

EVALUATION OF A VISUAL ASSISTANCE SYSTEM TO SUPPORT MANUAL SCARF REPAIRS FOR A DIGITALIZED AIRCRAFT MAINTENANCE

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Abstract

The historically grown regulations and organisational structures in aviation are a challenge for the intended digitalisation in the field of maintenance. In this context, manually performed scarf repairs are one of the hand operated workflows for which several projects have already been executed in relation to possible process automation. However, due to the very individual damage and component characteristics, this process will also require manual activities in the future.

At present, there is no measurable quality assurance and assessment both afterwards and during the grinding process within scarf repairs. The technician works according to the manufacturer's specifications, but he must be able to adapt his procedure for each case of damage and assess his work on the basis of his experience. For a better support of the technician during the scarfing process, an additional system component is proposed, which also allows him to check his work in the form of visual feedback.

In the context of the present work it is examined whether a visual assistance system is a suitable support for the technician and can ensure a usable evaluation regarding the quality of the scarf geometry. For this purpose, pilot tests are performed and analyzed on laboratory level as well as in cooperation with a maintenance company. Parallel to this, the process modification for the integration of the assistance system is demonstrated. Finally, possible application potentials in reference to current research activities for digital twins are discussed.

Keywords

Assistance, Aviation, MRO, Human-Machine-Interaction, Scarf Repair, Composites, Composite Repair, Quality Assurance

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1 INTRODUCTION

The historically grown structures in today's aviation maintenance industry offer great potential for digitized workflows.

The repair process for fiber-reinforced plastic composite structures in the form of a tapered scarf repair is just one of many manual but above all highly individual tasks within aircraft maintenance. A work package of the project FACTOR (Future Advanced Composite Bonding and Bonded Repair) is dedicated to the question of how a geometric in-situ deviation analysis during the scarfing phase can

contribute to decrease the geometric tolerances for quality improvement and process optimization.

Based on the proof of concept by A. Wilken et al [1], this paper focuses on the technological implementation of an assistance system that is designed to visually support the technician during tapered scarfing of a single curved structure. Thereby it is considered how the use of the assistance system can be integrated into the conventional process flow and whether the quality of the final scarf geometry can be positively influenced by an in-situ deviation analysis. Furthermore, pilot tests are intended to provide initial insights into user perception.

After the current state of the art and research of different systems for partially or fully automated scarf procedures, the appropriate technology selection is following depending on the process requirements. Subsequently, the base function of the selected system, the process modification and the test execution are explained. Finally, the results and further recommendations for action are outlined.

2 SYSTEMS AND TOOLS FOR COMPOSITE SCARF REPAIR

Today, an increasing number of aircraft components consist of fibre-reinforced composites such as carbon fiber reinforced polymer (CFRP), in most cases for primary and secondary structures of an aircraft. [2]

If a damage occurs, the structure is mostly repaired based on the manual tapered method, depending on how extensive the damage is, where is it located on the structure and it is still classified as repairable after the structural repair manual (SRM). [3] In this process, the individual material layers around the centre of the damaged area are removed from the technician with a hand-grinder and then rebuilt by inserting several fibre layers, see FIG. 1. [2]

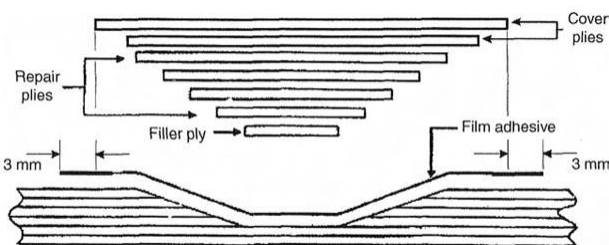


FIG. 1 Structure of a tapered scarf repair [3]

Currently, this repair procedure in aircraft maintenance is characterized by manual workflows. This is also related to the fact that the damage characteristics of the structures occur highly individually and can often only be processed with hand-held equipment because the damaged areas are difficult to access. Maintenance companies work according to the exact specifications of the manufacturers, but the quality of a final repair depends on the qualification and experience of the respective technician. [2]

Mechanical devices can be used to support the hand-guided process, see FIG. 2, here in the form of

a toolkit for a stepped scarf repair, which guides the grinder for increased accuracy during the grinding process. [4]

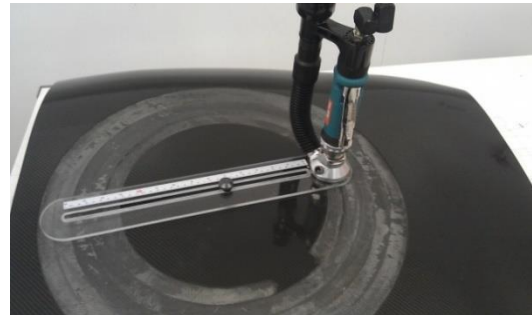


FIG. 2 Toolkit for stepped scarf repairs [4]

In contrast to the tool kit from FIG. 2, various systems have been developed in recent years in the area of research for a partially or fully automated scarf procedure. At this point a short overview of two selected systems follows.

