



## The use of Lightweight Materials in Electrical Power Distribution

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### ABSTRACT

This paper presents an overview of the MOET Primary Electrical Power Distribution Centers (PEPDCs) and the investigations into the use of alternative materials, such as carbon composites and polycarbonates, and the associated manufacturing processes.

With the objective to reduce weight and hence aircraft fuel costs the use of standard materials and processes are challenged and the relative performance characteristics for Primary Power Distribution are evaluated.

### INTRODUCTION

The use of lightweight materials and in particular composites, within aircraft are well documented with the latest state of the art aircraft such as the Boeing 787 and Airbus A380 publicly promoting the use and benefits of the materials.

Advantages: Low weight, high stiffness, high strength, good fatigue resistance.

Disadvantages: High Cost (compared to metals), Complicated failure mechanisms, time to manufacture, difficult to recycle (thermoset).

However, despite their advantages, composites are not seen as a panacea for aircraft structures, and the use within power distribution equipment presents a number of additional issues that are explored within this paper.

In particular the work covered has explored the use of a) composite materials in the construction of the primary power panels and b) Use of aluminium bus bars for weight reduction.

GE has previous development experience of using composites in primary power. The material and performance characterisation from practical tests and analysis has been fed into the design of the AC and DC panels to be used within the MOET program. In addition to the material development the MOET panel also investigates the use of light weight contactors.

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## PANEL CONSTRUCTION

Primary power distribution units and indeed avionic electrical enclosures in general, have traditionally been manufactured in various grades of aluminium. The larger primary power panels being fabricated sheet metal enclosures whilst the smaller distribution boxes utilise the advantages of machining advancements of enhanced cutting speeds and capabilities to machine thin wall sections.

The MOET architecture requirements of the AC and DC Primary Distribution Panels necessitate relatively large enclosures that are more aligned to sheet metal aluminium enclosures when considering current production designs.

## MATERIAL SELECTION

### CASE

This section discusses the potential use of a number of materials and construction techniques considered during the program.

The use of aluminium honeycomb structure has been considered. These materials are available in very thin sections (typically 2.0mm) and are attractive being metallic with extremely good weight/stiffness ratio. Material and assembly costs are more challenging with the need to maintain mechanical integrity throughout the enclosure and the requirement for aircraft and component fixings points to be added.

Metal Matrix Composites (MMC's), an example being aluminium matrix reinforced with ceramics such as silicon carbide (SiC), have also been considered. These composites exhibit low density, high thermal conductivity, excellent stiffness and strength. However the materials generally have a lower Technology Readiness Level (TRL) and are more expensive and heavier than the Polymer Matrix Composites (PMC's) discussed below.

PMC's are the most common type of composites used today. These are comprised

of a polymeric matrix (thermoplastic or thermoset) reinforced with short, long or continuous fibres. Regarding Mechanical performance, autoclave cured prepreg materials provide top performance within this material range. The most widely used combination of materials in prepreg are carbon/epoxy, a thermoset composite.

Some thermoplastic composites however, do offer similar properties to these carbon/epoxy prepreps. An example is carbon/PEEK providing high mechanical properties, high resistance to most chemicals and recycling possibilities. The main disadvantage of PEEK however is its high materials and processing costs.

The Primary Power Distribution panels and the volume packaging requirements, being relatively large enclosures, lend themselves to the use of pre-impregnated materials (prepreps) and the manual lay-up process. In comparison the secondary power distribution units typically produce smaller 'blackbox' type enclosures that are more aligned to compression moulding techniques.

The use of the carbon composites in the panel design achieves a lightweight "monocoque" structure replacing conventional fabricated, machined and riveted together aluminium components.

The MOET AC and DC panels were manufactured by Cobham Composites, using prepreg epoxy carbon fibre composite from the MTM range supplied by the Advanced Composite Group. A fibre reinforced composite material is a structural system comprising a matrix of one type of material, reinforced with a fibrous form of another material, in this instance the two constituents being carbon fibre and epoxy resin.

