New Metal Fuselage Section Arrangement Minimize Assembly Time

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Abstract

The development approach of the aircraft industry is briefly explained. Analyzing innovation attempts from 1950s to present showed the introduction of the coil fuselage concept and how it developed into the integral frames and panels concept currently pursued. The novel design is then proposed to bridge the gap between impractical novel ideas and industry needs which put cost first. The new structure is to require minimum time for assembly. It is also to eliminate the need for advanced manufacturing, usually suggested by innovative ideas in the field. The new structure is based on common aluminum alloy sheets to minimize variance from the conventional semi-monocoque structure manufacturing requirements. Whereas numerical comparison with the conventional structure showed up to 15% weight savings and about 45% decrease within inquired maximum stress could be achieved. The stress reduction was suggested to be a result of the new structure's arrangement homogeneity.

Keywords: *Fuselage; Integral; Airframe; Assembly; Design; Manufacture*

1. Introduction

Since 1930s the metal fuselage structure governing most aircraft design have had a single common arrangement i.e. Semi-Monocoque arrangement [1]. This arrangement although very established, it is impractical to be automated within the assembly phase. A single aircraft manufacturer can only assembly few dozens of a single aircraft series annually, if not less. Such low production rate can be justified by having similar low sales rate. However looking closer we would see such slow assembly i.e. manual assembly, require enormous man work hour, which consequently affect the prices. Higher prices render lower sales, hence capable aircraft manufacturers tend to go towards producing bigger airliner aircrafts. Whereas producing smaller aircrafts with a similar production rate would render much less profit. Hence, the assembly been automated with much smaller work force and higher production rate capability would render lower prices. Such approach might then end-up increasing sales as well.

1.1. Early Development

One study regarding aircraft industry current phase suggested the industry is four phases behind the automobile industry, from full eight a mature industry e.g. automobile's have to achieve [2]. Another study have investigated patents regarding the metal aircraft fuselage [3]. The latter rendered some main points:

1. Newer patents are concerned with minor issues e.g. better cabin window location
2. Less interest in solving major obstacles within new proposed designs
3. Implementation is more valid if supported by a given company rather than an individual
4. Huge effort is recently focused towards joining current conventional features of the semi-monocoque into integral units, without improvement in these features

While a good new structure should in fact start from the ground up with the new philosophy in mind rather than just trying to fit in the old structure within. John Cutler explained a similar issue regarding post-1955 designs in his book 'Understanding Aircraft Structures': "[W]hatever the size of the aircraft, the fuselage frames are always. about 500mm (20in.) apart and have between 75mm (3in.) and 150mm (6in.) deep cross-sections". Cutler also pointed-out that development post this date was only focused on reducing rivets number and effects of structural damage e.g. efficiency of conventional structure [1].

1.2. Innovation Attempts

Although the fuselage structure remained same since this period, some valid innovation attempts have been recorded. In 1956, it was suggested within one patent to manufacture a fuselage out of one spiral piece, having C-channel cross section. Whereas this structural piece is to be bonded together in one curing operation. Thus forming a closed structure to which the outer skin can be bonded [4]. In 1965, a similar spiral concept was approached but under term "spiral coil". Whereas longitudinal members are to be welded to the coil internally to strengthen the whole structure. Similarly the outer stressed skin would be fitted [5]. In 1981, a patent targeting the airframe assembly, suggested diffusion bonding and superplastic forming could be used to form and assemble an aircraft in one operation out of a metal blank [6]. In 1991, it was suggested, pre-formed rings having a peripheral recesses would be joined with other parts having counter recesses. Thus concluding the stringers and frames in a worthy structure [7]. In 2000, a NASA report followed a similar pattern. That is to convert structures into integral units. However instead of concluding a new design, the report suggested merging conventional structure features into bigger integral parts. It was indicated conducting three-axis machine then forming is most practical option. Thus manufactured integral units where termed "Integral Airframe Structures (IAS) panels". The IAS panels to comprise: skin, frames, shear ties, stringer clips and stringers [8].

