CLASSIFICATION AND DEVELOPMENT OF NEW COMPONENT TESTS FOR AIRCRAFT CABIN INTERIOR

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Abstract: *Honeycomb sandwich structures are widely used for cabin interior components in passenger aircrafts. The load introduction into the sandwich structure proves to be particularly critical. However, the verification takes place based on non-standardized tests abstracted from the application so that influences caused by boundary conditions and multiple load introduction points cannot be investigated. Moreover, these tests also do not allow comparisons of different designs. The variety of different test setups on component level has made the comparability of published results more difficult. This paper summarizes the state of the art of existing component tests. Based on that and using the example of an aircraft cabin partition, the existing test set-ups are checked for their suitability to cover all given load cases. New test setups with extended boundary conditions and several load introduction points are developed. For one test setup, test results are shown and compared to a conventional component test.*

Keywords: Sandwich; Component Test; Insert; Test Design; Cabin Interior

1. Introduction

Due to their good weight-specific material properties, honeycomb sandwich structures are widely used for cabin interior parts in commercial passenger aircrafts [1]. However, the load introduction into these sandwich structures often proves to be critical. The precise design of the load introduction points, which are conventionally realized by inserts for sandwich structures, is crucial for the safety of aircraft cabin components. Nevertheless, the verification takes place based on non-standardized tests abstracted from the application. Although various quasi-static component tests are suggested in the Insert Design Handbook [2], in the literature these tests have been performed differently and additionally, new component test setups have been developed [3–5]. In recent years this variety of different test setups on component level has made the comparability of published results more difficult. As shown in [6, 7] the consideration of the existing boundary conditions of the application has fundamental relevance for the quality of a design. This is usually not the case for the abstracted tests.

For the design of aircraft cabin monuments the Building Block Approach is mostly utilized [8]. Over different levels of complexity of a product, tests and analyses are carried out, starting from the material level via the component level to the complete product, in order to provide verification. However, many of the available test setups do not allow the evaluation of the performance of other designs at the component level. At the moment, only full-size tests are suitable for comparing new designs, such as additive manufactured designs using the direct energy deposition process [9], with conventional sandwich designs. Therefore, there is a need for design independent component tests.

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In this paper, the differences between the individual component tests are shown and compared. Based on that, the suitability of the individual tests is evaluated using the application example of an aircraft cabin partition. Concepts for more application-oriented and independent component tests are then developed. Finally, one of these developed tests is conducted and the results are compared with those of a conventional component test.

2. Analyses of the existing component tests

The Insert Design Handbook [2] suggests a number of different tests for component verification. A selection of the common tests is shown in Figure 1. These are supplemented by bending and shear tests, which do not investigate the strength of an insert joint. These various test setups are typically used to conduct the component-level verification of aircraft cabin monuments.

