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Full-scale fuselage panel tests

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ABSTRACT
In fuselage design studies there will always be the necessity to test components in a realistic way. The fuselage panel test facility at NLR offers the possibility to subject fuselage skin sections to residual strength and fatigue tests. The fatigue test loads simulate cabin pressurization in radial and axial direction and axial loads representative of fuselage bending. To verify the test methodology and the specifications of the test set-up, the performance of the test set-up is evaluated using a GLARE panel designed by Fokker Aircraft. The test results indicate the suitability of the biaxial load introduction systems to load a panel comparable to a panel in a pressurized fuselage subjected to bending. In addition, the tests show that compared to conventional fuselages, the designed GLARE Panel combines a substantial weight reduction with an excellent fatigue behaviour and sufficient static strength. Test on fuselage panels designed by Shorts, DASA and Alenia will be used to demonstrate the technological feasibility of GLARE fuselages also with window cut-outs, to study the growth of multiple site damage in stiffened lap-joints of aluminum curved panels and to determine the effect of multiple site damage on the residual strength of such panels.

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FULL-SCALE FUSELAGE PANEL TESTS

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Abstract

In fuselage design studies there will always be the necessity to test components in a realistic way. The fuselage panel test facility at NLR offers the possibility to subject fuselage skin sections to residual strength and fatigue tests. The fatigue test loads simulate cabin pressurization in radial and axial direction and axial loads representative of fuselage bending. To verify the test methodology and the specifications of the test set-up, the performance of the test set-up is evaluated using a GLARE panel designed by Fokker Aircraft. The test results indicate the suitability of the biaxial load introduction systems to load a panel comparable to a panel in a pressurized fuselage subjected to bending. In addition, the tests show that compared to conventional fuselages, the designed GLARE panel combines a substantial weight reduction with an excellent fatigue behaviour and sufficient static strength. Tests on fuselage panels designed by Shorts, DASA and Alenia will be used to demonstrate the technological feasibility of GLARE fuselages also with window cut-outs, to study the growth of multiple site damage in stiffened lap-joints of aluminum curved panels and to determine the effect of multiple site damage on the residual strength of such panels.

Introduction

In service, fuselages are subjected to the combined loading of cabin pressure and fuselage bending. It is therefore highly desirable that in case of fuselage design studies, curved structures are tested under those biaxial loading conditions. For this purpose barrel test set-ups are generally used. These set-ups, however, are less attractive for generic studies which are not directly related to a particular aircraft design: the radius of curvature is fixed, a large number of panels has to be tested simultaneously and the test frequency is rather low. In addition, barrel tests are expensive due to the large number of panels required and the long testing duration. The panel test facility at NLR (Fig. 1) was developed to avoid these disadvantages. In this facility, which is flexible in panel diameter, panel width and panel length, a single fuselage panel can be tested in a relatively short time(1).

In the full-scale fuselage panel test facility at NLR, fuselage panels with curvatures between those of relatively small aircraft such as the Fokker 50 and those of large aircraft such as the Airbus A300, can be tested under flight loading conditions or can be subjected to residual strength tests. The loading sequences will be derived from the aircraft flight loading conditions. This results in circumferential load sequences caused by internal air pressure, synchronized with an axial load spectrum representative of both cabin pressure and fuselage bending due to taxiing or gust loading. With an average number of 30 axial load cycles and one cabin pressure load cycle within one flight, the testing frequency is about 10,000 flights per 24 hours. Next to the fatigue tests static strength and residual strength tests can be performed. During these tests large cracks such as a two-bay crack can be allowed.

In order to verify the methodology to load a panel comparable to a panel in a pressurized fuselage subjected to bending, the radial expansion, the axial load introduction and the circumferential load introduction obtained in the test facility are evaluated using a GLARE• fuselage panel(2). This GLARE panel was designed and built by Fokker Aircraft within the Brite Euram IMT

• GLARE = Glass fibre reinforced aluminum laminate

2040 project "Fibre reinforced metal laminates and CFRP fuselage concepts".
Fokker Aircraft designed the GLARE panel to verify the applicability of GLARE as a fuselage skin material in the crown section of a Fokker 100. Therefore, the panel was subjected to a fatigue test in which 180.000 flights (two lifetimes) were simulated. The fatigue test was followed by static tests to Limit Load, Ultimate Load and failure. In the framework of the current Brite Euram programmes "Advanced concepts for large primary metallic aircraft structures" and " Structural maintenance of ageing aircraft" NLR performs durability tests, crack propagation tests and residual strength tests on several fuselage (side) panels of Shorts, DASA and Alenia. The tests are to demonstrate the technological feasibility of GLARE panels with window cut-outs, to study the growth of multiple site damage in stiffened lap-joints of aluminum curved panels and to determine the effect of multiple site damage on the residual strength of such panels.

