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The Influence of Water Ingress to Aircraft Cabin Components

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Abstract**—**The accomplished study is based on the appointment and identification of ageing effects and according to this absorption of moisture of aircraft cabin components over the life-cycle. In the first step of the study ceiling panels from same age and from the same aircraft cabin have been examined according to weight changes depending on the position in the aircraft cabin. In the second step of the study different aged ceiling panels have been examined concerning deflection, weight changes and the acoustic sound transmission loss. To prove the assumption of water absorption within the study and with the theoretical background from literature and scientific papers, an older test panel was exposed extreme thermal conditions (humidity and temperature) within a climate chamber to show that there is a general ingress of water to cabin components and that this ingress of water leads to the change of different mechanical properties.

Keywords**—**Aircraft Cabin, water ingress, ageing effects, sound transmission loss

I. INTRODUCTION

THE global warming and new regulations force the aircraft manufacturer and the airlines to reduce their emissions over the complete life-cycle of an aircraft. The aircraft industry focuses on the reduction of emissions during operation phase because during this phase of the life-cycle most emissions are emitted, for example 98% of the total carbon dioxide emissions were emitted during this phase [1]. According to the Advisory Council for Aeronautics Research in Europe (ACARE) the reduction of emissions during operation phase can be achieved mainly by aerodynamic improvements, weight reduction, new aircraft concepts and greater capacity of the entire aircraft cabin [2].

Most of the cabin components are made of lightweight honeycomb constructions that are able to carry high loads at minimum weight. However it is widely recognized that these structures are susceptible to moisture ingress related to environmental degradation. Thermographic inspection of a United Airlines 767 revealed that the nose landing gear door, a composite honeycomb structure, contained liquid water in 7500 cm² area (equivalent to 20 kg of extra weight if the cells were fully filled) [3]. The problem of an accumulation of water was also detected in the rotor blades from the McDonnell Douglas Apache and the Boeing Chinook helicopter [4]. Even if the examples of absorption of moisture are related to primary structure elements of aircrafts and helicopters and the primary structure elements are exposed thermal conditions that deviate from the climate conditions in an aircraft or helicopter cabin, it is not improbable that also the components in an aircraft cabin absorb water and increase their weight during operation phase. One characteristic feature is figured out for aircrafts with sandwich structures. Do these sandwich structures consist of a honeycomb core there are little leakages that show the following form of absorption of moisture.

After flights in great height in the honeycomb core arises depression. Through this depression the honeycomb absorbs wet air through the leakages. At an adjacent flight in great height the wet air condensates and remains as water in the core cells. This leads to an increase in weight and furthermore there is the existing danger of core cracking through freezing [5].

Not only the polluting emissions will be affected by absorption of moisture but also the physical properties of the cabin components can be influenced and changed by ingress of water. Both moisture sorption and thermal ageing are able to change the physical relationship between the fibers and the matrix in a composite: the former, degrading the properties of the matrix itself, the latter, inducing micro-cracking inside the structure. The micro-cracks result in a “swelling” induced in the resin matrix through the moisture inside the composite. This can lead to a modification of the pre-existing residual stresses conditions in the bulk matrix and the interface with the fibers. In general two different effects of the moisture have to be considered on the composites:

a) Modifications of the mechanical behaviour, directly connected to the presence of the water in the matrix (real time effects), which disappear for a large amount drying the material
b) Residual modifications of the mechanical parameters connected to “hereditary” phenomenawhich remain also having dried the material [6].

In Addition it is known that the potential for absorption of moisture or ingress of water is depending on the construction of the component and on the used materials for the composite. Li et al. figured out with infrared thermography that moisture ingress occurred mostly in areas around hinges and grounding studs [7]. In addition the used materials for the composite structure influence the potential for absorption of moisture. The potential absorption of moisture in weight percent is depending on the used fibers and on the used resin, for example aramid fibers tend to absorb water up to seven weight percent and natural fibers tend to absorb water up to 14 weight percent [8]. So not only the construction, even the kind of used materials for the composite structure influence the potential for ingress of water.