The system in FIG. 3 is build up within the *LuFo* projekt "CAIRe" (FKZ 20W1101A) and consists of a portable robot arm which is mounted directly on the damaged structure via suction cups and is equipped with a milling unit. A laser scanning system allows to scan the surface and based on this data the software calculates the travel path for the implemented milling unit which creates the scarf geometry automatically. [5]



FIG. 3 Automated scarfing with CAIRE System [12]

In contrast to the fully automated scarf unit in FIG. 3, a hand-guided milling unit was developed by the TU Hamburg within the project *Supcrafted*. The user is supported during the grinding process and can intervene directly in the process and make corrections in case of problems. The design is based on a three-axis system, whereby the X and Y axes are guided manually and the Z axis with integrated

milling unit automatically feeds the milling depth depending on the position in the X, Y - plane. [6]

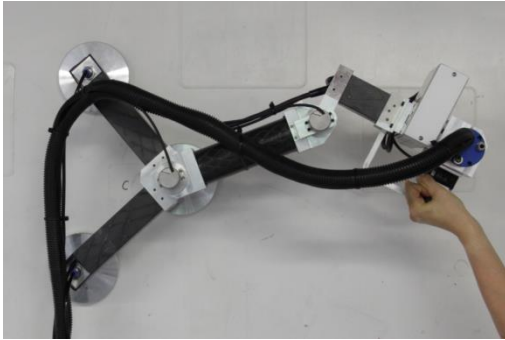


FIG. 4 Mobile hand-guided scarf unit [7]

Fully automated systems such as *CAIRe* are particularly suitable for the repair of major damage to large fuselage or wing segments which either cannot be disassembled or at least not without increased workload. The system from the *Supcrafted* project is also specially designed for on-wing repairs, but initially for slightly curved structures.

A visual assistance system on the other hand, offers the possibility to support the executing technician directly during the process. So the basic process steps which are certified are not directly influenced but only supported by the system. Thus, a future application in an industrial environment is expected to be easier to implement.

3 EVALUATION OF AVAILABLE SCAN AND PROJECTION SYSTEM

For the proof of concept in [1], the system *dentCheck* from the 8tree GmbH [8] calculates the deviation analysis between as-is and nominal geometry internally and visualizes the result as a colored projection on the component surface. The disadvantage of this system is that the specification of the nominal geometry can only be achieved with the help of a separate scan process. Due to the closed system, further program functions cannot be embedded without the support of the manufacturer. Therefore, in this paper an alternative scan/projection system is considered, which offers far-reaching adaptation possibilities with regard to the individual processing of scarf repairs. Various factors are important for the selection of a suitable system in order to enable the user to apply the system in the widest possible range of applications.

Based on the insights from [1], three different systems are compared in six categories. To quantify the evaluation, each category with its respective requirements has a different weighting. The categories are:

- Measurement accuracy in mm
- Field of view dimension in mm
- Component referencing with markers
- Housing encapsulated
- System mobility
- Software adaptability



FIG. 5 GOM Atos 5 system [9]

The *ATOS 5* [9] system, see FIG. 5, from *GOM* provides the best results, not at least because of its encapsulated housing [9] whereby the system has a significant advantage which allows its usage under real industrial conditions. Thus the system is safe from CFRP dust which occurs during grinding. The dust can be electrically conductive and can lead to short circuits of exposed electrical components. [10] After the surface is scanned by the structured light projector, the software interface allows to programm various application for calculating geometric bodies or contours. So the scanned surface and the calculated bodies/contours can be combined or compared within a deviation analysis for example. It's also possible to reproject these geometric contours and visualizes them on the component surface, see the example in FIG. 15 in chapter 7.1. It is one of the important functions to realize visual support during the scarfing process.

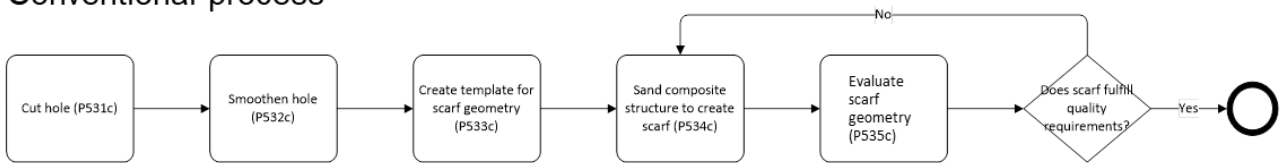
4 MODIFICATION OF THE SCARF REPAIR PROCESS

The basic idea of the visual assistance system is to increase the quality of the manual scarfing procedure. The process diagrams in FIG. 6 serve to compare the conventional process flow with that of a visual assistance system. Both diagrams were

created after the test series in the course of a holistic process analysis and concentrate on the grinding process. The numbering of the process steps comes from the holistic process view. During the tests these designs are used to analyze the process times. In the conventional process, the first step is to cut out the damaged area over the entire material thickness (P531c) from the component structure. After that the resulting hole is then finely ground (P532c). With the help of a previously created template, the technician marks the area of the contour to be grinded. (P533c). In the next stage of the process, the operator begins to remove the structural material to create the required scarf geometry (P534c) and checks the intermediate stages of the scarf based on his experience. (P535c). This is followed by the user's evaluation of whether the current intermediate state corresponds to the required scarf geometry. If this is the case, the next repair steps can be carried out. If not, the next iteration step of the grinding process is follows.

In the modified process, the evaluation of the current intermediate status during grinding is taken over by a visual assistance system (P534b). The deviation between nominal and actual state is carried out in the form of contour lines on the component surface and as color-coded deviation analysis within the evaluation software from GOM [11]. The projection of the nominal contour eliminates the need to manually create templates or drawings on the component surface. Furthermore, it is expected that the representation of the current deviation from the nominal state helps to increase the accuracy of the grinding process compared to the purely manual process.