The composite material selected has a mid range performance level and is cured at lower temperatures (80°C), without the requirement to use an Autoclave. The material, MTM46 has been developed specifically for the production of high quality laminates using a low-pressure process. In general the prepreg composition can be optimised for mechanical and thermal performance with high fibre contents

achievable within the matrix. However, cost can vary by factors of perhaps 10 times dependant upon requirements.

The prepreg material was laid up by hand into a female mould surface, vacuum bagged and then heated to 120°C. This allows the resin to initially reflow and eventually to cure. The resin is a near-solid at ambient temperatures, and the prepreg has a light sticky feel to it, which aids the lay-up of the layers into the mould.

Figure 1, Figure 2 and Figure 3 show the MOET AC case and central support section and associated tooling for the centre section.

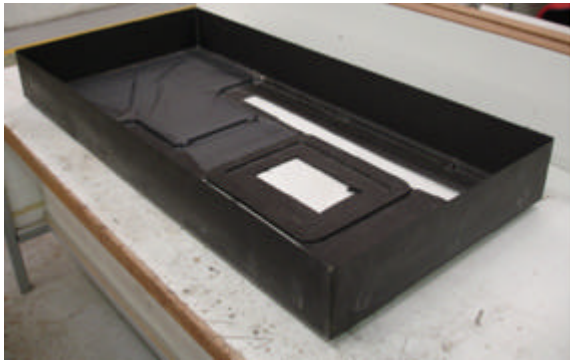


Figure 1 MOET AC Case



Figure 2 MOET AC Case Support Section

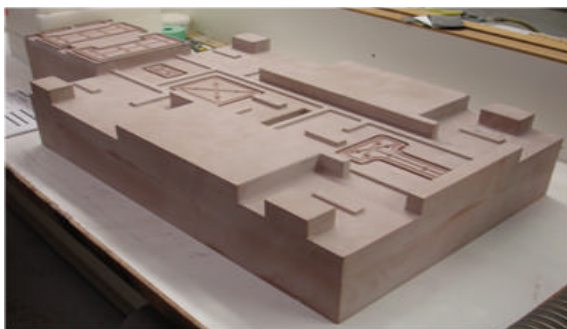


Figure 3 MOET AC Case Support Section Mould

Figure 4 illustrates the DC case assembly prior to the addition of busbars and associated components.



Figure 4 MOET DC Case

### COVER

The panel assembly front cover provides access to the Line Replaceable Units (LRMs) when installed on the aircraft. The cover acts as a heat shield to the internal contactors and busbars and prevents the admittance of Foreign Object Debris (FOD). The front cover also contains air vents allowing the circulation of the environment air across the internal components.

The cover, as illustrated in Figure 5, is manufactured using a Lexan F-6000 extruded polycarbonate sheet material. The manufacturing process involves heating the thermoplastic sheet over a mould and evacuating the air from between the mould and the sheet. Additional external pressure is applied to form the sheet into the mould. The high pressure forming provides the capability to achieve excellent surface profile definition such as embossed surface labelling.



Figure 5 MOET AC Case Front Cover

The use of plastics for the cover achieves a low cost light weight component. The selected Lexan polycarbonate material is commonly used in aerospace and the design features ensures that the mechanical performance is constant over the operating range.

### BUSBARS

Copper and Aluminium are the two most commonly used materials for electrical busbars in power distribution systems. The debate over the use of copper versus aluminium material for busbars has been discussed in some detail in a number of papers over a number of years.

Copper has traditionally been the preferred option having comparative advantages of low resistivity and high thermal conductivity. However, the increased emphasis on weight reduction within the aviation industry coupled with the increases in the cost of copper, the use of aluminium is becoming more desirable within power distribution.

Aluminium 5251 is used within the MOET panels. 5251 grade aluminium is stronger than the more common aluminium busbar alloys such as 1350 and 6101. The busbars in the MOET panel need to be mechanically tolerant to support the applied vibration and shock loads.

### **PANEL ASSEMBLY**

The MOET panel construction contains busbars, wiring and LRM's mounted direct to the internal composite support structure (see Figure 2), creating a reinforced central spine within the panel.

Figure 1, Figure 2 and Figure 4 illustrate the case and support structure as moulded and then secured into the panel. Insulating bushes are attached to the support structure to provide isolation for the busbars.

