Natural Laminar Flow Flight Demonstrator (NLFFD)

Design, Manufacturing and Qualification of an Improved NLF Wing Leading Edge and Upper Cover Flight Test Article

State of the art – Background

The NLFFD and ImpNLFFD programs are an ongoing area of research and technology aimed at developing the capability and understanding of Natural Laminar Flow (NLF) for the next generation of civil aircraft through the design, manufacture, test and demonstration of an integrated NLF Composite Upper Cover (UPR CVR) and Metallic Leading Edge (LE) Assembly. These programs are undertaken in support of the CleanSky Smart Fixed Wing Aircraft (SFWA) program to mature a NLF technology stream for future short range transport aircraft.

The NLF aerofoil coupled with improved aero-smoothness offers higher efficiencies in aerodynamic performance and a reduction in drag, contributing to an overall increase in an aircraft's efficiency; this in turn allows for potential reductions in aircraft emissions by reducing fuel burn. The requirements of a NLF wing differ significantly from a conventional turbulent wing, requiring changes to the architecture of the wing, the aerofoil definition, the detailed design concepts and manufacturing processes. The aerodynamic performance of a natural laminar flow wing is highly dependent on meeting very high aero-smoothness tolerances including steps and gaps, surface roughness and surface waviness tolerances, in the regions where laminar flow is to be maintained. Additionally, the performance of a NLF wing requires very tight surface roughness and waviness tolerances and contamination free surfaces in the areas where laminar flow is to be maintained.

Figure 1 shows the 'SFWA BLADE' program poster applicable to both to both NLFFD and ImpNLFFD projects. SFWA partners are stated at the base of the poster.

Figure 1: SFWA Poster. Image courtesy of Airbus.

Objectives

The SFWA "BLADE" project is a major flight test campaign with NLF outboard test wings attached to the port and starboard sides of the Airbus A340-300 MSN001 test aircraft with the primary objective to validate, in representative conditions, that such technical characteristics can be met for wing Upper Covers and Leading Edges using production processes. The demonstrator aims to validate that a jointed wing concept (Leading Edge and Upper Cover) can be manufactured in realistic and repeatable conditions appropriate to a civil short range aircraft to the required level of aerodynamic surface quality to achieve laminar flow.

Description of work

GKN is the responsible partner for delivering the NLF flight test hardware for the A340 starboard wing. Main activities included;

1. Manufacturing concept development;
2. C-Maturity gated review for design models and scheme drawings;
3. C-Maturity gated review for stress dossiers;
4. Design for Manufacture (DFM) product structure with production drawings;
5. Manufacture and assembly of the composite Upper Cover;
6. Manufacture and assembly of the metallic Leading Edge;
7. Wing Assembly support and non-conformance management.

The baseline configuration consists of a starboard composite Upper Cover and a machine metallic Leading Edge which is joined through a bolted interface which is then aerodynamically recovered; the baseline configuration is shown in Figure 2.

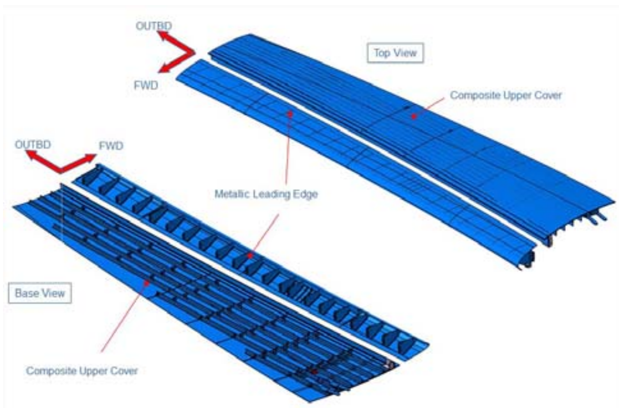

Figure 2: GKN Aerospace NLF Baseline Concept

Results

The GKN STBD wing assembly, the flight demonstrator, is a 9 metre significant evolution on previous NLF ground-based demonstrators with the challenge of revised and much tighter NLF requirements to be employed. The overriding test on the team was to impose and satisfy these stringent NLF requirements on a fit-for-flight assembly in a production environment where manufacturing processes, methodologies and tolerances are all accepted and baselined; this involved re-evaluation of programmed cutting routines, tooling methodologies and processes. Throughout the project timeline, baseline requirements, design office rules, manufacturing conventions and suppliers were all challenged to comply with stringent NLF requirements; the resultant output was a right-first-time metallic LE assembly involving over 184 intricate machined metallic components and a high quality first off composite UPR CVR assembly.

