Bombardier Global 7500 Fatigue Test Cycle Rate Commissioning to ¼ Life

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This paper describes the commissioning campaign on the Bombardier Global 7500 durability and damage tolerance test (DADTT), as conducted by the experimental department of Bombardier Aerospace (BAEX), located, in Montréal, Québec, Canada. A rapid test rig commissioning time and smooth increase of cycle rate was a key objective in order to meet the ¼ life milestone for certification. At the time of writing, the G7500 is the largest dedicated business jet in the world, and is on target for certification by Transport Canada at the end of 2018. The majority of structural and systems tests for the G7500 were conducted by BAEX, including the complete airframe static test (CAST), fatigue and endurance testing of the flaps, the integrated systems test rig (ISTCR) and high-lift systems test rig (HLSTR). These tests and many others are all typical and necessary elements to the development and certification efforts of modern passenger aircraft. As is customary for aircraft certification, the fatigue test (DADTT) was one of the final tests to be commissioned, due to the requirement to receive a production-equivalent test article. Due to schedule changes, the time available for commissioning the loading apparatus and achieving the initial target ¼ life milestone was reduced from the original plan, with approximately three months' time allocated to this goal.

In anticipation of this aggressive testing milestone, the BAEX test team employed several new approaches and techniques to the full scale test that had not been applied on previous BAEX fatigue tests. The intent of these extensive preparations was to reduce the amount of 'on-rig' learning curve time that was required to reach the optimum performance of the DADTT hardware, such that the schedule risk during commissioning could be minimized. A technical liaison from the National Research Council Canada was also on-site prior to and during commissioning activities to support Bombardier's efforts.

This paper summarizes the objectives of the G7500 DADTT test conducted at BAEX, and in particular the techniques and approaches used by the BAEX team to achieve a rapid, efficient and productive test commissioning phase, such that the target cycling rate was achieved in a faster timeframe than anticipated. These techniques included: judicious data-informed hydraulic and pneumatic hardware selections; informed design choices to minimize mass and actuator count; hydraulic and load controller training and procedure generation on a dedicated independent test platform; extensive hardware-in-the-loop tuning to maximize performance; and using the global finite element model (GFEM) of the test article, coupled with a simple pneumatic model to better estimate test load transition times.

Data Informed Hydraulic and Pneumatic Hardware Selections
Prior to test rig assembly, several design choices were required that would have direct impact on commissioning time and achieveable cycle rate. As in all fatigue tests, a particular difficulty lies in the unknown nature of the performance of the unique test rig, coupled to hundreds of load introduction points of varying stiffness, their relationship to the flexible test article, and their response to the closed loop servovalve hydraulic loading actuators. A great deal of engineering judgment enters into design choices during this phase, due to the impracticality of fully simulating the entire hydraulic / pneumatic loop prior to the test. In particular, pneumatic and hydraulic system selections that would drive the cycle time, and cost / benefit trade-offs were sometimes difficult to make, due to the reasons above. In order to provide data for pneumatic design choices, several experiments were conducted on the G7500 Complete Aircraft Static Test (CAST) test article, to validate assumptions about fill and discharge rates. In order to provide data for hydraulic flow requirements, a GFEM model of the test article was combined with the geometric data of the actuator locations to generate displacements for each load transition, thereby providing peak flow requirements for each actuator and hydraulic manifold location. This technique was also used to select the appropriate servovalve sizes.

Mechanical Loading Techniques
The effect of applying additional mass 'above' the load cell, i.e. between the load cell used for feedback control and the test article is typically to reduce the natural frequency of the system, which is typically

detrimental to closed-loop performance[1]. For the G7500 DADTT this axiom was applied during the design phase, and implemented on the structures anticipated to have the highest deflections, i.e. the wings and empennage. As a result, the G7500 DADTT was designed to use only hydraulic counterbalancing of these structures, in order to reduce deadweight mass and complexity, as well as designed to apply loading on a single side of these structures, applying loads using bonded loading collars. Not only did these design choices reduce the total mass 'above' the load cell, improving control, they also reduced actuator count and reaction structure complexity.

Training on a Dedicated Platform

In 2012, BAEX began transitioning to new off-the-shelf load control hardware supplied by MTS of Minnesota, USA. Although other full-scale tests had been conducted with the MTS hardware, no full aircraft fatigue tests at BAEX had yet been completed with the new systems. In order to fully leverage the capabilities of the controllers and provide valuable hands-on experience without engendering any article risk, approximately 6 months prior to the anticipated commissioning date, BAEX constructed a physical test platform exclusively for software / hardware familiarization and training. MTS test experts were engaged to provide training to test operators and engineers and demonstrate the full features of the hardware. During several intensive weeks, the full capabilities of the controllers were explored, and highly valuable hands-on hydraulic tuning training was performed. In addition, commissioning approaches were formalized and procedures generated in order to reduce the learning curve when commissioning the full DADTT.

Hardware-in-the-loop-tuning

Upon commissioning start, the BAEX test team embarked on an exhaustive but valuable hardware-in-the-loop tuning exercise, using the procedures and techniques developed on the dedicated training platform. This exercise allowed tuning parameters to be individually set, and coupling interactions to be understood and compensated for, prior to embarking on the actual 'official' test cycling. In particular, extensive use of test functions and filtering allowed substantial compensation for natural frequencies of the various loading and test article structures prior to encountering them during cycling.

Load Transition Time Estimation

There were approximately 3000 unique load transition types in the G7500 load spectrum. MTS has a built-in feature known as profile segment optimization (PSO) that can effectively iterate over a load profile and optimize the load transition times; however, this tool assumes a test that is well tuned and is based entirely on system response – it does not know how severe a given load transition may be or not *a priori.* Therefore the efficacy of PSO is driven by the 'starting point', or initial transition time. Without any knowledge of the initial transition time, the test would be substantially suboptimal during many initial passes of the load profile, and in particular may have unexpected shutdowns if the initial transition times are too aggressive. In order to overcome this trial and error process and generate starting times closer to those expected, the GFEM of the test article was coupled to the geometry and hydraulic data of the loading actuators and servovalves to generate theoretical 'maximum' transition times based on hydraulic performance for each transition time. This allowed a much better initial estimate than using engineering judgment, as it was informed by where the test article was in space in relation to each test actuator. A simple pneumatic system model was also used for transitions where the pneumatic system was engaged. These estimates were quite accurate, as after 1 full lifetime of testing and many iterations of automated PSO optimization, 75% of the load transitions for the most common flight type were within ±0.5 seconds of the original estimate.

Significance

The commissioning period of the G7500 DADTT was substantially faster than originally planned, led to faster cycling rates earlier in the test program than previous Bombardier DADTTs, and achieved the key milestone ¼ life within the original aggressive timeline. This success was driven by strong planning and preparation by the test team, including new loading methods, data driven pneumatic and hydraulic selections, and novel use of low-fidelity modeling pre-test in order to properly select hydraulics and optimize transition times.

[1] Hewitt, R.L, Albright, F.J., *Computer Modeling and Simulation in a Full-Scale Aircraft Structural Test Laboratory*, Applications of Automation Technology to Fatigue and Fracture Testing and Analysis, Third Volume, ASTM STP 1303, 1997, pp.81-95.