The MOET AC and DC panel assemblies are illustrated in Figure 6 and Figure 7 (front cover removed).

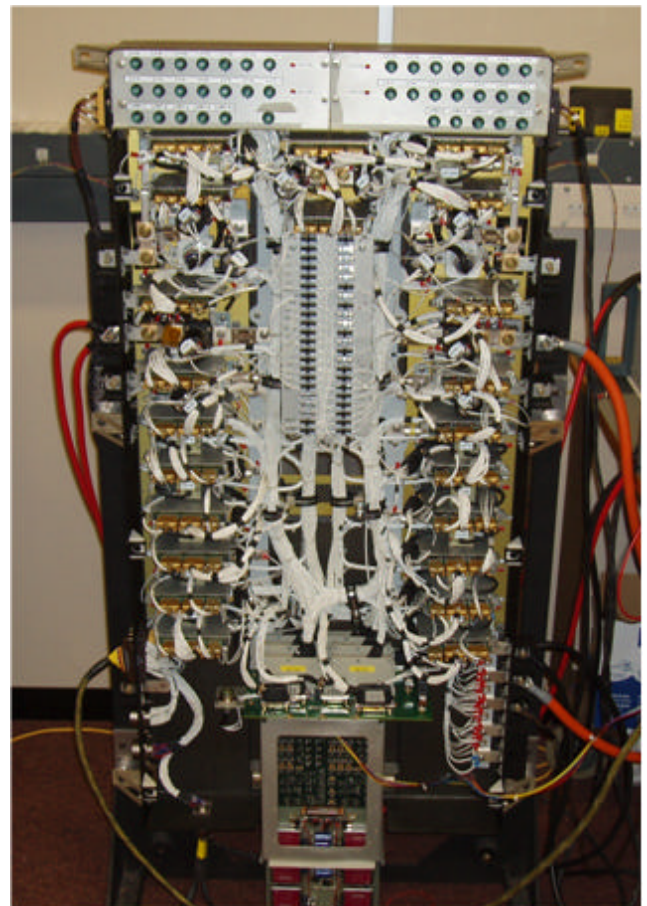


Figure 6 MOET DC Panel

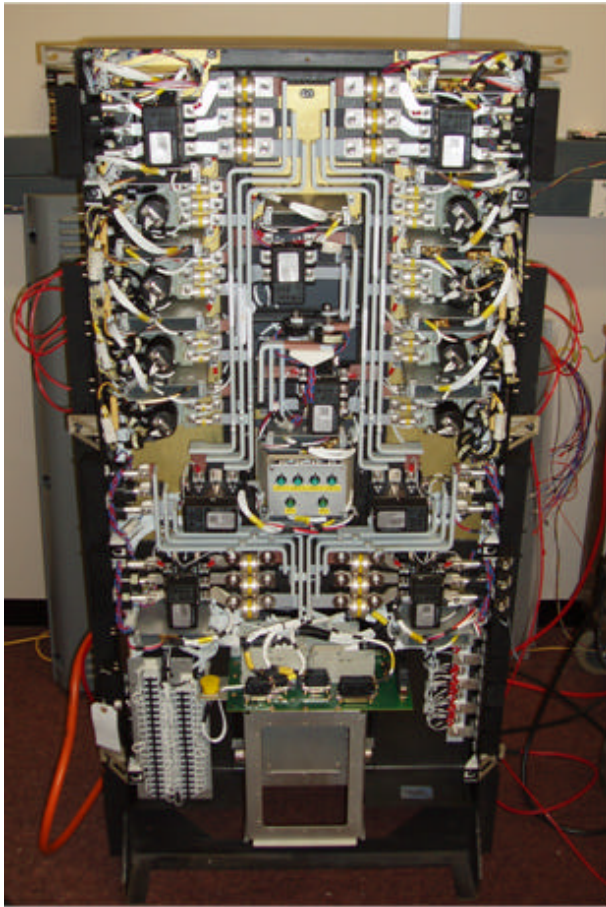


Figure 7 MOET AC Panel

## THERMAL

In general terms composites have largely been used to provide low weight, high strength products. The use of composite enclosures within Power Distribution provides additional issues such as thermal and shielding requirements.

