulic jacks and 6 restraint struts). All struts of the rig are connected by screws to special interface plates which are welded on the upper structural test floor surface. Due to the interface plates an easy build-up and dismantling procedure was possible. Every element of the support structures was positioned by a laser based measurement system to ensure the correct positioning of the interface to the hydraulic jacks. The maximal allowed deviation crosswise to the loading direction was 3 mm.

The design of the loading rigs was mainly influenced by stiffness and fatigue strength requirements. The maximal tolerance for the deformation of each loading rig under maximal load was expected with less than 1 mm for rigs with jack connections and less than 0.5 mm for rigs with rod connections, respectively. A model of the entire loading rig is shown in FIGURE 3.

The inspection platforms consist of a system of steel struts with several grating platforms. These platforms are located around and below the test article and are used for inspection and maintenance purposes as well as during the assembly of the test set-up. The inspection platforms are arranged in three levels. The lowest level, with a width of 2.8 m is located below the fuselage along the middle axis of the aircraft. The middle level is located approx. 0.5 m above the lowest level and allows access to the lower surface of the wings. The upper platform is located around the whole test article about 1 m above the mid level providing a platform width of minimal 1.4 m. A model of the inspection platforms is shown in FIGURE 4.

An important criterion of the design of these platforms was the access from each side to the test article. The inspection platforms are also designed with respect to the test hall infrastructure. The inserted safety railings of the upper inspection platform can be easily removed to allow a quick integration or removal of the complete assembled test article with the existing hall crane.

All loading rigs and inspection platforms were designed by a 3D-CAD system (CATIA). In the concept and design phase a realistic view of the complete set-up, to check the distances between jacks, rigs, loading systems and the test structure was possible. Furthermore the integration of the test article into the rig could be easily approved.

Load Introduction System

The loads generated by the hydraulic jacks in the F/A-18 FSFT are either distributed via whiffle trees to several load introduction points or introduced directly to fitting or dummy structures fixed to the test article. Altogether 44 jacks are equipped with whiffle trees each distributing their load to up to four load introduction points. Examples for the load introduction via whiffle trees (leading edge flap) as well as via dummy structures (wing tip dummy) are shown in FIGURE 5. All whiffle trees are designed under fatigue strength aspects and were modelled in 3D-CAD (CATIA) to ensure the necessary degrees of freedom due to deformations of the test article during the entire test performance and the stability under compression loading.

The load introduction to the test article is realized in general by the following different load introduction devices:

- 15 different dummy structures (fuselage, wings, horizontal tails)
- 6 different load introduction fittings (fuselage, wings)
- 48 shear pads (fuselage)

- 522 tension/compression pads (wings, flaps, LEX)
- 4 contour boards (vertical tails)

During the concept and design phase of the load introduction devices main attention was directed to a most accurate loading, especially at the redesigned areas. The load pads designed for tension and compression loading are distributing their load to a quite large pad area (pad size of 100 x 100 mm each) to reduce the specific local loading of the structure as far as possible but taking into account enough access to the test article for inspections. The pad layout at the wing is shown in the sketch in FIGURE 6.

The concept of the load introduction to the leading edge extension structures (LEX) requires load pads bonded only at the frame/spar connections. As the structure of the L/H LEX and R/H LEX have different frame positions, due to the ladder cut-out at the left hand side, different whiffle tree concepts for each side had to be worked out. Nevertheless the jack positions are equal on both sides.

For the fuselage, load introduction fittings were used where possible, due to its easy and effective load introduction. But in the centre fuselage (redesigned area) the required high loads could not be introduced directly via fittings. Therefore the technique of bonded pads which is used at the wing and LEX structures was extended to shear load introduction and a vertical bonding method was developed by RUAG. The whiffle trees were adapted to the shear load introduction and on each side of the fuselage 24 pads of different size have been applied to introduce shear loads. The shear pad layout at the centre fuselage is shown in the photo in FIGURE 7.