So from previous investigations and literature it is known that composite structures tend to absorb water and within this absorption of water the composite structures change their physical properties, for example through micro cracks. The literature refers to basic effects of moisture absorption of fibers and resins and the investigations done, generally concern with absorption of moisture and ageing for primary structure components of aircrafts and helicopters. These components are exposed hard weather conditions (humidity and temperature). In contrast the cabins of aircrafts and helicopters are exposed temperature and humidity conditions that are in general not as hard as the conditions the primary structure components are exposed to. Therefore it is from main interest if there are ageing effects to aircraft cabins, especially through absorption of moisture.

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II. TEST OBJECT

Down to the present day aircraft cabins are built up from several lining elements made from composite structures. The main components are the Sidewall-Panels, Dado-Panels, Cove Light-Panels, Hatracks and Ceiling-Panels. The chosen test object for the analysis of water ingress and possible ageing effects is the ceiling panel. The reason for this decision is that for the ceiling panels it is assured that these components carry same and constant loads during its operation phase and cannot be influenced by damage through the passenger or discontinuous load cycles through different weight of hand luggage.

III. EXPERIMENTAL SET-UP FOR MEASURING DIFFERENT PARAMETERS

The general parameters investigated in conjunction with absorption of water and ageing effects were general weight changes, the bending stiffness, measured through the deflection of the panels and the acoustic behaviour, measured through the sound transmission loss.

A. Measuring weight changes

The possible absorption of water, measured through the weight differences of the panel, is determined with a scale that is able to measure with accuracy of one gram.

B. Measuring deflections

The deflection of the ceiling panel provides information about the bending stiffness. The test rig used for determining the deflection was built from typical “Bosch-profiles” because the test rig has to be transportable, easy do assemble, disassemble and has to be adaptable to the geometry of the tested ceiling panels. In the middle of the test rig and according to this in the middle of the affectedceiling panel a dial indicator is positioned. The dial indicator has an accuracy of one micrometer. The used test rig is described in the following figure.

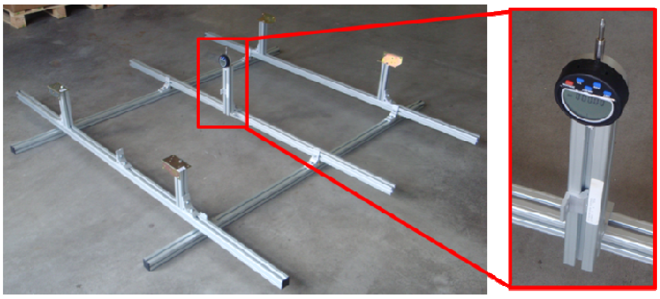

Fig. 1 Test rig for determination of theceiling panels deflection

C. Measuring the sound transmission loss

The two ceiling panels were mounted between the reverberation room and the anechoic room with several adapter frames. The experimental set-up is described schematically in fig. 2.

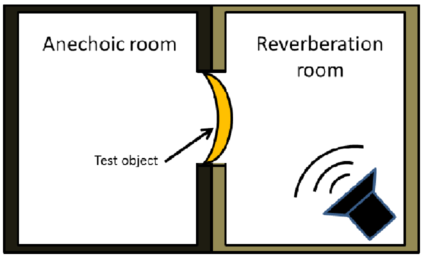

Fig. 2 Test rig for determining the sound transmission loss of ceiling panels

The transition area between the mounted ceiling panel and the adapter frames is masked with adhesive tape and cut outs in the ceiling panel are also masked with trimmed gaskets and adhesive tape. This is necessary to avoid the transmission of disturbing airborne noise. The mounted ceiling panel of an Airbus A320 between the reverberation room and the anechoic room is shown in fig. 3.

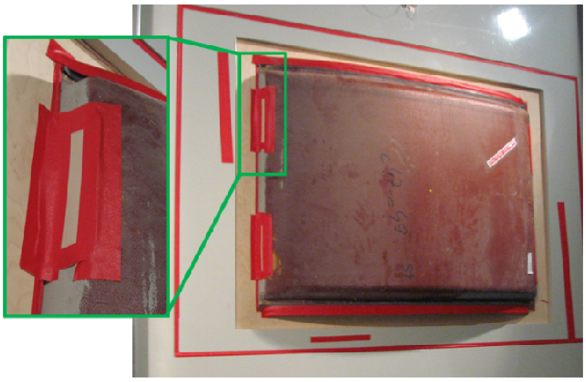

Fig. 3 Mounted Airbus A320 ceiling panel between reverberation and anechoic room (view from the reverberation room)

A suitable acoustic source generates pink noise in the reverberation room. The average determination of the sound pressure level in the reverberation room was arranged by a rotating “Galgen” (see fig. 4).

