Improved Method for Increased-Rate Stitched Composites Manufacturing

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Stitched composites, as defined herein, are created by stitching a dry preform, infusing the preform with resin and curing the resin. Stitched composites have been shown to have benefits over unstitched composites for stiffened structures, including improved damage tolerance, reduced weight, and fewer fasteners. However, conventional stitched composite structure production is very time and manual-labor intensive, and therefore is not conducive for high-rate production of commercial aircraft main structure. The National Aeronautics and Space Administration (NASA) Hi-Rate Composite Aircraft Manufacturing (HiCAM) Project has the objective to increase the manufacturing rate for future composite aircraft. Stitched resin infused (SRI) composites are one of the technologies being considered under the HiCAM Project, but to be viable, production rates must be increased (i.e., production time reduced). Previous work has shown that it is possible to reduce the time required to stitch a dry composite preform, such as a skin with integral stiffeners, but the stitching process is a small portion of the total time required to produce a stitched preform. To significantly reduce overall stitched preform production time, a study was undertaken to examine a new stitching method that would yield time reduction in the pre- and post-stitching activities that include all portions of a stitched preform production with the exception of the actual stitching process. The new method resulted in significant reduction in production time, from 27% to 40%, while at the same time reducing the costs associated with fabricating a stitched preform by eliminating stations within the production line, simplifying tooling, reducing labor, and reducing consumables.

I. Introduction

The National Aeronautics and Space Administration (NASA) Hi-Rate Composite Aircraft Manufacturing (HiCAM) Project has the objective to increase the manufacturing rate for future composite aircraft. Still in its early phases, the HiCAM Project has been examining numerous technologies. One technology being examined is resin infusion, and a subset included within resin infusion is stitched resin infusion (SRI). Stitched-resin-infused composites are created by stitching a dry preform then infusing the stitched preform with resin and curing the resin in an oven (an out-of-autoclave process, generally). Stitched composites have been shown to have benefits over unstitched composites for stiffened structures, including improved damage tolerance, reduced weight, and fewer fasteners [1-4]. These benefits make stitched composites attractive from a performance perspective, however, the nature of stitching the preforms prior to infusion includes additional manufacturing steps and equipment compared to conventional resin infusion. Therefore, a study to increase stitching efficiency and reduce tooling and manufacturing time was undertaken at NASA Langley Research Center (LaRC) using the Integrated Structural Assembly of Advanced Composites (ISAAC) Facility [5].

The conventional approach of stitching unitized dry preforms includes using a single-sided stitching head that has been designed, and been demonstrated, to reliably connect the stiffener elements to the skin using a modified chain stitch [6]. Because the needle centerlines on this head are separated by about 12 mm on the back side of the preform (at the tooling surface), where the two needles exit the preform and create the loop it is necessary to have a large slot for the needles to enter in the tooling (stitching jig) that is supporting the preform (Fig. 1). Additionally, because it is

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desirable to stitch close to a stiffener flange edge, and the slot for the needles is a large gap, the needles can push the flange material into the needle relief slot, referred to hereafter simply as the slot. To keep material from being pushed into the slot, the conventional single-sided stitching approach uses thin fiberglass material wrapped around the tool to cover the slot (Fig. 1), and results in a stitching jig comprising many small parts that must be individually wrapped and assembled to create the preform stitching jig [7]. Labeled in Fig. 1 are the two needles, the insertion needle that inserts the thread into the preform, and the catcher needle that catches the thread and pulls the loop through the preform to form the modified chain stitch.

To reduce the manufacturing time associated with stitching of the dry preform for stitched composites, there are two approaches that can be considered: 1) reducing the actual stitching time, or 2) reducing the non-stitching time associated with the pre- and post-stitching work. A method to reduce the stitching time for highly integrated stiffened preforms was developed that was shown to reduce the actual stitching time by 25-36% for a typical wing cover depending on the stitch length [8]. The time reduction was achieved by eliminating the cutting of segments at each stiffener junction and "jumping" to the other side of a stiffener to maintain a continuous stitch seam. While this manufacturing technique produced a favorable reduction in the stitching time, a large portion of the manufacturing time associated with stitching the composite preform is expended on the pre- and post-stitching work activities, which conventionally take an order of magnitude longer than the stitching process. Pre-stitching operations include wrapping the jig pieces with fiberglass, assembling the pieces into the complete stitching jig, and assembling the preform components (e.g., stiffeners and skins) into the jig. Post-stitching activities include disassembling the jig after stitching and removing as much of the preform support fiberglass as possible from the stitched preform (the fiberglass wrapping between the stitches and the preform cannot be removed). Presented herein is a new stitching method that will eliminate portions of the pre- and post-stitching operations to further reduce manufacturing time. At the same time, stitching jig tooling is simplified and the amount of necessary tooling reduced, leading to manufacturing cost savings (both capital and recurring) for an assembly line. The structure of the paper is as follows: the developed stitching method will be described, followed by a description on how the method reduces time and tooling, and will finish with concluding remarks.

