The Application of Shot Peen Forming Technology to Commercial Aircraft Wing Skins

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ABSTRACT

Shot peen forming was selected by the McDonnell Douglas Corporation as the only viable method of contouring wing skin planks for the DC10 airliner. The parameters to form the skin planks were developed by Metal Improvement Company Inc. An overview of the shot peen forming operations is presented covering the technical and tooling requirements and documentation. Reference is made to the subtle angular and/or dimensional changes which can occur during forming of complex contours on large skin planks. The significant engineering and manufacturing advantages of the process led to incorporation of the technology in the design of the new DC9 Super 80. These criteria are expected to be equally applicable on the next generation commercial aircraft.

THE McDONNELL DOUGLAS CORPORATION (MDC) selected shot peen forming as the method of shaping the wing skin planks for the DC10 Tri-jet airliner in early 1969. Shot peen forming was chosen as the only viable method in an analysis of all alternative methods, such as stretch forming, creep forming, etcetera. In order to appreciate the background behind the decision, the methods being used at that time for DC8 and DC9 production skins will be briefly described.

McDonnell Douglas Canada Ltd. (MDCAN), with its plant situated adjacent to the Toronto International Airport in Southern Ontario, was already manufacturing major structural components for the DC8 and DC9 aircraft including the complete wing for the DC9, and was selected to manufacture the main wing components for the DC10. The Metal Improvement Company, with considerable expertise in peen forming, was selected to develop the parameters for peen forming the DC10 wing skin planks. Metal Improvement Company (MIC) accomplished this task and formed skins for the early production aircraft at their Carlstadt, New Jersey, plant, subsequently setting up a Canadian facility in Southern Ontario, Metal Improvement Canada Ltd. (MICAN).

The continuing success with the DC10 production system and an excellent in-service record, led to the decision in 1979 to incorporate DC10 wing skin technology into the design of the new DC9 Super 80 wing. Again the peen forming production program has been an unqualified success. To date some 5500 DC10 and 1050 DC9 Super 80 wing skins have been produced.

PREVIOUS FORMING METHOD

Essentially the method used to form the wing skin planks on DC8 and DC9 Series 10 thru 50 models was similar, and is still in use at MDCAN for noted DC9 models.

The DC9 wing utilizes eight skin planks, two on each upper surface, two on each lower surface with a chordwise joint on the centre line of the aircraft, see Figure 1: also noted are skin plank material approximate thicknesses. The skins are machine tapered in a spanwise sense only and supplied by the mill in Temper T351 for the 2024 alloy skins and Temper W for the 7075 alloy skins. All skins are clad one side. The wing has a major dihedral/sweep break positioned at the side of the fuselage and two minor aerodynamic shape breaks on the outer wing panels, as well as the normal aerodynamic chord form shape.

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The individual skins planks are shaped by mechanically stretch forming in a chordwise direction across the dihedral/sweep break only, inducing angular breaks and local chord form shapes, see Figure 2. This is accomplished by gripping the skin in trim areas on each side and inducing skin stretch across a male die in a 4000 ton Verson press, an elongation of 0.3% is normally achieved to ensure some measure of stretch stress relief.

The disadvantages of this forming method are:

- one shot attempt - the formed shape may change as the trim material is removed after the forming operation,
- oil canning/local distortion occurs in the skin area where the stretched material and base material blend,
- mechanical means are required during assembly operations to induce the chord/aerobreak form over the remaining skin area, and
- 7075 alloy skins require to be shipped to McDonnell plant packed in dry ice, are formed quickly out of the dry ice condition and subsequently heat treated to the T6 condition.

It can be appreciated that although this forming technology has been utilized for over two decades it does leave room for technical and manufacturing improvement.

DC10 APPLICATION

The aerodynamic shape of the DC10 wing evolved with a unique aerodynamic break where the rear spar has a 'gull-wing' shape and the front spar is essentially straight, see Figure 3. In addition the technology of 5-axis numerically controlled machining and large machine capacity was available to permit the design engineer to profile the skin to meet optimum design thickness requirements and achieve minimum weight. The skins are tapered in both spanwise and chordwise directions with integrally machined doublers. The skins, made from 7075 T651 alloy on the upper wing surface and 2024 T351 alloy on the lower surface, are produced fully machined by Reynolds Metal Company (REYNOLDS).
of varied severity. The lower skin planks are shot peen formed for full span chord form and the 'saddle-back' aerodynamic shape of varied severity, see Figure 5. The skins vary in length from 31 feet to 82 feet, are 3.5 to 7 feet wide and vary in thickness in the aerobreak from 0.300 inch at the front spar to 0.762 inch at the lower rear spar.

Detail Engineering drawings fully define the skin and its features within the aircraft geometry and are normally drawn as a view which is parallel to the wing reference plane with spanwise and chordwise dimensions related to various wing reference planes. Drawing notes invoke other data which is required to fully supplement the manufactured skin plank definition.

Process Specifications control the peening process with the fundamental requirements for saturation peening and peen forming. All surfaces receive a light shot peen coverage, this operation is commonly referred to as saturation peening, to ensure that they are under surface residual compression stresses. For peen forming the utilization of a range of shot sizes is defined with the appropriate limitations. Note; actual peen forming coverage for individual skin planks is not defined in this document. Additional information re cleaning requirements, surface finish requirements and skin fit acceptance criteria are contained in this specification.

