Process Development for the In-house Manufacture of Aircraft Cabin and Cargo Composite Panels

Michael A. Saliba and Ian Attard
Faculty of Engineering, University of Malta
Msida, Malta
e-mail: michael.saliba@um.edu.mt

***Abstract*—Mishandling of luggage while it is being loaded into the aircraft cargo compartments, as well as wear and tear of the various panels in the cabin and cargo compartments can result in the aircraft being grounded, with serious loss of revenue to the operator. Delays can be considerable, since ready-made replacement panels from the supplier can take days to arrive at their final destination, and due to the very high prices of these panels and the very large variety which exist it is not economically feasible to stock the panels. This work explores the feasibility of manufacturing replacement cargo liner panels, and cabin and cargo floor panels, in-house and on demand in the aircraft maintenance facility. The panels are grouped into part families, and reconfigurable specialized jigs are designed for the manufacture of panels within each family. A feasibility study shows that in addition to avoiding delays, this strategy can result in cost savings of up to 30% for panel replacement.**

Keywords-aircraft maintenance; group technology; panels; GFRP; reconfigurable manufacturing

I. INTRODUCTION

In the aviation industry, maintenance, repair and overhaul (MRO) facilities face a lot of difficulty in supplying their customers with just in time material spares during very tight layover schedules, such as experienced during C Checks, which can be as short as three days on relatively new aircraft. This schedule must be met by MRO facilities even in the presence of logistical problems, e.g. in the case of aircraft maintenance facilities that are not within easy transportation access by the supplier. This problem is accentuated by the fact that replacement parts can be bulky, hence air freight becomes a problem due to the limited space available on commercial aircraft. Shipping by land or sea is often problematic due to time limitations. Shipping by any means also incurs the risk of parts damage, resulting in further delay to the aircraft repair. The provision of spares via long distance transport incurs additional problems due to costs, which in addition to the transport costs themselves include charges due to inventory holding, administration, customs, insurance, and handling and packaging [1].

In the light of the above, the objective of this work is to report on a study that has been carried out to investigate the feasibility of manufacturing composite cabin and cargo floor panels and cargo liners, as per the requirements of the aircraft manufacturer, within an MRO for their immediate use on an aircraft concurrently undergoing maintenance within the same facility. The envisaged scenario is that when a damaged panel is discovered on an aircraft during a maintenance check, a replacement panel is promptly manufactured in house and fitted to the aircraft before the aircraft leaves the hangar, without causing delays. This study is important because if these panels are found damaged beyond Aircraft Maintenance Manual (AMM) limits, the aircraft would be grounded, or at best, if the damaged panel is in the cargo hold, the aircraft can be dispatched with the affected cargo hold blocked, i.e. cannot be used. Operating with a blocked cargo hold is normally not acceptable for an operator as this would greatly affect normal revenue flight operations. Furthermore, another potential problem associated with shipping these panels is that they are commonly offloaded from the cargo hold of an aircraft due their bulky nature to make way for other priority goods, hence causing a delay for aircraft delivery after maintenance.

II. AIRCRAFT COMPOSITE MATERIALS AND THEIR MANUFACTURE

The main feature of fibre reinforced composite materials is that their properties are superior to those of either of the constituent materials. One of the most important mechanical properties in the application of laminates, especially those employed in the aircraft cargo compartments, is the impact resistance. In this respect, fibre reinforced composites typically provide high impact resistance at a low weight expense [2]. Glass-fibre-reinforced polymers (GFRP) can use various glass types, and require chemical treatment of the glass before usage inside polymers [3]. The machining of fibre reinforced composite materials can present major challenges, including discontinuity of the fibre affecting part performance; exposure of the fibres to chemicals and moisture; and material degradation if the curing temperature of the resin binder is exceeded [4]. It is also usually fairly difficult to obtain a smooth cut edge with composites.

Aircraft cargo and cabin compartments typically use sandwich panel construction, wherein a laminate of fibre reinforced material is used at the top and bottom, and the two laminate sheets are kept separated by the core material, thus maximizing stiffness with the lowest possible weight penalty. Cargo lining panels fall under three main classifications according to the position they are installed in, namely ceiling panels; sidewall panels and partition walls; and decompression panels. These provide for fire protection, component protection, and pressure compensation. Cabin

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and cargo floor panels in addition provide a means of transferring the load carried by them to the aircraft primary structure. To this end, metal inserts are used at fastener locations to avoid the risk of fastener hole damage.

