A NEW CONCEPT FOR TESTING FATIGUE AND DAMAGE TOLERANCE AT AEROSPACE STRUCTURE

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Abstract

Within the 728 Jet Full Scale Fatigue Test, the Spoilers will be tested simultaneously to the wing loading. The spoilers are made of a CFRP sandwich with a solid Honeycomb core. The load assumptions are based on a rectangular pressure distribution on the spoiler surfaces. The loading point of the total spoiler force is the geometry of the trapezoid formed spoilers. The spoiler loads will be introduced in the structure by a pair of bellows on the spoiler surface.

1 Introduction

The 728 - 100 was a new airplane developed by Fairchild Dornier, Oberpfaffenhofen, Germany. This aircraft was designed to carry about 70 passengers from or to large international airports, and to provide the regional airlines with appropriate airplanes. A version for about

Figure 1: The 728 – 100 [3]

90 and 50 passengers was planed as well as a business and a cargo plane (528/728/928 Jet Family). The 728 - 100's rollout took place in March 2002 and the first flight was scheduled for May of the same year. Before the first aircraft can be delivered to a customer the aircraft has to be certified. This includes not only a flight test program but also two full scale tests performed on the ground. The structure has to pass a static test applying ultimate loads before the first flight. The demand on the fatigue test is to simulate the entire service life c[1]onsidering the expected loads. Fairchild Dorniers fatigue department is engaged to prepare and carry out the fatigue test based on the JAR/FAR 25.571[5] as described in the Fatigue and Damage Tolerance Guidelines [9].

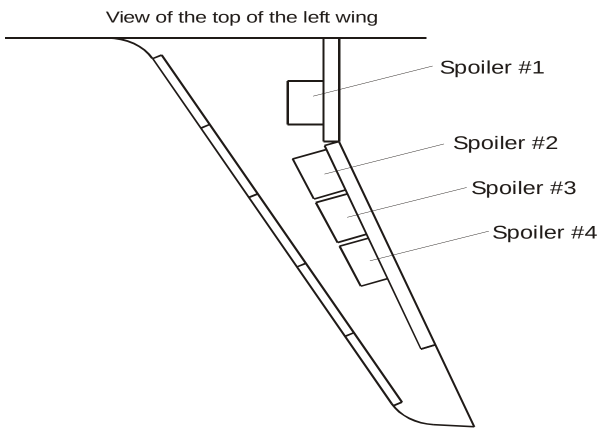

Figure2: Spoiler arrangement along the wing [9]

The FAR/JAR demands the stress and fatigue evaluation of the primary structures and control surfaces. The flight control surfaces of the 728 - 100 consist of ailerons, flaps, slats, vertical and horizontal stabilizer, rudder, krueger flaps and the spoilers. The 728 has four spoilers on each wing. As shown in Figure 2 they are numbered from inboard to outboard. The one closest to the fuselage is named spoiler #1, the following spoiler in spanwise direction is spoiler #2 and so on. Because the spoilers #2, #3 and #4 are

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located on the outer wing, they are named outboard spoilers. This group of spoilers is also named as multi function spoiler, because they support several tasks. Spoiler #1 on the other hand, located on the Spoiler arrangement along the wing inboard wing is the inboard spoiler. Its a origin ground spoiler. The three outboard spoilers are designed in a similar way. The surface area is shaped like a trapezoid and the actuator system is linked centered in spanwise direction. Once again spoiler #1 differs.

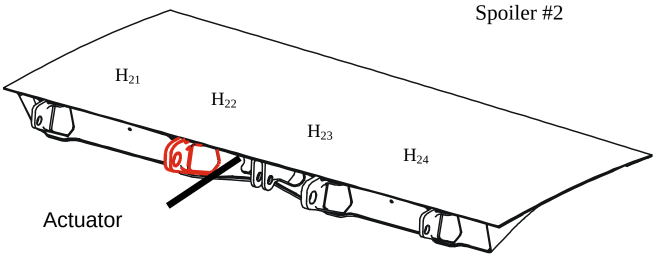

Figure 3: Denomination of the hinge fittings [9]