II. Sideslip Stitching

A new stitching control method was developed that deviates from the conventional method for stitching composite preforms with the single-sided head. In conventional stitching, the stitching direction of a seam is perpendicular to the leading edge of the presser foot as shown in Fig. 2. During stitching, the head continues to move in the seam direction while the needles are in the preform. Therefore, as stitching is performed and the head moves across the preform surface, the needles traverse within the head as controlled by an internal linkage mechanism so that the needles remain in the same location with respect to the preform while they are in the material, as shown in Fig. 3. The action of the needles moving within the head to keep them stationary in position with respect to the preform during the stitching process is termed the needle walk, henceforth referred to simply as “walk.” As the linkage mechanism is controlled by the stitching drive motor, it is not possible to change the walk except to make the walk longer or shorter depending on the stitch length. The walk always follows in a direction parallel to the head motion. As previously mentioned, using two needles in the conventional stitching method determines the size of the slot width at the tool surface (see Fig. 1) that necessitates the use of a thin fiberglass veil material (see Fig. 1) being wrapped around the tooling pieces to support the preform above the slot and to prevent the preform from being pushed into the slot. To eliminate the need for the veil and the many associated small pieces required to assemble the stitching jig, a means to stitch in a much narrower slot was desired. A method termed “sideslip stitching” was developed that enables stitching in a much narrower slot without the need for the supporting veil material.

Given that the two needles used to perform the single-sided stitching are fixed in their relationship to each other, the only way to fit the needles into a narrower groove was to rotate the head so that the needles are rotated with respect to the groove. The maximum possible rotation, leading to the narrowest slot, is when the head is rotated 85° from the conventional orientation as shown in Fig. 4. The resulting seam has the insertion needle and catcher needle stitch portions much closer to each other. In the case of the 85° orientation, the seam maximum width is about 3.5 mm on the outer mold line (OML) as indicated in Fig 5, which is significantly less than the conventional seam maximum width of 16 mm on the OML for this 6-mm thick preform. Due to this significant reduction in seam width, stitching can be accomplished using a much narrower slot (Fig. 6) than is required for conventional stitching. The width at the tool surface for the slots shown in Fig. 6 are only 6-mm wide to accommodate the needles as compared to the conventional stitching slot that is 17-mm wide. Because of this much narrower needle slot, manufacturing time and tooling costs are reduced as discussed in the next section. A description of the stitching process is presented in the remainder of this section.

The control of stitching with the head in this orientation is a decoupled approach similar to the approach used to decouple translation and rotation for highly curved stitching seams [6]. In the case of sideslip stitching, the stitch formation step is decoupled from the movement to the end of the stitch. First, the stitching head carries out one stitch formation cycle with the head moving in the sideslip direction to account for the needle walk that occurs (shown as a green arrow on Fig. 4). Next, the head moves to the beginning of the next stitch where it will commence the next stitch cycle, and so on. When the stitching motion begins on the next stitch, the loop for the stitch just completed finishes formation on the surface of the preform. The decoupled motion results in the sawtooth head path pattern shown in Fig. 5, even though the stitch seam maintains the smooth path. Therefore, each stitch is formed in two head motions. The first head motion is the stitch formation that moves the head in the direction of the walk (green arrow) while the needles perform the stitch operation. The second head motion moves the head from the position after the stitch formation to the beginning of the next stitch on the seam (orange arrow) without the needles being driven in the stitching motion. That is, the needles are stationary within the head during the second head motion. The sideslip stitching method at a few locations during the stitching process is shown in Fig. 7. The pictures in Fig. 7a are from a camera mounted on the stitching head, and the pictures in Fig. 7b are from a stationary front-mounted camera that is oriented looking along the seam length. A demonstration stiffener fabricated using the sideslip approach is shown in various views in Fig. 8 using both 5-mm and 10-mm stitch lengths.

III. Manufacturing Time/Cost Reduction

Manufacturing time and tooling are reduced by using the sideslip stitching approach as compared to the conventional stitching approach. As noted, the sideslip approach requires a much narrower needle slot than the conventional approach, which can be as narrow as 6 mm at the tool surface for the 85° head orientation compared to the conventional slot width of 17 mm at the tool surface. Slot width is important when considering stitching of a stiffener flange, because it is advantageous to stitch as close to the free edge of the flange as possible. Additionally, it is desirable to stitch as close to the blade of the stiffener as possible. For a narrow flange, this can be accomplished with a single seam using the conventional method. Unfortunately, because of the large gap compared to the overlap of the flange material with the tool, it is very easy to push the flange material into the stitching slot with the needles. Therefore, for conventional single-sided stitching, a thin fiberglass veil is wrapped around the stitching jig to support the flange material as shown in Fig. 9a. The advantage of the sideslip seam is that with the small slot width, it is possible to stitch the flange without the need for a support veil for the material as shown in Fig. 9b. The elimination the support veil yields reductions in both manufacturing time and tooling costs.

Manufacturing time is reduced significantly due to the elimination of the support veil for pre- and post-stitching activities. Time reduction in the pre-stitching operations consists of two parts. First, the time required to wrap each segment of the stitching jig is completely eliminated. Second, the presence of the veil necessitates constructing the stitching jig from many pieces so that each piece can be wrapped to ensure all slots are covered, therefore, eliminating the veil eliminates assembly time of the complete jig from the many pieces. In a manufacturing environment, the stitching jig could be an assembly of many pieces that could remain assembled unless the preform cannot be removed from the jig. As a result, the only common part of the pre-stitching process for both conventional and sideslip stitching approaches is that the stiffeners and skin must be inserted into the stitching jig. Time reduction in the post-stitching operations also consists of two parts. First, the stitching jig must be disassembled while at the same time separating the veil from the jig parts in the conventional method. Second, the veil must be cut back as close to the stitch seams as possible to remove as much of the veil as possible from the preform, and this process is labor intensive because it must be done by hand. Because removing the veil under the stitching is not practical, some veil material will be cured with the part.