Typical processes used in the manufacturing of sandwich panels and of cargo lining laminates are drilling and cutting. Drilling is used to create holes in the laminates for insertion of fasteners, and for starting holes for routing operations. A large variety of drill bits can be used. In cutting, the cutting speed should be the highest that the material can sustain to obtain the best results. Circular saws, in combination with a good vacuum system, can be used to cut fiberglass panels. Non-conventional machining technologies such as water jet cutting or laser machining can also be used [5], [6]. It is noted that adequate safety precautions need to be taken during machining of GFRP [3]. In the case of both cargo lining and cabin/floor sandwich panels, other important manufacturing processes are routing and edge filling [4].

III. PANEL FAMILIES

A. *Group Technology*

In manufacturing, the necessity to simplify the routing of parts between different machines to reduce transportation costs gave rise to the concepts that inspired the theory of management named *group technology* (GT) [7]. This is an engineering and manufacturing methodology that groups parts together based on their similarities (geometrical and/or manufacturing processes) in order to achieve economies of scale in jobbing and batch production equivalent to that of mass production [8]. Parts can be grouped into *families* based on either visual inspection (intuitive, experience-based grouping); or on design classification (through classification of part drawings according to similarities in form or in production requirements); or on production flow analysis (using similarities in the production route sheets of the parts) (e.g. [9]). In the present work, GT was applied to group the aircraft panels into families to facilitate their manufacture.

B. *Family Assignment Process*

The aircraft type chosen as the main focus of this investigation was the Airbus A321. The panels studied were the cabin compartment floor panels, the cargo compartment lining panels, and the cargo compartment floor panels. The manufacturing of these three categories of panels follows a similar process, except that in the case of floor panels an additional process is required (potting of the insert). Thus the main focus for panel assignment into families was not on the manufacturing process used, but rather on the features, even though the former was also considered, when appropriate.

The first step in the grouping of panels into families was to identify the panels to be studied. For the identification process, two main documents were used, since no single document describes all the parts for both structural and non-structural components. For the cargo liner panels (non-structural), the Airbus A321 Illustrated Parts Catalogue (IPC) was used to identify the panel part numbers and their position in the aircraft. For the cabin and cargo floor panels (structural), the Airbus A321 Structural Repair Manual (SRM) was used to identify the drawings in which the floor structure panels are present. After obtaining the parts list from the drawings of the floor structures from the Airbus Online Support Website [10], all the parts were identified together with their respective positions on the Aircraft.

The list of panels (103 in all) was compiled. The panel drawings were then physically analyzed for all common features, and a list of these features was compiled. A correlation matrix was constructed from the data obtained, showing all the combinations of features to panels.

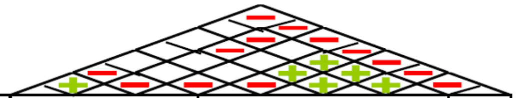
Due to the large variety and the large number of panels in subject, the panels were assigned to families in two phases. First, external dimensions only were considered, resulting in six major panel families as shown in Table I. The internal features (e.g. hole features) were then considered for the final family classification. The final grouping resulted in a total of fourteen families, six of which shown in Table II.

TABLE I. LIST OF PRELIMINARY FAMILIES

Family	**Number of Family Members**	**Family Characteristic**	
		Length Range	*Width Range*
1	10	2592 to 3093mm	1444 to 1670mm
2	18	1318 to 1992mm	649.5 to 903mm
3	25	775 to 1203mm	375 to 640mm
4	30	1595 to 2814mm	375 to 592mm
5	11	420 to 642.5mm	220 to 528.5mm
6	9	1036 to 1121mm	649.5 to 1036mm

TABLE II. EXTRACT FROM LIST OF FINAL FAMILIES

Original Family	**New Family**	**Number of Family Members**	**Predominant Feature For Family Assignment**
1	1	10	Decompression Cut-out 700x380mm
2	2.1	9	Hole 12mm from edge – D=10mm
	2.2	9	Hole 13mm from edge – D=15mm and Others
3	3.1	5	Hole 12mm from edge – D=10mm
	3.2	12	Hole 13mm from edge – D=15mm
	3.3	8	Hole 13mm from edge – D=15mm and Others