Conventional process



Modified process with visual assistance

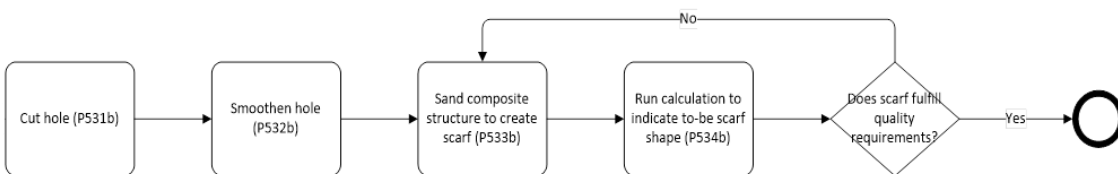


FIG. 6 Conventional scarf process vs. modified process within the visual assistance

5 APPLICATION FOR AUTOMATED CALCULATION OF SCARF GEOMETRY AND DEVIATION ANALYSIS

In order to visually assist the manual scarfing operation, the generation of a nominal contour is an elementary step. To optimize the total process this generation must be done as soon as possible. Therefore a routine within the GOM software [11] was programmed with support of the GOM GmbH in Braunschweig. The first pilot test, see 6.1, were performed with a previous version which was restricted on ellipse or circle scarf geometries. For the second pilot test, it is also possible to generate more complex contours by manual settings, explanation at the end of this chapter. The following description explains the automatic generation of ellipse and circle scarf geometries.

(1) Scanning and calculating the initial surface

First of all the original surface is scanned. It needs to have some glued on reference points around the assumed outer contour of the scarf. These are necessary to calculate the relative orientation between object and scanner in all coming steps. Furthermore a coded reference point has to be in the middle of the damage, another on the outside of the maximum scarfing distance. Based on the coded points the surrounding area is deleted and the initial surface is calculated. The coordinate system is centered in the middle of the damage and is orientated by using a fitting cylinder. The x-axis is orientated towards the non-curved direction, the y-axis towards the curved direction and the z-axis is perpendicular to the surface, see FIG. 7

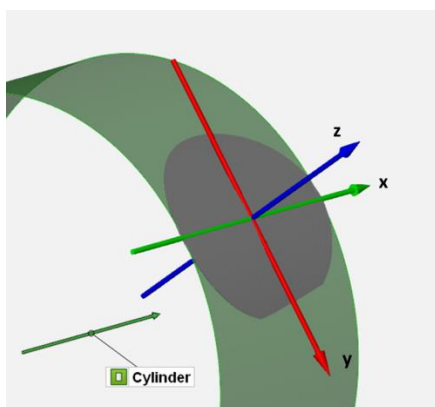


FIG. 7 Scanned surface (grey) with reference points and coordinate system oriented by a fitting cylinder (green)

(2) Generation of nominal contour

Secondly, a user input window asks for the scarfing parameters. Based on this, the inner and outer ellipse (or circle) are generated. The inner contour has a constant offset in the negative z – direction in the amount of the material thickness. Then the outer and inner curves are connected to create a taper geometry (in the first test series outer and inner contour are linear connected as simplification). Based on this a point-cloud for the nominal scarf geometry is generated. In the subsequent step this point-cloud is meshed and smoothed to become the nominal scarf structure. It contains the information of the reference points and the coordinate system.

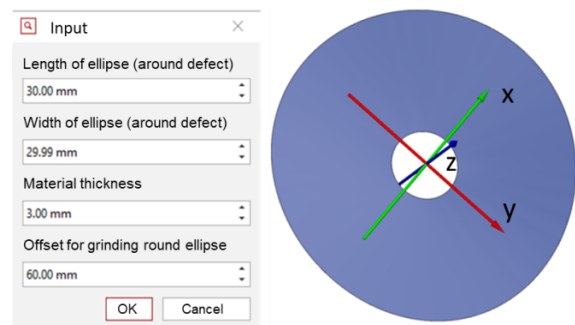


FIG. 8 User input window (left) and nominal scarf contour (right)

(3) Comparison of nominal to actual surface and projection of results

The next step is to compare the nominal contour to the actual scanned surface. The result is then displayed as a color plot with level lines. The calculated level lines can be reprojected with ATOS 5, shown later in FIG. 15. [9] The software automatically corrects the distortion, as long as at least three reference points are located in the projection area.

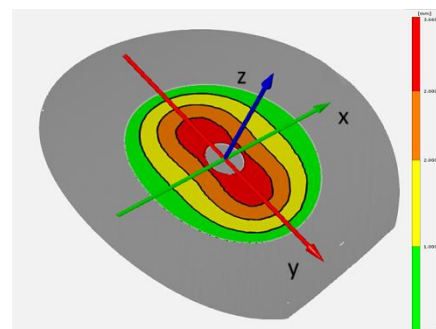


FIG. 9 Deviation between scanned and nominal surface, max. grinding depth = 3.6 mm (red area)

(4) Repetition of intermediate scans and automated recalculation of the deviation nominal to as-is state

During the grinding process, the surface scan needs to be repeated to compare the as-is state to the nominal surface. For this step the grinding has to be paused. The necessary steps for the recalculation are:

1. stop the projection mode
2. start a new scan, following calculation runs automatically
3. reactivate the new reprojection of the new deviation analysis

To be more flexible by generating individual scarf geometries, the program was adapted so that the inner scarf contour can be additionally set with manual input depending on the damaged area. The outer contour is creating by an offset parameter around the inner contour. The process step "Calculation of stepped intermediate curves" in FIG. 10 signals the adapted method to connect the outer with the inner contour to create a smoother tapered geometry. So now the user can set intermediate steps between the single scarf contours to adjust the tapered scarf geometry to curved structures, see FIG. 17 in chapter 7.3.

