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Designer Solid Shims for Assembly of Advanced Carbon Composite Pre-preg based Aircraft Structures

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ABSTRACT:

A modern combat aircraft uses considerable amount of advanced composite material in structure build for better flight performance, stealth requirement and higher payload. Combat aircrafts made using composite structure require large numbers of custom shims of various thickness and shapes throughout interface surface, which are presently prepared by suit on assembly process to fill gaps measured between sub-structure parts and skin. The scope of study is four plus generation combat aircraft like Indian Light combat aircraft. These gaps arise due to composite raw material characteristics, mould tool and manufacturing process which results in geometry variation. This research has focussed the delta wing integral fuel tank composite structure. However, these research findings can be applied in other wing shapes made by composite part within the scope. The shims, whether liquid or solid, are necessary to eliminate gaps, maintain structural performance and minimize pull-down forces required to bring the aircraft into engineering nominal configuration for aerodynamic efficiency. Customized shims amount to significant delays in production with much of the time being spent in the critical path of the aircraft assembly. In this research work, we present an alternative strategy for the use of designer solid shim, based on redesign of lay-up moulding tool (female type) and shims manufacturing with change in existing manufacturing value stream. The experimented method has reduced the manufacturing cost of wing assembly, shorten the shimming process cycle and improve the assembly efficiency, product quality and performance.

KEYWORDS:

Designer solid shim; Mould; Lay-up; Aircraft assembly; Wing; Fighter aircraft; Carbon composite

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1. Introduction

Advanced composite material is used in aircraft primary structures, secondary and tertiary surfaces. The authors have studied the delta wing structure of four plus generation aircrafts of indigenous design. The wings are the principal components of an aircraft, which are used to generate lift force during flight. An aircraft delta wing is a torsion box structure composed of an upper panel, sub-structure and a lower panel [1-2]. These components are contoured surfaces made of advanced carbon composites of AS4 grade of 914 resin system and have strict predefined assembly tolerances. However, due to composite material characteristics and manufacturing process, the gaps between the mating components are inevitably produced. If the wing components are forcibly assembled using fasteners (e.g. bolts and rivets) with assembly gaps over the design tolerances, profile error and high residual stress will occur, which directly influence the aerodynamic performance and structural strength of the aircraft [3-4]. In aircraft manufacturing, to avoid this situation and to achieve integral joint structure and better load capacity, shims are usually used to compensate for assembly gaps [5-6].

In composite structures, shims are generally required to be inserted in gaps between mated parts prior to drilling operations and subsequent fastener installation. These assembly gap tolerances, above which shims are required, are tighter than the tolerance met in fabrication carbon/epoxy parts. Composite assembly issues have been identified through an analysis of quantitative and qualitative data and information acquired. The composite assembly issues identified in this analysis are organized into the following categories:

(1) The material, design and manufacturing process attributes which impact the "ease of assembly" of carbon/epoxy parts,
(2) Detail parts and fitting supply variability, and
(3) Other operational attributes which impact assembly productivity.

The current method of correcting for tolerance build-up in detail parts and fittings is to shim the resulting gaps when the parts are mated for assembly [7]. Thus, in order to reduce the amount of labour-intensive shimming required during assembly, detail parts and fittings need to be fabricated to closer tolerance, with better accuracy and better control of dimensional variation [8-10].

Liquid shims and solid shims are mainly used in the aircraft assembly process. These shims are used depending on the characters of the gap, for example, liquid shim can only be used to fill gaps up to 0.8mm and solid shim can be used to fill bigger gaps (e.g. more than 0.8mm). Existing techniques [5], using suit on assembly of solid shims between structure and skin surfaces are time consuming and results depend upon the skill of the technician who makes the operation. However, present methods mainly focus on manual shimming method results in excessive time and material waste. The purpose of this study is to develop a concept of designer shim in place of suit on assembly shims. Shimming practice has been a worrying point for the aerospace company in order to maintain product quality, fuel leak proof and structural efficiency. This research has also aimed to study the present design and manufacturing issues composite structure shimming process. It is learned from people experience and subject specific literature survey that there are many possible areas to look for solution but the research work has focused towards designer solid shim concept.