Potentially composite materials can be manufactured with enhanced thermal properties, with Pitch based carbon fibres having distinct thermal advantages over Pan based carbon fibres. However the cost of the enhanced thermally conductive fibres can be several orders of magnitude higher. As the cost of carbon fibres dominate the raw material costs of the composite this can prove prohibitive and should only be considered for specialist applications. The use of prepreg materials provides scope to add higher performance materials into the lay-up process in specifically defined areas where required.

Part of the materials selection process consisted of conducting a thermal analysis to establish impact of changing from an aluminium alloy case to a composite case.

Primary Power Distribution Panels mainly generate heat in contactors and bus bars. In both cases heat appears at bus bars where it is transferred to external wiring and internal air/ enclosure surfaces.

Internal air acts as heat spreading medium so the cabinet structure does not have to be used as a heat spreader. This is significant in comparing aluminium with composites because conductivity difference only affects heat transfer through thickness of enclosure. Analysis shows that the internal cabinet air temperature rise due to the change in in-plane conduction by moving from aluminium to a composite structure will be of the order of 3°C. This is critical to the design considerations when considering the passively cooled assembly.

Thermal Analysis was performed on both the AC and DC panel assemblies using the numerical Flowtherm analysis package, subjecting the panels to both typical and maximum power loadings. The load scenario simulated for the analysis was repeated by test to allow correlation between numerical and actual data. Temperature monitoring points and measured voltage drops were added to the model configuration to optimize this correlation.

During the testing an infrared thermal camera was used to establish the temperature profile across the panel as illustrated in Figure 9 Thermal Heat Gun View. The camera measures infrared energy radiated by body surfaces and the temperature is calculated by relating the measured energy to an equivalent amount of energy radiated by a black body (using Planck's Law).

The use of instrumentation and the thermal camera were used to confirm the predictions as identified with Figure 8, Figure 9 and Figure 10.