Its surface area is rectangular and the actuator is linked to a bearing hinge position, but not at the center. Figure 3 shows spoiler #2 and its hinge fittings. The letter H means hinge. The first number in the index describes the spoiler the hinge belongs to, the second one the position of the hinge at the spoiler. The numbers are counted spanwise, for both numbers. E.g. H_{22} means: Hinge fitting of spoiler #2, the second hinge from inboard to outboard (cf. Fig. 3) The spoilers do exactly what their name implies. They spoil the aerodynamic lift of an airplane. The outboard spoilers of the 728 fulfill different functions during a flight. There is the support of a roll maneuver, the reduction of the speed on cruise and the lift dumping immediately after touch down, to increase the deceleration during the role out. Spoiler #1 is defined as ground spoiler. It is only used after touch down. Then all spoilers deflect to 45° (full deflection) to spoil the aerodynamic lift (lift dumping). Thus lift dumping is done by all four spoilers together. A roll maneuver will be supported by deflection of the outboard spoilers (#2 - #4) to a maximum of 30°. An important function in flight is the so called speed brake. Spoiler #2 and #3 fulfill this task by deflections between 0° and 30°. The operating conditions of spoilers are different. They have to withstand corrosion caused by great differences in temperatures, sun radiation and humidity. In each flight segment the way they are loaded is varying. The weight of fuel and the pay load determines the different loading conditions. Therefore appropriate loads and flight conditions are important for a fatigue investigation.

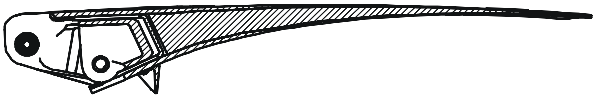

Figure 4: Section view of a 728 Spoiler [9]

The spoilers are made of CFRP. A section view shows the setup of the spoilers (cf. Fig. 4). The skin is made of laminated CFRP. The thickness differs as shown Figure 4 corresponding to the local strains. The spoiler is filled with honeycombs. The hinges are machined of aluminum which are riveted to the front spar of the spoiler. The aim is to make a proposal of a test setup for a fatigue test evaluation to verify the calculated results by test.

2 Certification requirements

Certification requirements for an aircraft are established in a few compendia which contain the entire requirements of the certification authorities. The guide responsible for the certification of the 728 - 100 is named FAR/JAR 25. This manual is composed to avoid aviation catastrophes considering its rules in every design and certification phase of structure and systems. It is compulsory for every system or subsystem of an airplane.

2.1 Use of Templates Fulfillment of requirements

To fulfill the fatigue and damage tolerance requirements the substantiation will be demonstrated by test and analysis. Generally, it is impossible to test every structural significant item (SSI) for damage tolerance characteristics, but the most important representative areas will be tested directly. So only one spoiler will be part of the fatigue demonstration covering all other spoiler in a conservative manner. In absence of direct test results, sufficient test evidence will be demonstrated applying strain measurements in affected SSI areas at a representative test specimen, measuring stresses including local effects. These results will be used as input data for fatigue and damage tolerance calculations. Similar aspects with directly tested areas will be taken into account. In the case of natural damages arising during the tests, which show insufficient fatigue life, fast crack propagation, or low residual strength, structural with retrofit and modified production design will be defined. For these measures fatigue and damage tolerance evaluations will be prepared by analysis supported by results of the above tests. The fatigue and damage tolerance of spoiler CFRP-parts will be substantiated mainly by test. The test articles contain typical damage that may occur during fabrication, assembly and in-service and repairs. These tests will be performed unconditioned at room temperature. A fatigue test with appropriate enhancement of loads covers adequate inspection intervals of primary composite structure. The objective of fatigue and damage tolerance justification is to provide an inspection program for each SSI including:

- threshold inspection (Tl)
- inspection interval (II)
- inspection method

In addition to this, a large number of repairs will be tested and simultaneously certified, to be introduced into structural repair manual as accepted repairs. The threshold inspection (TI) for each SSI (time of first „fatigue detailed inspection") will be provided by showing an adequate life of the structure, either as a crack free period (metallic parts), and/or as a period during which the growth rate of initial cracks or damages is sufficiently low. Threshold inspection for composite parts is provided as a no growth period of initial, barely visible defects caused by manufacturing, handling or accidental damage. The inspection interval for each SSI is provided on the basis of a safe crack / damage growth period from a detectable length to critical length at limit load according to FAR/JAR 25.571 (b) (deterministic approach) or on a sufficient residual life of the remaining load path(s) in a multiple load path structure system (probabilistic approach) up to a residual strength at limit load according to FAR/JAR 25.571 (b).

2.2 Evaluation by Test

Spoiler structure will be justified in one of the fatigue tests described. For each SSI the threshold inspection will be derived from the fatigue test life, alternatively from propagation life of initial flaws of the real structure.