The problem with shimming process is that it is time consuming and subject to quality issues. The liquid shimming process itself can consume over 60 manufacturing hours per aircraft since it is completely manual. Initially, technician applies the liquid shim to the sub-structure and manually spread it with plastic sticks to cover the surface. This present process is cumbersome and required extensive rework in many cases. The research work objective is to derive a method, which shall replace the existing method of shimming. There can be many solutions to the problem of shimming but aim here is to research for solution which is cost effective and without much disturbance in existing manufacturing value chain, new solution can be implemented. The research arrives at types of designer solid shims required for specific composite part. These designer shims shall be supplied along with corresponding parts to assembly shop floor. It has been proved through manufacturing of representative C section part of complex contour shown in Fig. 2 of existing delta wing.

2. Material and methods

Composites parts and solid shims are manufactured with carbon pre-impregnated Unidirectional (UD) fibre of AS4 grade with epoxy resin. Lay-up of ply is carried out as per standard manufacturing process [11-13] of 0°, 45° and 90° ply orientation. Lay-up stack is autoclave cured at 177°C temperature with standard cure cycles. The present manufacturing process and solid shim requirement is shown in Fig. 3. One-layer carbon UD pre-preg thickness is 0.15mm as per manufacturer process sheet. Layup stack with existing process is shown in Fig. 4. Composite parts and solid shims are manufactured with same process. The relative data on cost input of various factors are shown in Fig. 1. The data is referenced from method cost data sheet for a C section contour composite part. The purpose is to emphasise the importance of assembly cycle time reduction, which will have effect on productivity. The study is focussed on only the use of female moulding tool and C section spar which is manufactured on female type moulding tool as shown in Fig. 2. The moulding tool does not have tooling hole provision, co-ordinated with assembly jig. Skin is manufactured on a tool (contoured open tool) where outer aerodynamic surface is tool surface. The inner surface of the skin is not controlled, which is in contact with top and bottom flange of spar. Caul plate is usually used on inner surface to control contour growth.

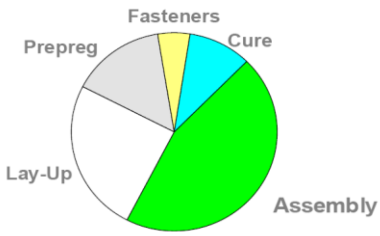

Fig. 1: Relative cost distribution of Tejas composite wing assembly

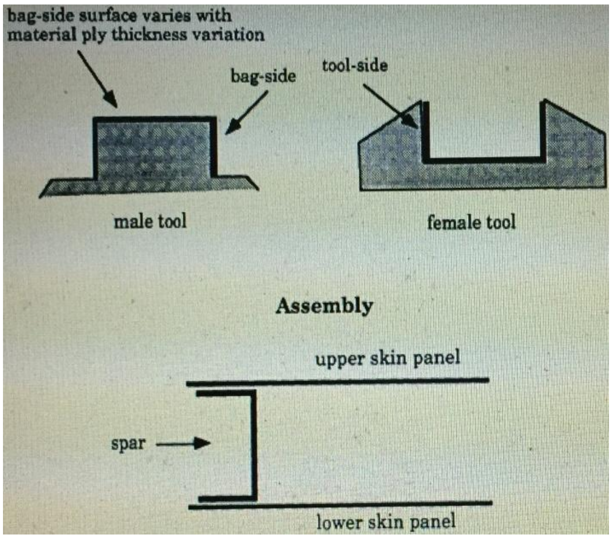

Fig. 2: Male vs. Female tool and spar assembly process

Spar-1 is manufactured with newly designed mould tool coordinated with assembly jig hole as shown in Fig. 3. However earlier mould tool Spar-2 is shown without tooling hole. Both parts are manufactured with female type moulding tool where a greater degree of geometrical control is obtained in process. Spars are of C section wing parts. Wing structure has multi spar construction. These spars are having fuel transfer and vent holes. Spar is manufactured through pre-preg layup and autoclave curing at 177°C temperature. Pre-preg material high young's Modulus is of AS4 grade 914 epoxy resin, 40% by weight. Spars are laid on female type mould tool where outer surface is controlled however it is observed that uneven surface is obtained post autoclave curing due to inherent composite nature. Coordinate Measuring Machine (CMM) reading on two spars are carried out for study purpose and are shown in Tables 4 and 5 accordingly. There is a considerable variation of part geometry in the range of 0.5 - 2.0mm. When C section spars are assembled with lower and upper panels made out of UD composite tape, gaps are observed at this stage. The contour of spar-1 and spar-2 are measured by CMM and placed at table. Spars are made by bidirectional composite material and autoclave cured. Detailed ply direction and stack is not presented on confidentiality grounds.