Test facility

The major components of the test facility are the main frame, the pressure chamber and the load introduction systems (Fig. 1). The main frame is a very stiff steel structure. It consists of heavy bottom and top beams and two vertical main columns. A triangular shaped frame, which houses the hydraulic actuator, is mounted above the top beam and two auxiliary vertical columns. The panel is mounted in the frame such that the centre of gravity of the panel cross-section is in the working line of the actuator. The height of the test facility is about 7.2 m, the width is about 4.5 m. The pressure chamber is formed by a seal and base structure. The base structure of the pressure chamber is formed by a stiffened base plate and two support beams which are bolted to the vertical columns of the main structure. The base plate has a large central hole for air supply. At the front side the base plate has curved wooden blocks around the edges which form the side walls of the pressure chamber. An inflatable inner seal is mounted on the wooden blocks and the pressure chamber is closed by the panel. In order to accomplish an air-tight seal without net radial force acting on the panel edges, an inflatable outer seal is mounted at the outside of the panel just opposite the inner seal. The outer seal is bonded on the reaction frame, which consists of an open rectangular steel frame with curved wooden blocks. With a transport system the base structure of the pressure chamber can easily be shifted aside during the test, which significantly enhances the inspectability of the inside of the test panel. The chamber pressurization, axial loads and seals pressurization are regulated by a control system.

The philosophy of the full-scale fuselage panel test facility is that a curved test panel should be loaded comparable to a panel in a pressurized fuselage subjected to bending. Therefore, a radial expansion of the fuselage panel due to cabin pressure should be accommodated (Fig. 2). Pressurization of a fuselage results in the development of circumferential stresses in the skin and the frames. The stress levels in the frames will largely depend on the stiffness of the frame-skin connection. To obtain an appropriate radial expansion for all kind of frame-skin connections, the ratio of stresses in the skin and frames must be correct and adjustable. Therefore, NLR chose to use separate loading mechanisms for the skin and frames. The circumferential stresses in the skin are reacted by bonded unidirectional glass fibres. The loads in the frames are transferred to steel rods.

To transfer the loads in the frames to the steel rods, the ends of the panel frames are locally reinforced. In addition, the wooden side walls of the pressure chamber have several holes through which the panel frame tensile rods are guided. The openings between the panel frame tensile rods and the hole edges are sealed air-tight with silicone rubber collars. The steel frame loading rods bend due to the applied cabin pressure and the axial panel loads (Fig. 3). To keep these undesirable bending moments as small as possible, the diameter of the rods are minimized and the length is maximized. In case the undesirable bending loads become too high, pre-stressing of the frames, by displacing the frame loading rods, reduces the frame bending loads.

The advantages of using unidirectional glass fibres is that the loads are introduced very evenly over the length of the panel(2)(3). Therefore, in the panel hardly any distance is required for stress redistribution. In addition, the use of unidirectional fibres does not result in local stiffening of the panel edges in axial direction. The length of the glass fibre sheets can be chosen sufficiently large to limit the rotation of the fibres at the upper side of the panel due to the axial elongation of the panel. The glass fibres are bonded to steel tangential plates. Because of their large width, the tangential plates act more or less as hinges. The outward movement of a panel due to pressurization is therefore nearly radial and does not result in a significant change in the shape of the panel from circular to oval. The tangential clamping system is designed such that the angle between the tangential plates and the vertical column was adjustable to allow for a large range of panel diameters to be tested.

In axial direction tensile loads simulate the fuselage bending. To introduce these loads into the skin and stringers a single load concept was chosen: At the axial panel-ends the stringers are ended and the stringers loads are carried by a gradually increased skin thickness. This reinforced skin is loaded by tensile rods using steel brackets (Fig. 4). The termination of the stringers makes it possible to seal directly on the skin.

GLARE panel test

In order to verify the applicability of GLARE A[•] as a fuselage skin material, Fokker Aircraft designed and built a Fokker 100 fuselage panel, representative of the crown section just in front of the wing, with a GLARE A skin and GLARE N stringers. The panel (1210 mm x 3030 mm, R = 1650 mm) consisted of a stringer stiffened skin, attached to aluminum frames by means of rigid aluminum stringer attachments (cleats) and a longitudinal riveted lap-joint in the panel centre (Fig. 4). A complete GLARE Fokker 100 crown section would have a weight that is 63 % of the current design in aluminum.

Before subjecting the GLARE panel to a durability and a residual strength test, the GLARE panel is used for evaluation of the test facility. The evaluation tests showed a radial expansion of the panel and a uniform load introduction in axial and circumferential direction: By using glass fibres hardly any distance is required for stress redistribution, i.e. the tangential strain distribution is uniform after one stringer pitch from the panel edge (Fig. 5). In addition, the use of unidirectional fibres did not result in local stiffening of the panel edges in axial direction (Fig. 6). The chosen axial load introduction concept achieved a smooth distribution of the axial strain levels in the middle of the panel (Fig. 6, 7) and the stringer run-outs, skin reinforcements showed a negligible influence after the first frame (Fig. 8). The fact, that the GLARE panel did not expand radially (Fig. 9) is caused by the presence of the lap-joint and different radii of the panel halves.