Loft Data consists of a full size layout of the wing skin plank developing the aircraft geometry into a single flat plane, defining the actual shape and positioning thickness transitions points and sculptured areas.

Tooling Data Sheets (TDS) contain additional data affecting the physical wing skin plank as required for the manufacturing process. The information provided includes datums for machine programming, tooling holes, handling holes, trim allowances and allowances for other subtle angular/dimensional corrections which are required. These latter aspects are discussed in more detail later.

Hard Tooling consists of essentially a full size checking fixture for each skin plank to check the geometry of the air passage side of the formed skin. A typical fixture, see Figure 6, consists of a series of easily removable aluminum contour boards, contour representative of the aerodynamic wing shape, set on a jig frame. Critical hard points and tooling hole locations are also checked by these tools.

The following media are used to specify the technical requirements and control the shot peen forming process:

- Engineering Drawings
- Process Specifications
- Loft Data
- Tool Data Sheets
- Hard Tooling
- Peening Process Schedules
Peen process schedules define, in an orderly and precise manner, the specific peen forming requirements appropriate to each wing skin plank. Items in the schedule include, but are not limited to, shot sizes, coverage, dimple diameters, holding or pre-stressing fixtures, number of passes, wheel speeds, masking, sanding requirements, cleaning and checking. Peen process schedules are developed on early production skins and when firm are utilized for each production skin.

Typically the peening of a wing skin plank involves the following operations:

- Saturation peening
- Peen forming the aerodynamic break contours
- Peen forming the aerodynamic chord contours

Saturation peening is applied to both inside (stringer) and outer (aerodynamic) surfaces of skin, normally to an Almen intensity of .006 - .008A.

During the peen forming for aerodynamic contour, masking is required where light and heavy skin thicknesses adjoin to avoid overforming the thin areas when forming heavier thicknesses, or for thin edges which tend to curl or form waves.

The peen forming of the aerodynamic break contour requires the use of heavier shot. More severe forming requirements, from a combination of aerobreak shapes and/or metal thickness, may also require a mechanical assist to induce a preform. The skin plank is preformed under applied loads, with the skin plank material stresses below the elastic limit, and peened to produce the required curvatures.

Views of typical machinery used for the peening operations are shown in Figure 7 and 8.

After peen forming the skin planks are checked for contour, and local contour improvement forming, using portable shot peening equipment, is accomplished when required.

The skin planks are sanded both sides to drawing finish requirements, nominally 100/63/ as a general finish, with 63/ in designated areas where high load transfer between skin and sub-structure occurs.

The skin planks are finally inspected for contour fit and thickness, see Figure 9 and 10.
The skin planks are cleaned using a decontamination acid solution, to remove iron oxides deposited from the steel shot, to avoid in-service galvanic corrosion problems. Protective oiling, wrapping and shipping completes the operations.

The above shot peen forming operations are performed by MICAN. Upon receipt of the skins by MDCAN, trimming, local operations at access doors, anodizing and painting prepare the skins for the wing production line.

Manufacturing assembly experience with DC10 wing skins highlighted the positive advantages of the technology, with consistently produced net fit skin planks reducing assembly time and costs.

**GROWTH AND FANNING PHENOMENA**

Of interest, two side effects of the shot peen forming operation must be recognized and catered for if the final formed skin is to fit the wing frame structure as defined by engineering design, these effects are termed "growth" and "fanning".

The stretching effect of shot peening, saturation plus chord forming, manifests itself in skin "growth". The growth factor is typically in the order of 0.25 inch on fifty (50) feet. Chord lengths on the skin planks are short so the growth factor can be ignored. However, since the spanwise length is relatively long progressive displacements of significant skin features, such as reinforcing pads, access hole doublers, etcetera, occurs. Adjustments in the positions of these features are made during skin plank machining to cater for this growth.

Geometric changes occur in the flat plane form of a wing skin when it is formed across an aerodynamic aerobreak area, see Figure 11. This significant angular change is known as "fanning". The fanning movement and magnitude are functions of aerodynamic aerobreak geometry and again displacements of the skin periphery and significant features occur which must be catered for by relocating during the skin plank machining operation.

Data to effect these positional changes is provided in the TDS's.
The skin planks are shot peen formed by MICAN. The dihedral break area, see Figure 14, required some process development work before production of skins commenced.

The manufacturing experience with the Super 80 model, see Figure 15, has closely followed DC10 experience with similar benefits being accrued.

**SUMMARY**

McDonnell Douglas Corporation has had excellent manufacturing experience with this technology and has no known service-related difficulty with shot peen formed aircraft wing skins.

For the airframe design engineer the technology allows optimum structural design for weight/cost efficiency. For the manufacturing effort the technology reduces costs.

New generation commercial aircraft, utilizing latest technology material alloys and tempers, are either coming into production or are being engineered. The use of shot peen forming in these programs is already indicated.

The significant advantages of the process are expected to be equally applicable to the next generation MDC commercial aircraft program.