Hydraulic Loading System

For the Swiss F/A-18FSFT a hydraulic power supply of approx. 450 l/min with a working pressure of 280 bar was installed in the test laboratory. As mentioned above 68 hydraulic jacks have been installed, generating push/pull loads during the test performance. The complete arrangements of all hydraulic jacks, including the manifold block, have been specified in detail by IABG and have been delivered by ELAND Engineering Ltd.

All jacks are equipped with a load cell at the piston rod end and are force-controlled by the control & monitoring system. As a control and safety device each jack is equipped with a specific hydraulic manifold block supporting a servo valve (control unit), two switching valves (shut-off system), a throttle valve and a load limiter for each pressure chamber. A hydraulic jack with its manifold block and valve system is shown in FIGURE 8.

An important function of the hydraulic system is the safety concept which ensures a safe unloading of the test structure even for uncontrolled conditions. In case of an emergency shut down both chambers are switched off from the hydraulic power supply by the switching valves and are bypassed via the adjustable throttle valve. The whole test article will be unloaded evenly. During the commissioning phase these throttle valves have been adjusted by series of pre-tests to ensure a safe unloading of the test article at every shut-off procedure regardless of the actual load condition. To prevent a local overloading of the test structure, due to an eventual malfunction of the servo valve or the control system, load limiters are used. These load limiters connected to each hydraulic chamber are pre-set to a value of approx. 120% of the maximal load occurring in this loading direction. A local overloading due to any malfunction of the entire system is therefore prevented.

Pneumatic Loading System

The cockpit section of the test article will be loaded by pneumatic pressure loading during the flight-by-flight simulation with two pneumatic load cycles per flight. The pneumatic loading system with its valve system is defined essentially by its requirements concerning the pressure cycles. The cockpit pressure has to be increased to Δp = 38 kPa within max. 5 to 6 seconds. The pressure has to be reduced again to 10% of the maximal pressure (Δp = 3.8 kPa) within approx. 15 seconds. To make sufficient pressurized air available a pressure reservoir ($V=0.09m^3$) is included to the pneumatic loading system and connected to the in-house air power supply. To reduce the pressurized volume in the cockpit section to 90%, polystyrene structures are integrated to the cockpit area. The entire pneumatic loading system, integrated to its special rig, and the connection to the cockpit section can be seen in FIGURE 9.

Control & Monitoring System and Measurement & Data Acquisition System

In order to efficiently simulate the test article life, the test concept includes an automatically operating digital control and monitoring system for the loading of the test article, including safety aspects and data acquisition purposes. The requirements for the control system were specified in detail by IABG. The SmarTEST control system from FCS Test Systems was selected because of its modular system which offer the opportunity to fulfil our special requirements. In total 77 closed loop control channels are implemented to the control and monitoring system to fulfil the following tasks:

- closed loop force control of all 68 hydraulic jacks
- control of jacks in “normal fatigue mode”, “strain survey mode” and “maintenance mode”
- measurement of the reaction loads at the 6 struts
- pressure control for the cockpit section
- transformation of the numerical loading program

- ensure the safety concept of the FSFT to prevent overloading of the test article
- perform complete start-up, fail-safe and shutdown procedures

The measurement system for all 1,100 strain gauges consists of the MGC+ data acquisition system from HBM designed to measure 1,720 channels during the strain survey and to measure up to 300 channels simultaneously during the fatigue test with a sampling rate of 10 Hz. All measurements can be initiated via an interface connection (CAN BUS) between the control & monitoring and the measurement & data acquisition system.

TEST PERFORMANCE AND INSPECTIONS

After the completion of the pre-test activities (elaborating a modern test concept, preparing an individual test spectrum, building up FE-Models etc.) and the test set-up phase (developing a flight-by-flight loading spectrum, designing and building up the mechanical test set-up, installing all loading systems and commissioning of the entire test equipment) the fatigue cycling of the F/A-18 FSFT started in time beginning of this year and has now reached already 4,000 SFH.

The concept of the inspection plan were mainly based on the results of the ASIP study, the redesigned parts, as well as on all manufacturing non-conformances concerning the Swiss aircraft fleet and the test specific items (structural parts nearby load introduction systems). The description of the above features of the test set-up will allow visual inspections using in depth NDI technology. Daily walk around inspections will be performed by qualified staff for 24 hours/day. Major inspections will be performed after each 1,000 SFH. After the removal of covers and selected bolts detailed visual inspections and videoscope inspections will be performed. On some critical locations ultrasonic and eddy current techniques will be used. All detected non-conformances will be recorded by a database and can be compared to the test results of several former F/A-18 tests (FT01, ST16, FT93).