A penalty of the sideslip stitching approach is that each flange will require two seams, one adjacent to the web and one adjacent to the flange edge. If the stitch length is the same for the conventional and sideslip stitch seams, then the stitching time for the sideslip method will be greater than for the conventional stitching approach. However, while adding another stitching seam in a flange, it is possible to have the same stitch density in the flange by increasing the stitch length of the sideslip stitching as seen in Fig. 10, where the single conventional seam has a 5-mm stitch length and the double sideslip seam has a 10-mm stitch length. Unfortunately, the stitch time for the comparison shown in Fig. 10 will be slightly longer for the sideslip seam due to a doubling of the stiffener jumps required in the approach of Ref. 8. The time savings is a function of the preform being stitched, and herein a wing upper cover will be used to determine the realized time savings associated with the sideslip stitching approach.

The representative wing cover from Ref. 8 is used in this study, and the planform is shown in Fig. 11. The demonstration wing has 10 stringers and 18 ribs as labeled in the figure. Based on the example wing cover, total savings for the pre- and post-stitching is about 27% when using the sideslip stitching versus the conventional stitching, when multi-piece stitching jig tooling is required to be disassembled to remove the stitched preform. However, if the preform can be removed without disassembling the stitching jig tooling, then the time savings is about 40% because of the elimination of tool assembly and disassembly. Stitching time is based upon the approach of Ref. 8 and considering two 10-mm stitch length seams per flange. Because of the penalty of the sideslip stitching requiring two rows of stitching, the time savings is reduced to about 10% of the stitching time, which is less than the 25% savings for a conventional 5-mm stitch length seam utilizing stiffener jumping. As mentioned, the pre- and post-stitching activities are the bulk of the overall process, and the resulting overall savings by combining the sideslip method presented herein and the stiffener jumping method of Ref. 8 is about 28% (when jig disassembly is required) to 41% (when jig disassembly is not required) in total stitching fabrication time, where only 1% of the reduction is contributed by the stiffener jumping method because the pre- and post-stitching activities are significantly more time consuming than the actual stitching activity.

Another benefit of not requiring the veil is a reduction is tool costs because, as mentioned previously, less tooling is required because of fewer stations that require the tooling. A set of stations to conduct stitching operations using a conventional approach to produce a part is shown in Fig. 12a. Because of the significant time required for the pre- and post-stitching operations, a minimum of three sets of stitching jig tooling will be required so that pre-stitching, stitching, and post-stitching operations can be executed simultaneously. For sideslip stitching, only one station will be required, as shown in Fig. 12b, so the stitching jig tooling costs will be 33% less for sideslip stitching, at minimum. Also, the costs associated with having a post-stitching station can be eliminated because the stitched preform can be transferred directly from the stitching jig to the infusion/cure tooling. The reduction in tooling results in a reduced capital cost to start up the manufacturing facility. At the same time, a significant reduction of recurring labor costs is realized by not requiring personnel to wrap the jig, assemble the jig, disassemble and unwrap the jig, and cut the veil from the preform. Additionally, eliminating the requirement for the veil reduces the consumables cost because there is no need to purchase veil material. Therefore, a significant savings in manufacturing costs results by using the sideslip stitching approach.

IV. Concluding Remarks

A method of stitching control dubbed "sideslip stitching" has been presented that will decrease the manufacturing time and costs for producing aerospace structures comprising stitched structures. Time savings obtained in the pre- and post-stitching activities by utilizing this approach are approximately 27% to 40% depending on whether the stitching jig tooling has to be disassembled in order to remove the preform or if the preform can be removed without disassembly, respectively. When combining sideslip stitching with the stiffener jumping approach, the stiffener jumping approach contributes only a marginal increase in overall time savings of about 1% (although it was a 10% time savings in stitching time). Including stiffener jumping makes the overall time savings approximately 28% to 41%. Therefore, a decent decrease in time percentage of stitching, when compared to the entire stitching fabrication process that includes the pre- and post-stitching operations, is a significantly reduced value when presented as a percentage of the entire stitching fabrication process. While the method was presented with aerospace structures in mind, NASA is currently investigating using this approach on the production of stitched wind tunnel fan blades. Indeed, the process is applicable to any large components that can be fabricated using stitched composite structures, including but not limited to shipping containers, truck bodies, railroad cars, wind turbines, civil engineering structures, and many others.