After the verification tests a fatigue test was performed in which 180,000 flights (two lifetimes) were simulated. The axial loading sequences of the fatigue spectrum are derived from the spectrum applied in the Fokker 100 full scale test(4). The axial load is written as:

F_{axial} = $a_1 * M_y + a_2 * \Delta p$ with
F_{axial} = axial load in fuselage panel (N)
M_y = bending moment at particular Fuselage Station (Nm)
Δp = differential cabin pressure (N/m^2)
$a_{1,2}$ = Fuselage Station dependent constants.

The spectrum consists of 36 repeating testblocks of 5000 flights. Each testblock of 5000 flights is subdivided in four subblocks of 1250 flights. Three subblocks are exactly equal, the fourth block is equal but for one severest flight. Within this spectrum eight flight types with different gust loading severity have been defined. Figure 10 shows the axial loading and frequency per 5000 flights for these eight flight types. Each flight has five segments: ground, initial climb, climb/descent, cruise and approach. During the ground segments the cabin pressure Δp=zero, during the cruise segment $\Delta p = \Delta p_{max}$. In case of climb/descent the cabin pressure variates between zero and Δp_{max}.

The test frequency was 10,000 flights per 24 hours. After

[•] GLARE A=GLARE 3-2/1-0.3: 2*(0.3 mm 2024 sheet) + (0.25 mm cross-ply glass prepreg)
GLARE N=GLARE 1-3/2-0.3: 3*(0.3 mm 7475 sheet) + 2*(0.25 mm UD glass prepreg)

prescribed numbers of flights the panel is inspected by eddy current at the axial lap-joint and stringer run-outs. The panel is also checked visually at the stringers, frames, stringer-frame connections and load introduction points of the frames. In accordance with the lifetime predictions(5) no cracks or damages were found.

The fatigue test is followed by static tests. The GLARE panel is subjected to one Limit Load case, two Ultimate Load cases and a failure strength test. These static load cases are intended to demonstrate that after two times the design life (2*90,000 flights) and possible undetectable cracks in the GLARE skin the residual strength is still sufficient to carry Limit and Ultimate Load. During the Limit Load case ($\Delta p=\Delta p_{max}$, $M_y=M_{y,Limit\ Load}$) and the cabin pressure Ultimate Load case ($\Delta p=2*\Delta p_{max}$, $M_y=0$) pillowing occurred and the panel expanded linearly without permanent deformations. After the cabin pressure Ultimate Load case the second Ultimate Load test ($\Delta p=1.5*\Delta p_{max}$, $M_y=1.5*M_{y,Limit\ Load}$) was applied. No final failure occurred and the strain distribution was, except for plasticity which occurred above Limit Load, conform the distribution during the Limit Load test. The second Ultimate Load case is followed by the failure strength test at $\Delta p=\Delta p_{max}$ by increasing the axial load until failure of the panel. Failure occurred at an axial load equal to 1.32* axial Ultimate Load(6). This axial load is 15 % higher than the axial failure load expected according to the theory(5).

Conclusion. The results of the GLARE fuselage panel tests proved that the use of GLARE A in the crown section of a Fokker 100 leads to a substantial weight reduction without affecting the fatigue or static strength. The full-scale fuselage panel test facility has shown to induce a satisfactory radial expansion of the panel and a uniform load introduction in axial and circumferential direction.

Current tests

In the framework of the Brite Euram programmes "Advanced concept for large primary metallic aircraft structures" and " Structural maintenance of ageing aircraft" NLR performs durability tests, crack propagation tests and residual strength tests on several fuselage (side) panels of Shorts, DASA and Alenia.

To demonstrate the technological feasibility of complex GLARE panels with window cutouts, NLR will tests two RJ130 GLARE side panels (1215 mm x 3032 mm, R=1346 mm), designed and built by Shorts. The first panel has GLARE stringers, the second panel has extruded AL7150 stringers. During the fatigue test, at least two lifetimes will be simulated by applying internal air pressure, synchronized with an axial load spectrum. In the course of these durability tests artificial damages will be introduced. Finally, residual strength tests will be done.

The objective of the tests on full-scale aluminum fuselage panels of DASA and Alenia is to study the growth of multiple site damage (MSD) in complex stiffened structural joints in curved panels and to determine their effect on the residual static strength. The test results will be used to assess and to improve predictive models.

The aluminum ATR42 fuselage panel of Alenia (1249 mm x 3032 mm, R=1432 mm) will have a lead crack in the longitudinal lap-joint, with additional MSD in adjacent fastener holes. After a limited number of flights, to achieve sharp cracks tips at the artificial cracks, residual strength tests will be performed. The applied loads will be a combination of pressurization and axial loads.

