Thèse Cifre ICA – AIRBUS (site Toulouse)

Residual strength and sizing of aeronautical composite assemblies exposed to electric currents

Airbus is a global pioneer in sustainable aeronautics and space, with a workforce of around 135,000 employees. The company constantly innovates to provide efficient and technologically advanced solutions in aerospace, defense, and connected services. In commercial aviation, Airbus offers modern and fuel-efficient passenger airliners and related services. Airbus is also a European leader in defense and security, as well as a global player in space. In civil and military helicopters, Airbus provides the most efficient solutions and services worldwide.

1- Background information and industrial context

Several electrical functions provided by a metallic airframe are not directly provided anymore by a CFRP (*Carbon Fiber Reinforced Polymer*) airframe. A set of metallic conductors called ESN (*Electrical Structural Network*) or MBN (*Metallic Bonding Network*) were designed and integrated on the latest composite aircraft 'A350) to compensate for the *a pri*ori poor electrical performance of the CFRP (see last section for details on the bonding network). The first electrical functions relate to functional currents (power supply return current, or signal return current, or leakage current) as well as non-functional currents in case of electrical fault for instance. The functional currents are by essence permanent and exist in normal mode of operation of the systems. The non-functional currents in case of electrical fault (short-circuits) are of a non-permanent nature since they are detected/cleared by short-circuit prevention devices (eg a ''circuit breaker'').

Efforts on the electrical distribution technologies, and short circuit prevention technologies (''fast tripping''), makes it possible to reduce the overall current load that would be injected into the carbon structure. Research programs have in their objective the optimization, or suppression, of the MBN which industrial footprint on the product is substantial. However, an important hurdle is the knowledge of the capability of a CFRP junction to accept a certain amount of current, either permanently and accidentally (in electrical fault conditions).

The ''MBN free'' / ''No-MBN'' concepts makes necessary to understand the effect of an electrical flow into those junctions over long period of time, or associated to short transient events to understand the possible knockdown effects on the mechanical properties and possible microdefect accumulation [Hart-Smith L. J. 2003, Hühne C 2010]. Ideally, beyond the results of an empirical approach, a physical model of the physical phenomena at stake making possible to anticipate performances would be a significant breakthrough.

The objectives of the research and PhD are as follows:

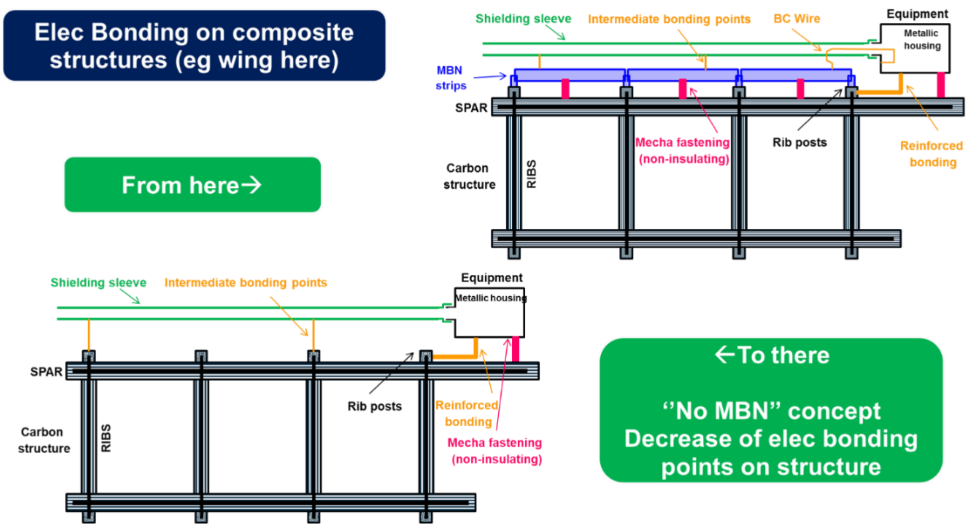
- to understand the CFRP interaction with an electrical flow,
- to provide the knockdown laws enabling the ''MBN free'' electrical distribution concepts, eventually associated to some sizing models,
- to pave the way to a methodology for certifying those concepts without having to test all configurations of junctions.

The understanding of the interaction between electrical current flow [Pyeong-Su Shin et al. 2018] and CFRP (ageing aspects and mechanical knockdown factors with a prediction capability) is of an academic nature. The physics of the interaction, and the mechanical implications, fits with a mechanical academic lab.

The PhD contributes to the functionalization of the carbon structure for electrical functions. This does fit with electrification, and optimization of electrical distribution/installation. The understanding of current injection and flow on carbon structure and the determination (with a prediction capability) of the electrical allowable at the junctions are crucial factors. This is an important the objective of the PhD linking with the residual behavior of composite bolted joints [Camanho 2006].

''Functionalization'' of the structure, i.e. allowing more electrical functions to the structure, is an industrial challenge that requires technical knowledge of electrical/mechanical interaction of carbon structure. This is valid for the junctions/assemblies we know of today, but also on different/innovative schemes and materials.

The generic principle of the ''No-MBN'' concept, in reference to the ''as is'' situation (eg A350) is given on the following figure. In such concepts all functional currents returns are wired back to the fuselage (power and signal), no structural return (see appendix for more details).