FIG. 10 shows the complete workflow within the calculation program for the assisted grinding process.

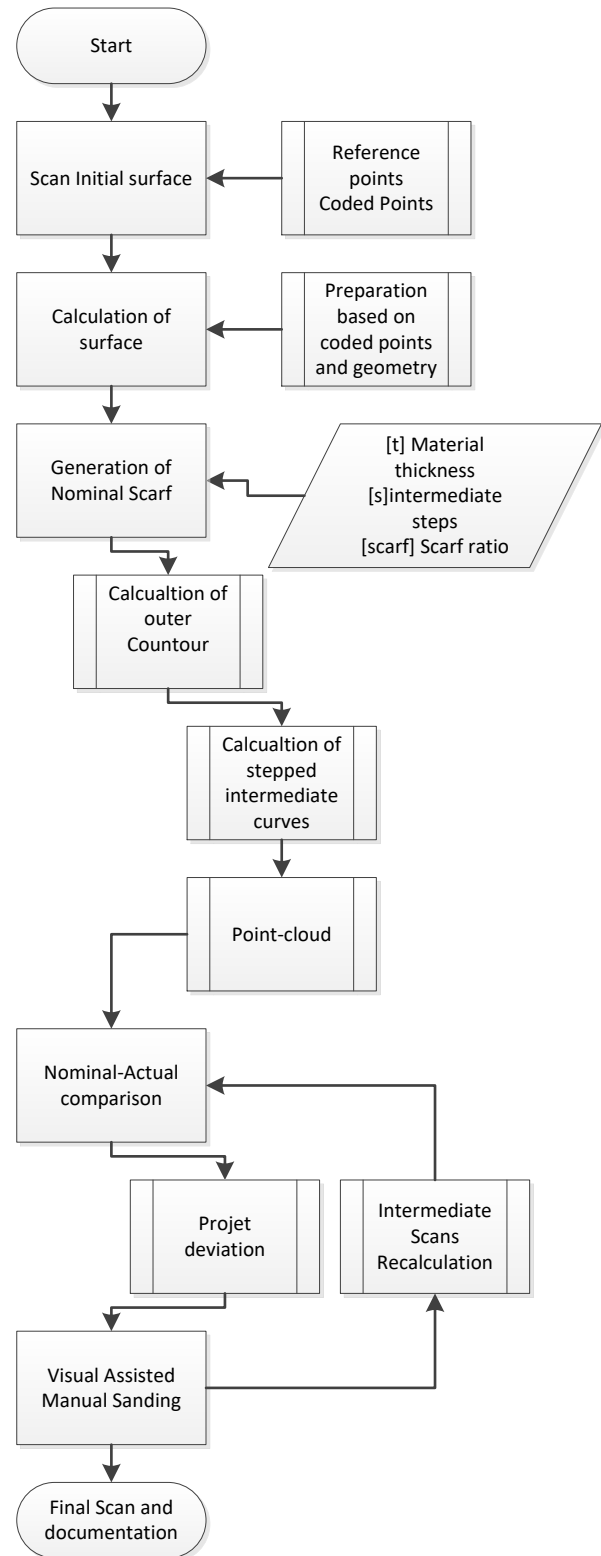


FIG. 10 Workflow of the calculation program for assisted scarf repairs

6 PILOT TESTS

The pilot tests are performed in cooperation with Lufthansa Technik in Hamburg. This makes it possible to test the system under real conditions by experts and to obtain their feedback. The *GOM GmbH* supplies the system *ATOS 5* for the test series. [9]

6.1 Execution of first pilot test

In cooperation with the project partner Lufthansa Technik the modified process is demonstrated on two single curved CFRP samples.

The aims of the test series are:

- A detailed examination of the modified process with regard to time and quality aspects under real conditions
- The gathering of further knowledge regarding the applicability of an assistance system to support manual operations

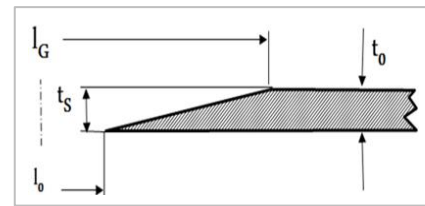
To ensure comparability, both samples should have the same scarf geometry, grinded by the same experienced technician. The scarf geometry should have the following parameters, compare with FIG. 11:

- $l_0 = 30 \text{ mm}$
- $l_G = 150 \text{ mm}$
- $t_s = t_0 = 3 \text{ mm}$

Both samples are curved with a radius of about 900 mm.

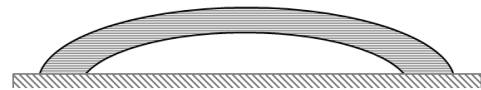
As already mentioned, a total of two experiments are planned, the first of which will be performed according to Lufthansa Technik current repair standards and the second with the support of the visual assistance system. The applicability of the system in practice is then discussed with experts from Lufthansa Technik in order to plan possible more in-depth test series in the future.