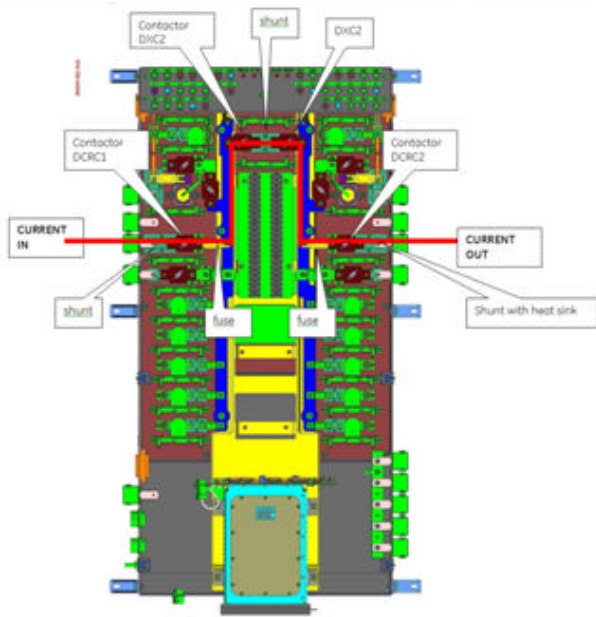


Figure 8 MOET DC Panel Test Layout

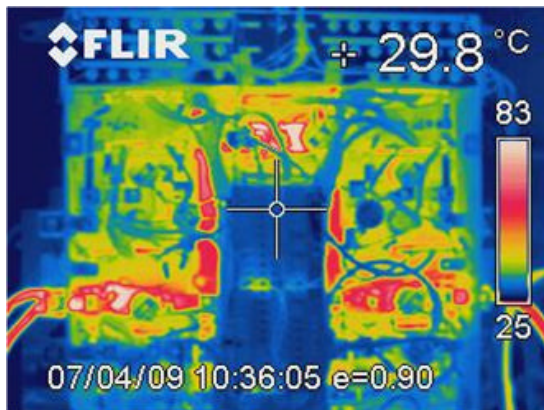


Figure 9 Thermal Heat Gun View

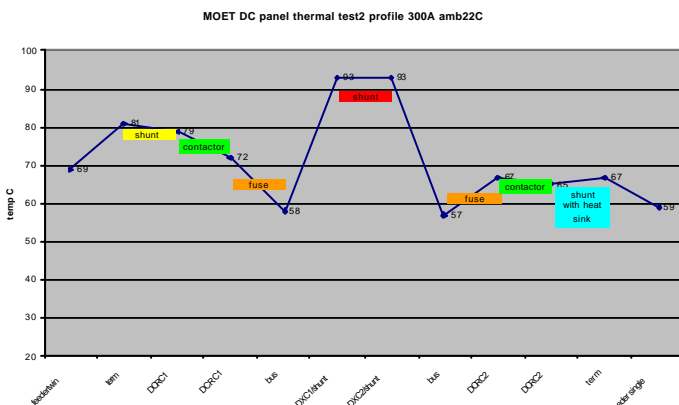


Figure 10 Flowtherm Thermal Prediction

## ASSEMBLY WEIGHT DISTRIBUTION

The use of composites is perceived as providing a major weight saving over equivalent metal counterparts with composite densities being up to 50% lower than Aluminium. In practice a target of 30-40% is more realistic, partly due to the need to add fixings inserts and other specific application parts to the final assembly.

Whilst the AC MOET panel assembly is 15% lighter than its nearest current production equivalent, direct correlation is more difficult due to the difference in part geometries, which is largely driven by the variance in system requirements.

Figure 11 illustrates a comparison of the total assembly weight for the MOET AC and DC panels in addition to the nearest equivalent current production panel. The production panel consists of an aluminium case and cover and copper busbars.

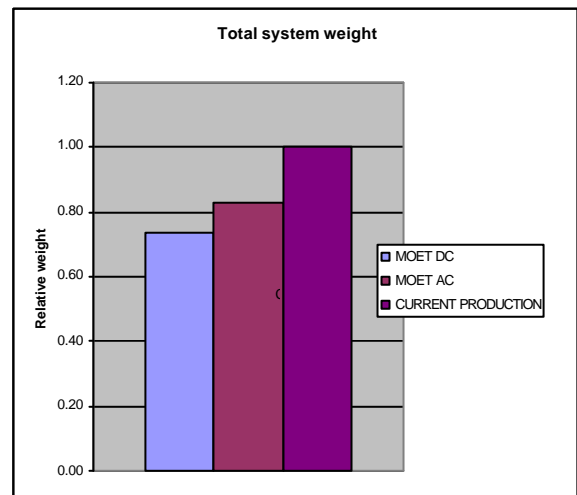


Figure 11 Panel Assembly Weight Comparison

By analysing the relative assembly components regarding the functionality it is possible to identify significant weight savings in a number of specific areas:-

## MAIN PANEL CASE AND COVERS

The AC and DC panel MOET cases (carbon fibre composite, aluminium and polycarbonate) provide a weight advantage over an all aluminium construction (current production equivalent panel).

As stated a direct correlation can not be made between the MOET and the current production panels as the architecture, and therefore component content and size, is different. However, analysing the usable case volume versus the associated case weights identifies a clear advantage in favour of the MOET panels.

This is illustrated within Figure 12. The panel and covers encompass the components within the assembly, largely consisting of busbars, contactors, circuit breakers, shunts and fuses. The panel functionality is common across the panels and the relative weight in comparison to the volume is a good means of measuring efficiency of the panel materials and the contribution to weight.

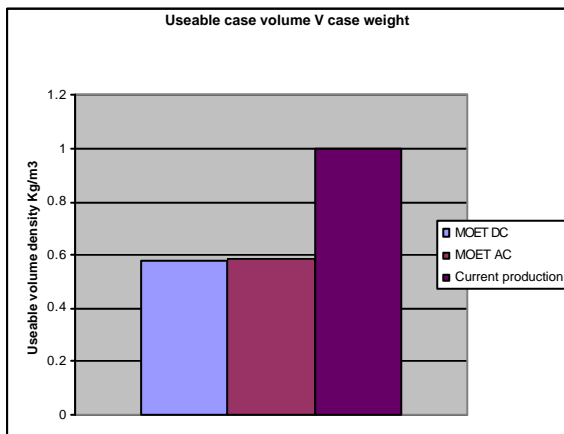


Figure 12 Panel Assembly Case Weight Comparison

## BUSBARS

The use of aluminium busbars in comparison to copper have been discussed within this paper. The electrical conductivity of the appropriate grade of aluminium is roughly 60% of copper, whilst the density of aluminium is 30% of copper.