In case of an electrical fault and short circuit within the equipment, the short-circuit current is shared between the various parallel electrical bonding paths. Suppressing the MBN will results in higher current injection in the carbon structure, hence the objectives of the PhD to understand the interaction current/carbon, and the determination (with a prediction capability) of the electrical allowables at the junctions to avoid any maintenance action.

2- Organization of the research activities

The research works will be split into three phases:

- Phase 1: State-of-the art and establishment of a test strategy and potential modeling strategy.
- Phase 2: Exploratory experimental campaign.
- Phase 3: Detailed analysis, understanding and modeling of the failure mechanisms [Montagne 2020].

Phase 1: State-of-the-art and test strategy

During the first phase, the following activities will be performed:

- Review and analysis of the existing data within Airbus on current conduction capabilities of composite assemblies.
- Review and analysis of the sizing methods for assemblies and methodologies for residual strength determination.
- Review and analysis of the open literature on damage and ageing mechanisms on composite assemblies, at junctions/fasteners and on plain material, further to electrical current flow.
- Preliminary definition of the electrical current profiles to be applied to the composite assemblies: short and intense stimulus (corresponding to short circuits), or more permanent but low level stimulus (corresponding to leakage currents).

The essential objective of this first phase is to identify the potential failure mechanisms, or ageing mechanisms, that an electrical current flow could either generate or exaggerate. The different manufacturing defects or micro defects, acceptable in the mechanical perspective, need also to be understood to figure out whether an electrical stimulus could possibly promote some detrimental evolution. This analysis goes with the determination of the overall ‘’pass/fail’’ criteria required for the residual strength assessment and mechanical properties.

These first tasks are required to delineate the principles of a test program and test definition. The focus will be at this stage on the ‘’what & why’’ aspects of the test strategy. The different dimensions of testing will be investigated in terms of test sample definition (unitary mono-fastener, single lap joint …), test conditions and environment (current return structure and boundary conditions), as well as on the diagnostics and observables.

Even if the overall criterion is the residual strength [Wang H-S 2003], some specific diagnostics might need to be defined/implemented to enrich the understanding of the composite/ electrical current interaction and response. Likewise, the approach for the assessment at the injection point (at fastener/ joint location) or far from it (on the material itself) might need to be tailored.

During this state-of-the-art phase, the prediction capabilities by modeling will also be reviewed, relating to the different failure mechanisms, or defect formation [Tsai MY 1990, Wang 1996].

Phase 2: Exploratory test program and electrical/thermal/mechanical test bench development

This phase will consist in the detailed establishment of the test program, test preparation and test execution. The objective is to engineer a test campaign making it possible to explore the territories spotted during the first phase.

The field of possibilities being wide, an informed short selection will need to be devised to map at least three main factors of interest:

- The mechanical properties and impact on the residual strength.
- The electrical stimulus themselves, in magnitude/energy.
- The fastener type, eg interference fit or clearance fit.

The overall objective being to – ideally - determine knock-down factors, once understood the potential failures (or aggravation) mechanisms, some extremes will have to be explored to get damages or get changes in the samples pre/post application of the electrical current stimulus.

The detailed test definition and procedure will be produced at the beginning of this second phase, test samples manufactured, and tests executed. The tests per se will be executed in Airbus facilities.

Phase 3: Detailed analysis of test results, understanding and modeling of the failure mechanisms

The test campaign in phase 2 will reveal some damages or conditioning of the test samples. This observed findings / damages will be analyzed to determine if they are of a conventional nature (eg identical or like known damages or degradation) or if they happen to be singular and novel.

Should the observed damages be equivalent to other known damages (from non-electrical stimulus) then the subsequent activities will be focused on the validation and expression of this equivalence.

Should however some degradation/damages be novel or singular then the subsequent activities will focus on the understanding of such novel failure mechanisms.

Damage modeling [Whitworth HA 2003, Zhang J 2013] will use damage and failure models developed at ICA. Depends on observation these models have to be adapted in order to better predict failure /behavior

Key words : Fatigue and damage tolerance, composite bolted joints, FEM, numerical modeling, Damage and failure of composite laminates, static and cyclic tests, thermal and electrical ageing

Thèse à caractère Industrielle :
Cette thèse Cifre sera réalisée avec la société AIRBUS Toulouse et l'encadrement scientifique sera assuré par l'Institut Clément Ader. Localisée sur le site de l'Espace Clément Ader, la personne recrutée sera à 100% à Toulouse.

Durée : 36 mois avec un démarrage prévisionnel septembre/octobre 2025.

Laboratoire d'accueil :
Le laboratoire d'accueil est l'Institut Clément Ader (ICA), CNRS UMR 5312, au sein des groupes Modélisation des Systèmes et Microsystèmes Mécaniques (MS2M) en lien avec l'axe transverse « Assemblages ». http://institut-clement-ader.org/

École Doctorale :
École doctorale d'inscription MEGeP (Mécanique, Energétique, Génie civil & Procédés)
https://www.adum.fr/as/ed/page.pl?site=megep&page=inscription

Candidature :
Pour candidater à cette offre de thèse, merci d'envoyer :
- Un CV actualisé,
- Une copie d'une pièce d'identité,
- Une lettre de motivation soulignant l'adéquation avec le projet de recherche,
- Les relevés de notes obtenus dans le cadre d'un master (1 et 2) ou/et d'un diplôme d'ingénieur,
- Une ou deux lettres de recommandation récentes (2022).

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