References

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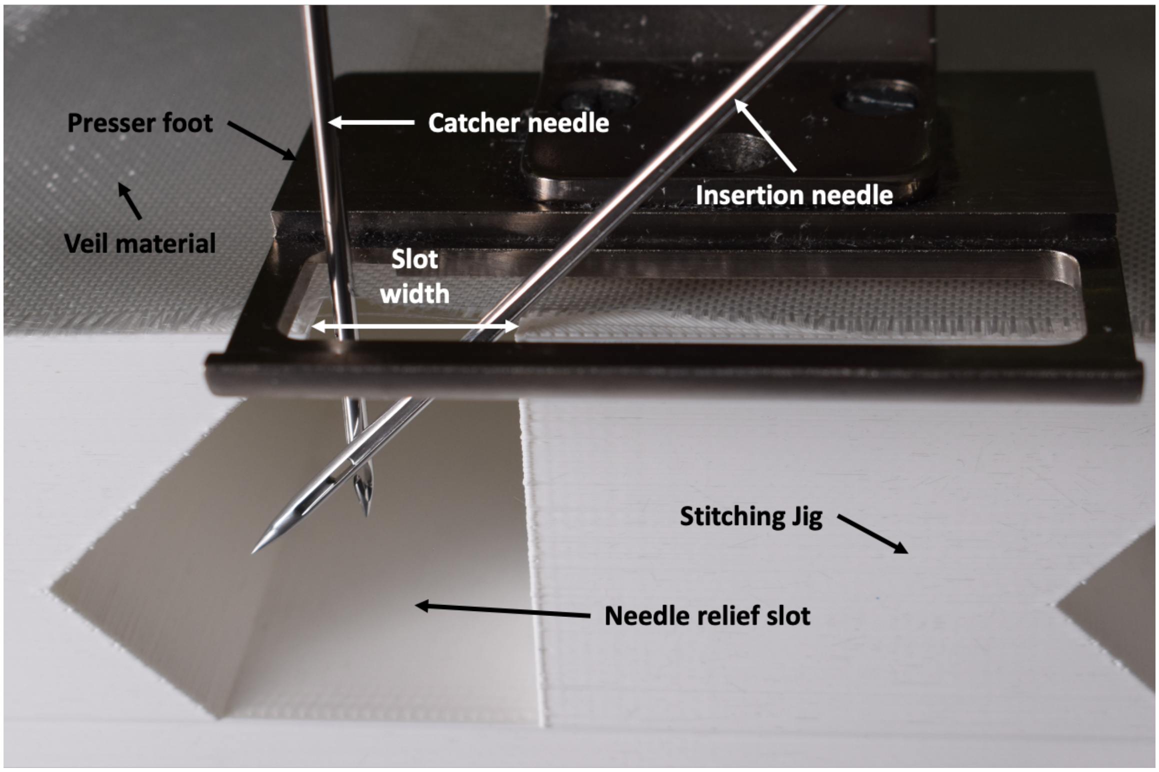


Fig. 1. Conventional single-sided stitching needle slot arrangement and veil material on tool surface.

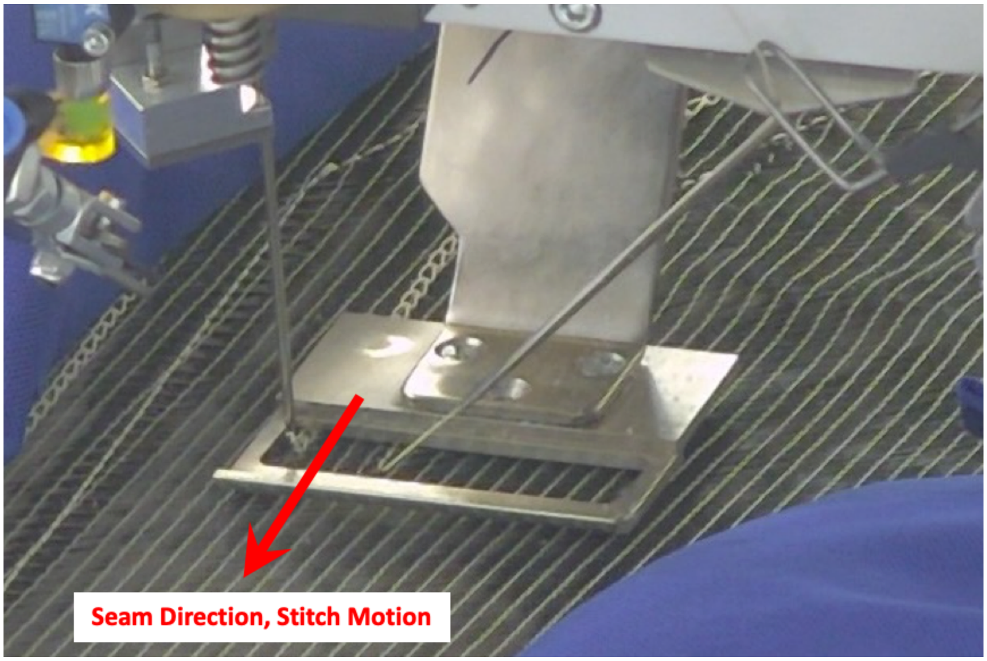
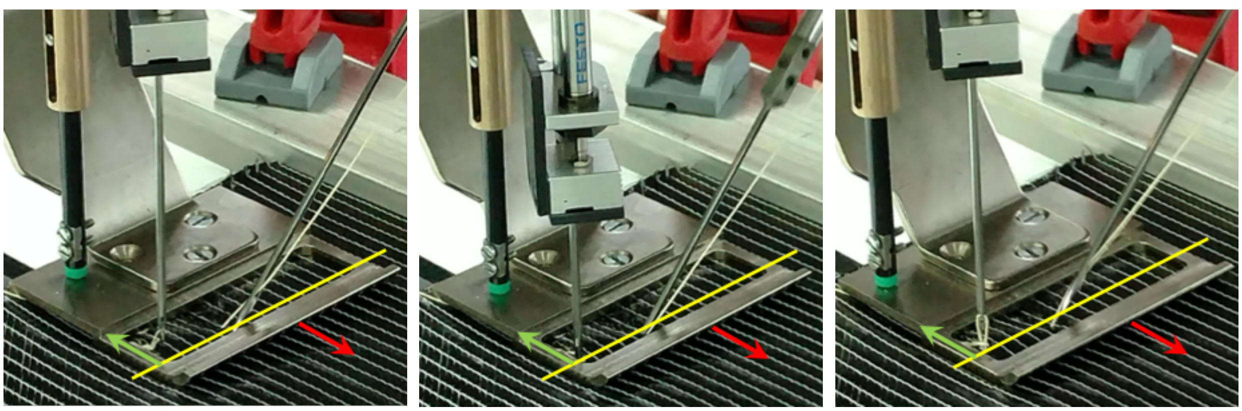