For metallic parts:

- as a crack free period (without detectable cracks)
- as a period, during which the crack growth rate of small initial cracks is sufficiently low for metallic parts with partly non inspected / inspectable areas of first load path
- as a period, during which the delamination growth rate of initial damages in bonded areas is sufficient low for bonded areas which are partly non inspected / inspectable

For composite parts:

- a damage initiation free period
- a no growth period of initial damages like delamination and barely visible impact damages
- repairs

The investigation of the damage tolerance characteristics results in determination of the inspection intervals, which are primarily dependent on the crack / damage propagation behavior. This behavior will be investigated during the damage tolerance test periods, either by monitoring the propagation of naturally or artificially initiated damages.

3 Spoiler loads

As described above there are several operating positions (retracted and various deflection angels) of the spoiler inducing different loads to the wing structure and the spoiler. Within a flight the loading changes permanently [7]. However, determining the loads properly a flight spectrum is created. By omitting and truncation of non relevant load sequences a duty cycle is derived for each spoiler, representing a typical flight, enveloping the loads of n_z-spectra and spoiler aerodynamic loads.

3.1 Load spectra

The basic spectra are statistics about random events disturbing the steady operating conditions of an aircraft [1]. Frequency distributions for these events adapted to the specific service life requirements of 728-100 are derived from statistical data measured during normal airline in service.

3.2 Duty cycle

The spoiler usage is assumed similar each flight. Therefore a conservative spoiler loading sequence is defined, covering spoiler usage of most operators. This sequence is called “duty cycle” for spoiler #1, #2, #3 and #4. Duty cycle of spoiler #1, it is assumed that they occur in once per flight. Spoiler #1 only works as a ground spoiler. Duty cycles of spoiler #2 and #3, the spoilers #2 and #3 work as multifunction spoilers, i.e. airbrakes, roll spoiler and ground spoiler. All these functions are reduced to three extensions at the stages assumed to be the most critical ones. The loads are calculated by interpolation of the force coefficients given in [1]. Spectra of spoiler #4, the spoiler works as a multifunction spoiler, as roll and ground spoiler. These functions are reduced to two extensions at the stages assumed to be the most critical ones. The loads are calculated by interpolation of the force coefficients given in [1].

3.3 Duty cycle for fatigue test

The duty cycle used for spoilers fatigue and damage tolerance test have to ensure the entire load spectrum of all four spoilers (conservative envelope). Thus a spectra of the most critical loads of each spoiler is created. The spectra is depicted in Table 1.

Flight Segment	Aerodynamic Loads	
	Loads	Moment
	PN-res	MLE-res
	[KN]	[KNm]
taxiing with negative acceleration Dnz = -0.5	0.057	-0.019
taxiing with positive acceleration Dnz = 0.5	0.057	-0.019
flap retraction	4.218	-1.413
flap retraction	0.735	-0.207
climb to 18000 ft	2.219	-0.743
power change, level off & acceleration	2.157	-0.723
positive gust at cruise Dnz = 1	1.797	-0.507
negative gust at cruise Dnz = -1	4.776	-1.539
power change, level off & deceleration	2.562	-0.722
power change, level off & deceleration	3.590	-1.203
descend to 1500 ft	2.004	-0.671
descend to 1500 ft	-3.325	1.008
flap extension	3.510	-1.176
deceleration, flap extension & descend to 500 ft	2.062	-0.581
deceleration, flap extension & descend to 500 ft	6.263	-2.098
ground spoiler extension, braking, thrust reverse	-1.826	0.612
taxiing with positive acceleration Dnz = 0.5	0.048	-0.016
taxiing with negative acceleration Dnz = -0.5	0.048	-0.016

Table 1:Duty cycle spoiler test [11]

3.4 Limit loads

The limit load cases represent the highest loads in service. They have been calculated by considering the highest loads in service life. This load is estimated to occur for a entire fleet of an airline once in service life. The fatigue test phase will be ended applying this loads. Spoiler has to sustain these cases at the end of each damage tolerance phase, too. The limit loads results from a suction pressure of –0.8849 mbar (negative sign means suction on spoiler surface) for all spoiler surfaces.