More recently in 2007, a patent suggested deck sections could be included in the frame in the form of a cord within its peripheral circle [9]. In 2009, Airbus inventors introduced a new frame design that would accommodate the fuselage windows within, instead of having them act as stress raisers between frames [10]. This latter design can be seen implemented in Airbus 380. In same year, an inventor introduced a fuselage structure formed out of a plurality of shells which are fitted later with the skin to form a transverse fuselage section [11]. In 2010, the same inventor also suggested the structure to comprise an integral frame including connecting elements to the outer skin, where the latter have stringers integrated [12]. In same year, a research regarding the very light jet (VLJ), suggested revising the semi-monocoque members' arrangement [13]. However within same period, more researches where concerned with the VLJ aerodynamic profile and performance [14-16]. In 2011, Tavares and de Castro dicussed in an article the need for designs to seek lower number of fasteners in the airframe. They also incoraged new designs to be more integral and to be manufactuerd by welding to approach stronger lightweight strucutres [17]. Most recently a study published in June 2013 discussed the advantages of using Lattice structure over the conventional semi-monocoque arrangement. Whereas the Lattice structure is composed of a shell (skin) supported by a grid pattern (Lattice). The study, however not detailed, suggested based on a simple FEA the Lattice structure being used in a given light jet fuselage is rigid and safe [18].

Thus it can be concluded the innovation approached the coil concept within 1950s and 1960s. The interest then diverted to the integrated frame philosophy starting in the 1990s to later be concerned with integral panels as well, post-2000s.

2. Proposed novel structure

In order to participate in the development, the study proposed a novel structure, shown in Figure 1. The structure to be alongside the integral design philosophy, which is very helpful for the speeding up the manufacturing pace. However unlike other structure this novel design was started from scratch with mass production in mind. Thus it was decided not to include any unconventional or expensive material e.g. composites, titanium, and not to make the structure dependent on any unconventional manufacturing. This structure would be called hereinafter Coque[1].

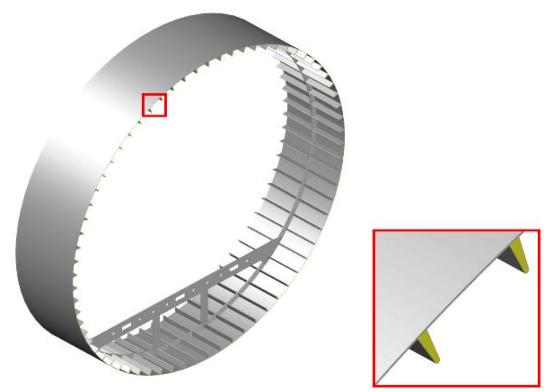

Figure 1 Proposed novel structure

2.1. Description

The novel structure was composed of the most popular metal alloy within the aircraft industry i.e. Aluminum Alloy 2024-T4. It is to compile two shells formed of two metal alloy sheets. Whereas one forms the outer shell and is simply a plain cylinder, while the other is intended so as to compromise peripheral and longitudinal grooves i.e. internal supporting skeleton. The latter grooves to act as frames, stringers and longerons. The two sheets are superimposed. It was suggested to include a light core which can be the "DIAB Divinycellr H 45 Semi-rigid PVC" foam core having density equal to 43.3Kg/m^3, as shown in Figure 2 and the zoomed view of Figure 1.

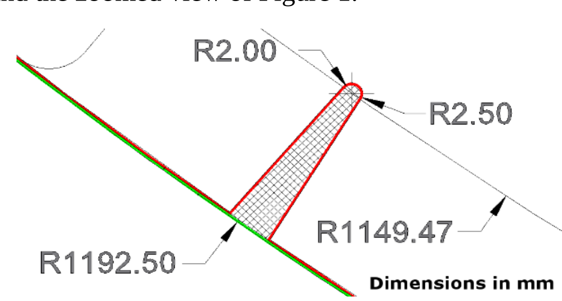

Figure 2 Foam core (hashed) in a longitudinal groove

Although the structure proved valid without the use of the foam core, it is suggested such core would increase the buckling resistance. Later the structure assembly is finalized by bringing both metal sheets

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together by means of suitable riveting or resistive spot-welding (RSW). Whereas attack points e.g. rivets, are applied as near as possible to grooves within inner skin, as possible; to acquire maximum transfer of forces/loads to groove sections. Moreover the cabin floor support (deck) can be added as two parallel metal strips connected by another strip, where all could be a single formed sheet, as shown in Figure 3.