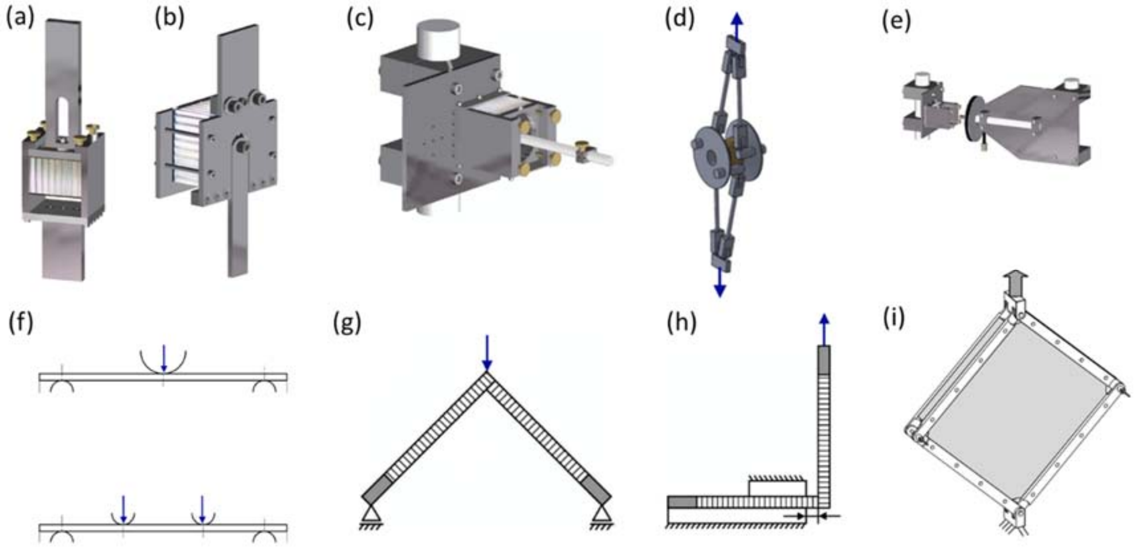

Figure 1. Variety of component tests: (a) pull-out test [2], (b) shear test [2], (c) insert bending test [2], (d) torsion test [10], (e) insert torsion test [2], (f) 3 and 4 point bending test [11], (g) bending test for corner joints [3], (h) shear test for corner joints [3], (i) frame shear test [12]

Usually, several load introduction points are located in the application near each other. Interactions between the individual points cannot be investigated in one of the test setups shown in Figure 1. For this, several inserts must be involved in the specimen. A selection of test setups with multiple load introduction points is shown in Figure 2.

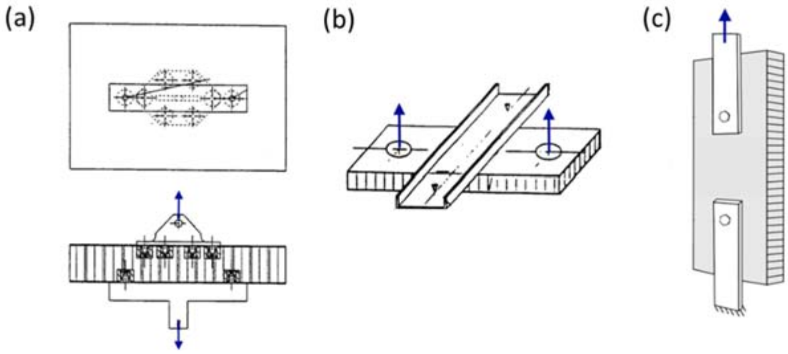

Figure 2. Component tests with multiple load introduction points: (a) and (b) ARIANE 4 tensile (pull-out) test methods [2], (c) insert shear test based on ASTM F606-95b [12]

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Thus, these test designs are closer to an application than those shown in Figure 1. However, a test setup with several load introduction points for pull-out tests as shown in (a) and (b) has not been established so far. In contrast, the shear test with the two inserts, as shown in (c), has already become accepted in the application.

Furthermore, there are many different variations of a test type, which make it difficult to compare them with each other. Table 1 shows the variance of different pull-out tests conducted in the literature. For example, the cutout diameter, the loading rate and the specimen size vary. Therefore, a good comparability of the results of different test setups is not given. A defined standard would lead to better comparability of results.

Table 1: Variations of pull-out tests

Reference	Specimen size [mm]	Shape of the cutout [mm]	Loading rate [mm/min]	Number of inserts
[13]	80 x 80	⌀ 70 circular	1	1
[14, 15]	100 x 100	⌀ 70 circular	1	1
[12]	100 x 100	⌀ 80 circular	10	1
[16]	100 x 100	⌀ not given, circular	1	1
[17]	120 x 120	⌀ 80 circular	1	1
[18]	120 x 120	⌀ 80 circular	1.27	1
[3]	127 x 127	⌀ 100 circular	1, 500	1
[19]	140 x 140	⌀ 60 circular	0,5	1

3. Component tests for an aircraft cabin partition

3.1 Existing load cases in the example of an aircraft cabin partition

The application example considered in this paper is an aircraft cabin partition wall as used in entrance areas of commercial aircrafts. The requirements of such a partition are specified in CS-25.561 and CS 25.562 [20]. Figure 3 shows possible loads on the cabin partition.