4 Proposal of a certification test scenario for spoiler

For certification of primary structure a fatigue test simulating 200,000 (2.5 x 80,000) flights is recommended. The test scenario is divided into two phases – fatigue and damage tolerance. During the fatigue phase (100,000 flights) fatigue failures are not allowed to occur. For proof of composite elements and structure, the loads of the duty cycles have to be enhanced to 112% [9]. The damage tolerance phase consists of 100,000 flights. During those flights all assumed failure modes are tested one after another. For each failure mode a test scenario of three times 5,000 flights (minimum inspection interval) is demanded at least. Every failure simulation will be ended by the application of limit load. The damaged structure has to withstand this load once for each failure mode.

4.1 Test setup requirements

The following requirements should be covered by the test setup.

- the test has to be carried out with one spoiler, one actuator with electronic control loop
- tensile and compressive forces have to be induced by the upper surface of the spoiler
- the external loads have to be induced as pressure loads on the surface, the hinge moments reacted by the actuator
- the actuator loads have to be acted by the original hydraulic cylinder
- the deformation of the spoiler has to be realized in retracted and deflected case, the test setup must not disturb this mechanism
- axis of rotation for the jig is the HL as well
- to simulate most damaging loads the setup has to realize spoiler positions of 0° and 45°
- there should be low influence from the jig to the structure of the spoiler, the displacements of the spoiler should be real
- the connection between rig and spoiler has to be realized without additional drilling holes, screws or rivets. It is to ensure, that the surface of the spoiler will not be damaged
- the measurement of the actual actuator force is necessary
- the necessary value for the control loop is the actuator force
- the setup has to allow the inspection of bearings, lugs and the spoiler structure
- to simulate a failed bearing or lug, it has to be possible to remove each hinge-bolt during the test
- the setup is to be placed on the top of the wing
- wing bending and other displacements of the wing may not be influenced by the test setup
- the duty cycle has to be simulated for each flight

4.2 Test setup proposal for spoiler #2

The principle of the test setup is depicted in the figures below. Figure 5 shows the spoiler in loaded 0° and Figure 6 in loaded 45° position. This proposal is developed on conclusions resulting from the spoiler loads.

Conclusions:

- The aero load is to be simulated by using a pair of bellows on the spoiler surface
- the bellow has to withstand the loads resulting from differential pressure between inside and outside
- the deformation of the bellows is stopped by two strokes, one for the 0° and one for the 45° position
- the strokes have to possess a mechanism to calibrate the position
- the pressure in the bag should be controlled by a manometer

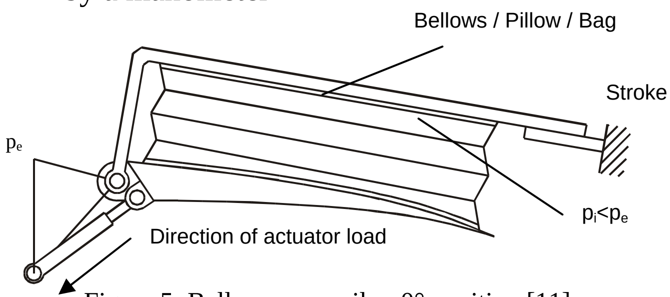

Figure 5: Bellows on spoiler, 0°-position [11]

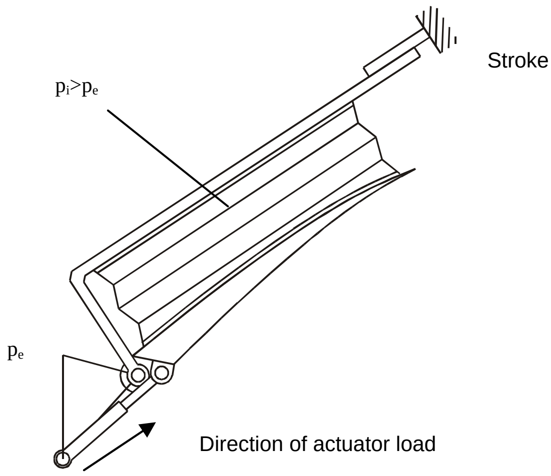

Figure 6: Bellows on spoiler, 45°-position [11]

The most important load sequence of the duty cycle described in chapter 2 can be controlled by one servo-hydraulic actuator only. The test time for simulating one duty cycle is estimated less than one minute. In a full scale fatigue test all recommended 200,000 flights could be simulated within 4-5 months. The proposal will be realized by Fairchild Dornier, adapting the test setup into full scale fatigue spectrum.