Fig. 4 Rotating "Galgen" for determining average sound pressure level

IV. EXPERIMENTATION

The general experimentation is divided in several parts. At first it is figured out if the ceiling panels show noticeable weight changes depending on their position in the aircraft, especially in the area of galleys and entrance/exit doors.

Therefore ceiling panels from an Airbus A300-600 were inspected according to weight depending on the position in the aircraft cabin.

In the second part of the investigation ceiling panels from different age from an Airbus A320 were inspected according to weight differences (possible water ingress), to the deflection of the ceiling panels and to the acoustic sound transmission loss. Goal of the second part of the investigation is to determine coherence between the named parameters and a possible absorption of water and ageing effects. To demonstrate that there is a possible coherence between the change of different material properties and absorption of moisture a ceiling panel from an Airbus A300-600was aged in a climate chamber under different cycles. The results were used as data basis for the investigation of ageing affects and absorption of moisture under real flight conditions and in addition to the information from literature.

Only the experimentation for the second part of the investigation is more complex and not self-explanatory. So the experimentation for determining the deflection of the ceiling panels and the sound transmission loss is described in detail.

A. Experimentation for determining deflection

The test rig for determining the deflection of different ceiling panels was already shown in fig. 1. The ceiling panel was deposited on the test rig and the dial indicator was balanced. After that the ceiling panel was loaded with four different load factors. The sequence of loading was 1kg, 3kg, 5kg and 10kg and is displayed in fig. 5.

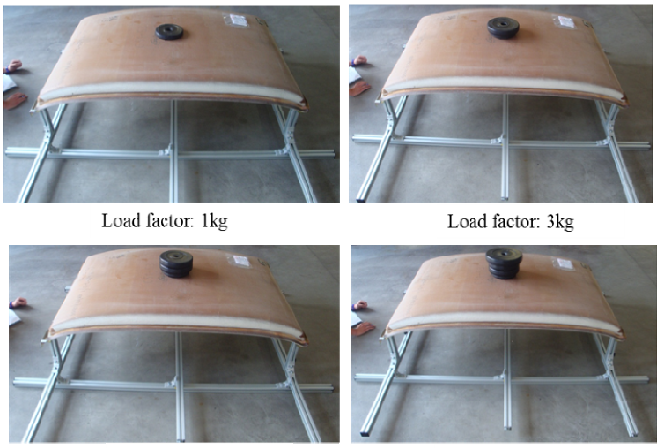
Load factor: 1kg
Load factor: 3kg
Load factor: 5kg
Load factor: 10kg

Fig. 5 Sequence of loading the ceiling panels

The deflection of the ceiling panel was taken from the dial indicator after every load factor.

B. Experimentation for determining the sound transmission loss

The transmitted sound intensity through the ceiling panels was measured three times for every ceiling panel. The intensity sensor was guided in three different ways over the area of the ceiling panels.

After having mounted the ceiling panels between the reverberation and anechoic room in the reverberation room the acoustic source generates pink noise. The adjusted sound pressure level within the reverberation room was recorded for the analysis and is displayed in fig. 6.

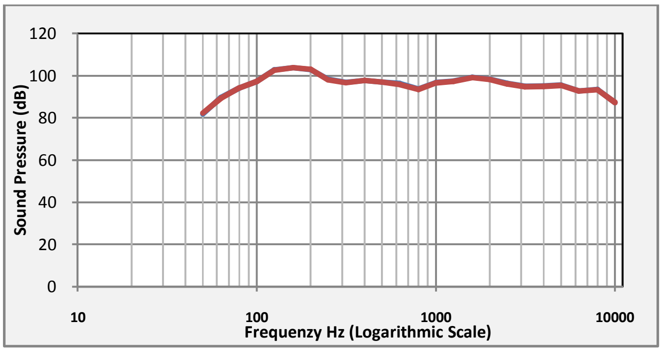

Fig. 6 Sound pressure in reverberation room

After having switched on the acoustic source, the measurement of the sound intensity started. Therefore the sound intensity probe was guided meander shaped over the area of the ceiling panel. The three different guided ways of the sound intensity probe over the area of the ceiling panels are displayed in the next figure.