Fig. 2. Conventional single-sided stitching seam orientation (stitching direction).



a) At needle insertion **b) During stitch** **c) At needle retraction**

Fig. 3. Needle walk evidenced by yellow line between needles traversing within presser foot (green arrow) as head moves along material (red arrow).

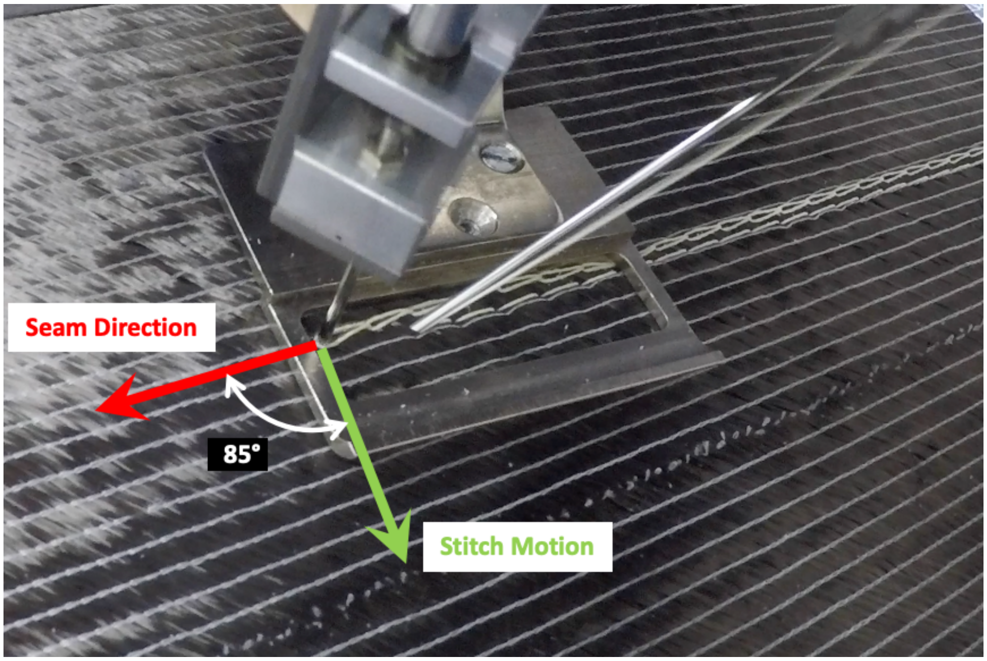


Fig. 4. Sideslip single-sided stitching seam orientation (stitching direction).