4.3 Feasibility study and variations

The maximum aero load resulting from the duty cycle is about 3500 N in the 0° position (tensile forces on upper surface). In the case of

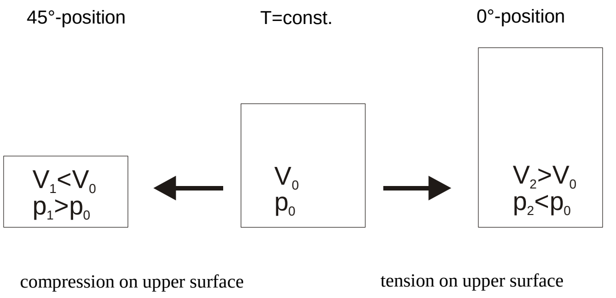

Figure 7: Air volume in bellows during testing [2]

deflection to 45° the load is estimated to be -2200 N (compression forces on upper surface). To ensure the bellows not to fail the loads for the calculation are set to ± 5000 N in both cases tensile and compression forces on the upper surface. The air pressure of environment (p_e) is set to 1 bar. The loads are applied by the actuator, simulating differential pressure on the upper surface caused by the modification of the closed gas volume V_0 (internal bellows volume). For Δp>0 the volume is reduced by ΔV (differential bellows volume). For Δp<0 the volume V_0 is expanded.

The study demonstrates feasibility for two cases:

- ΔV is practicable with a pair of bellows
- the bellows is able to withstand the loads, resulting from the difference in pressure Δp, between in- and outside of the hull

Δp is calculated with equation 1. Since the absolute value of the tensile and pressure loads are identical, the derivation is done in a general way only. The effective surface used in the derivation is called A_{F_2}. It is estimated to be 90% of the spoiler #2 upper surface area.

The pressure difference is:

$$\Delta p = \frac{F}{A_{F\_2}} \tag{1}$$

where $F = -5000N$ for the tensile case and $F = 5000N$ for the compressed case.

The surface area is:

$$A_{F\_2} = 0.9 \cdot 0.728 m^2 = 0.6552 m^2 = 655200 mm^2 \tag{2}$$

Hence, the magnitude of the pressure difference is 76.3 mbar. The pressure p_0 in the bellows in unloaded condition, is set to p_0=1 bar. The relation between pressure and volume is described with the "ideal gas law". If the temperature is constant and the volume is given as specific volume the following equation is useable.

$$v_0 \cdot p_0 = v \cdot p \tag{3}$$

The pressure p is $p = p_0 + \Delta p$, while the volume v is $v = v_0 + \Delta v$.

This leads to an expression for the volume difference of:

$$\Delta v = -\frac{F}{A p_0 + F} \cdot v_0 \tag{4}$$

The differential specific volume Δv for the tensile case is calculated in relation to v_0.

$$\Delta v = +v_0 \cdot 0.0826 \tag{5}$$

The differential specific volume Δv for the compressed case is calculated in relation to v_0.

$$\Delta v = -v_0 \cdot 0.0709 \tag{6}$$

The relations for the specific volume are also applicable to the absolute volume values.

$$\Delta V = +V_0 \cdot 0.0826 \text{ for tensile case} \tag{7}$$

$$\Delta V = -V_0 \cdot 0.0709 \text{ for compressed case} \quad (8)$$

The differences in volume has to be transformed into values representing the difference in height. Thus a bellows is created with an area of A_{F-2} and a mean height in neutral deflection of h_0=100 [mm]. This value is estimated, because a transformation in other values can easily be done.

$$V_0 = A_{F\_2} \cdot h_0 \quad (9)$$

$$V = V_0 + \Delta V \quad (10)$$

$$h = \frac{V}{A_{F\_2}} \quad (11)$$

$$\Delta h = h - h_0 \quad (12)$$

The difference in height can be calculated using Equations (7) – (12) as $\Delta h = 0.0826 h_0$ for the tensile case, while it is $\Delta h = -0.0709 h_0$ for the compressed height. The result of the