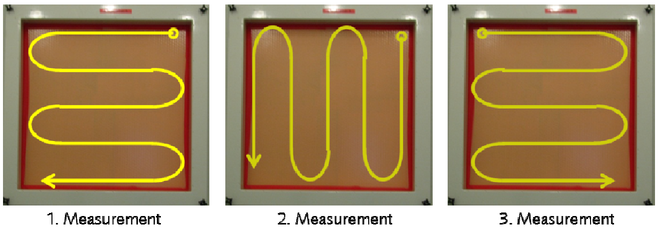
1. Measurement
2. Measurement
3. Measurement

Fig.7: Course of the sound intensity probe for the three measurements of one ceiling panel

With the recorded sound pressure in the reverberation room and the measured sound intensity it is possible to determine the transmission loss for the frequency range from 50Hz to 10000Hz. This is the relevant frequency range for the aviation industry.

For the determination of the transmission loss it has to be considered that an adjustment of the law of mass has to be accomplished, if there are any weight differences between the ceiling panels.

V. RESULTS

A. The influence of the position of the ceiling panel to weight and water ingress

In the first step of the investigation it was inspected if there were conspicuous weight differences between ceiling panels depending on their position in the aircraft. The position of the inspected ceiling panels is displayed in fig. 8; the only difference between the red and green marked ceiling panels is that the red ones contained lamps.

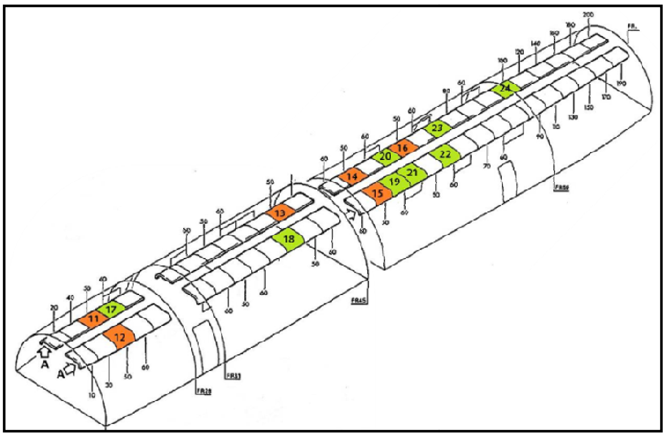

Fig. 8 Position of ceiling panels in the cabin of an Airbus A300-600

The position of the ceiling panels was compared with the measured weights of the ceiling panels, shown in fig.9 and fig. 10.

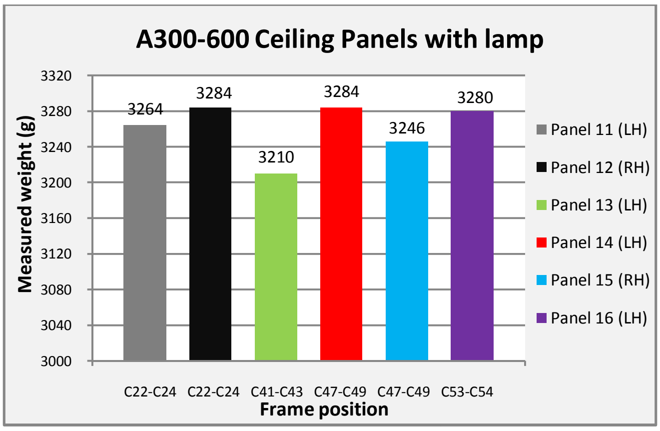

Fig. 9 Measured weight of ceiling panels with lamp

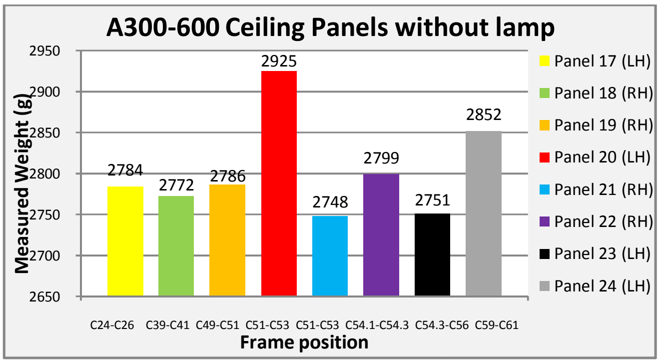

Fig. 10 Measured weight of ceiling panels without lamp

There is no coherence between the measured weights and the ceiling panel’s position in the cabin. The ceiling panels differ in their overall weight but this is not dependent on the position of the panel in the cabin. So there is no noticeable weight impact to ceiling panels that are mounted in the area of galleys and entrance/exit doors. Instead the deviations in the weight of the ceiling panels might result in manufacturing tolerances.