A like for like comparison of aluminium versus copper using the current production busbars (see Figure 13) demonstrates significant weight saving could be achieved by changing the busbar material to aluminium.

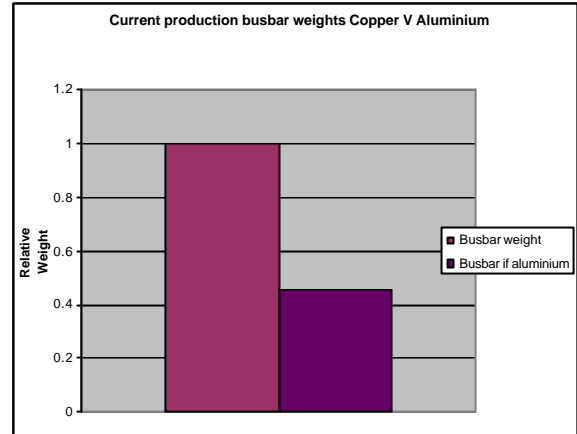


Figure 13 Relative Busbar Material Weight Comparison

## CONCLUSION

The manufacture and test work undertaken during this program has identified that the use of carbon composites for Power Distribution enclosures has significant potential. One major challenge to the viability of composites replacing aluminium as the materials choice is the associated material and manufacturing costs. In general composite materials are more expensive to produce than traditional materials such as aluminium or steel. Composites can become more cost effective in the design process by reducing the part count requirements.

Lower labour and material costs can potentially be achieved by producing parts and purchasing materials from low cost labour environments. Countries like China are heavily investing in composite facilities and will have the potential to produce high quality composite parts.

Although it is established that current carbon fibre reinforced composites will have higher costs compared to both aluminium and glass reinforced composites they are more favorable from a weight perspective. As such the value of weight savings is a true measure of the cost effectiveness of the technology. In aerospace this can be measured by the life cycle fuel savings.

This study has used a material from the MTM range of thermoset composites. It is anticipated that Thermoplastic composite development will increase as concerns for the environment put pressure on companies to use recyclable materials.

This paper has investigated the use of lightweight materials for enclosures in Power Distribution. Having shown the potential to use the materials, further studies are required to establish the structural, electromagnetic interference (EMI) shielding effectiveness (SE) of the panels and subsequent finish options.

## ACKNOWLEDGMENTS

The MOET project is a European Project, co-funded by the European Commission within the Sixth Framework Program .

## REFERENCES

The following resources were referred to in this module:

1. 'Novel Electronics Enclosure Design and Technologies' report compiled for GE Aviation by research establishment TWI, December 2008.

## 2. CONTACT















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## Definitions, Acronyms, Abbreviations

 <b>AC</b>	<i>Alternating Current</i>
 <b>DC</b>	<i>Direct Current</i>
 <b>EMI</b>	<i>Electromagnetic Interference</i>
 <b>FOD</b>	<i>Foreign Object Debris</i>
 <b>LRM</b>	<i>Line Replaceable Module</i>
 <b>MOET</b>	<i>More Open Electric Technology</i>
 <b>MMC</b>	<i>Metal Matrix Composite</i>
 <b>PEEK</b>	<i>Poly-ether-ether-ketone</i>
 <b>PEPDC</b>	<i>Primary Electrical Power Distribution Centre</i>
 <b>PMC</b>	<i>Polymer Matrix Composite</i>
 <b>SiC</b>	<i>Silicone Carbide</i>
 <b>SE</b>	<i>Shielding Effectiveness</i>
 <b>TRL</b>	<i>Technology Readiness Level</i>
 <b>TSB</b>	<i>Technology Strategy Board</i>