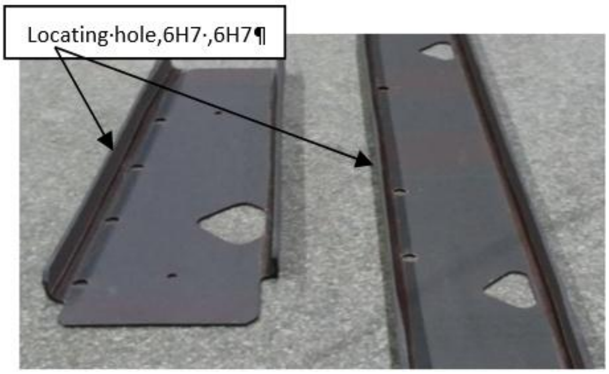

Fig. 3: Composite spar manufactured with newly designed tool

Fig. 4 and Fig. 8 show that how the existing process is taking place and this is just to compare with the modified process which are shown in Fig. 5 and Fig. 9. Composite parts layup stack and bagging process is typical in nature and shown in Fig. 4. The process shown below is followed to manufacture composite parts and solid shims with AS4 grade UD carbon pre-preg and de-bulking was followed after each four layers. This layup sequence is a standard one followed during composite parts manufacturing process. Bagging material is not reusable one. There is reusable bagging material but that is not explained in this paper.

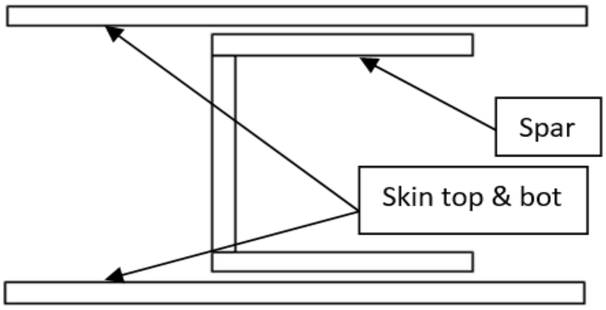

Fig. 4: Existing process

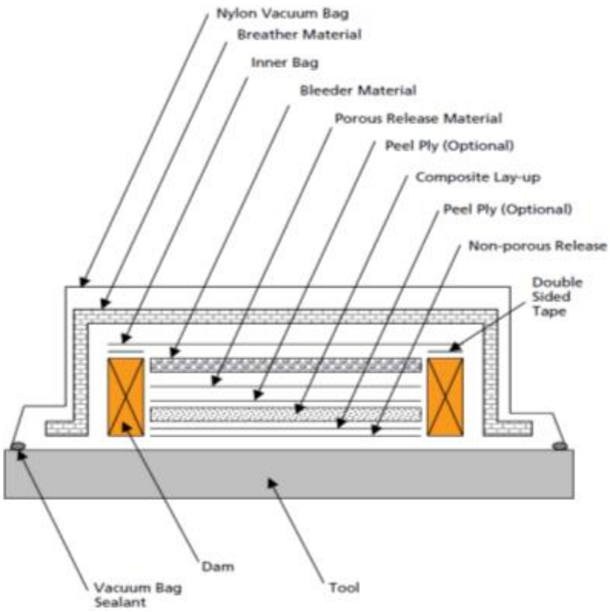

Fig. 5: Composite part layup process

Existing layup mould tool available at shop floor was selected for study work. The tool contour was measured by CMM and it was reworked using CAD data for tooling hole provision, trim line, assembly NMG marking and contour measurement details at various points. These points are marked on newly designed tool-female type shown in Fig. 6. Existing spar tool was selected and modified as per research objective and findings. Newly designed tool, as shown in Fig. 7, is marked for interface area, and sample composite part has been produced.