B. The change of material properties by artificial ageing in a climate chamber

This investigation gives information about the behaviour of composite structures after absorption and discharge of moisture and shall confirm the results in literature for composite structures.

In the first step the ceiling panel was dried (dry-cycle: 65°C and humidity of 0%) until saturation. After 379 hours drying the panel saturation arose and the ceiling panels weight decreased by 1, 39% from starting weight. After that the panel was exposed a wet-cycle (35°C and humidity of 85%) until saturation. The weight of the ceiling panel increased by 1, 66% from starting weight until saturation. The curves for saturation after having exposed the panel the wet and the dry cycle are shown in fig. 11.

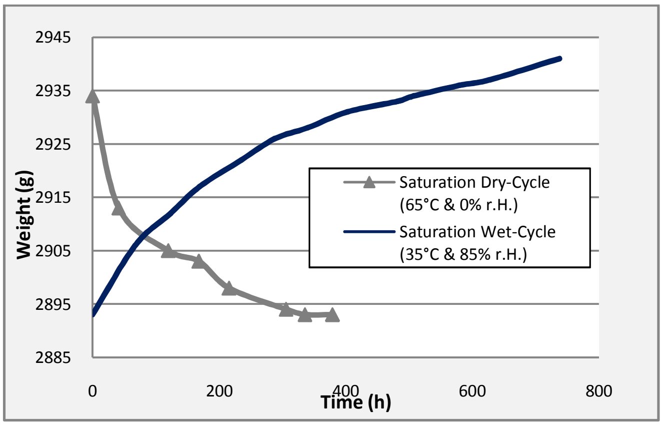

Fig. 11 Absorption and discharge of humidity until saturation

Parallel to the saturation process of the ceiling panel the deflection has been measured several times for the ceiling panel during wet and dry cycle (test rig is shown in fig. 5). These results are shown in fig. 12.

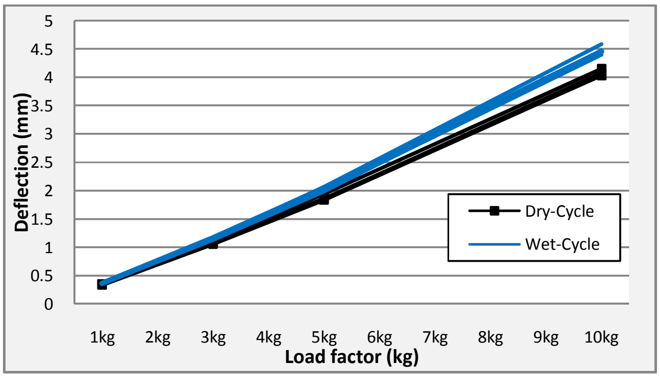

Fig. 12 Deflection of ceiling panel depending on the climate-cycle

As shown in fig. 12 the deflection of the ceiling panel is greater when the ceiling panel absorbs water in a wet climate. After exposure the ceiling panel a wet and dry climate, the ceiling panel was exposed a changing climate, first wet, than dry and again wet. Depending on the climate cycle the weight of the ceiling panel increased or decreased. The chosen climate cycles are described in fig. 13.

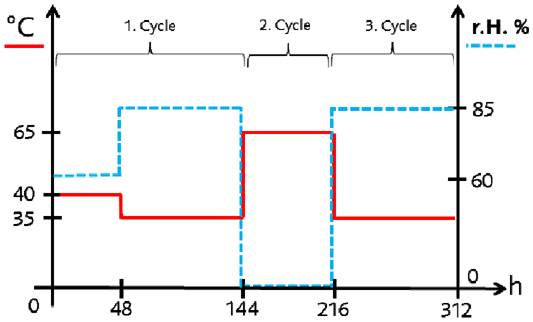

Fig. 13 Climate Cycles for determination of changes in weight and deflection

Fig. 14 describes the changes in weight depending on the climate cycle. It becomes apparent that the weight increases during a wet cycle and decreases during dry cycles.