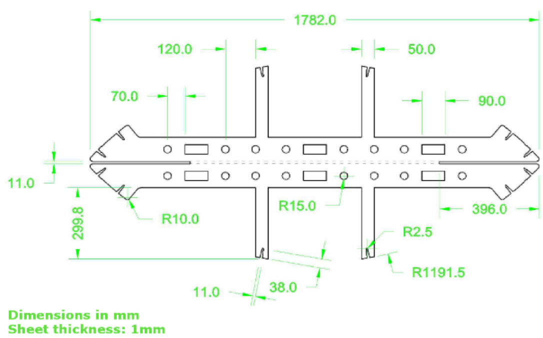

Figure 3 Cabin floor support forming sheet dimensions

This support is to be then fitted onto the peripheral groove in the inner sheet, as shown in Figure 4.

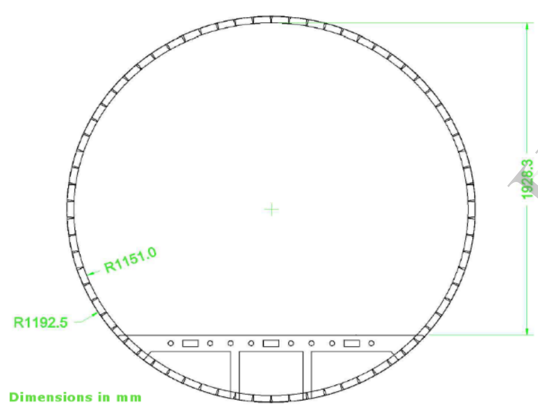

Figure 4 Novel structure frame dimensions

The novel structure components are shown in Figure 5.

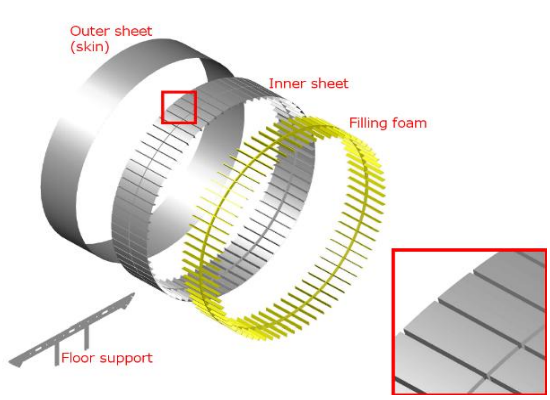

Figure 5 Components of the novel structure

It is worth to mention, the structure was intended to be of a thinner stainless steel to benefit from its spot-welding abilities [19]. However a recent research suggested that aluminum can be as well spot-welded, while only increasing the number of electrode pairs needed. The same research also suggested RSW is more cost effective than riveting [20]. Moreover using thinner sheets would have created a buckling resistance problem.

2.2. Motivation & Advantage

The reason which lead to such novel design being not obvious to others concerned with similar issues, might be their concern on optimizing the conventional structure. In addition wherever innovative designs were previously proposed for the fuselage, although faster to assemble, they were usually equal or more expensive than the conventional option or simply not structurally sound.

The novel proposed design in this paper was initiated in an effort to reduce production cost of Light jet aircrafts. Rough estimation of resulting expected total operating cost savings, is as high as 8%. That is based on total operating cost breakdown presented in reference [8]. The design aims at reducing production time of the fuselage. Hence facilitate mass production of a given light jet aircraft, implementing design. The new structure to target easily produced structure for aircraft fuselage. Whereas it looks similar to semi-monocoque fuselage structure produced through assembly process. The latter structure needs multi-thousands of assembly parts and fasteners. Moreover such process of manufacturing needs manual interventions on most levels. Thus it was suggested instead of having to fasten multi-parts with thousands of fasteners we can use a single sheet which has grooves acting as implemented strings and frames. So when time comes to assemble, it is only needed to fold the latter sheet into a cylindrical form. The pursed design was then initiated from scratch to achieve all objectives and avoid previously repeated inefficient approach.

2.3. Disadvantage

The new structure, although can solve many production problems, it is envisioned to be only practical for smaller aircrafts e.g. light jets. Moreover it needs a specially formed sheet, rather than the traditional assembly formed panels which could be formed from conventional metal sheets. Maintenance of new structure could be complicated as it's almost formed out of one panel instead of small panels that can be replaced when found defective. The structure might encounter a reduce lifetime as maintenance of the skin (outer sheet) and the inner sheet is restricted by one another and therefore the fuselage transverse section is meant to be replaced as a whole if found defective.