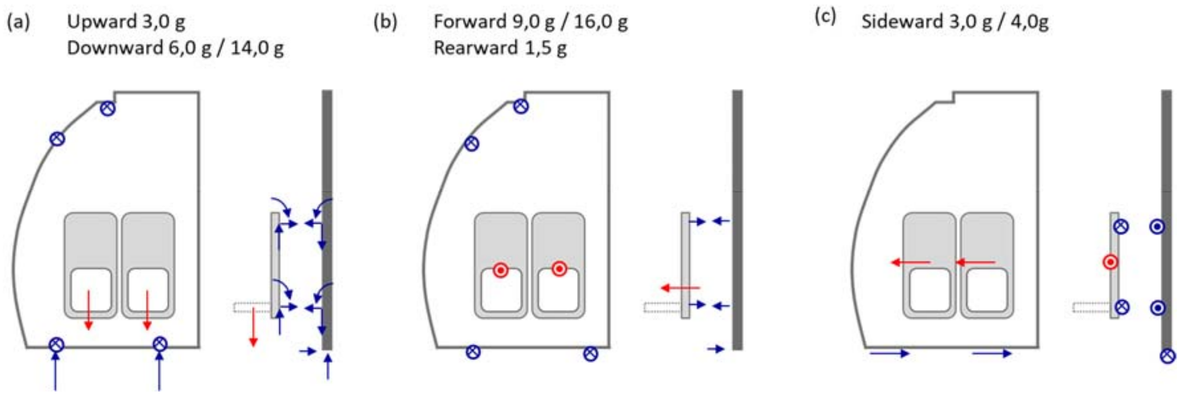

Figure 3. Load cases on an aircraft cabin partition according to EASA CS-25 [20]

This design regulation specifies accelerations for the various three-dimensional directions, which are used to calculate static design forces. For load introduction points of cabin attendant seats, even higher loads must be withstood during forward and downward loading. These are also indicated. The masses of the individual attachments are considered as they are in the application. The weight of a flight attendant is assumed to be 77 kg according to CS-25 [20].

As shown in the free-body diagrams in Figure 3, tensile, compressive and shear forces essentially act at the interfaces or at the load introduction points from the attachment parts into the partition. Thus, the partition itself is exposed to a global bending load in the critical load case of the forward direction.

3.2 Suitability of the current component test setups

Therefore, a pull-out test and a shear test, as shown in Figure 1 (a) and (b), are suitable for the strength verification of the individual load introduction points. In order to investigate the bending behavior of the materials used, bending tests such as those shown in Figure 1 (f) are recommended. Thus, the strength of individual joints as well as the material behavior can be verified with the present test setups.

However, if individual load introduction points are close together, there may be interactions between them. These cannot be detected and analyzed in the existing test setups. Furthermore, the boundary conditions of the bearing are abstracted from the application in a way that their influence on the structure cannot be investigated. Moreover, most established tests only consider the strength verification of insert connections. They are usually located at such a low level of structural complexity that they are not suitable as a component test for evaluating the performance of other designs. Additively manufactured structures, for instance, do not require inserts. Therefore, it makes sense to develop test setups that use larger components with more load introduction points and bearing points which are more oriented to the real application. The influence of various variables, such as the distance between the load introduction points or the influence of the shape between the bearing and load introduction points, can then also be investigated on test setups that are much closer to the application.

4. Development of new component tests

The development of the new component tests is done by combining a bottom-up with a top-down approach following the Wishbone approach from Ostergaard et al. [21]. The analysis from chapter 3.1 has shown that tensile and shear loads are the most relevant loads in the design of load introduction elements. For this reason, the shear as well as the pull-out test are used as a starting point and are successively extended to the new component tests (bottom-up). In chapter 3.2, it was further shown that the real bearing situation corresponds more to a bearing over load introduction elements than to a bearing over a fixation. Such a bearing situation realized by four joint connections is abstracted from the application (top-down) in the newly developed component tests, which are shown in Figure 4. Here, the load introduction in the test setups (a) and (b) is done via one load introduction point and in the test setups (c) and (d) via two load introduction points. In addition to the more realistic boundary conditions in the new component tests, the test setups are characterized by the fact that the same specimens can be used for both tensile and shear loading. This allows easy validation of virtual models, since only one type of specimen has to be manufactured and modelled for physical testing and numerical simulation and only the load direction in the numerical simulation has to be changed.

Furthermore, reductions of the loadbearing capacity of the individual load introduction elements due to a superposition of their stress fields can be taken into account.