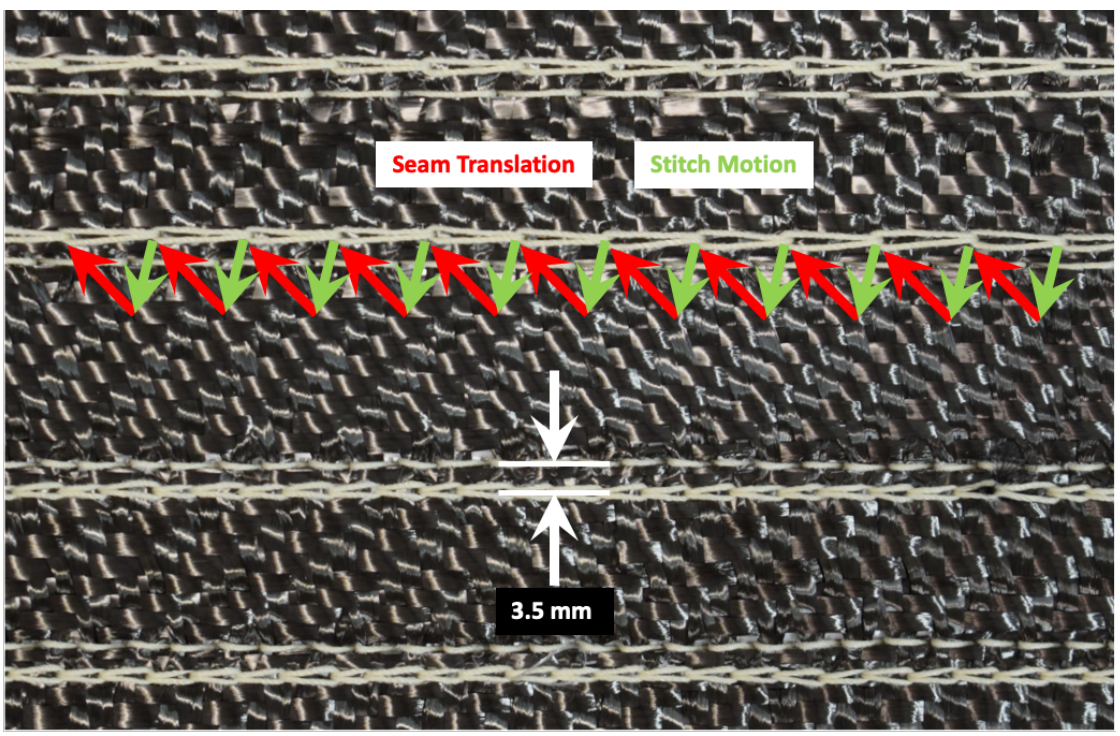


Fig. 5. Sideslip single-sided stitching path definition with green and red arrows showing the head path during in the walk and stitch directions, respectively, and the white arrows showing the seam width.

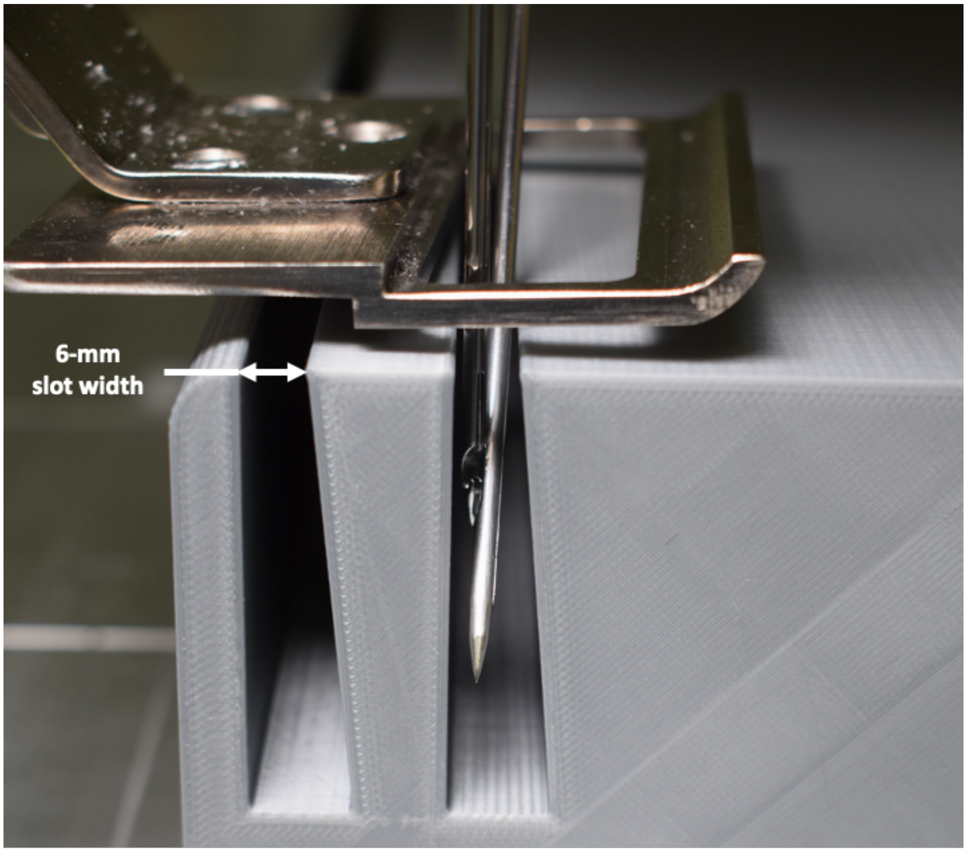
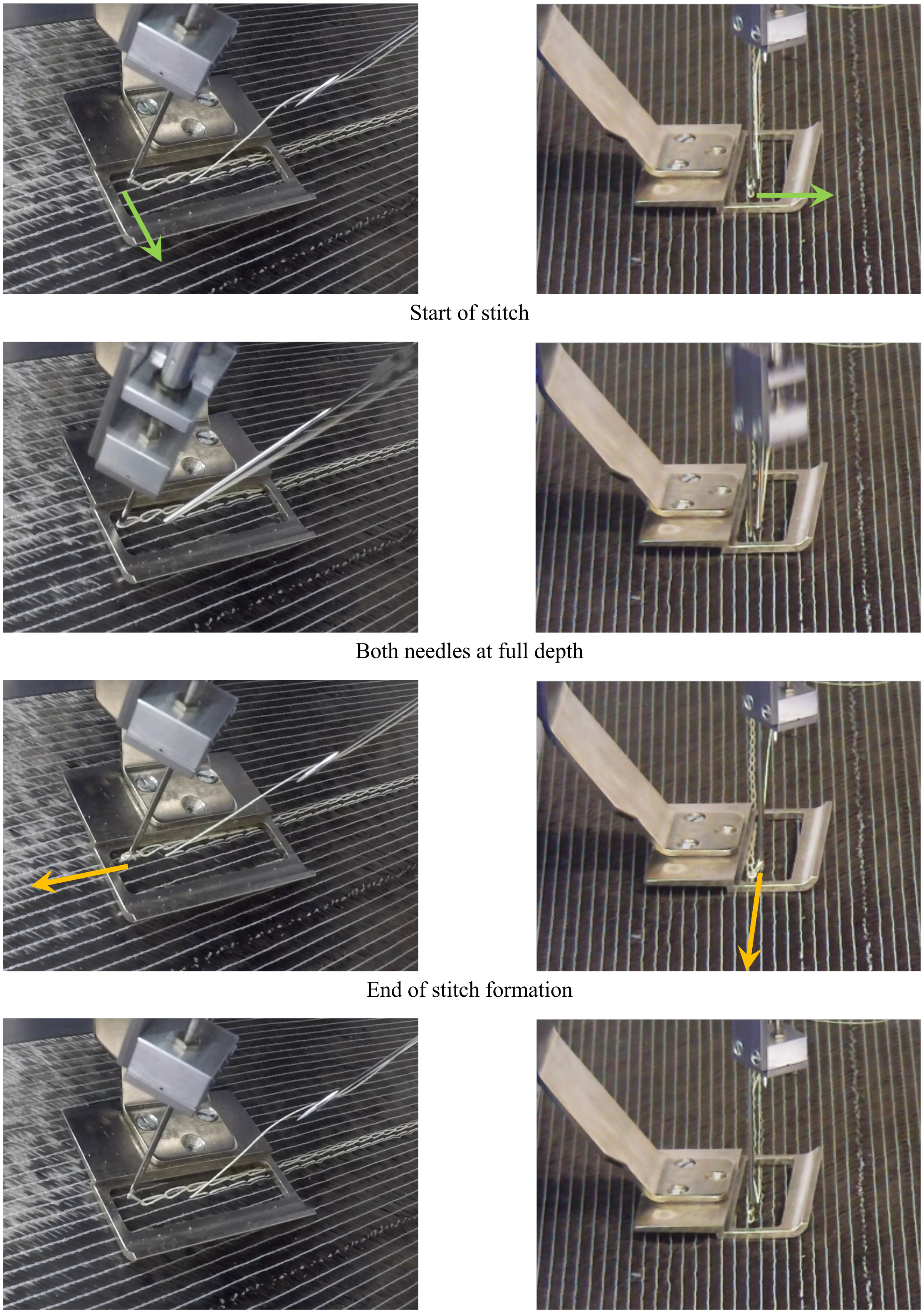