CONCLUSION

The Full Scale Fatigue Test for the Swiss F/A-18 is designed and able to support the qualification and validation of the Swiss redesign. It provides all necessary knowledge about the F/A-18 structure for a safe and economic operation of the entire Swiss F/A-18 Air Force fleet and provides the basis for an optimized maintenance program.

The decision of RUAG to team with IABG led to a modern and efficient test philosophy and together the most state-of-the-art test set-up (see FIGURE 10) was developed, installed and taken into operation. With the reasonable test- and inspection program RUAG is able to fulfil all the required goals of the F/A-18 qualification project.

ACKNOWLEDGEMENTS

The author would like to thank the entire RUAG F/A-18FSFT project team and especially the project leader Dr. Michel Guillaume for the excellent teamwork.

REFERENCE LIST

(1) M. Guillaume, Swiss F/A-18 Full Scale Fatigue Test, RUAG Presentation at 21st Symposium of ICAF, Doc. No. 2287.

FIGURES

FIGURE 1 Simulation accuracy of vertical load over the entire test article.

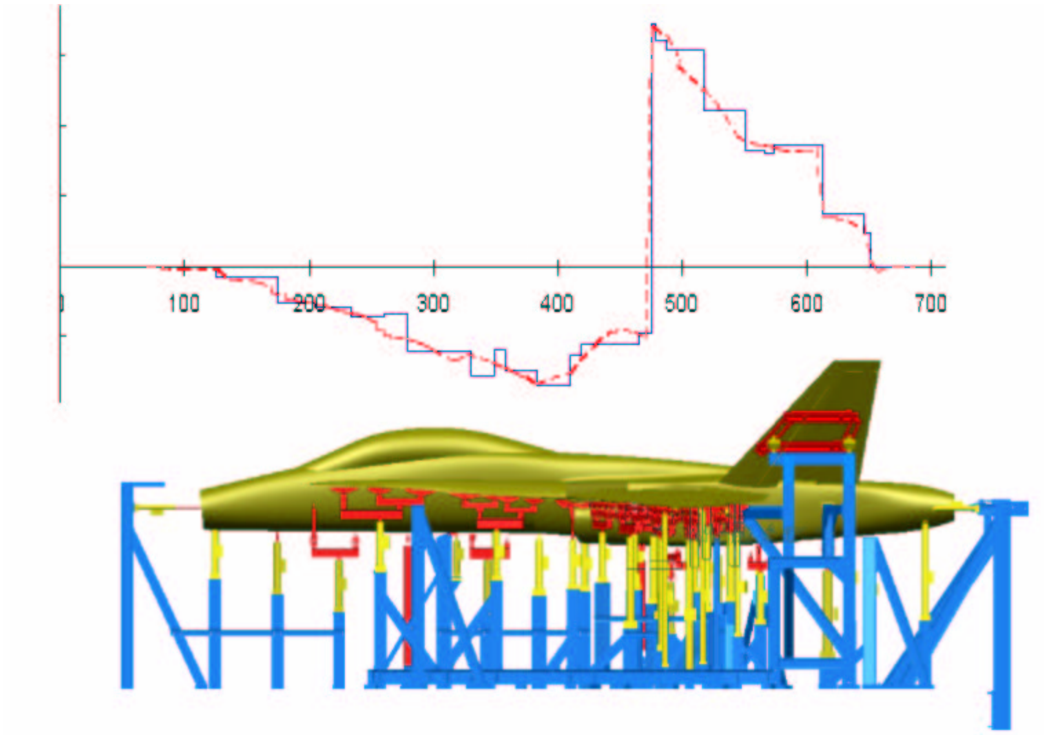

FIGURE 2 Arrangement of the complete specimen restraint system

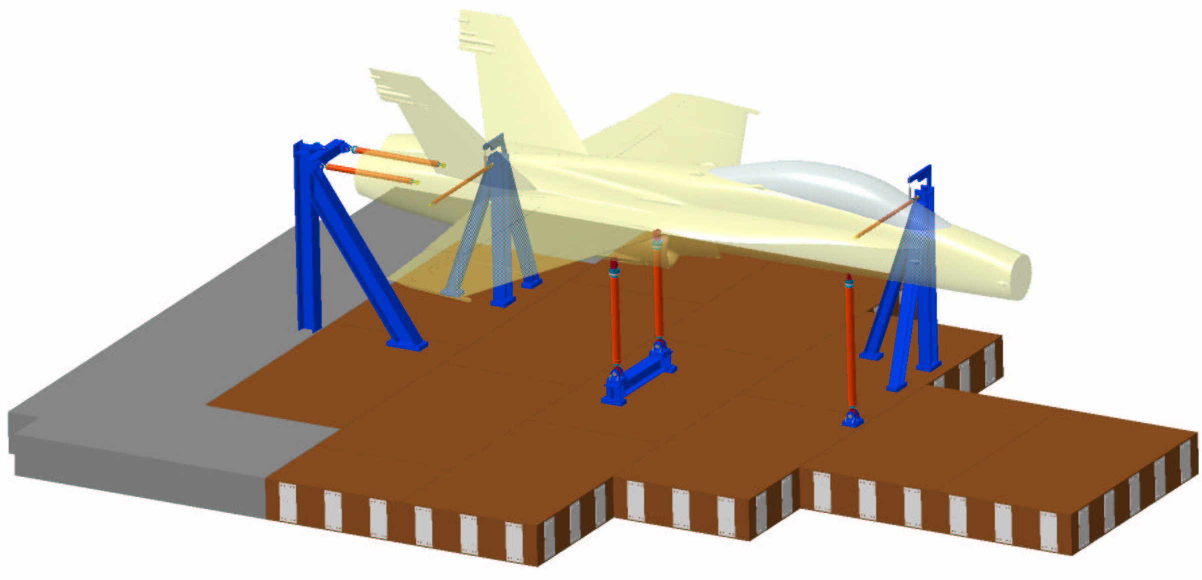

FIGURE 3 Complete loading rig and load introduction systems (rigs, whiffle trees, pads, etc.)

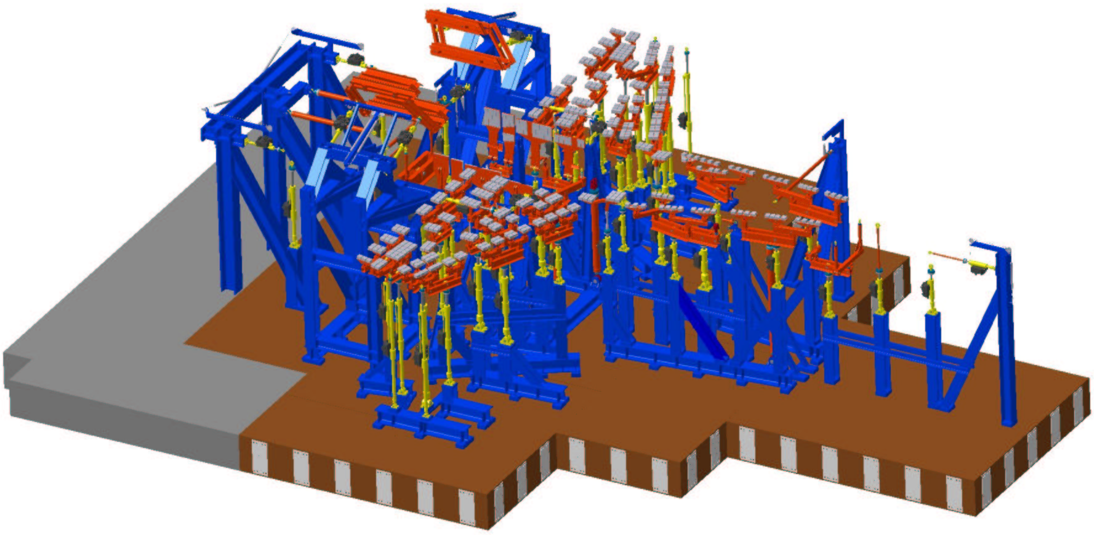

FIGURE 4 All 3 levels of the inspection platforms with staircases and inspection office