The two aluminum fuselage panels of DASA (1128 mm x 3030 mm, R=2820 mm) are cut from old A300 aircrafts. One panel has an artificial lead crack with additional MSD in the longitudinal lap-joint. The other panel has only a lead crack. Like the ATR42 panel, the A300 panels will be subjected to a limited number of flights, to extend the artificial cracks. During these flights only cabin pressure will be simulated. Finally, residual strength tests will be done.

Conclusions

The biaxial load introduction system of the full-scale fuselage panel test facility showed to apply uniform loads in axial and circumferential direction.

Because of the excellent fatigue behaviour and sufficient static strength combined with a weight reduction of 37 % the designed GLARE panel proved the feasibility of GLARE as fuselage material.

The full-scale fuselage panel test facility is developed to have in case of fuselage design studies a test set-up which offers the possibility to test single panels with variable radius of curvature, panel width and panel length at a high test frequency. The test performed on a Fokker fuselage panel and the current tests on panels of Shorts, DASA and Alenia indicate the interest of the aircraft industry in testing curved structures under biaxial loading conditions to evaluate fuselage design concepts, to demonstrate the feasibility of fuselage materials and to improve crack growth predictive models.

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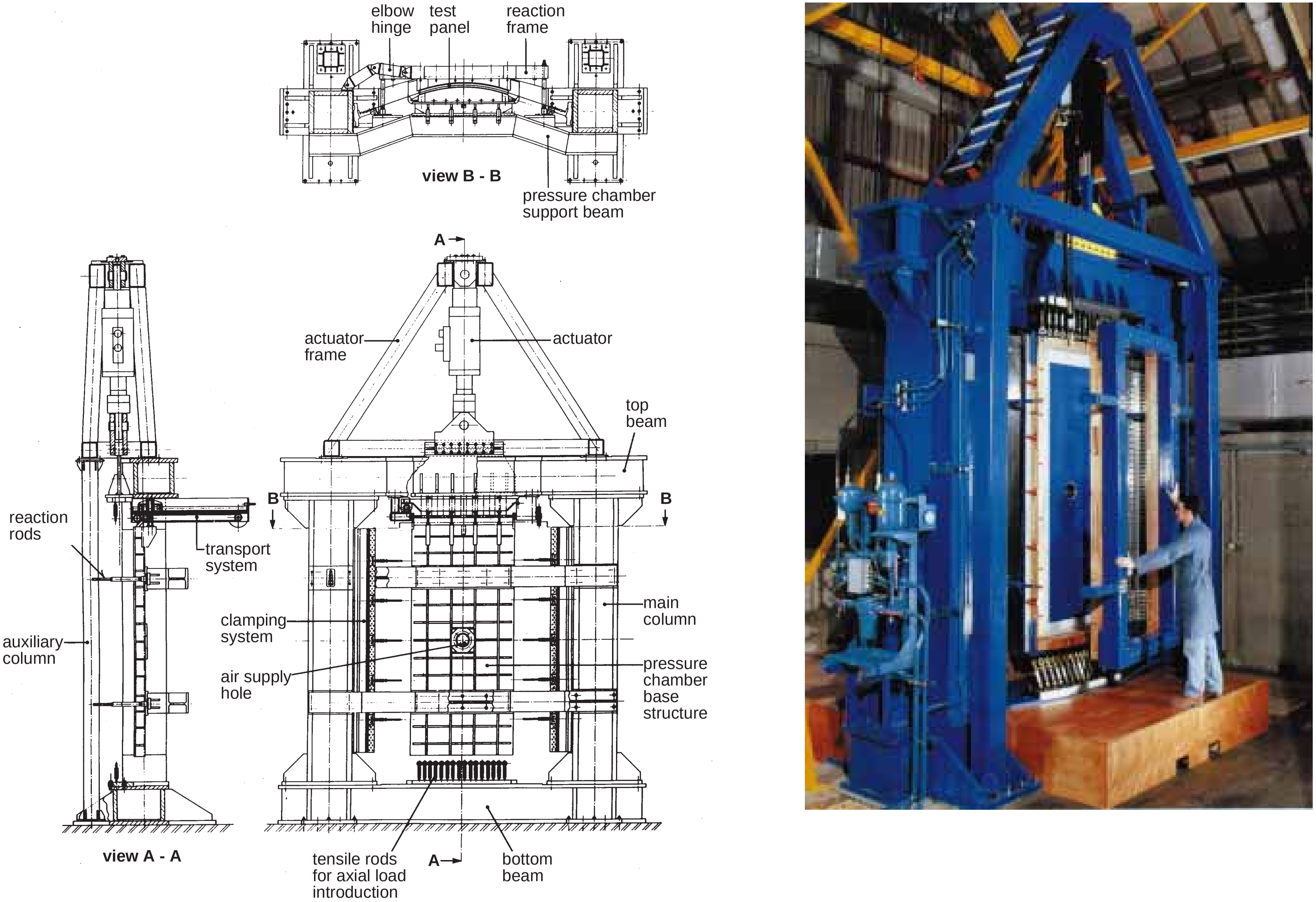

