Fatigue Considerations in the Development and Implementation of Mechanical Joining Processes for Commercial Airplane Structures

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The durability of commercial airplane structures is strongly influenced by build quality and the extent to which assembly processes are controlled throughout the production life of the airplane program. This is a direct consequence of the fact that for mechanically fastened (bolted, riveted) joints, fatigue performance is highly sensitive to assembly process-related parameters like hole quality, hole fill, and joint clamp-up. New developments in assembly technology and the perennial quest for manufacturing cost reduction under increasing production rate pressures are translating into new, often non-traditional parts and build processes being applied to commercial airplane products. This in turn requires for the structures engineering community to work in close partnership with assembly specialists throughout all stages of build process development and implementation, in order to assure the structural integrity and economic life of the airframe.

Described in this paper are some of the new processes being used at Boeing Commercial Airplanes to produce metallic and hybrid (composite+metal) assemblies for large commercial transports, from a structural fatigue perspective. The discussion focuses on three distinct mechanical joining technology thrusts: (1) One-up assembly (OUA) and process automation, (2) full-size determinate (or determinant) assembly (FSDA), and (3) non-traditional fastening systems. A number of case studies are outlined and considerations such as process selection, control, fatigue characterization, and qualification are also highlighted.

OUA is used at Boeing as a generic term to designate assembly processes (typically machine-based) where fastener holes are drilled upon assembly without the joint being separated, cleaned, inspected, and holes deburred after drilling, as would be the norm under a more traditional build process. This approach has the obvious benefit of reducing process labor and increasing production throughput, but it may also sometimes come at the expense of reduced fatigue lives. OUA is not a new idea –it has been employed at Boeing in areas like wing panel and spar production for several decades, but with the increased drive toward machine automation and robotics –where OUA often becomes an intrinsic process feature, use of OUA is rapidly spreading. Among new examples of the process is the new Boeing 737 wing panel assembly line (PAL, Figure 1), which is helping make the current 40+ airplane-per-month 737 NG/MAX production rate possible. Implementation of OUA in this kind of an environment typically requires an early structural assessment that considers the effect the process could have on fatigue performance, establishing mitigation strategies where pertinent, and process qualification (once the process is deemed stable), the latter often involving dedicated fatigue tests (Figure 2).

Figure 1. Boeing 737 NG/MAX Wing Panel Assembly Line (PAL)

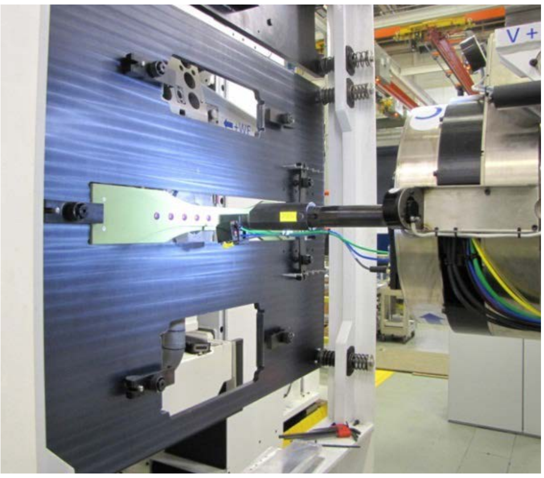

Figure 2. PAL System fatigue qualification (image shows a fatigue test specimen being drilled and riveted)

FSDA is an assembly strategy centered on the principle that with the right machine tools and process controls, it is possible to build structure at the detail part level to an extent where assembly tooling and the practice of drilling on assembly can be sharply reduced or eliminated altogether. With the advent of precision machining, the range of FSDA applications is expanding into primary structure and beyond the traditional domain of areas like airplane floor structure, where Boeing has been using FSDA for more than 20 years. Recent, highly successful examples of FSDA include the 787 vertical fin (Figure 3) and 787-9 horizontal stabilizer, both of which are large all-composite and composite-titanium assemblies. FSDA implementation on structural components involves many of the same steps as with OUA, but with a well-planned, coordinated process and sufficient controls in place, the need for dedicated fatigue testing is not typically necessary for process qualification.

Figure 3. FSDA: Boeing 787-8/-9 Vertical fin

Processes traditionally designed for manual aluminum sheet metal construction, like riveting, are giving way to new build techniques like OUA and automation that are more amenable to the use of multi-piece fasteners –pins + collars or nuts, and structural blind or one-sided installation solutions. Though heavier and more expensive (in terms of unit cost), this approach greatly simplifies fastener installation and inspection, and results in a more consistent product. Additional requirements such as electrical bonding and grounding in fuel-wetted wing hybrid structure place additional challenges for the fasteners and the structure (particularly in composites), and are currently the focus of additional development and structural characterization.

Keywords: Fatigue, mechanical joints, one-up assembly, determinate assembly, Boeing