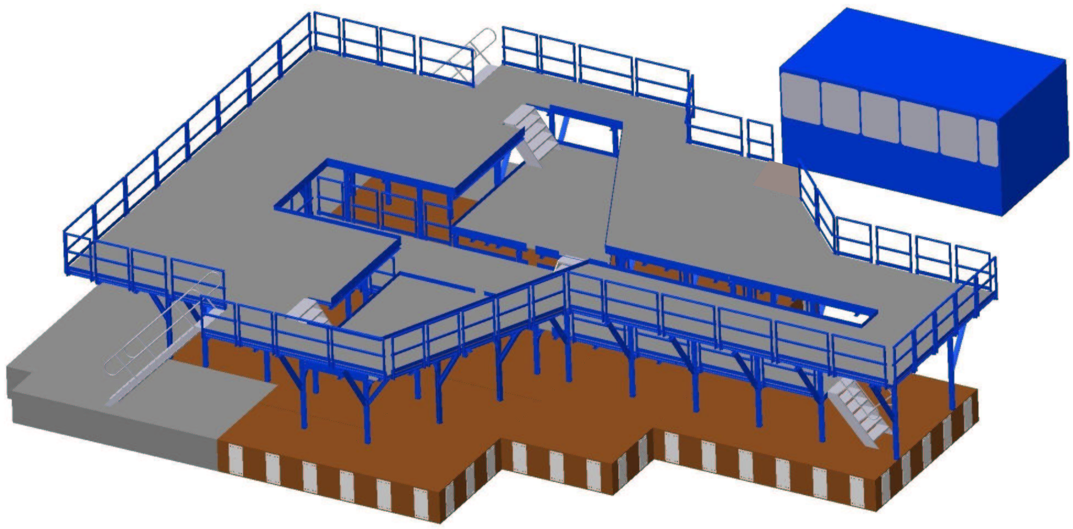

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FIGURE 5   Load introduction on the outer wing via whiffle tree (OLEF) and dummy (wing tip)

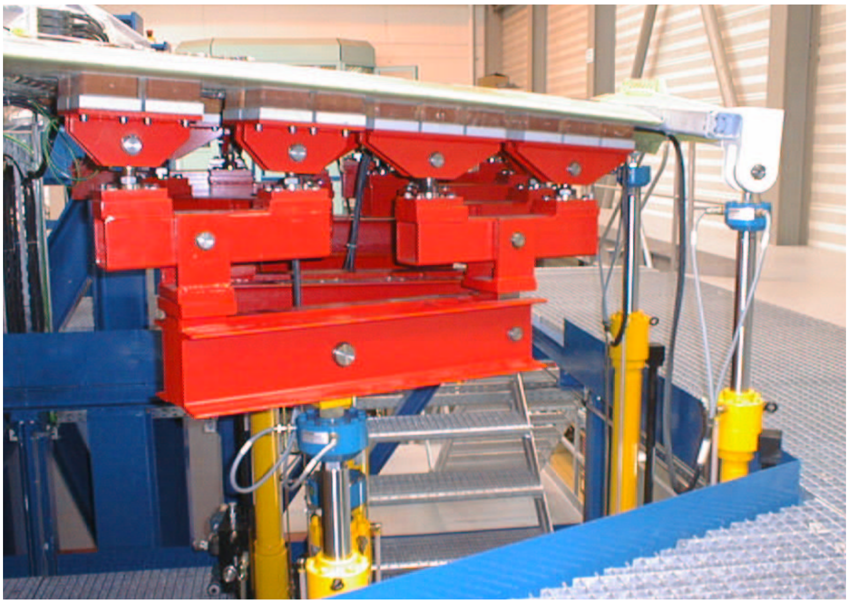

FIGURE 6   Sketch of the realised pad layout on the L/H wing (wing box, leading edge flaps, trailing edge flaps and aileron)