Figure 1 Fuselage panel test facility at NLR

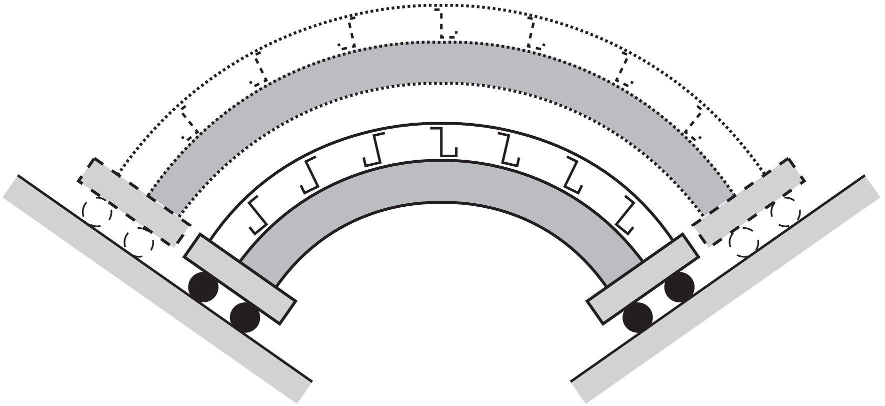

Figure 2 Ideal boundary conditions

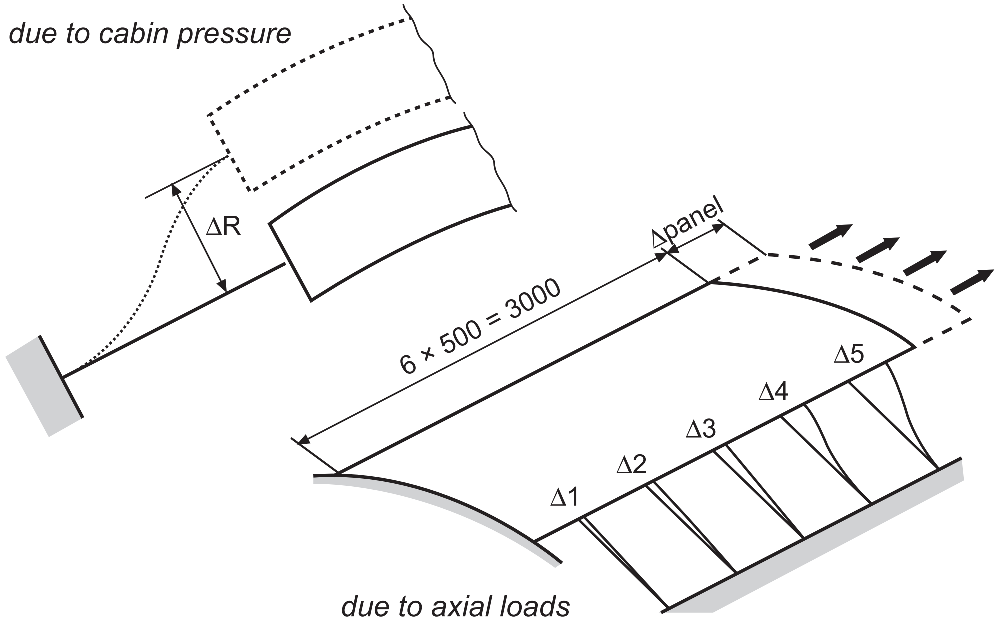

Figure 3 Bending of frame loading rods