Demand Quality Deployment Chart				Quality Element Chart: 1st Level	Ergonomics			Manufacturing				Cost
				2nd Level	Portability			Material		Methods		Cost
				3rd Level	Dims	Shape	Weight	Hard	Crystal Structure	Precision	Finish	Cost
Customer Verbations	Re-worded Data - 1st Level	Means - 2nd Level	3rd Level	IFC \ DOI	↓	↓	↓	↑	↑	↑	↑	↓
Must be east to carry from the store to the work place	Ease of Transport	Easy to Hold	Small	0.05	◎	◎	◎	△	△	△	△	△
			Light	0.1	◎	△	◎	△	△	△	△	○
Easy to use	Does not require training to use	Poka-Yoke	Alignment Method	0.05	△	◎	△	○	△	◎	◎	◎
			Anchorage Method	0.05	△	◎	△	○	△	○	○	◎
	Clear Marking	Assign Tool Part Number	Marking	0.05	△	○	△	◎	○	△	△	△
	Easy to move from one place to another (on the workpiece)	Easy to engage/dis engage	Easy to Engage	0.05	△	◎	△	○	○	◎	◎	◎
			Easy to Disngage	0.05	△	◎	△	△	△	◎	◎	◎
	Does not require special tooling to assemble tool parts	Use of inserts for 12mm and 13mm	Ease of Assembly	0.05	△	◎	△	○	△	◎	◎	△
			Repeatability in Assembly	0.15	△	◎	△	○	△	◎	◎	○
Long Lasting	Durable	Hard and Tough	Choice of Material	0.05	△	○	◎	◎	◎	◎	○	◎
		Replace-ment of parts	Use of Inserts	0.1	○	◎	○	◎	○	◎	○	○
		Chemically Stable	Does not rust	0.05	△	△	△	○	◎	△	○	◎
Cheap	Produce	Easy to Manufac-ture Locally	Cost	0.1	△	○	○	◎	◎	◎	○	◎
	Maintain	Easy to Clean	Cleanable	0.1	△	◎	○	△	○	△	◎	△
HOW MUCH					max 76mm x 76mm x 51mm	Rect	<1.0kg	>50HRC	Har-dened	±0.1mm	≥1µm	max €200
RELATIVE IMPORTANCE					7	18	9	12	9	16	15	14
RANK					8	1	6	5	6	2	3	4

LEGEND

IFC	IMPORTANCE FOR CUSTOMER
DOI	DIRECTION OF IMPROVEMENT
↑	INCREASE RESULTS IN IMPROVEMENT
↓	DECREASE RESULTS IN IMPROVEMENT
◎	STRONG CORRELATION (9 POINTS)
○	AVERAGE CORRELATION (3 POINTS)
△	LOW OR NO CORRELATION (1 POINT)

Figure 1. Quality Function Deployment Chart for the 12mm to 13.5mm from edge hole drilling jig.

IV. Jigs Designed

A. *Overview*

This section presents the design methods and criteria used for the design of the jigs which could be employed as an aid to the manufacture of the aircraft composite panels being studied. For ease of classification, the jigs designed were categorized as follows: frames to provide effective fixture of the panels (see section IV *C*); internal jigs for accurate routing and drilling of common features (see section IV *D*); and external jigs to provide accurate hole drilling, using the frame as fixing point (see section IV *E*).

B. *Quality Function Deployment and Morphological Chart*

A quality function deployment (QFD) matrix was constructed for each jig, and an example is shown in Fig. 1. These consisted of: construction of a demanded quality deployment chart (left portion of the QFD); construction of a quality elements deployment chart (top portion of the QFD); and final interview with customer to assign measurable attributes to the demanded quality elements (3rd level) characteristics (labelled "How Much" in QFD).

A morphological chart was drawn up for each jig. For the given example, four independent parameters were identified: insert assembly, poka-yoke approach, jig alignment, and jig anchoring. The resultant chart is shown in Fig. 2.