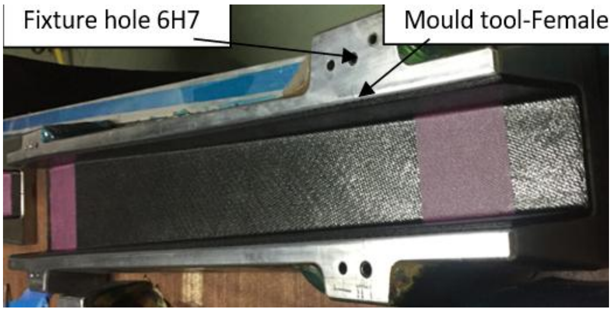

Fig. 6: Composite part lay-up in newly designed tool

Fig. 7: New mould tool with 6H7 mm tooling hole

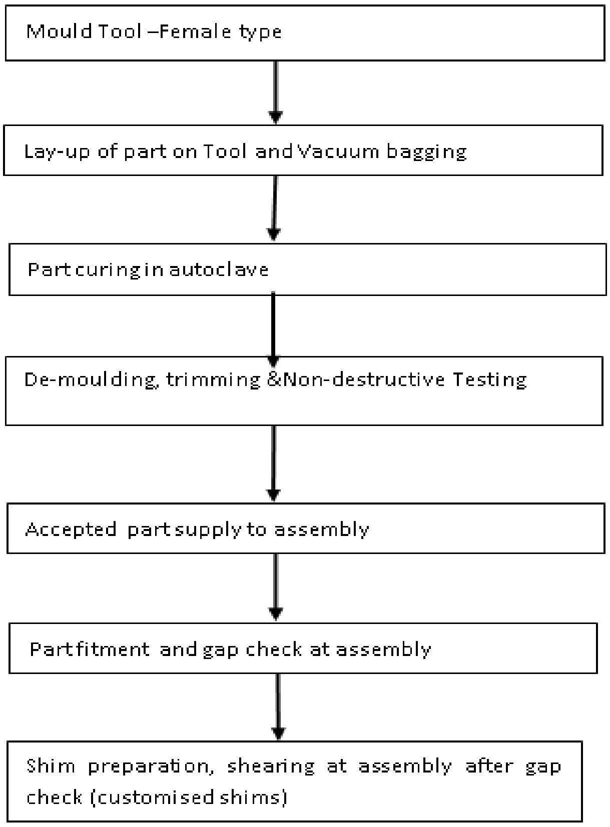

Fig. 8: Flow chart of existing composite part manufacturing

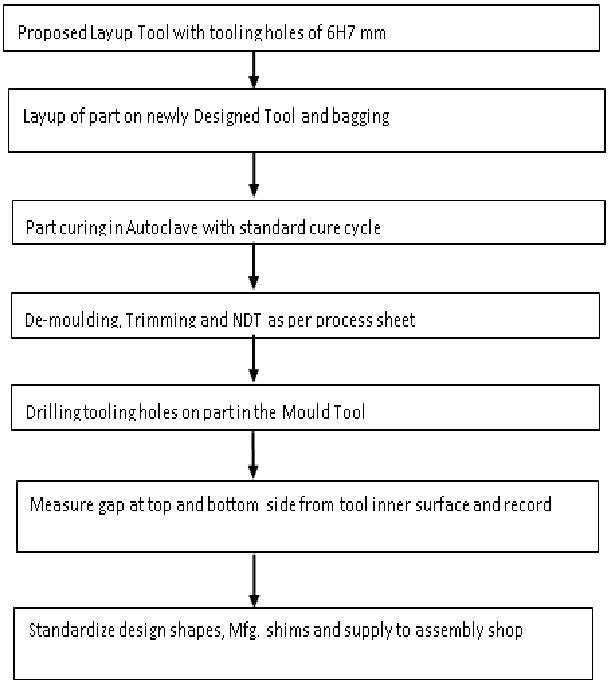

Fig. 9: Flow chart of newly designed composite part manufacturing

3. Results and discussion

Two C section composite spars were manufactured with newly designed layup tools and gap data as per Fig. 10 are reported in Table 1. Based on contour and gap measured with new tool after autoclave curing as reported in Tables 2 and 3, solid shim thickness is calculated (see Table 4). The composite laminated designer solid shims are manufactured as per the same manufacturing process followed for the composite parts. Table 5 summarises the designer solid shims (x1 off) required in terms of length, width and thickness. Solid shims post manufacturing are trimmed and supplied along with the parts to assembly shop. Fig 11 shows that skin made with advanced composite is shimmed (patches on yellow colour skin).