FIG. 12 shows the test setup for assisted scarfing with the *GOM ATOS 5*. The tests were carried out in a separate workshop area of Lufthansa Technik (Hamburg) with the room lighting switched on in order to evaluate the visibility of the projections on the surface under realistic conditions.



Sectional view

curved CFRP sheet



curved CFRP sheet with scarf geometry

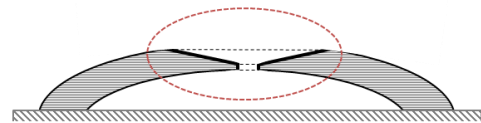


FIG. 11 Grinded scarf geometry

The measuring system requires an additional computer with a corresponding software package, which is connected to the scanner via a control unit. After the damage location has been defined on the CFRP sample, it has to be prepared with optical markers which are glued on around the damaged area.



FIG. 12 Test setup for assisted scarfing process at Lufthansa Technik (Hamburg) on single curved CFRP samples [12]

6.2 Execution of second pilot test

The Lufthansa Technik test series within the FACTOR project has opened up the possibility of a second test run for the assistance system. The aim was to repair a large area of damaged material, but

this time, due to the limited field of view of the assistance system, the overall scan surface has to be composed from several partial scans using glued markers. In addition, the further development of the software application within the individual manual curve generation method, see the end of chapter 5, is tested. The following FIG. 13 shows the complete scarf contour within the software interface from GOM. In the end, the findings during the test are discussed with the experts from Lufthansa Technik.

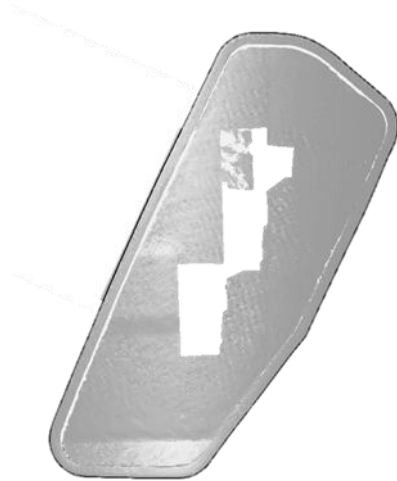


FIG. 13 Complete scarf contour of second pilot test in GOM Software

7 SUMMARY AND INTERPRETATION OF TEST RESULTS

This section summarizes the findings from the two test series at Lufthansa Technik. First a comparison between unassisted and assisted scarfing of the first pilot test is described. Subsequent the process time and the deviations analysis of both final scarf geometries during the the first pilot test are shown. In the end the findings from the second pilot test are presented.

7.1 Unassisted vs. assisted scarfing process

In the conventional scarfing process, the technician uses a marker to transfer the nominal contour to the structure, with using a circular template for the outer radius of the scarf contour. A compressed air grinder is used for the implementation.

During grinding, the technician orientates himself on the light reflection of the fibre layers which signals the different fibre orientation and checks the

intermediate status by touching along the grinded contour combined with a visual inspection. Cause experienced and well-trained technicians are able to assess the quality of their work very well themselves and thus meet the requirements for repair.

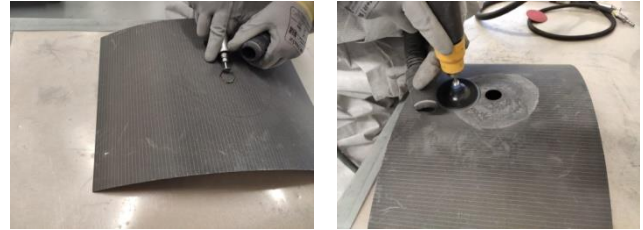


FIG. 14 View during the unassisted scarfing process [12]

FIG. 15 shows intermediate statuses during the assisted scarfing, with the first figure showing the initial situation before the grinding process begins. By means of the coded marker in the centre of the damaged area, the software detects for which area of the previously measured component surface the nominal scarf geometry should be calculated. Due to the hardware limitation of the GOM ATOS 5, the reprojection of the calculated nominal geometry is realized with two colors. The colored deviation analysis is shown on the computer display within the ATOS software [11].

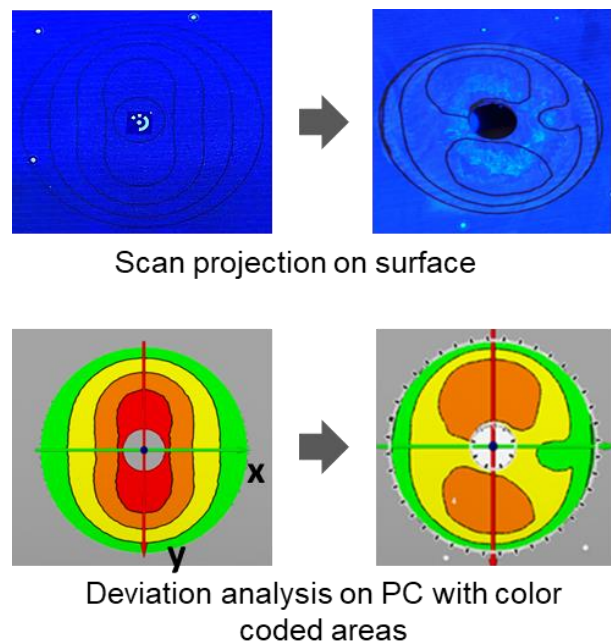


FIG. 15 Initial and intermediate status of the assisted scarfing process

The number of scans for the analysis of the current status was freely chosen by the technician. The contours adapt to the respective status of the scarf and indicate the current deviation from the nominal geometry in mm via the colored scaling.