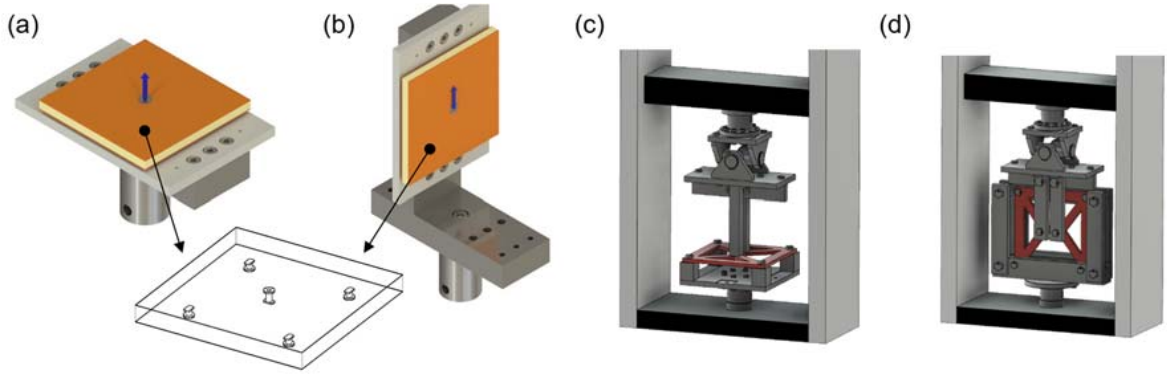

Figure 4. Concepts for pull-out test and shear test with extended boundary conditions (a), (b) and multiple load introduction points (c), (d)

By transferring the analytical formulas from the Insert Design Handbook [2] into a graphical representation, corresponding reduction areas were identified, which is shown in Figure 5 (a). Building on this, the mounting plate for fixing the specimen in the experimental setups (a) and (b) was designed in such a way that different effects can be investigated, which is shown in Figure 5 (b). Furthermore, an extension to a test setup with two load application points is also possible, as shown in the test setups (c) and (d). In these test setups, an additional universal joint is used for load application to avoid the introduction of transverse forces into the structure.

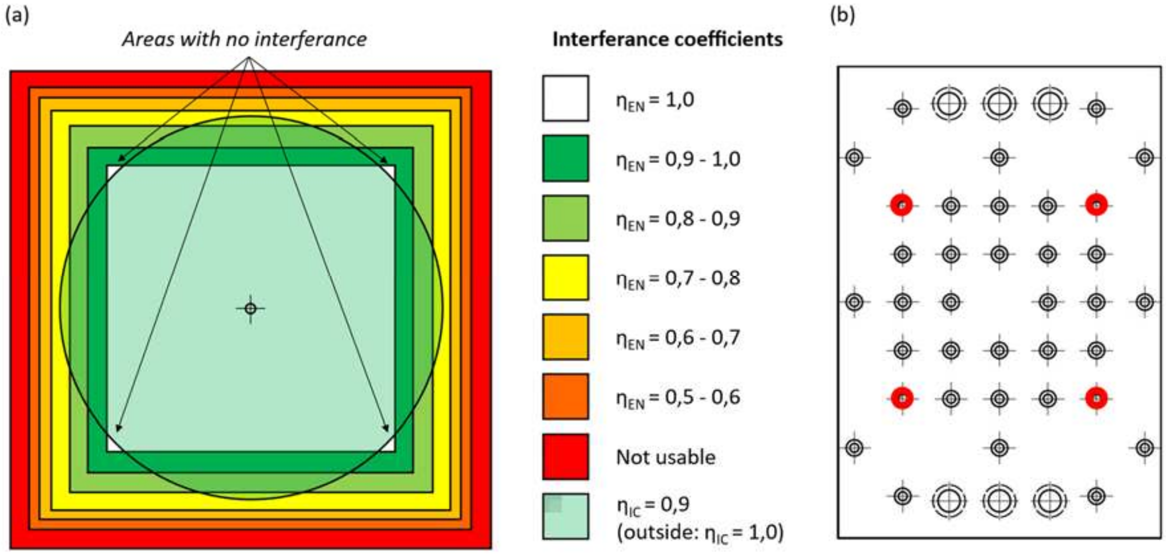

Figure 5. Graphical representation of interference areas for a 200 x 200 specimen (a) and mounting plate with red colored drill holes for configuration without loss of load bearing capacity of inserts (b)

5. Results

Figure 6 shows the test results of a sandwich structure with Nomex honeycomb core and face sheets of phenolic resin impregnated glass fiber fabric in the conventional pull-out test (red curve, test setup on the left) and in the new component test (blue curve, test setup on the right) according to Figure 4 (a). Both tests were performed on the same Galdabini Quasar 100 universal testing machine with a loading rate of 2 mm/min. Furthermore, the optical 3D measuring system ARAMIS Adjustable from GOM was used in each case for displacement measurement as well as a HBM S9M-10 kN load cell is utilized for force measurement. For the pull-out test, a cutout diameter of 70 mm was selected, as recommended in the Insert Design Handbook [2]. In addition, the mounting of the inserts in the new component test was selected that, according to the analytical formulas from the Insert Design Handbook [2], no reduction in the load-carrying capacity of the individual inserts occurs.