2.4. Specification & Validation

The dimension and thickness although can be varied from one mentioned. However, dimensions specified here are for the numerically validated model. The validation methodology, detailed in a separate study, was based on a matching conventional structure section as a reference which was used ahead to verify load values and their application methodology before these loads were used to validate the novel structure. Thus the structure dimensions were scaled to the same outer diameter as the respective conventional structure sample used i.e. Gulfstream SP-IV fuselage structure section. The dimensions of the frame and other detailed dimensions are shown in Figure 4, Figure 3 and Figure 2, where the depth of the structure section is 500mm.

3. Results & Discussion

The proposed novel structure and the conventional structure are compared in terms of design and performance parameters. Whereas performance and structural ability is inquired from a FEA conducted within a separate study.

3.1. Design Comparison

While the conventional structure have stringers providing longitudinal strength and buckling resistance and frames providing peripheral strength and form (shape) preserving, the new structure provide similar strengths and abilities using longitudinal and peripheral grooves. The stringers in the conventional structure have to be riveted along the stressed skin as requires its frames. However the grooves emulating the same job are already available within the inner sheet of the new structure, while keeping the outer skin (sheet) away from structural disturbance. The latter disturbance can be seen from displacement inquiry within the FEA for the conventional structure verses the novel during climbing, as shown in Figure 6. Whereas a similar pattern for both structures but with much less displacement inquired was obtained within the landing scenario.

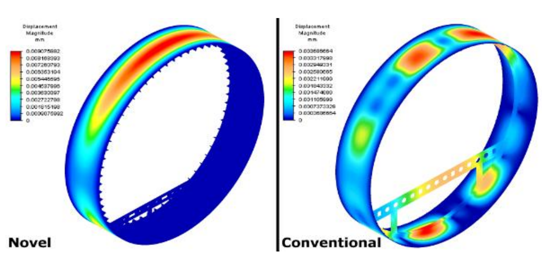

Figure 6 Displacement inquired during climbing

3.2. Performance Comparison

The structure weight for the 500mm deep section of the fuselage, based on the material volume gave $0.0056444942424 \times 2780 = 15.69$kg for aluminum parts and $0.0116165925432 \times 43.3 = 0.5$kg for the optional foam core. Whereas comparing this to the respective conventional section sample, the weight of the aluminum parts was 18.5kg. Thus, apart from fact this structure is suitable for mass production (minimize assembly time), it also give about 15.19% weight saving within the fuselage airframe.

The FEA comparison of the novel structure to its conventional rival predicted the novel can provide up to a consistent 45.2% decrease within the maximum inquired stress over the conventional, within various flight states. The inquired stress during climbing was higher than that during landing for both the novel and conventional structures. The maximum inquired stress values for the novel and conventional were 69.49MPa and 126.9MPa within the climbing scenario and 42.16MPa and 76.96MPa within the landing scenario, respectively. The graphical representation of the inquired stress for both structures during climbing is shown side-by-side in Figure 7. Whereas a similar pattern was obtained during landing, using the same FEA software i.e. Autodesk® Simulation Multiphysics. It is worth to note that the maximum inquired stress values are in nodes not included in presented view and thus not included in the legend scale as well.

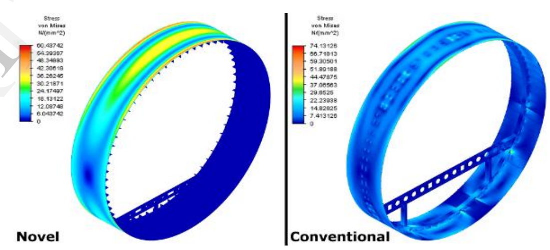

Figure 7 Stress inquired during climbing

4. Conclusion

The new proposed design also being novel is yet a concept among other previous introduced innovative concepts. Such concepts which are being introduced since the 1950s. The novel structure have the ability to save on the structural weight, reduce inquired stress during flight states and moreover be faster to produce. These abilities are to give it a lead over other introduced ideas. Where latter mentioned ideas only improved one factor over the others resulting in impractical innovation.

The novel structure only comprises main portion of an aircraft fuselage. While ways to attach it efficiently and incorporate it within whole aircraft traditional form are to be investigated. The suggested potential industries which could make use of such an innovation are those present in South-East Asia and China, where both regions have an increasing need for small aircrafts.

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