C. *Frames for Panel Containment and Jig Fixture*

A framing system was designed for the fixture of the sized blank panels to allow use of the jigs to produce the internal details. The working principle of the frame is similar to that of a vice. The frame, mounted on a table, provides a constraint to the panel in one planar degree of freedom and provides a fixing point for the smaller jigs on both sides. When work is finished on the first two sides, the panel is rotated by 90° to perform work on the other two sides. The fixture is provided by two L-sections, one fixed, and one movable on a guide. The dimensions of these sections were chosen such that routing and drilling of the new panel can be performed by using the old (U/S) panel as a template.

The clamping force is maintained by the use of a pair of precisely machined spacers, fixed to the edges of the frames to provide for the exact distance between the frames. Fixture of these spacers is provided using two dowels on each side.

D. Internal Jigs for Accurate Routing and Hole Drilling on Common Features

Since it was decided to use the old (U/S) panel as a template, and a suitable jig for this operation was found 'off the shelf', no jig for the routing operation was designed. The jig chosen can be mounted to a hand held pneumatic router. For the internal routed features requiring hole drilling around them, jigs were designed which can sit tightly in the routed hole, having suitable guides for accurate hole drilling. The concept of such a jig is illustrated in Fig. 3. Other jigs were designed in a similar manner.

		Components				
		A	B	C	D	E
Parameters	Assembly of Inserts	Interference	Bolt and Nut	Screws - Dome	Screws - Countersunk	Spring loaded ball - Rachet type
	Poka - Yoke Assembly of Insert	Non Symmetric Fastening of Insert	Shape of Insert for Single Possible Fit	Clear Alignment Marking Features	-	-
	Alignment of jig on panel	Slot With Eye Hole	Slot With Dowels	Use of US Panel as Template for Location	Slot and Jig traced on wooden Template	-
	Anchor	Human Hand	Interference	Screws - Sideclamp	Sliding Dowels	-

Figure 2. Morphological Chart for the 12mm to 13.5mm from edge hole drilling jig.

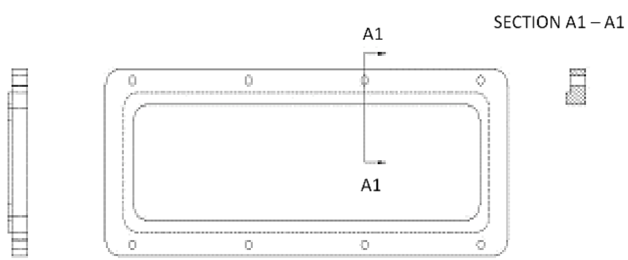


Figure 3. Jig design to produce holes in maintenance cut-out – 472mm by 140mm.

E. External Jigs for Accurate Hole Drilling on the Perimeter of Panels

The external jigs are used in conjunction with the frame described in subsection IV *C*. Hence, a common feature of these jigs is a groove that can mate with the L-section within the frame with a transition fit. For ease of jig use, the critical groove width was used only at the edges of the jig, with the rest of the length having a looser, more accommodating fit.

F. Design for Jig Manufacturing and Assembly

Various provisions were made for the ease of manufacturing of both the jig and the inserts, and for their assembly and dis-assembly. For example in the jig pocket, all the corners are filleted, while in the male inserts the mating corners are chamfered. Moreover, it was agreed with the customer that a finish of 1μm or better would be sufficient, hence milling can be used without the requirement of other processes for finishing, except deburring by hand using sand paper to remove any sharp edges. To allow for fast assembly and dismantling, the fastener holes for the countersunk screws should only have thread on the bottommost 5 mm. A channel on the bottom side provides easy location in the frame for both alignment and location of the panels, and the depth of the channel allows for use of the jig with all the panel thicknesses required.

V. MANUFACTURING OF SPECIMENS

The manufacturing process that was designed and followed for the sample manufacturing stage was manual, where most of the time hand tools were used for the sample preparation. The process flow is shown in Fig. 4.

The raw panels for the production of the samples were provided by M. C. Gill Corporation [11]. These were first identified by their label, and the layout of the test specimen was decided to minimize material waste. A major advantage of the sandwich panel material is that the properties are isotropic, due to the weaving direction of the laminates. Hence no special consideration has to be taken to the flight direction of the panel, and the usage of the panel raw material can be further optimized.