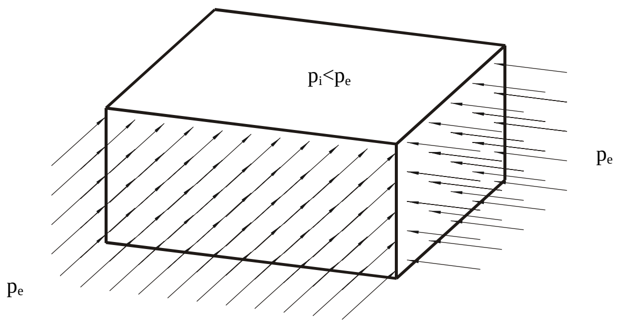

Figure 8: Airbag loaded with forces resulting from Δp. [2]

investigation is an elongation of about 8.3% for tensile forces (-7% for pressure forces) to realize the calculated difference of volume. The differential pressure induces another problem. In the investigation above, the hull of the bellows is set with no displacement or reduction of the volume caused by pressure loads to the side walls of the bellows. In Figure 8 the bellows is depicted as a cuboid. Top and bottom surfaces are set as rigid plates. The resulting forces applied to the side walls deform the bellows. In the following investigation Δp is estimated to 80 [mbar] and the dimensions of the cuboid are set in relation to the length of the spoiler l_{ges}.

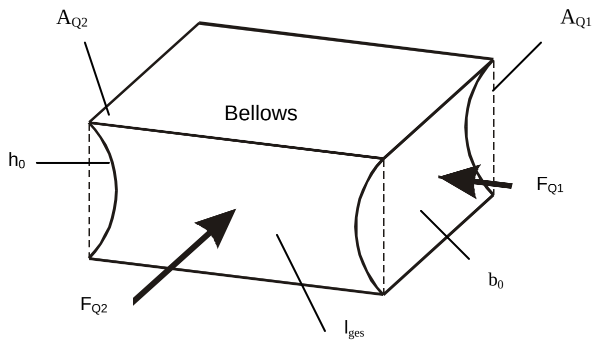

Figure 9: Deformation of the bellows induced by enlarged volume [2]

The length of the cuboid is l_{ges} the width is $b_0 = l_{ges}/2$ (estimated) and the height is $h_0 = l_{ges}/10$ (estimated). In the calculation l_{ges} is set to 1200 [mm].

F_{Q1}:

$$F_{Q1} = A_{Q1} \cdot \Delta p \quad (13)$$

$$A_{Q1} = b_0 \cdot h_0 \quad (14)$$

$$F_{Q1} = \frac{1}{20} \cdot \Delta p \cdot \ell_{ges}^{\ 2} \quad (15)$$

F_{Q2}:

$$F_{Q2} = A_{Q2} \cdot \Delta p \quad (16)$$

$$A_{Q2} = \ell_{ges} \cdot h_0 \quad (17)$$

$$F_{Q1} = \frac{1}{10} \cdot \Delta p \cdot \ell_{ges}^{\ 2} \quad (18)$$

For the given values the force F_{Q1} and F_{Q2} become 400 [N] and 800 [N] respectively. This is not an exact analysis, but the results show the magnitude of the expected loads. This implies the need for stabilizers in each fold of the bellows. Otherwise deformations will occur in the hull. These deformations induce loads on the surface of the spoiler. So attention is to be paid on the bonding line between bag and spoiler. The loads induced by the differential pressure in- and outside have to be reacted in the bonding line. It is possible to reduce these bonding loads by using stabilizers in the folds of the bellows.

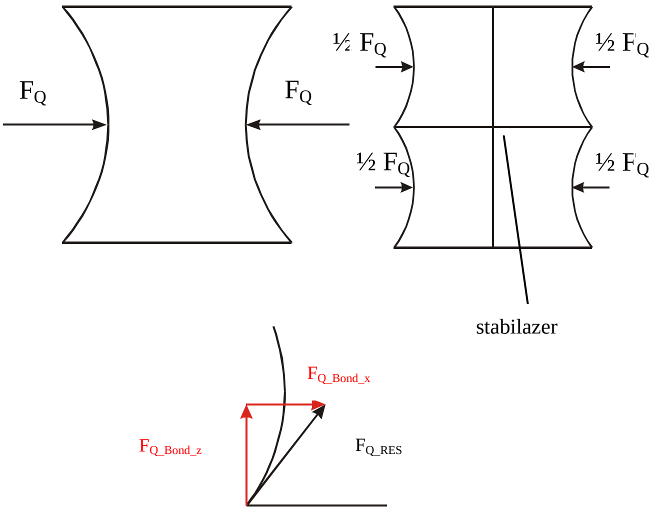

Figure 10:Reduction of bonding loads [2]

In the bonding line the entire reaction forces of the spoiler load are reacted. The objective is, to avoid / reduce tensile forces perpendicular to the spoiler surface. Because they induce pealing stresses in the bonding line. Within the test the bellows is applied with dynamic loads, which may be cause the delamination of the bonding line. Only shear forces have to act onto the surface. The following paragraph lists some alternatives considering the conclusion of the feasibility study. A alternative solution is connecting the bellows to the spoiler using a suction unit.