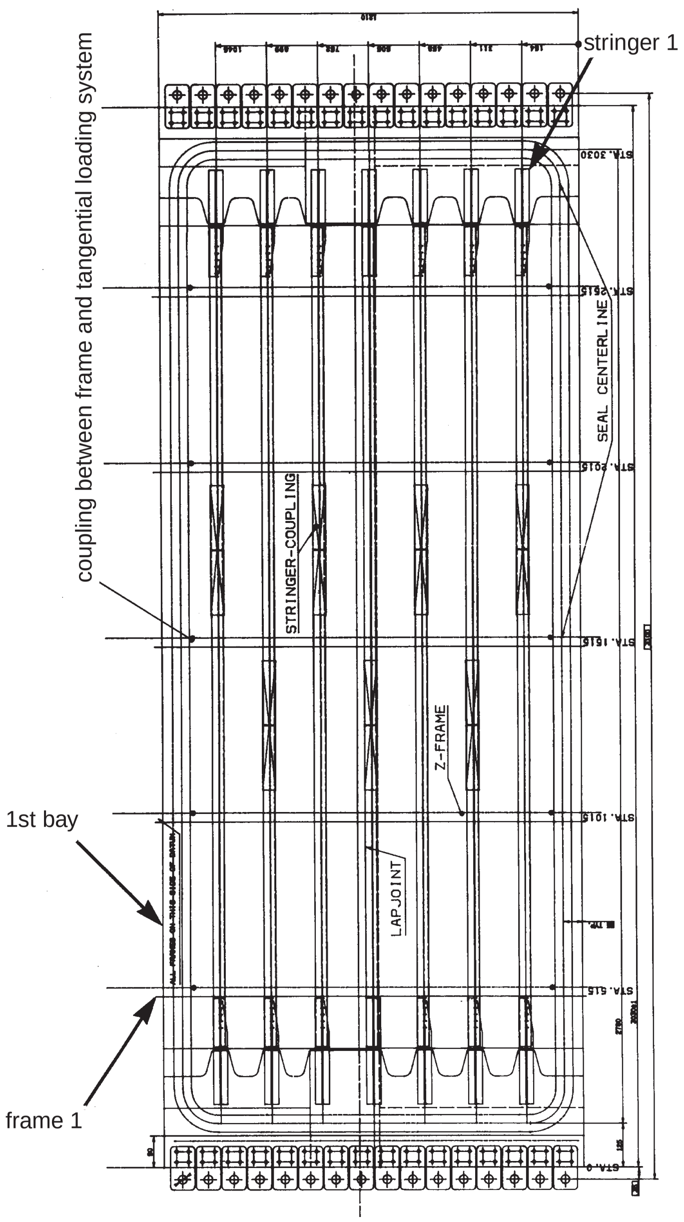

Figure 4 GLARE panel

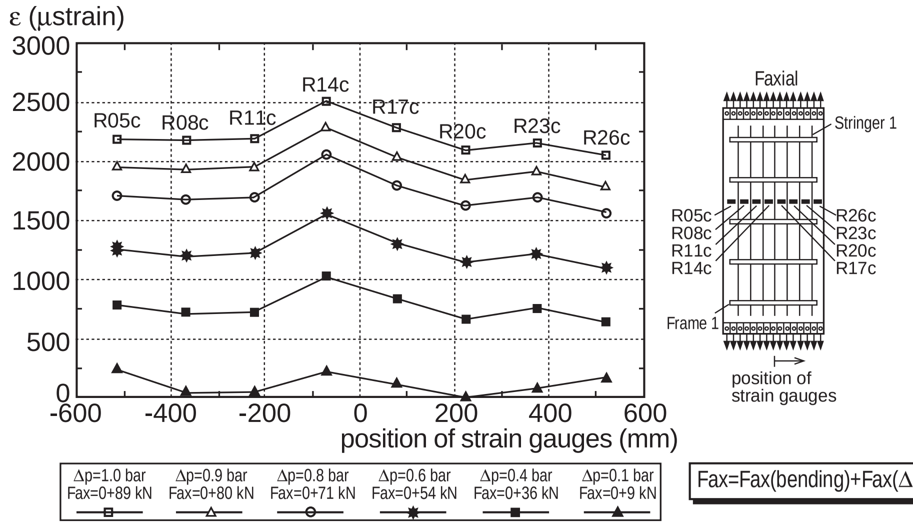

Figure 5 Tangential strains during 1st Ultimate Load test, in the middle of the panel

