Avoiding that shrinking feeling: adopting a chemically unstable material for conservation

Andrew Pearce
Australian War Memorial

Abstract: *During 2003 the Australian War Memorial undertook conservation work on two large aircraft, a DAP Beaufort and an Avro Lancaster. This work included the repair and re-covering of control surfaces with doped fabric. Physical evidence present in the Memorial's aircraft collection and the written and verbal testimony from a number of individuals involved in the operation and re-covering of vintage, fabric-covered aircraft has strongly indicated that cellulose butyrate (a doping compound used since the mid 1950s) continues to contract over the long term, resulting in the damage and destruction of doped fabric surfaces and their underlying framework. This paper discusses the use of cellulose nitrate based doping compound which, while considered by many to be unstable, is present on a number of the Memorial's First and Second World War aircraft in extremely good condition. Discussion of the fabric-covering process deals with the processes involved and the training of members of the large technology conservation team in what is a largely forgotten skill.*

Doped fabric has been used on the fuselages, wings and control surfaces of aircraft from the earliest aircraft of the Wright brothers and Bleriot through to enthusiasts' planes still being manufactured today. Doping refers to the application of a tautening medium to the fabric stretched over the aircraft frame. This results in a tightly stretched surface with aerodynamic attributes.

As with all cultural institutions around the world whose collections include aircraft dating from the early to mid twentieth century, the Australian War Memorial has a significant number of aircraft with fabric surfaces.

Initially, the main material used to dope fabric surfaces was a lacquer based on the material cellulose nitrate. Some of you may be more familiar with cellulose nitrate as "gun cotton", an explosive propellant used in the same manner as gun powder. Herein lies one of the main difficulties associated with the use of cellulose nitrate to coat the fabric surfaces of aircraft. It is highly flammable. To be in an aircraft with a wooden frame and cellulose nitrate coated fabric on the fuselage, wings, tailplane and control surfaces, fronted by a high temperature engine belching smoke, flames and fuel is to place oneself in a hazardous position. Additionally, cellulose nitrate dope is soluble in aviation fuel. Due to the proximity of powered aircraft to aviation fuel and the possiblilty of spillage, this resulted in significant extra maintenance and the potential failure of the doped surfaces. Despite these difficulties, cellulose nitrate was widely used from the dawn of powered flight through to the 1950s.

At the beginning of the 1950s, a new lacquer compound was developed for doping aircraft fabric. This was cellulose butyrate. Cellulose butyrate had a number of significant advantages. It was not explosively flammable and it also did not dissolve in aviation fuel. For these two reasons alone, its initial uptake and continued use was substantial. Although some limited use of cellulose nitrate continued, the safety advantages meant that its widespread use was largely phased out.

Under normal operational conditions, the fabric surfaces of any aircraft require maintenance. Moisture, ultraviolet light, insects, physical impact and the like all take their toll on the fabric surfaces. For this reason, surfaces require continual patching, repair, repainting and complete recovering at regular intervals. An additional treatment available to the operators of aircraft was a process known as “rejuvenating”. Rejuvenating involves the application of a “dope rejuvenator” to the fabric surface. This softens the dope lacquer, releasing the tension on the fabric. Following the application of rejuvenator an aircraft requires repainting.

Contrast this with the treatment of an aircraft stored indoors in a museum environment where it is (hopefully) not exposed to moisture, direct sunlight and ultraviolet radiation, insects, fuel, impact or the stresses of flying. Many aircraft stored under these conditions are kept for decades, half centuries even without the need for significant maintenance. Certainly in the case of museum pieces, especially those with historic paint finishes, the use of substances like rejuvenators every few years is neither a financially or ethically viable proposition.

This is the crux of the problem. Were any difficulties, deterioration or faults to be present on fabric surfaces of an airworthy aircraft, they would be picked up in routine maintenance and would need to be remedied in order for the aircraft to remain airworthy. In the museum environment, there is no such requirement for continual upkeep and so the doped surfaces are left alone to remain in their original state. But do they?