The manufacturing process of the holes and inserts was carried out as per specifications of the panel manufacturer. It is noted that process qualification is required to install the in-house manufactured cabin or cargo floor panels on to the aircraft. Upon meeting the quality criteria (in this case, the specified pullout force of the inserts), a certificate of qualification can be issued for the in-house manufacturing of the composite panels. The certification issued covers panels in a wide range of Airbus aircraft.

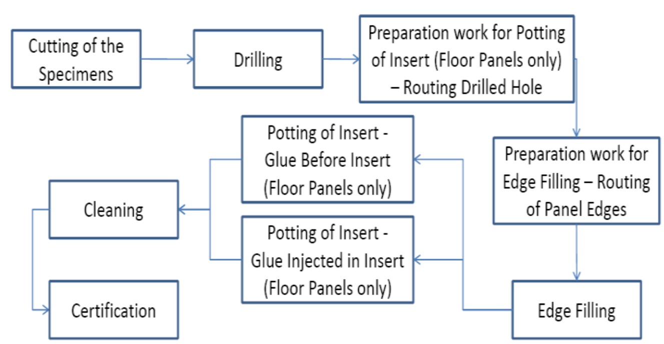


Figure 4. The designed manufacturing process flow.

VI. FEASIBILITY STUDY

For the feasibility analysis, a panel from each of the fourteen families was investigated to get an estimate of the cost of in-house manufacture, in order to gauge the feasibility of the approach. In the feasibility studies, various assumptions were made, as follows:

- the hourly labour rate used was the lowest rate from all customer contracts up to the date of this study;
- the tool usage hourly rate was taken to be equal to the labour rate, and when both machine and operator were being employed both were accounted;
- for comparison reasons, the studies presented aimed to get the panel to the configuration in which it would be received, had it been procured ready-made, and not in the “as installed” configuration. Thus items such as fasteners and washers were omitted;
- layover time was assumed to be sufficiently long such that if the panel had to be ordered, it would arrive on time with no delay charges incurred;
- apart of the obvious liability of cost, should a delay occur, no accounting of goodwill liability was made;
- ready-made panels were assumed to be purchased as re-stock, not on an aircraft on ground (AOG) basis;
- the labour and machine hours assigned during this study are estimates and are based on experience;
- the opportunity cost associated with relocating a manpower resource for panel manufacture was not included in the calculation;
- cost of storage of the raw material until required within the facility stores was not considered;
- the price of the panel material was taken proportionally from the size of the blank from which it is cut, by area;
- blanks for non-rectangular (e.g. trapezoidal) panels where taken as the minimum dimension rectangles from which the panels could be cut;
- for edge filling compound and adhesive, it was assumed that only the volume required to fill the empty channels is used plus a 5% wastage factor;
- all features within the panels were assumed to be rectangular in shape, and hence no consideration is taken of any chamfers or fillets

The estimated percentage saving for panels from each part family is shown in Table III, and varies between 12.1 % and 31.3 %.

VII. Conclusion

This work has explored the feasibility of manufacturing aircraft GFRP composite panels in-house, to reduce costs and minimize delays during aircraft maintenance. Due to the limitations imposed by authorities in the aviation industry the approach adopted was towards the development of a manual process. A large number of cargo liner panels, and of cabin and cargo floor panels were considered, and were grouped into part families to facilitate economic jig design. The manufacturing process has also been described.

Fourteen panels (one from every panel family) were checked for feasibility. The conclusion of every feasibility study was that the manufacturing of the panels in-house (both floor and liners) is economically feasible, to various extents, since some panels have shown to produce a higher percentage saving to the customer, than others.

TABLE III. Estimated Percentage Cost Saving for a Panel from Each Part Family

Part Family	Percentage Saving
1	12.5 %
2.1	17.5 %
2.2	17.9 %
3.1	27.3 %
3.2	29.1 %
3.3	15.8 %
4.1	25.0 %
4.2	19.1 %
4.3	20.0 %
5.1	25.0 %
5.2	31.3 %
5.3	27.5 %
5.4	19.4 %
6	16.3 %

The manufacturing of these panels is in fact expected to be even more feasible, since goodwill is conserved because delays due to panel replacement requirements are avoided. Furthermore, panel stock material can be procured as restock, keeping a minimum stock level, which is much cheaper for shipment than if AOG shipment is used.

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