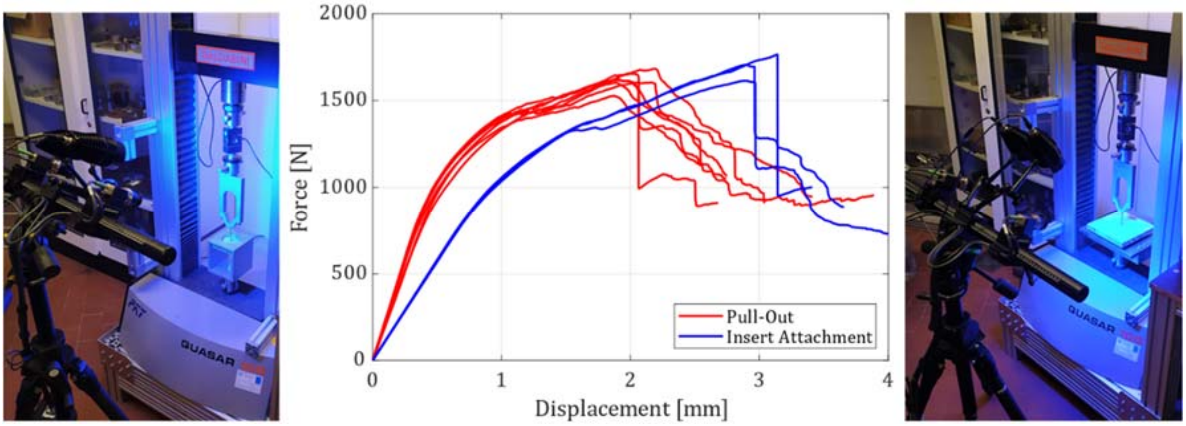

Figure 6. Comparison of a normal pull-out test with one with extended boundary conditions (insert attachment)

In the tests, deviations in the stiffnesses can be seen which, in addition to the changed bearing situation, can also be attributed to the larger specimen dimensions and the reduced stiffness of the sandwich specimen compared to the bearing. Furthermore, deviations in the strengths are evident. This can be explained by the changed load and the differentiated damage mechanisms occurring in the new component test compared to the conventional pull-out test. Due to this superimposed and more realistic loading, the new component test is well suited to validate virtual models also at structural complexity levels above the pull-out test. Furthermore, the new punctual bearing situation makes it possible to optimize the structure to the occurring load under the more realistic boundary conditions in a test setup that is less complex and less expensive than tests at the product level. With regard to the sandwich design, this optimization can be realized, for example, in the form of an optimization of the inserts and core filler or a reinforcement of the face sheets. Innovative designs, such as rod structures or additively manufactured structures, can also be compared with each other, since the advantages resulting from topology optimization, for example, are taken into account in the new component test.

6. Conclusion and Outlook

For the design of aircraft cabin components, there are a variety of different component tests for verification. Many of them are based on the specifications of the Insert Design Handbook [2], but still vary in test dimensions and execution. Test setups that consider multiple load introduction points are mostly unestablished. The same is also the case for the consideration of realistic boundary conditions. This is also illustrated by the example of an aircraft cabin partition considered in this paper. Furthermore, most of the test setups are only suitable for testing sandwich insert joints, so they are not suitable for a component-level design comparison.

Therefore, based on the identified gap, a number of more application-oriented component tests are developed. These investigate both tensile and shear loads. In a first step, the boundary conditions are extended and one load introduction point is considered. In the next step, the number of considered load introduction points is increased to two. Finally, the first developed test setup is implemented and used. Compared to a conventional pull-out test, a lower stiffness is determined. However, slightly higher loads are obtained under the more application-oriented boundary conditions, since the failure behaviour changes.

In the future, the other test setups will be implemented and their influence on structural performance will be determined. In a next step, other designs such as additively manufactured load path optimized structures will be tested and their performance compared to the conventional sandwich design.

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7. References

[1] Zenkert D. Handbook of Sandwich Construction. 1997.

[2] European Cooperation for Space Standardization - ECCS. ECSS-E-HB-32-22A: Space Engineering Insert Design Handbook. 2011.