Composite Upper Cover (UPR CVR):

The baseline solution for the composite UPR CVR is a uni-Directional Automated Tape Laid (ATL) structure, shown in Figure 3, which is then cured on a spring-compensated Invar OML tool. The composite UPR CVR, including prolongation for First Part Qualification (FPQ), has approximately 9m span and 1.9m chord.

Figure 3: ATL at GKN Production Plant

Key features of the UPR CVR are as follows:

- Co-Cured Spring-Compensated ATL Upper Cover
- Co-Cured joggle
- Co-Cured ATL Drape-formed stringers with pre-cured noodle
- Co-Cured ATL Drape-formed spar cap
- Metallic machined rib feet

The Upper Cover plain skin, defined as the cover with no integral features, varies in thickness from 13.5mm at the inboard end with a constant taper to a mid-span position where the thickness is 5.4mm and is maintained through to the outboard portion. Nominally the full skin uses standard layup convention in all locations, except with the addition of a higher than normal percentage of chordwise plies which are required to stiffen the skin against chordwise waviness driven by aero pressures which can be detrimental to laminar flow aerodynamic behaviour.

The Upper Cover contains six stringers which are co-cured onto the skin; they are parallel to the Front Spar and are manufactured from 4mm thick double diaphragm formed (DDF) back-to-back angles with a zero dominated lay-up. The stringers also contain a pre-cured and pre-machined noodle which is co-bonded into the structure and is provided to help with manufacturing of the stringer. The Spar Cap provides an interface to the Front Spar but removing the need for bolting through the UPR CVR, which is a risk to aerodynamic laminar flow behaviour. The Spar Cap is constructed from two DDF back-to-back L angles, the forward angle being 8mm thick, the Aft angle being 4mm thick; both with a quasi-isotropic lay-up. Consistent with the stringers, the Spar Cap angles are co-cured onto the skin. A representative section of the Spar Cap is shown in Figure 4.

Figure 4: Cross Section Cut of Spar Cap showing the Pre-Cured Noodle

The UPR CVR is assembled in a purpose made fixture allowing the part to be constrained at datum points and held in a horizontal attitude to allow the assembly operator access to either side of the part. Held in this attitude a number of operations are performed on the UPR CVR, namely the location and installation of the machined metallic Rib Feet which are wet assembled and bolted through the cover. A GKN developed process is then utilised to recover the aero-surface in NLF zones. Subsequent operations on the cover include priming and painting of the NLF surface and local NDT inspection of the Stringers and Spar Cap; shown in Figure 5.

Figure 5: Manual NDT Inspection

Figure 6 shows the UPR CVR assembly held in jig with Rib Feet installed. Also shown is the LE assembly, which interfaces with the UPR CVR joggle step.

Figure 6: GKN STBD UPR CVR Assembly, shown also with the LE Assembly

Metallic Leading Edge Assembly:
The baseline metallic Leading Edge assembly is machined from Aluminium billets and split into 4 span-wise sections of nominal 2.2m length. The LE skin is nominally of a construction similar to that of a metallic aircraft; however, due to the one-off nature of this project the LE skin must be machined from a single large billet of aluminium, as opposed to the formed nature of a conventional LE skin. A typical LE skin section is shown in Figure 7.

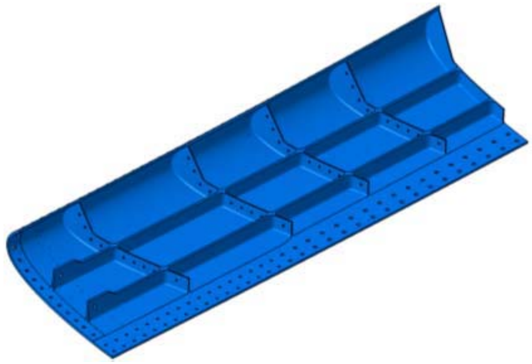

Figure 7: Typical LE Skin

Furthermore, the laminar flow requirements of the design mean that the thickness of the skin must be locally increased in order to restrict the aero deflections imposed under 1G flight conditions and Bird Strike Analysis undertaken as part of the GKN work package. In addition there are 184 intricate machined sub-components also manufactured from billet material, shown in Figure 8, and these include:

- LE Ribs
- LE Rib Posts
- Access Panel Angles
- Z-Plates
- LE Skin joint straps

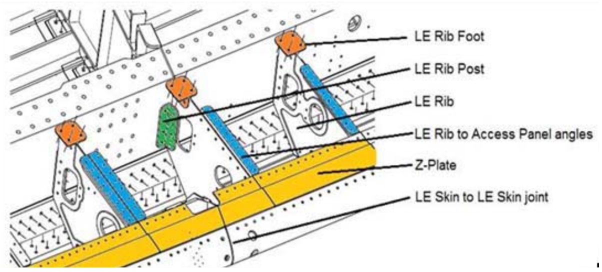

Figure 8: Representative View of a LE Skin with Sub-components

A detailed bird strike assessment was conducted by GKN for the STBD wing assembly. The purpose for the bird strike assessment was to determine the fastener loads at the upper cover Spar Cap joints during a bird impact event, and to assess the fastener strength. The simulation, conducted with Abaqus/Explicit, was also used to provide evidence that the bird would not penetrate the metallic leading edge skin. A detailed FEM was created from a typical section of the GKN Leading Edge between ribs 14 and 17 which included the internal structure and a small portion of the wing box. For the high speed case, four bird impacts were considered; one mid-bay and two near LE ribs at various Angles of Attack (AoA); shown in Figure 9. The critical impact position was determined from the maximum equivalent plastic strain on the LE (assuming no damage has occurred).

The validity of the numerical simulation that was undertaken showed that all requirements were met.

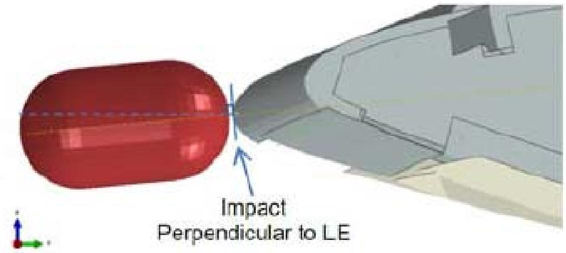

Figure 9: GKN Bird Strike,
Mid-Bay Impact scenario

Representative machining trials on a small scale flat specimen and D-Nose specimen were deployed in advance of full-scale machining with the primary objective to ascertain the expectations on the machined surface condition and to quantify the relationship of this surface to the processes undertaken at FAL to satisfy the final flight surface condition. The challenge on the manufacturing partner was to machine components to a right first time surface finish of 1.6 RA (typically 3.2 RA is achieved in production machining's).

The challenging nature of NLF tolerances meant the LE billets had to be maintained within a machining envelope that is bolted to a fabricated steel fixture; this can be seen in Figure 10. This is especially critical with the 7010 alloy as the material is known to be unstable and prone to distortion. Additionally, due to the complex nature of the one-shot machining process and the machine head clearance required for the D-Nose IML, meant that the LE must also be held at a pre-determined angle; this can be seen in the graphic in Figure 10.

Figure 10: LE Section Machining Jig (Left) and LE Section Roughing Out (right)

The utilisation of 'tie-rods'/tabs around the periphery of the LE skins maintained a rigid work-holding method that mandated a machining approach from either side of the component; the minimum number of tags to prevent in-process distortion is adopted for each LE skin machining. In all machining process a dwell period is adopted between each major machining step in order to reduce residual machining stresses.
The LE assembly was machined right-first time and within the stringent NLF design requirements. Figure 11 shows the final inspection of the LE assembly prior to dispatch to the SFWA assembly partner.

Figure 11: Inspection of GKN Machined LE Assembly

Timeline & main milestones

The planned project duration has been 19 months and commenced in July 2014. However, following delivery of the GKN hardware in November 2015, GKN has continued to support the SFWA program into 2016 and throughout assembly of the GKN hardware. Main project milestones include:

- C-Maturity Gate Review complete;
- DFM Gate Review complete;
- Manufacture and component assembly of starboard flight hardware;
- Concession Support;
- Wing Assembly support.

Environmental benefits

The NLF aerofoil coupled with improved aero-smoothness, offers higher efficiencies in aerodynamic performance and a reduction in drag contributing to an overall increase in an aircraft's efficiency; this in turn allows for potential reductions in aircraft emissions by reducing fuel burn. Achieving these reductions would be a significant step towards reaching the ACARE goals for 2020, including a 50% reduction in CO2 emissions and an 80% reduction in NOx emissions.

Dissemination / exploitation of results

GKN project results have been primarily disseminated by scientific publications and CleanSky presentations.
Further information on GKN and other GKN led CleanSky projects, please visit www.GKN.com.

The GKN starboard wing flight hardware was installed on to the A340 MSN01 at during 2016 with first flight trials planned later in 2017.

Project Summary

Acronym:	ImpNLFFD
Name of proposal:	Design, Manufacturing, Qualification and Assembly of an Improved NLF Wing Leading Edge and Upper Cover Flight Test Article
Involved ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement:	641530
Instrument:	Clean Sky
Total Cost:	€ 2,150,000.00
Clean Sky contribution:	€ 1,075,000.00
Call:	SP1-JTI-CS-2013-03
Starting date:	July 2014
Ending date:	Nov 2015
Duration:	19 months
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