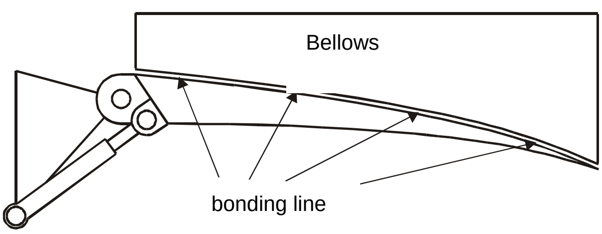

Figure 11: Bonding line [2]

A chamber built up on a spoiler shaped foil with a large number of small holes in it, a suction chamber and the suction unit. The suction unit reduces pressure in the chamber to a rate lower than the pressure of the environment. An airflow is induced between spoiler surface and foil through the holes into the chamber. Spoiler and foil will be connected by the low air pressure in the gap between spoiler and foil. Disadvantages are that the stiffness of the spoiler will enlarged and a lot of technical equipment is needed. Another alternative solution is the connection using pasted Velcro fastener.

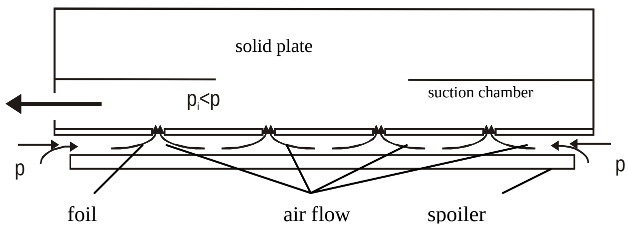

Figure 12:Suction chamber build up on spoiler surface [2]

The bellows gets a closed bottom which is fixed to the spoiler surface by pasted fasteners. The advantage of this configuration is an easy check of the surface simply by taking away the bellows. After inspection the bellows can easily fixed again. The permanent fixing by bonding is a further possibility. The problems applying this method are the tensile forces in the expanded case. There are high forces in the bonding line. The problem of pealing has to be avoided reducing the tensile forces $F_{Q\_Bond\_z}$, which are induced by the walls of the bellows. Figure 13.1

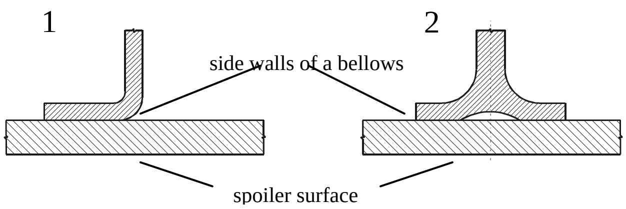

Figure 13: Connection of bellows and spoiler [2]

shows the usual connection of a bellows to a surface. If non-symmetric profiles are used, the probability of pealing is high as well as concentrated tensile forces in the surface. An improvement is depicted in Figure 13.2 by symmetric profiles. Pealing is avoided, tensile forces in the bonding line are reduced. To ensure a test scenario close to real conditions profile #2 is proposed. To reduce the loads on the bonding line the resulting forces to the side walls should be minimized. This can be done by using stabilizers or by reducing the height of the bellows. A bellows with a lot of stabilizers and a low height is most effective.

4.4 Realization at Fairchild Dornier Spoiler Fatigue Test

Within the Full Scale Fatigue Test, the Spoilers will be tested simultaneosly to the wing loading. The load assumptions are based on a rectangular pressure distribution on the spoiler surfaces.

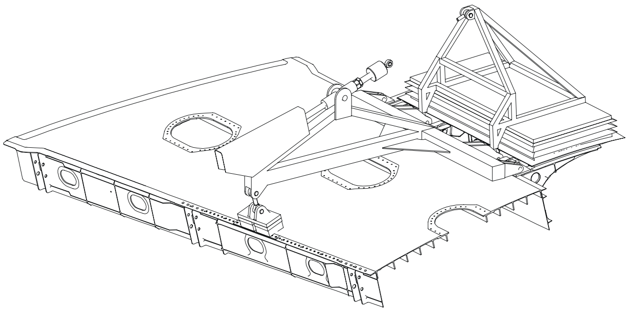

Figure 14: Test setup spoiler #2 [11]

The loading point of the total spoiler force is the geometry of the trapezoid formed spoilers. The spoiler loads will be introduced in the structure by a pair of bellows on the spoiler surface. To move the spoiler and to initiate the loads it will be used the originally actuator.