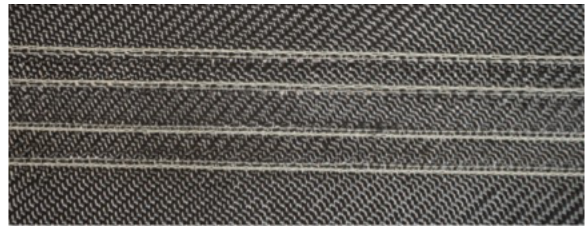
Fig. 6. Sideslip single-sided stitching needle slot arrangement.



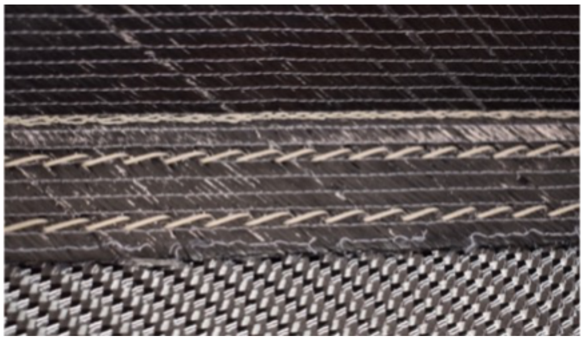
a) Camera mounted on head from side b) Stationary camera from front

Fig. 7. Single-sided stitching sideslip motions.

a) Blade side



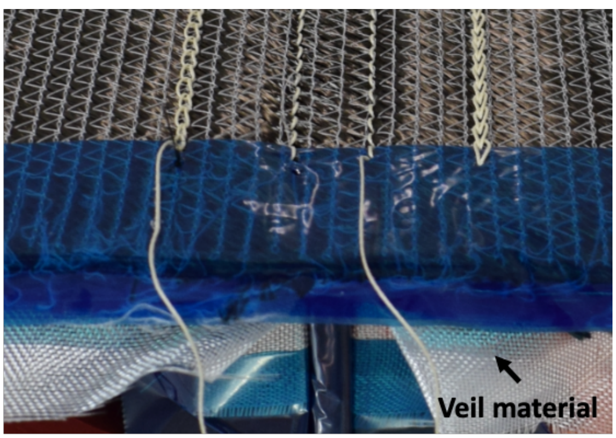
b) Skin side



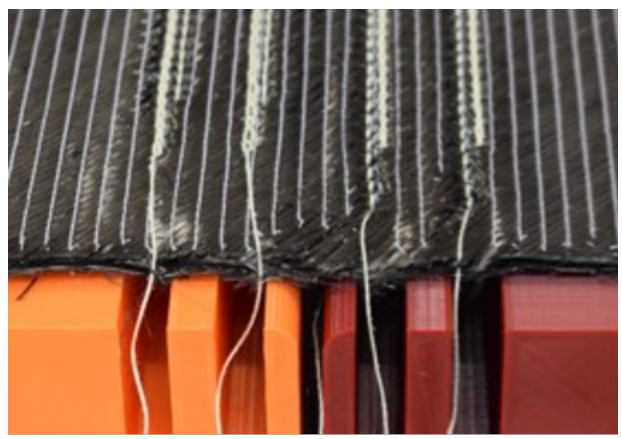
c) 10-mm stitch blade side close-up

d) 5-mm stitch blade side close-up

Fig. 8. Sideslip single-sided stitching stiffener demonstration article.