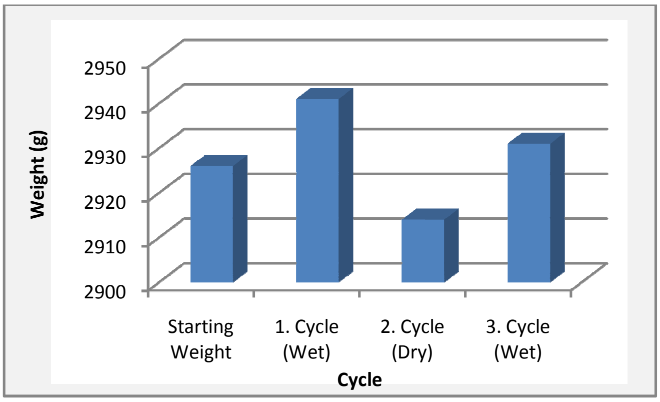

Fig. 14 Weight changes during wet and dry climate cycles

In coherence with the weight, the deflection of the ceiling panel to the depending climate cycle has been determined. In this process it is conspicuous that the deflection does not return in the origin deflection after having dried the panel (see fig. 15).

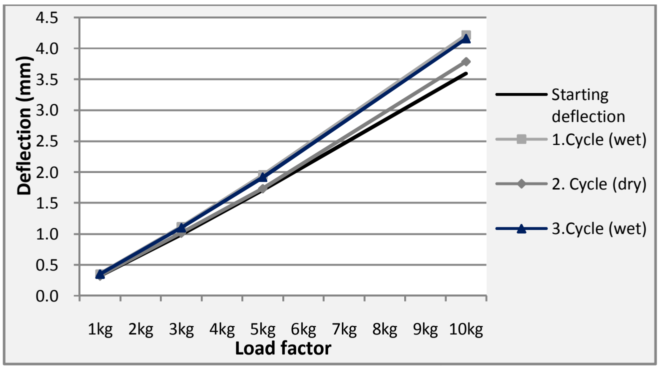

Fig. 15 The influence of changing climate cycles on the deflection of a ceiling panel

The tests in the climate chamber are accordant to the results and information from literature. Depending on the climate cycle, the ceiling panel absorbs or discharges water. And the absorption of moisture leads to persistent changes of the structure of the composite because the deflection does not return in the initial conditions. With the general knowledge about the behaviour of composite structures under wet and dry climate conditions and with the composites behaviour when absorbing water it is easier to analyze real ageing affects to cabin components through absorption of moisture.

C. Examination of material properties from different real aged ceiling panels

General approach of this investigation is to determine the change of material properties over the life-cycle of an aircraft cabin. In general it is hard to give a correct statement whether cabin components have absorbed water because of the panels manufacturing tolerances. But it is assumed that cabin components absorb water because there are general weight differences from date of manufacturing until the date of integration into the aircraft cabin. Fig. 16 describes the weight of different Airbus A320 ceiling panels after manufacturing and before their integration into the aircraft cabin. First of all it becomes clear that there is a deviation in the ceiling panel’s weight that might result in manufacturing tolerances. Furthermore the weight of the ceiling panels increased until these panels are integrated into the aircraft cabin so it is assumed that the ceiling panels absorbed water during the time between manufacturing and integration into the aircraft cabin.

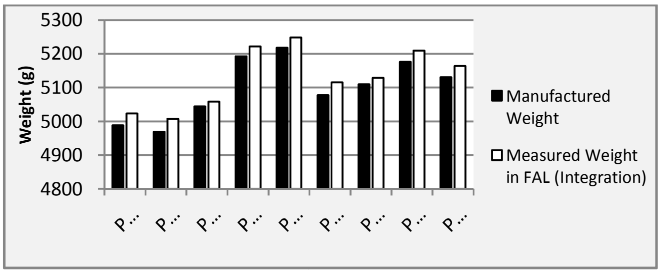

Fig. 16 Weight differences of ceiling panels after manufacturing and before integration into the cabin

For the investigation of real ageing effects of cabin components, ceiling panels from different age have been examined according to weight, deflection and the acoustic sound transmission loss. The ceiling panels were manufactured in the year 1988 and 1998, so these panels feature a difference in age of ten years but feature the same material properties.