While the chemical process involved in the doping of a fabric surface is complex, the physical process can be relatively simply described:

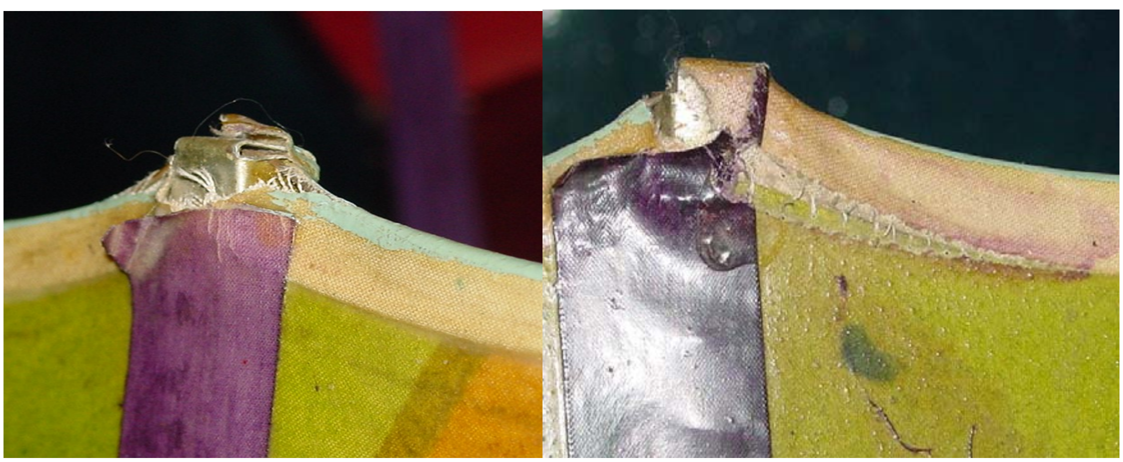
- Fabric (cotton or linen) is stretched and sewn into a tight bag covering a frame of wood or metal.
- The fabric surface is then coated with a thinned layer of tautening dope.
- Once the lower layer of dope has dried it is sanded smooth. Subsequent layers of dope with a decreasing content of thinner are then applied, the dried surface being lightly sanded before each new coat.
- The final coats applied to the surface are undiluted dope lacquer.
- The surface is then left to tension up and become tight, rather like a drum skin. At this point, the fabric surface is hand stitched to the framework of ribs below the surface to prevent it from shifting or vibrating and the stitch lines are covered with fabric tapes to seal and protect them. Again this surface is painted with full strength dope and is sanded. (Sanding greatly smooths the surface of the fabric resulting in a surface with significantly less resistance to airflow and substantially enhanced aerodynamic behaviour.)
- The final cosmetic paint coats are then applied to the fabric surface.

In the case of cellulose nitrate, a few weeks following the application of the doped coating to the fabric surfaces full tension is achieved, at which point further contraction or shrinkage of the doping lacquer appears to cease. This being the case, a “museum piece” doped with cellulose nitrate is likely to stand the test of time admirably. Indeed, the Memorial has a number of First World War aircraft (including an SE5a scout/fighter and Avro 504K bi-plane) and Second World War aircraft (including a Tiger Moth, Wirraway and the rudder and elevators of the Spitfire and Messerschmitt Bf109) within its collection that appear to have never required maintenance of the fabric surfaces since the day they were made and show little deterioration apart from some minor crazing due to embrittlement of the lacquered surface. The only major point of concern with having cellulose nitrate based items within a collection is that should they catch fire, they burn readily and are all but impossible to extinguish.

In contrast, cellulose butyrate dope appears to behave quite differently. The application process is effectively identical and again, after a number of weeks the contraction of the doped fabric surface slows markedly. Note the use of the word “slows”. The physical and anecdotal evidence indicates that in many circumstances the contraction does not ever totally cease.

Continued contraction of the doped fabric surface can result in the eventual destruction of the fabric, the stitching seams, the underlying framework or all of the above. Think if you will on the examples of a boa constrictor attempting to strangle either a 44 gallon drum or a square block of concrete. In one case, the drum will eventually be crushed; in the other case the unfortunate snake will eventually snap.

In recent discussions with a number of museums and aviation enthusiasts as widespread as Europe, America and Canada, numerous instances have been reported of aircraft with distorted fuselages, warped wings, torn stitching, wing ribs puncturing the fabric surface, all due to the continual tensioning of the butyrate doped fabric. A number of the Memorial’s aircraft have also been re-coated in fabric doped with cellulose butyrate. In the case of our German First World War Albatros D.Va scout aircraft, the trailing edges of the wings clearly demonstrate the damage and failure that can occur on aircraft doped with cellulose butyrate.



Figures 1 and 2: Deterioration and seam destruction on Albatross wing

During the period 2000 – 2004, the large technology conservation section of the Memorial were in the process of extensive refurbishment and conservation treatments on our Second World War Beaufort and Lancaster bombers. In the case of the Beaufort, the Memorial was conserving what is, to date, the only complete example held anywhere in the world. Much of the structure was being fabricated from salvaged parts and none of the original doped fabric remained. For the Lancaster, the situation was a little different. Enthusiastic but somewhat under-resourced restoration of three of the four fabric surfaces on the Lancaster had produced a result that left much to be desired as regards final finishing details and neatness. Additionally, the possibility of water damage to the steel-framed elevators meant that detailed inspection and treatment of the framework was essential, requiring the removal of the fabric from these sections.