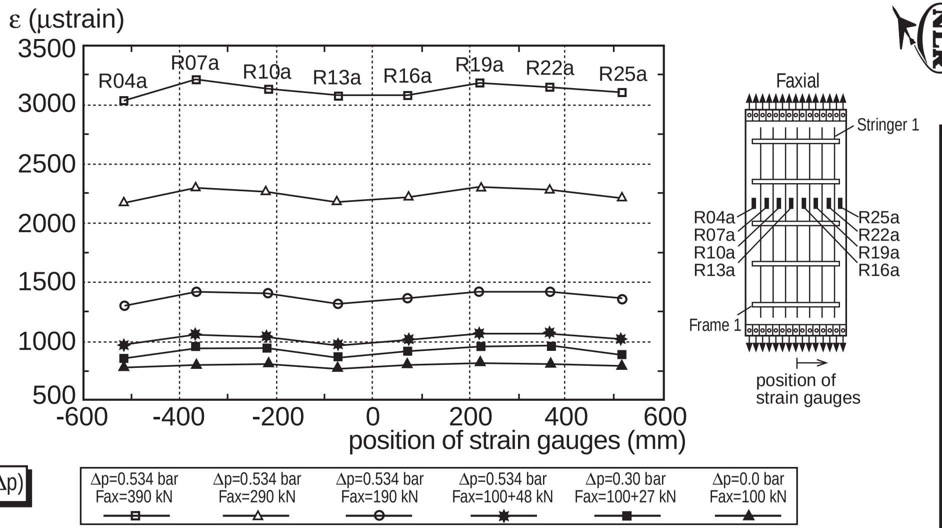

Figure 7 Axial strains during the Limit Load test, in the middle of the panel

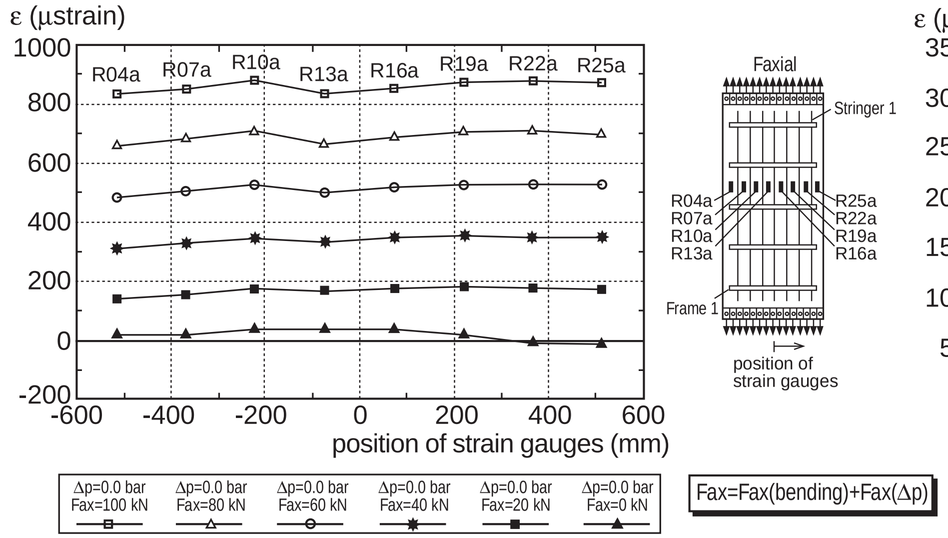

Figure 6 Axial strains due to axial loads

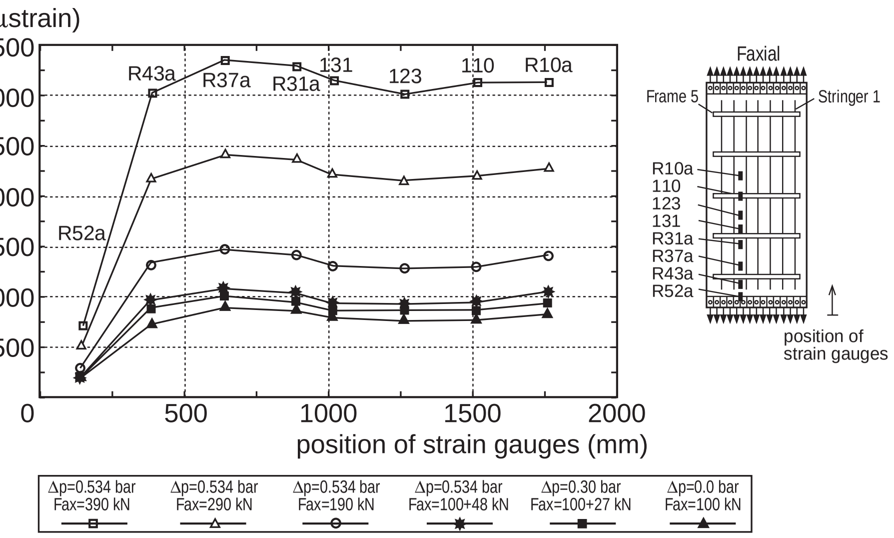

Figure 8 Axial strains during Limit Load test, between bottom and 4th frame