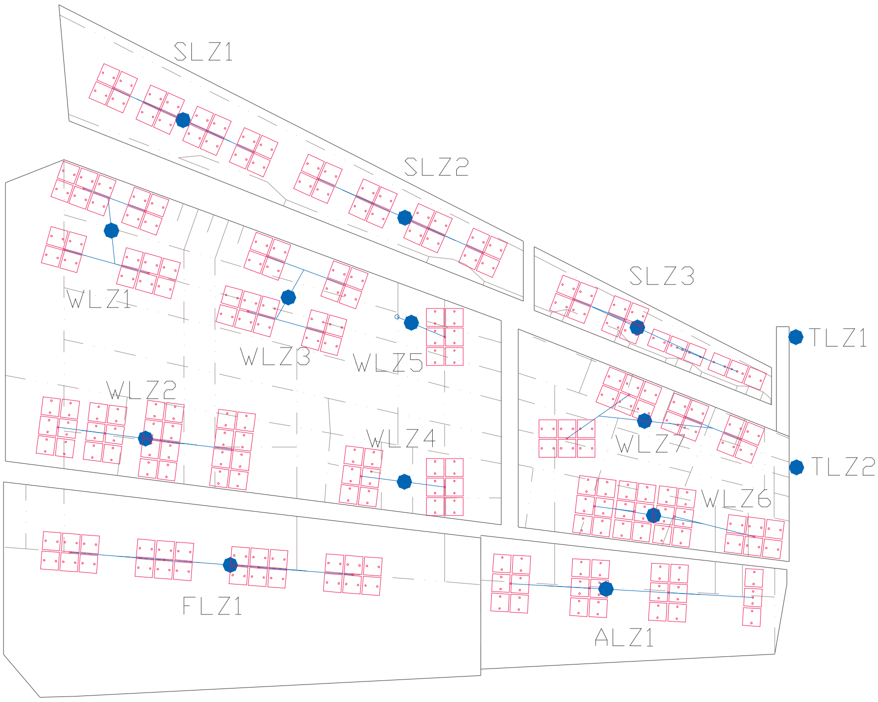

FIGURE 7 Shear pads applied to the centre fuselage (L/H fuselage)

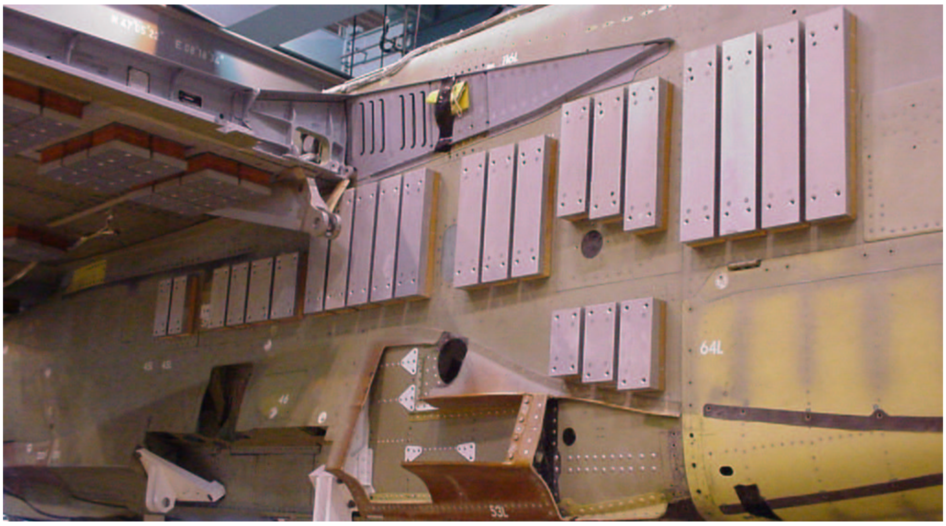

FIGURE 8 Complete assembly of hydraulic jack (FFZ2) at the front fuselage with manifold block, valves, load cell and bearings

FIGURE 9 Pneumatic loading system: rack with pressure reservoir and cockpit hose assembly

FIGURE 10 Complete test set-up for the Swiss F/A-18