Due to the blue light source of the projector, the technician is able to see the individual layers of the material much easier, but the projections are sometimes quite complicated to interpret, so the feedback from the technician during the process.

In addition, the technician has to constantly transfer the result of the color-coded display on the PC screen to the projection, so at this point a small portable display like a tablet pc for example could improve this. Because then the deviation data could be displayed directly in the technician's field of view. Nevertheless, the system gives the technician a good feeling during the work due to the visual feedback from the deviation analysis. On the expert's side, this could help inexperienced technicians and trainees in particular to improve their skills faster which could reduce the overall training period.

Alternatively, a direct colour projection using the *dentCheck* system from *8tree GmbH* [8] was demonstrated to the experts too. According to them, the *dentCheck* coloured projection makes it difficult for the technician to see the individual layers of material.

7.2 Comparison of process time for the first pilot test

As mentioned in chapter 6.1, the individual process times were recorded during the first test series. FIG. 16 shows the time intervals for the scarf process. The time for evaluating the intermediate status during the unassisted scarfing is included in process step P533a, since the technician carries out his evaluation within a few seconds and resumes the grinding process immediately.

The time required to cut out the center of the damaged area differs only marginally, whereas the grinding process P533a with the assistance system increased by 34% to 28 minutes compared to the unassisted process.

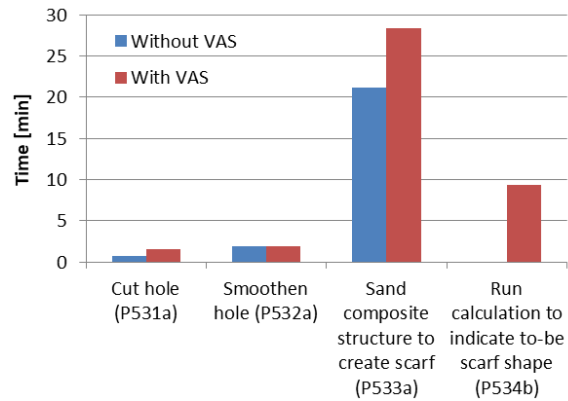


FIG. 16 Comparison of time values between unassisted and assisted grinding

In addition, the technician needs 7 minutes for the first initialization and projection of the scarf geometry compared to the 2 minutes required for marking with a color marker. Due to the recording and calculation of the intermediate statuses, the entire process is extended by a further 10 min (P534b) to a total of 50 min. This increases the time for scarfing within this test series from 27 min (unassisted) to 50 min (assisted). A part of the additional time required can be explained by the fact that the technician was using the system for the first time for scarfing and wanted to work as accurately as possible with the help of the system. Currently some manual process steps must be performed by the technician which could be reduced to a minimum by a better workflow within the program, remind FIG. 10. So together with the system set-up at the beginning, the increased time expenditure can be explained. But it is therefore assumed that once a technician is fully familiar with the system, the time differences could be decrease.

7.3 Deviation analysis of the first pilot test

The following deviation analyses (DA), executed with *CATIA V5*, are used to evaluate the scarf quality compared to a nominal geometry.

First of all, an effect from the calculated nominal geometry by the programmed script has to be explained. The calculated nominal geometry for the assisted repair was generated with a simplification, see 5 (2). The following sketch in FIG. 17 shows the difference between the calculated nominal geometry by the programmed script and the designed nominal geometry with *CATIA V5*. Because the inner and outer contours are linearly connected in the script to create a tapered scarf geometry (initial simplification), the curvature of the nominal

geometry results in an elliptical formation of the contour lines in the direction of Y, see FIG. 15 (lower left). The contour should correctly be circular. This has the effect that too much material is removed in the marked area (FIG. 17) due to an incorrect deviation analysis between nominal and as-is status.

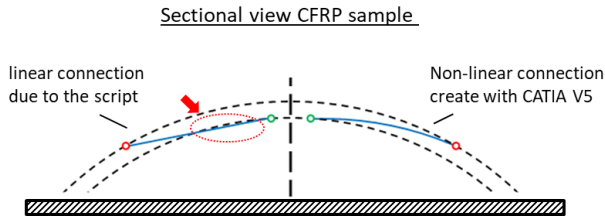


FIG. 17 Sketched section view of the nominal geometry from the script (left) and designed with CATIA (right)

For the two manufactured scarf contours, DA's are executed:

- 1) Unassisted grinding with non-linear connected nominal geometry designed with CATIA V5
- 2) Assisted grinding with linear connected nominal geometry calculated by the script

For a DA, the reference surface has to be positioned correctly into the point cloud of the scanned as-is surface. While the nominal geometry of the assisted scarf is positioned by the script, the nominal geometry of the unassisted scarf has to be positioned by a best-fit procedure. Furthermore the nominal geometry for the unassisted grinding has to be designed afterwards, because it wasn't intended to use the assistance system. Therefore only the final geometry was scanned and thus only the outer tapered contour of the final geometry is used for designing and positioning the nominal geometry for a deviation analysis. The results can be seen in FIG. 18 and FIG. 19.