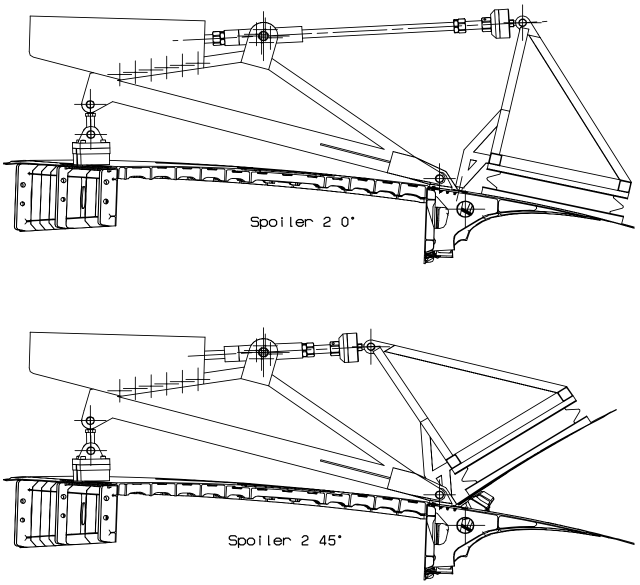

Figure 15: Spoiler #2 loading with contour formers [11]

In Figure 14 the test setup for spoiler #2 is illustrated. Avoiding bending and torsion moments the test rig is designed only with a centered support bracket. The measurement of the loads is realized by a force transducer in the rod. The strokes are realized in the rod. Rotation axes of the rig is the HL as demanded. The aero loads are simulated using a glued pair of bellows. Main loads are reacted in the rear spar of the wing box according to the real conditions. The measured strains of the spoiler are arranged to measure bending moments M_x and M_y the loads in the bearings. The test specimen of spoiler #2 is equipped with twelve strain gauges.

5 Conclusion

For certification of primary structure a fatigue test simulating 200,000 flights is recommended. The test scenario is divided into two phases – fatigue and damage tolerance. During the fatigue phase fatigue failures are not allowed to occur. For proof of composite elements and structure, the loads of the duty cycles have to be enhanced to 112%. The damage tolerance phase consists of 100,000 flights. During those flights all assumed failure modes are tested one after another. For each failure mode a test scenario of three times 5,000 flights is demanded at least. Every failure simulation will be ended by the application of limit load. The damaged structure has to withstand this load once for each failure mode.

The new concept in this paper shows us to use bellows for the load introduction. The example show´s us the load introduction in the structure by a pair of bellows on the spoiler surface. It is not only for use at spoiler, it is specially to use by all control surfaces e. g. Slats, Krueger flap, Flaps, etc. This new load introduction concept demonstrate us new ways to create new test set ups. We can create with this concept the exact loads for every control surface.

List of abbreviations

ACD	Aircraft Certification Document
CFRP	carbon fiber reinforced plastics
FAR	Federal Aviation Requirements
FD	Fairchild Dornier GmbH
H	hinge
HL	Hinge-Line
JAR	Joint Airworthiness Requirements
NDI	non destructive inspection
SSI	structural significant item

List of symbols

F	force	[kN]
F_A	resulting actuator load	[kN]
F_{aero}	resulting aero load	[kN]
II	Inspection Interval	[flights]
N_c	Fatigue Cycles	[flights]
N_d	Design Service Life; Design Life Goal	[flights]
N_{det}	Life at Detectable Crack Length	[flights]
N_r	Remaining Life after Failure	[flights]
N_t	Number of tested Fatigue Cycles	[flights]
p	air pressure	[bar]
p_{diff}	difference between air pressure on the upper and the lower surface	[bar]
p_e	air pressure of the environment	[bar]
pi	air pressure in below	[bar]
p_l	aerodynamic pressure	[bar]
rec	value belongs to triangular pressure distribution	[ ]
TI	Threshold Interval	[flights]
tri	value belongs to triangular pressure distribution	[ ]
t_s	depth of the spoiler (chordwise)	[mm]
ℓ_{aero}	lever arm in Spoiler-COS y-direction of the resulting aero load	[mm]
$\lambda_{\sigma\pi o}$	spoiler length (spanwise)	[mm]
σ	stress	[MPa]

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