Given that the Memorial staff would have to re-cover the fabric surfaces of the Lancaster and Beaufort, it was important to investigate what options were available and what aesthetic and ethical issues were associated with them

At present there are a range of options open to persons interested in fabric covering the open framed sections of their aircraft (wings, fuselages, control surfaces).

These include:

- Cellulose nitrate dope on cotton or linen. As previously discussed this combination is flammable and not solvent stable. It is the "traditional" method of aircraft covering for most historical aircraft.
- Cellulose butyrate dope on cotton or linen. This combination is not highly flammable, is solvent stable and appears aesthetically similar to nitrate doped surfaces. There is significant anecdotal and physical evidence to indicate that long term storage of butyrate doped aircraft can result in significant physical damage or destruction of structural elements or fabric surfaces.
- Ceconite or Stits ™ Polyester heat shrinking fabrics (these must never be treated with tautening dope). Unfortunately, Ceconite fabric systems tend to result in a glossy almost "plastic" looking surface that does not have the correct reflectivity and has too great a colour saturation to appear authentic. At present, the majority of aircraft restorations and almost all newly constructed aircraft with fabric surfaces are covered using Ceconite or similar fabric coatings.

In the case of the Memorial's aircraft, an authentic visual appearance was vital for any proposed method of treatment. Similarly, for ethical reasons, adopting a methodology as close as possible to that originally used was felt to be most sympathetic to the historical aspects of the aircraft in question.

Given the known issues relating to the deterioration and damage caused by the shrinkage of butyrate doped fabrics, the decision was made to re-dope the control surfaces of the Beaufort and Lancaster using the traditional methods and materials, including Grade A aircraft cotton, Irish linen, waxed linen flosses and threads and cellulose nitrate tautening dope. Given that we have aircraft presently in the collection with nitrate-doped surfaces that appear satisfactorily stable after greater than eighty years, it was hoped that careful application of a similar technique using similar materials might result in a treatment lifespan of equal longevity. Certainly, when one contrasts the long-term survival of the nitrate coatings with the visible results of premature failure in the butyrate-treated aircraft, the arguments for the use of cellulose nitrate become substantial.

George Bailey, the project manager for the Lancaster and Beaufort work teams was fortunate enough to spend some time working at the Duxford Aircraft Museum in the United Kingdom some years ago. While there he was involved in the work conducted to re-fabric one of the aircraft held within the collection and during this work took extensive notes on how the work was carried out. With George's assistance and using these notes, a number of staff began to pick up the skills of what is today largely a lost art.

Initial work commenced on the cotton covering of the Beaufort ailerons. These were supplied in a primed and painted state ready for re-covering. The first work involved the covering of the aileron ribs with aluminium foil. The foil is used to prevent the dope saturated fabric from adhering to the ribs. Were this to occur, sections of the fabric would become adhered in place and even tension would not be developed across the entire fabric surface. Traditionally ribs were covered with waxed paper which would stick to itself and hold its position, while not adhering to the doped fabric. Waxed paper was not able to be used however due to supply constraints. The ability of aluminium foil to be wrapped around a rib and take shape without shifting made this a viable replacement material.

In the case of the Lancaster elevators, the framework over which the fabric was to be applied was fabricated from steel tubing. As the proximity of aluminium foil and steel would have resulted in the onset of localized bi-metallic corrosion, the ribs of the Lancaster were wrapped with white Teflon based plumber's sealing tape prior to the installation of fabric.

Figure 3: Placement of cotton bag over aileron

Following the application of the aluminium foil, the cotton fabric was cut to produce an oversize covering for the aileron and was clipped into position along the trailing edge with edges rolled under. The trailing edge seam of the aileron fabric was then stitched, using waxed linen thread in a modified running blanket stitch. For aviation purposes, running blanket stitch is knotted at regular intervals. This prevents any chance of the entire seam becoming unraveled should localized damage occur to the seam.