For this investigation the weight of four ceiling panels from the year 1988 and 1998 has been determined. The results are shown in the following figure.

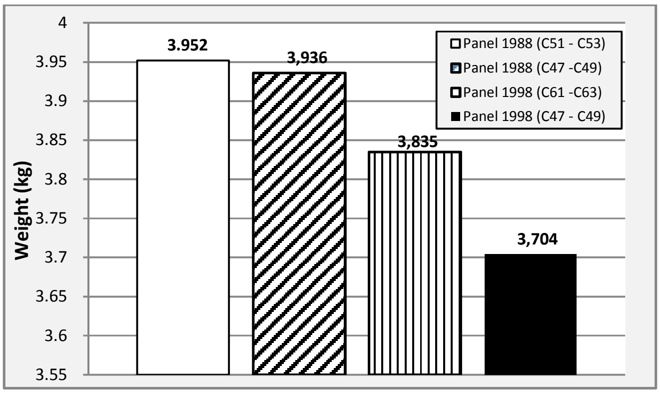

Fig.17: Weight of different real aged ceiling panels

It becomes apparent that the weight of the ceiling panels from 1988 is higher than the weight of the ceiling panels manufactured in 1998. This might result in a possible absorption of moisture; however manufacturing tolerances cannot be excluded.

With the results from the investigations in the climate chamber the deflection of the ceiling panels from the year 1988 should be higher than the deflection from the ceiling panels manufactured in 1998. But the determined deflection of the ceiling panels declares completely the opposite. The deflection of the ceiling panels manufactured in 1998 is greater than the deflection of the older panels manufactured in 1988 (compare fig. 18).

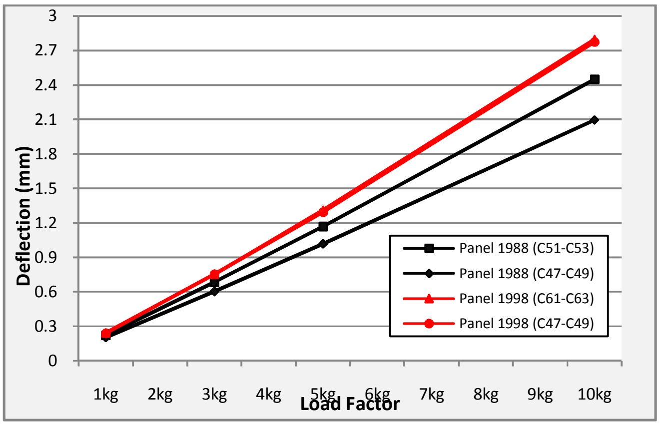

Fig. 18 Deflection of different real aged ceiling panels

So the expected result is missing. The reason for this result could be that there was no absorption of moisture and the difference in weight is only the result from manufacturing tolerances. This would also give the reason why the deflection of the older panels is less than the panels from 1998; the panels in 1988 are heavier through the manufacturing process and this could raise the bending stiffness of the panels and decrease the deflection. In addition to the weight and deflection the sound transmission loss has been determined for one ceiling panel from 1988 and 1998. Both panels were integrated at the same position in the aircraft, between frame C47 and C49. The sound pressure in the reverberation room was already described in fig.6. The transmission loss for the ceiling panels from 1988 and 1998 is figured in fig. 19.