Both analyses show the final deviation in mm from the required nominal geometry. The deviations from the nominal geometry can be derived from the resolution of the color scales. Light green – dark green areas indicate that the nominal geometry has been reached, orange – red indicates that material has yet to be removed and blue – purple indicates that too much material has already been removed. The DA in FIG. 18 shows quite good results, especially in the outer areas. This might be caused by the fact, that the technician has many years of experience, however it also becomes obvious that

the scarf has not yet achieved the required nominal geometry. The deviations up to 1 mm in the inner area can be explained with the common practice, not to grind the inner contour up to a thickness of 0 mm.

It is noticeable that the color pattern of the second deviation analysis in FIG. 19 shows an irregularity. The red colored areas in y - direction can be explained by the order, not to grind further material away. At this point the negative effect of the simplified geometry as described before became apparent. According to the assistance system, the technician should have partially grinded away the last layer of CFRP at these areas. Nevertheless the maximum deviation is also up to 1 mm, just as with the unassisted scarf geometry.

Due to the minimal curvature in x – direction, the deviation analysis is evaluable in these areas and shows deviations around ± 0.2 mm to the nominal geometry. Important at this point is that the technician can hardly estimate when, for example, 0.2 mm of material has been removed. Due to the usual mechanical vibrations during grinding, it is difficult to recognize if a material thickness of 0.2 mm has been removed, according to the expert. However, in order to make an exact statement about the tolerances to be achieved with the assistance system, further test series would have to be carried out in the future.

In case of the assisted scarf, the technician had to adapt to a system that was foreign to him and modify his approach. More practice and experience with the assistance system may lead to less deviation from the nominal geometry in the future.

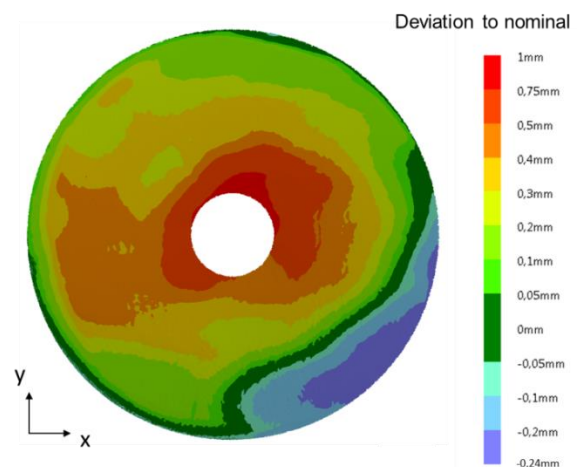


FIG. 18 DA No.1, unassisted scarf vs. designed nominal geometry (non-linear connected, compare FIG. 17)

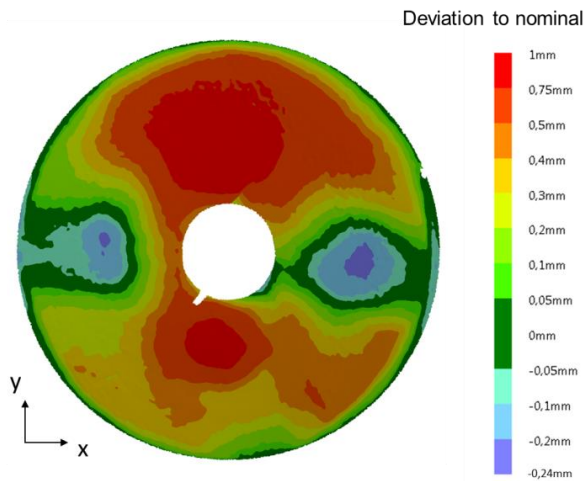


FIG. 19 DA No.2, assisted scarf vs. calculated nominal geometry (linear connected, compare FIG. 17)

7.4 Evaluation of the second pilot test

The second test series essentially showed that a large scale support requires significantly more time for the initialization of the complete surface. But the implemented method to generate an individual scarf contour has worked well, so the system can be used more flexible for different damage scenarios in the future. During the grinding process, the feedback from the technician regarding the presentation of a deviation analysis was very positive. Due to the complex and large CFRP structure, it is a quite difficult tasks for the technician and requires a high level of concentration for a long time period, so he was glad to be able to check his work status via the assistance system. The DA in FIG. 20 shows a part of the lower left corner of the complete scarf contour during the grinding process. As in the DA's from FIG. 18 and FIG. 19, the light green to dark green areas indicate similarly good results of the deviation from the nominal scarf contour about only 0 - 0.2 mm. But in contrast to the first test series, the component in FIG. 13 has different material thicknesses around the calculated scarf contour. This thickness variation cannot be considered by the system so far, so that some areas such as the purple colored, show inaccuracies.