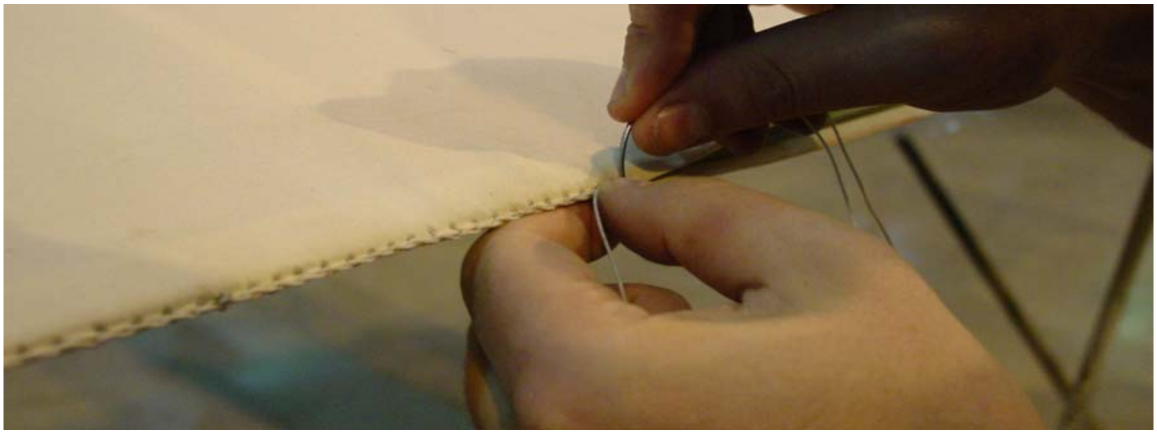
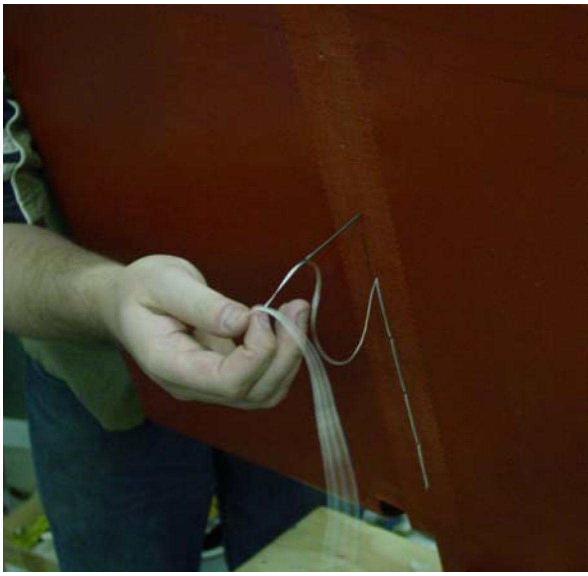


Figure 4: Stitching of trailing edge seam

Following the neat sewing of all external seams, the fabric surface was given its first coat of tautening dope at approximately 50:50 v/v dope and thinners. Following the initial application and drying of this coat the surface was sanded smooth with 360 grade emery paper in preparation for the subsequent dope layers.

Figures 5 and 6: Well saturated doped fabric surface and the application of rib strips

After the application of about seven layers of dope the surface was satisfactorily tight, the fabric weave was well filled with dope and the surface was smooth ready for the application of rib tapes. These tapes are strips of linen which follow the line of the ribs within the aileron and are used for local reinforcement of the fabric surface.
Once the rib tapes were adhered in position using dope and had dried, the laborious process of using waxed floss to stitch the doped fabric surface to the ribs began.



Figures 7 and 8: Rib stitching

After the rib stitching was complete, a second run of rib tapes was applied over the stitching and the surface was coated with layers of dope until the same filled and smooth surface was achieved.

Once the doping of the upper rib tapes had been completed, seam sealing tapes, drain holes and other finishing details were applied to the ailerons. On drying, the finished product was given a final rub back with 360 grit emery paper and sprayed with non-tautening silver coloured nitrate dope. The newly fabric covered ailerons were then given their final display paint coatings and were ready for installation.

The fabric work conducted on the ailerons and elevators of the Beaufort and Lancaster aircraft in 2003 was a new process for the large technology conservation staff at the Memorial. By examining the evidence within our collections and obtaining corroborating information from others, be they pilots, aircraft fabricators or other institutions, we believe that we have chosen a material and method that will extend the useful display life of the newly applied fabric. We will continue to observe and monitor the fabric surfaces on the aircraft within our collection to see how they do behave over the long term.

Over the years, the conservation profession worldwide has identified a range of compounds and materials that, through their presence and deterioration, are problematic. This list includes deteriorated leather, polyvinylchloride plastics, many rubber compounds, woods such as oak, medium density fibreboard, sodium chloride, soluble nylon and nearly anything composed of cellulose nitrate.

In the case of the last of these, (in its aircraft dope form at least), it seems that we may have been avoiding the compound that has shown the greatest long term stability and object survival of the covering options available. Although being on the hit list of “unstables and troublesomes” it would seem that cellulose nitrate dope has a valuable role to play within our profession.