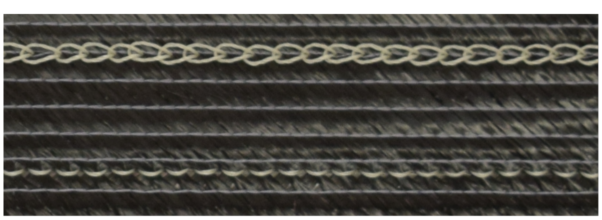


a) Conventional

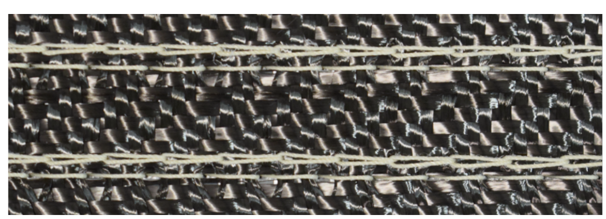


b) Sideslip

Fig. 9. Comparison of conventional and sideslip single-sided stitching setups.



a) 5-mm stitch length conventional seam



b) 10-mm stitch length sideslip seams

Fig. 10. Same stitch density from a single conventional 5-mm stitch seam and two 10-mm sideslip stitch seams.

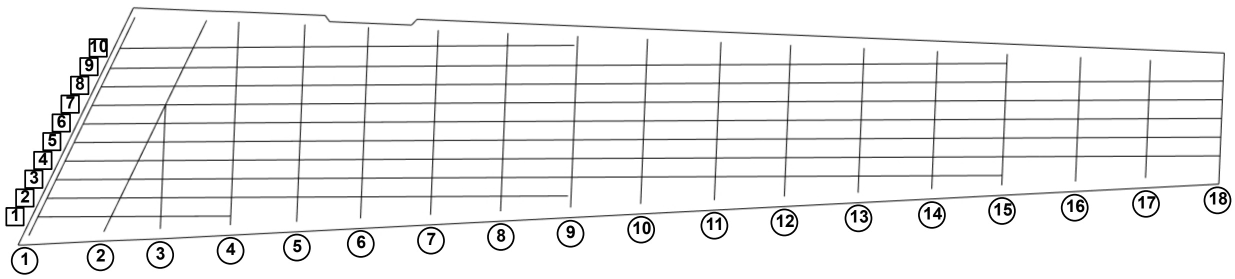


Fig. 11. Stiffener (squared numbers) and rib (circled numbers) pattern for an example wing upper cover.

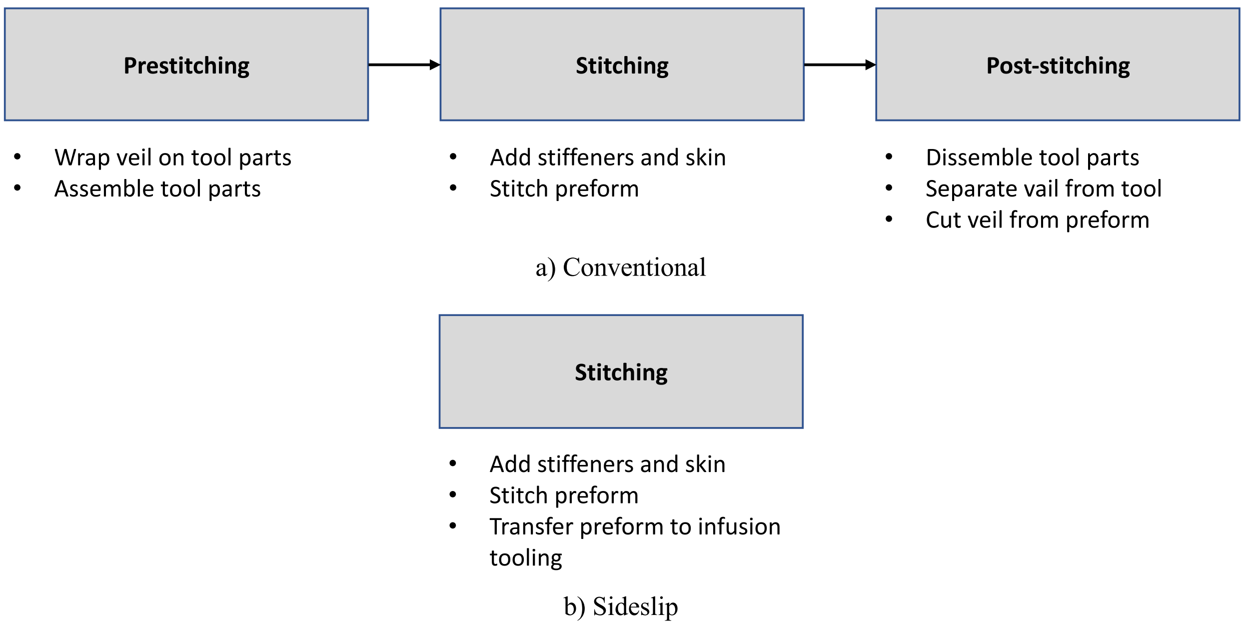


Fig. 12. Comparison of conventional and sideslip single-sided stitching manufacturing stations.