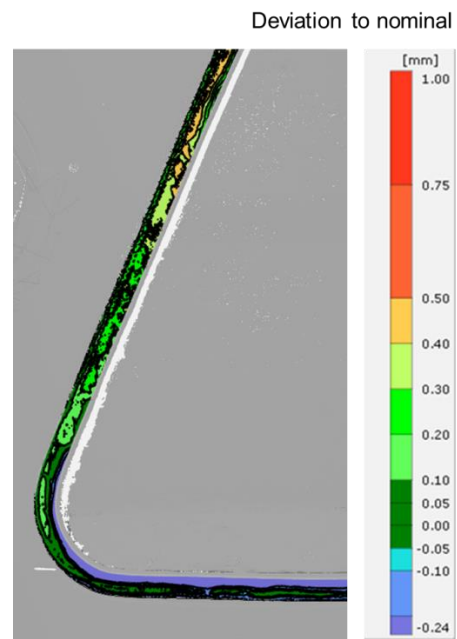


FIG. 20 In-Situ DA of assisted scarf vs. calculated geometry

8 CONCLUSION

The support of manually performed scarf repairs proves to be quite possible, especially in view of the fact that it can simultaneously be used as a quality check for the grinding process.

The two pilot tests made it possible to get first valuable findings and opinions of experts to be collected in order to define further possible milestones in the field of research.

The amount of time required for grinding with the visual assistance system is significantly higher due to additional control tasks by the technician, but this could be reduced by further improvements within the calculation program and trained handling of the system. In principle, the larger the contour to be machined, the larger the time required for setting up and aligning the system in order to provide the technician with the desired support.

The in-situ deviation analysis in colour coding was evaluated very positively by the experts, which provides them with continuous feedback and evaluation of their work. Up to now this has been done by the technician's own assessment, but not by a measuring system. The blue light source of the projector also had a positive effect on the view of the layer orientation of the composite material. Another point is that a measuring accuracy of the system of less than 0.2 mm is not suitable, because a hand-

guided grinding process in this area cannot be implemented even by very experienced technicians. The experts found the fact that the color deviation analysis is carried out on a separate display to be a disadvantage. Thus, the technician has to mentally transfer the current deviation coding to the two-color display in the form of contour lines on the component surface. A separate portable display could therefore be a better alternative. According to the experts, the scanning and calculation speed is currently too slow for a flowing repair process. During the second series of tests at Lufthansa Technik, it also became clear that a future assistance system would also have to work with variable material thicknesses, which are omnipresent in real composite structures.

9 OUTLOOK

Initially, additional test series are required in order to be able to make a quantitative statement about the manufacturing tolerances to be achieved with the support of the assistance system.

At the current development state the parameters for the surface generation are coded directly in the routine. The plan is to improve the user input window to setup significant repair parameters as simple as possible. First the type of repair should be selected and then all necessary scarf parameter are defined. This also includes variable material thickness. Another planned improvement is to save the intermediate scans to document the repair process. Even though this work concentrates on the execution of the grinding process within the overall repair, it is quite possible that further process steps can also benefit from the data generated during the grinding process. A use case would be, for example, that based on of the calculated nominal contour by the assistance system, the required dimensions of the repair patches are sent to a cutter device by data transmission. At the same time, the required amount of material would already be clarified at the time of calculation and could be made available in a time-saving manner. Especially with regard to the vision of the digital twin of aircraft components, the data generated with the visual assistens system can be stored digitally for the respective component. This could make it easier to access or share information from previous repairs or maintenance tasks in the event of further damage to the component, resulting in more efficient and predictable process flows.

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BIBLIOGRAPHY

- [1] A.Wilken, M. Albrecht, J. Kosmann, E. Klaas: *Concept development and demonstration of a visual assistance system for manual scarf repairs of composite structures made of fibre reinforced plastics*, 2019
- [2] K.B. Katnam et. al. : *Bonded repair of composite aircraft structures: A review of scientific challenges and opportunities*, Elsevier Progress in Aerospace Sciences, 2013
- [3] Keith B. Armstrong et al. : *Care and Repair of Advanced Composites, Second Edition*, SAE International, 2005
- [4] Dark Matter Composites:
<https://www.darkmattercomposites.com/composites-repair-equipment.html> , called on 03.08.2020
- [5] M. Höfener, T. Schüppstuhl: *A method for increasing the accuracy of "on-workpiece" machining with small industrial robots for composite repair*, German Academic Society for Production Engineering, DOI 10.1007/s11740-014-0570-y, 2014
- [6] R. Rodeck, T. Schüppstuhl: *Repair of Composite Structures with a Novel Human-Machine System*. In: VDMA, VDE, ITG, DGR und IFR (Hg.): *Proceedings of the 47th International Symposium on Robotics. 47th International Symposium on Robotics*. München, 21.-22. Juni 2016: VDE Verlag, S. 660–666. ISBN 978-3-8007-4231-8
- [7] TUHH Institut für Flugzeug-Produktionstechnik:
<https://www.tuhh.de/ifpt/forschung/forschungsprojekte/supcrafted.html>, called on 03.08.2020
- [8] 8tree GmbH:
<https://www.8-tree.com/applications/dentcheck/>, called on 25.08.2020
- [9] GOM a Zeiss Company:
<https://www.gom.com/de/messsysteme/atos/atos-5.html>, called on 06.08.2020
- [10] DGUV-Information: *Bearbeitung von CFK Materialien Orientierungshilfe für Schutzmaßnahmen*, Ausgabe 10/2014 FB HM-074, Berufsgenossenschaft Holz und Metall
- [11] GOM Inspect: <https://www.gom.com/de/3d-software/gom-inspect-suite/systemunabhaengige-inspektionssoftware/3d-inspektion.html>, called on 27.08.2020
- [12] Images from test series, Lufthansa Technik AG, Hamburg Germany