Table 1: Gap measured for new design

Over spar length (mm)	Spar 1 gap (mm)		Spar 2 gap (mm)	
	Bottom skin	Top skin	Bottom skin	Top skin
0 - 150	0.9	1.2	1.4	1.0
150 - 300	1.3	1.5	0.9	1.0
300 - trim line	1.4	1.2	1.5	1.0
			1.8	1.1

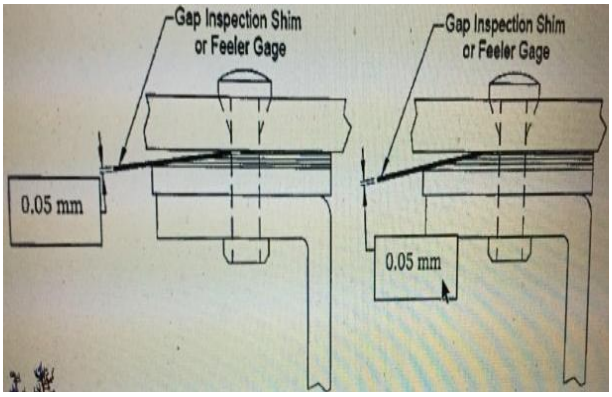

Fig. 10: Gap measurement method at spar to skin interface

Table 2: Spar - 1 contour measurements in mm by CMM on eight points along flange

Point No	Absolute X	Absolute Y	Absolute Z	Measured gap	Deviation on contour
1	6770	-1079.95	312	1.93	+1.07
2	6770	-1129.9	302	2.03	+0.97
3	6770	-1179	292	2.03	+0.97
4	6770	-1229	282	2.05	+0.99
5	6770	-1279	272	1.95	+1.07
6	6770	-1329	262	1.75	+1.07
7	6770	-1379	251	1.75	+1.07
8	6770	-1429	242	1.84	+1.15

Table 3: Spar -2 contour measurements in mm by CMM on eight points along flange

Point No	Absolute X	Absolute Y	Absolute Z	Measured gap	Deviation on contour
1	9100	-3470	408	0.9	+0
2	9100	-3520	398	1.03	+0.5
3	9100	-3570	388	1.53	+0.97
4	9100	-3620	378	2.05	+1
5	9100	-3670	368	0.95	+0
6	9100	-3720	358	1.15	+0.5
7	9100	-3770	348	1.25	+1
8	9100	-3820	338	1.64	+1.2

Table 4: Solid shim thicknesses after gap measurement

Gap measured (mm)	Solid shim required (mm)	No. of plies
0.9	0.6	4
1.0	0.9	6
1.1	0.9	6
1.2	0.9	6
1.3	1.2	8
1.4	1.2	8
1.5	1.2	8
1.8	1.5	10

Table 5: Designer shims dimensions

Spar 1 (mm)		Spar 2 (mm)	
Bottom skin	Top skin	Bottom skin	Top skin
150×58×0.9	150×58×0.6	150×58×0.9	150×58×1.5
150×58×0.9	150×58×0.9	150×58×1.2	150×58×0.9

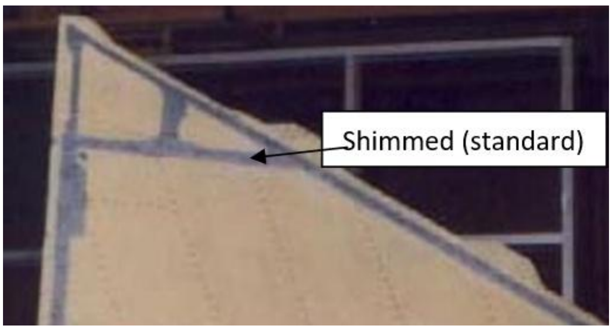

Fig. 11: Shimming process carried out on composite skin with new mould tool using research experiment

4. Conclusion

Solid and liquid shims are generally used at the interface surface of composite parts. Liquid shim is prepared with Hysol 931 system consisting base and hardeners and aluminium powder. It is mixed in the ration of 100:40:50 by weight. Liquid shim is applied if gap is less than 0.8mm. Solid shims manufactured by carbon pre-preg material, laid in 0°, 45° and 90° orientation. The research has come out with a solution to eliminate presently in use customized shimming concept. The research has successfully demonstrated for designer shim concept. Solid shims requirement evolves at assembly stage of structure build. The outcome of research work is a new layup mould tool design. Lay-up with AS4 grade carbon material is carried out on new tool. Cured part has been located in tool and subsequently gaps have been measured in tool itself. This has facilitated to know the requirement of shims. This provides shop floor enough time to manufacture solid shims and supply along with parts. This has reduced 30% assembly time and lead to a better-quality product.

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