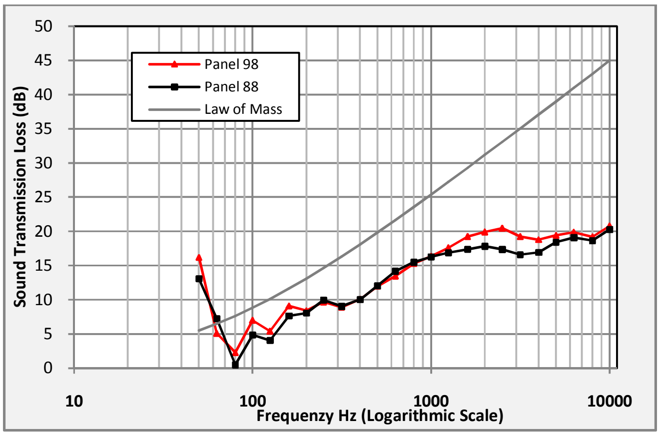

Fig. 19 Transmission Loss of different aged ceiling panels

In the area between 50 Hz up to 200 Hz and in the area between 1000 Hz up to 10000 Hz the sound transmission loss of the ceiling panel, manufactured in 1998 is higher than the sound transmission loss of the panel manufactured in 1988. The ceiling panel from 1998 has a higher deflection and according to this a lower bending stiffness than the panel from 1988. This could be the reason why the sound transmission loss in the frequency area between 50 Hz up to 200 Hz and between 1000 Hz and 10000 Hz is higher than for the ceiling panel manufactured in 1988.

Furthermore it becomes apparent that the sound transmission loss of the ceiling panel from 1988 as well as the ceiling panel from 1998 follows the acoustic law of mass and features nearly the same incline in the frequency area between 315 Hz and 1000 Hz like the acoustic law of mass [9].

But seen from these results it is hard to define ageing effects for cabin components under real cabin climate conditions because of the general appearance of manufacturing tolerances. Through the present manufacturing tolerances it is hard to make a statement about a possible ingress of water.

VI. CONCLUSION

There are weight differences between the tested and investigated ceiling panels. The deviations in weight result in manufacturing tolerances and the position of the ceiling panels in the aircraft cabin has no influence to the ceiling panel’s weight and a possible ingress of water. Through the appearing manufacturing tolerances it is hard to identify the differences in weight as the result of absorption of moisture. To clearly identify absorption of moisture, it will be necessary to examine the composite structure on the microscopic layer, for example with a scanning electron microscope.

However it is assumed that the composite structures absorb water because from point of manufacturing until the point of integration there was an increase in weight for various ceiling panels.

The results achieved with the tested ceiling panels in the climate chamber are conform to the theoretical background information from literature.

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The results achieved with the ceiling panels aged under real cabin climate conditions do not behave as if they absorbed water because the deflection according to the weight does not provide the same and expected results that were achieved within the climate chamber. A reason for the difference in the results might be the manufacturing tolerances because they have an influence to the ceiling panel's weight and according to this to the deflection, to the bending stiffness of the ceiling panel and to the acoustic sound transmission loss. Another reason for the different results might be that the real climate in an aircraft cabin avoids great absorption of moisture or that the absorption of moisture is too low to recognize great changes in the tested material properties.

REFERENCES

[1] Streamlined Life-Cycle Assessment: Presentation Cabin & Cargo; Airbus internal paper 2009
[2] Advisory Council for Aeronautics Research in Europe (ACARE): Strategic Agenda Volume 1 and Volume 2; Brussels 2002
[3] Shafizadeh, J. E. J. C. Seferis, E. F. Chesmar, and R. Geyer, Evaluation of the In-service Performance Behavior Honeycomb Composite Sandwich Structures; Journal of Materials Engineering and Performance, 8(6): 661-668, 1999
[4] Stabilizers-Elevators-Inspection and Protection against Water Ingress, Airworthiness Directive, No F-2004-118R1, 2004
[5] Konstruieren mit Faser-Kunststoff-Verbunden, 2. Bearbeitete und erweiterte Auflage; Helmut Schürmann; Springer Verlag Berlin Heidelberg 2005, 2007
[6] Effects of Moisture and Thermal Ageing on Structural Stability of Sandwich Panels; F. Morganti, M. Marchetti, G. Reibaldi; 34. Congress of the International Astronautical Federation (IAF); Budapest 1983
[7] Investigation of moisture ingress and migration mechanisms of an aircraft rudder composites sandwich structure; Chin Li, Julie Teuwen and Vivier Lefebvre; N.R.
[8] Handbuch Verbundwerkstoffe – Werkstoffe, Verarbeitung, Anwendung; Manfred Neitzel und Peter Mitschang; Carl Hanser Verlag München Wien, 2004
[9] Taschenbuch der Technischen Akustik, 3., erweiterte und überarbeitete Auflage; Gerhard Müller und Michael Möser; Springer Verlag Berlin Heidelberg 2003