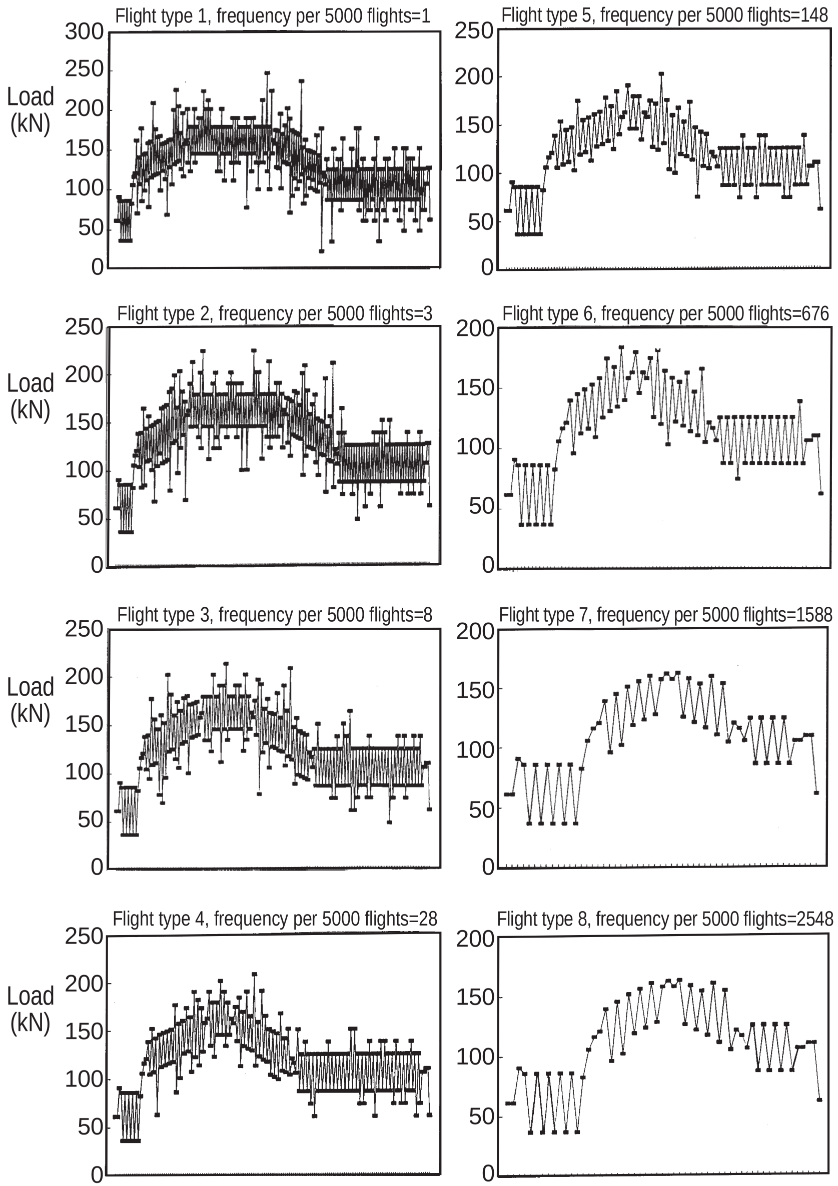

Figure 10 Axial load on the GLARE panel for the eight flight types

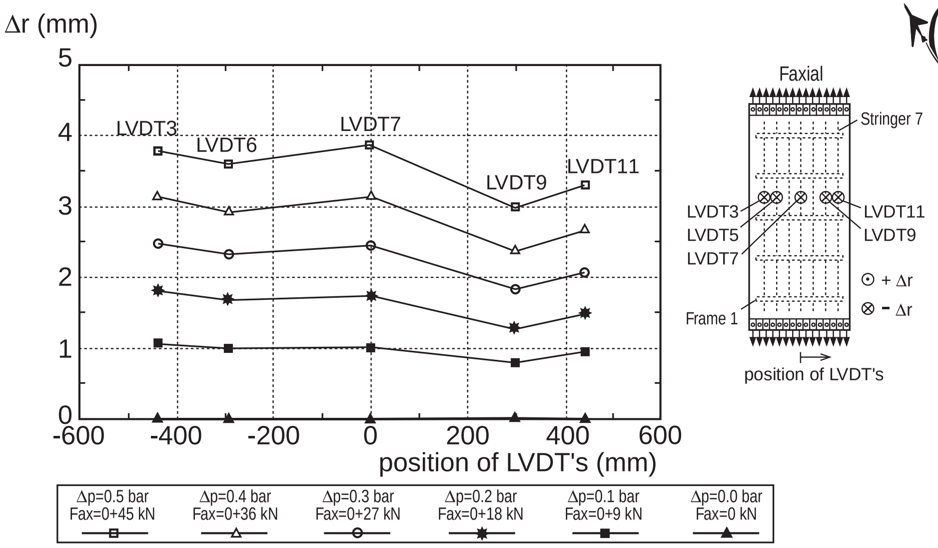

Figure 9 Radial expansion of the GLARE panel

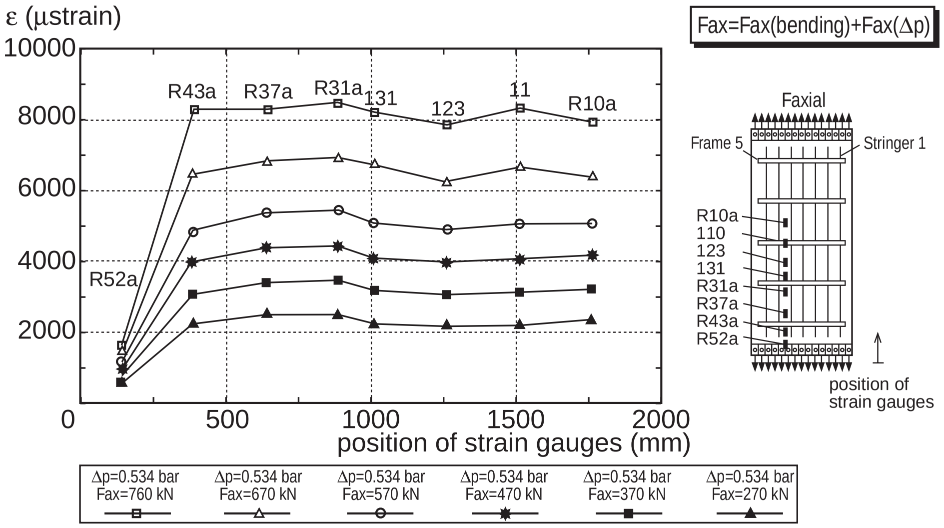

Figure 11 Axial strains during 2nd Ultimate Load test, between bottom and 4th frame