[3] Heimbs S, Pein M. Failure behaviour of honeycomb sandwich corner joints and inserts. Composite Structures 2009; 89(4): 575–88.

[4] Rodriguez-Ramirez JdD, Castanié B, Bouvet C. On the potting failure of inserts for sandwich panels: Review of defects and experimental analysis. Mechanics of Advanced Materials and Structures 2021; 28(21): 2210–2228.

[5] Seemann R, Krause D. Experimental and numerical analysis of nomex honeycomb sandwich panel inserts parallel to the face sheets. In: ECCM 17. Proceedings of the 17th European Conference on Composite Materials; 2016 June 26-30; Munich, Germany; 2016.

[6] Heyden E, Hartwich TS, Schwenke J, Krause D. Transferability of Boundary Conditions in Testing and Validation of Lightweight Structures. In: Krause D, Paetzold K, Wartzack S, editors. DFX 2019. Proceedings of the 30th Symposium Design for X; 2019 September 18-19; Jesteburg, Germany; 2019.

[7] Schwan L, Hüttich P, Wegner M, Krause D. Procedure for the transferability of application specific boundary conditions for the testing of components and products. In: Krause D, Paetzold K, Wartzack S, editors. DFX 2021. Proceedings of the 32nd Symposium Design for X; 2021 September 27-28; Tutzing, Germany; 2021.

[8] Department of Defense. Composite Material Handbook - Volume 3 Polymer matrix composites materials usage, design and analysis. 1997.

[9] Dambietz FM, Hartwich TS, Scholl-Corrêa J, Hoffmann P, Krause D. Influence analysis of the layer orientation on mechanical and metallurgic characteristics of DED manufactured

parts. In: LiM 2021. Proceeding of Lasers in Manufacturing Conference 2021; 2021 June 21-24; Munich, Germany; 2021.
[10] Mharsi K, Casari P, Sellami A, Fajoui J, Kchaou M. Mechanical Characterization of a Composite Sandwich Core Under Shear Stress Based on a Torsion Test. In: Kharrat M, Baccar M, Dammak F, editors. Advances in Mechanical Engineering, Materials and Mechanics. Springer International Publishing. 2021; 299–305.
[11] DIN Deutsches Institut für Normung e. V.. DIN 53293 - Prüfung von Kernverbunden, Biegeversuch. Beuth Verlag GmbH. 1982.
[12] Seemann R. A Virtual Testing Approach for Honeycomb Sandwich Panel Joints in Aircraft Interior. Springer Berlin Heidelberg. 2020.
[13] Bianchi G, Aglietti GS, Richardson G. Static Performance of Hot Bonded and Cold Bonded Inserts in Honeycomb Panels. Journal of Sandwich Structures & Materials 2011; 13(1): 59–82.
[14] Schwenke J, Krause D. Optimization of load introduction points in sandwich structures with additively manufactured cores. Design Science 2020; 6.
[15] Schwenke J, Hartwich T, Krause D. Optimierung von Inserts in Sandwichstrukturen durch additive Fertigung. In: Lachmayer R, Lippert RB, Kaierle S, editors. Konstruktion für die Additive Fertigung 2018. Springer Berlin Heidelberg. 2020; 243–259.
[16] Park H-S, Hwang D-H, Han J-H, Yang J. Development of shock-absorbing insert for honeycomb sandwich panel. Aerospace Science and Technology 2020; 104: 105930.
[17] Roy R, Nguyen KH, Park YB, Kweon JH, Choi JH. Testing and modeling of Nomex™ honeycomb sandwich Panels with bolt insert. Composites Part B: Engineering 2014; 56: 762–769.
[18] Nguyen K-H, Park Y-B, Kweon J-H, Choi J-H. Failure behaviour of foam-based sandwich joints under pull-out testing. Composite Structures 2012; 94(2): 617–624.
[19] Bunyawanichakul P, Castanié B, Barrau J-J. Non-linear finite element analysis of inserts in composite sandwich structures. Composites Part B: Engineering 2008; 39(7-8): 1077–1092.
[20] European Union Aviation Safety Agency EASA. Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes - CS-25 Amendment 26. 2020.
[21] Ostergaard MG, Ibbotson AR, Le Roux O, Prior AM. Virtual testing of aircraft structures. CEAS Aeronaut Journal 2011; 1(1-4): 83–103.